Chapter 8. Transmission Development Plan

8.1 Characteristics of Transmission Network Systems in Sri Lanka and the Objects to be investigated

The current network system in Sri Lanka consists of a 200kV transmission network as a trunk system and a 132kV transmission network as a local system. Colombo and the surrounding area are the center of electricity demand, dominating 40% of the demand in the country. In addition, hydro power in the central region and thermal power generated from small thermal power plants in the regions provide electricity to Colombo and the surrounding area.

Both the 220kV system and 132kV system are formed in mesh currents. However, there is also a single circuit transmission line in the network. Thus, when a fault occurs in a single circuit line (N-1), there are many cases in which a great impact is caused by the fault.

Amid intensely increased demand, and enormous development of electricity generation and deployment of renewables, the development of electricity generation transmission lines and local transmission lines which will supply electricity to consumers in the city of Colombo and other areas are in progress.

As mentioned in Chapter 1, the planning of various potential energy generations is under way, including coal as a base-load power plant, LNG as the base-load and the middle power plant, renewable energy, and Pumped Storage Power Plants, which work efficiently in addressing the fluctuations in renewable energy.

Various types of electricity generation are planned to be developed in different regions all around the country: renewables in the northern and southern region; coal-fired in the eastern region; Pumped Storage in the central region; and LNG thermal power in Colombo and the surrounding area and the southern region. Each plan is large in degree, and the development is decentralized. Thus, integration of each development plan and strengthening of the transmission network systems are essential.

8.2 Present Network System and Review of the Existing Plan

8.2.1 Present Network System

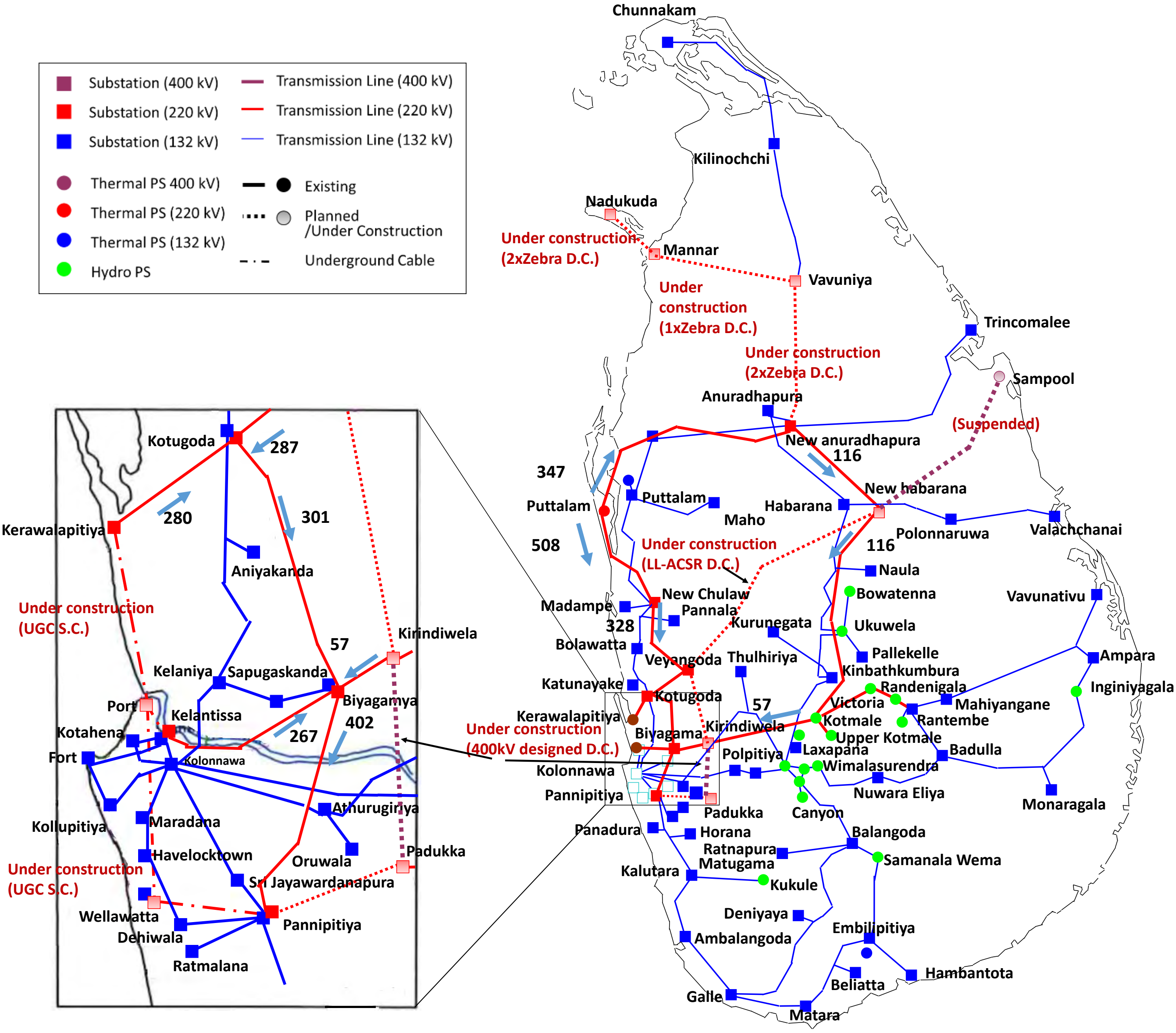
The power transmission system in 2017 and the 220kV power flow at night-time peak demand are shown in Figure 8-1 (when the output of the thermal PP is large) and Figure 8-2 (when the output of the hydro PP is large).

The Kerawalapitiya TPP and the Kelanitissa TPP in Colombo city are connected to the 220kV transmission line and are transmitting electricity to the mountain side. When the output of both TPPs is large, power flow of about 550MW flows to the mountain side, and the power flow from Kotmale and other hydro PPs is as low as about 60MW. On the other hand, when the output from the hydro PPs is large, the power flow from Kotmale to Colombo reaches nearly 500MW.

The Pannipitiya substation in the south of Colombo City is at the end of the 220kV transmission system, and electric power of about 300MW to 400MW is supplied at peak demand.

The Puttalam TPP is located in the north of Colombo, and a total generated power of about 600MW to 900MW is transmitted to the northern region and Colombo via the two routes of 220kV transmission line in both directions.

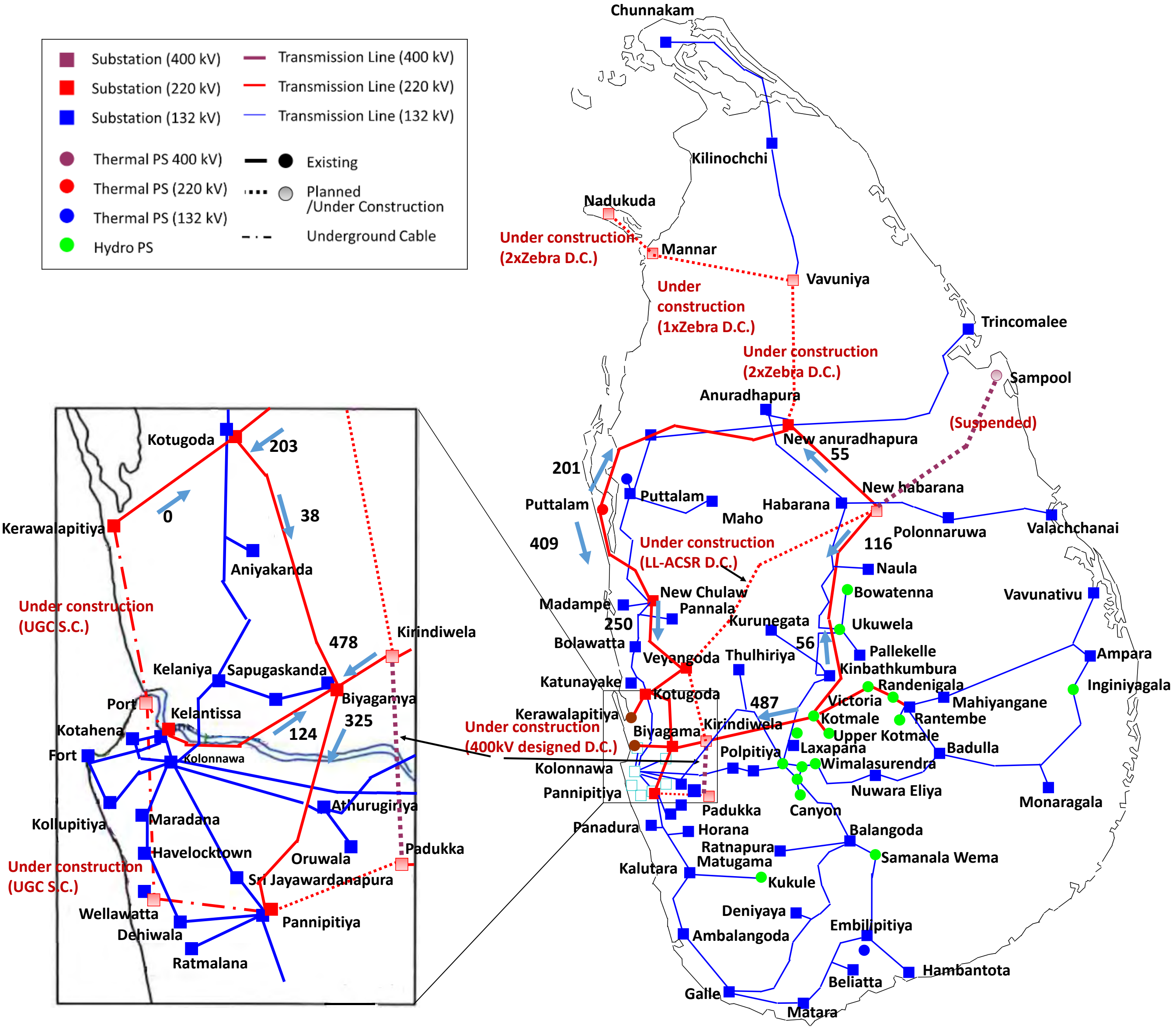
2017



(Source: JICA Survey Team)

Figure 8-1 Power Flow of 220kV Transmission Line at Peak Demand (When the Output of the Thermal PP is large, 2017)

2017



(Source: JICA Survey Team)

Figure 8-2 Power Flow of 220kV Transmission Line at Peak Demand (When the Output of the Hydro PP is large, 2017)

8.2.2 Transmission System under Construction

The 400kV and 220kV transmission lines currently under construction are shown below.

- 220kV New Habarana-Veyangoda transmission line (2 cct)
  Using low-loss electric cables, it is under construction via a Japanese ODA loan.
- 220kV Nadukuda-Mannar-New Anuradhapura transmission line (2 cct)
  It is planned to be constructed with ADB funds in order to transmit the electricity from windpower plants to be constructed at the Nadukuda site.
- 220kV Kerawalapitiya-Port-Wellawatta underground transmission line (1 cct)
  A 220kV underground transmission line (1 circuit) between Kerawalapitiya TPP and Port in the city center is being constructed via a Japanese ODA loan.
- 400kV Kirindiwela – Padukka transmission line (2 cct)
  It is a 400kV design, but initially it operates at 220kV.
- 220kV Veyangoda-Kirindiwela transmission line (2 cct)
  It is in the process of bidding via a Japanese ODA Loan.
- 220kV Kotmale- New Polpitiya transmission line (2 cct)
  It is in the process of bidding via a Japanese ODA Loan.

8.2.3 Review of the Existing Plan

The CEB transmission system comprises a 220kV and 132kV transmission network interconnected with switching stations, grid substations and power stations. Development and strengthening of the transmission and associated grid substation facilities are of paramount importance to meet the growing electricity demand in the country. It is the function of the transmission system to transmit electricity in bulk, generated at power stations, to grid substations to meet the demand of customers. The necessary transmission system reinforcements to maintain satisfactory power system performance are identified by detailed power system analysis carried out during a long-term transmission development planning process.

The period of the latest long-term transmission development plan in CEB (LTTDP 2015-2024) is 10 years (2015-2024). This is the updated version of the previous long-term transmission development plan (LTTDP 2013-2022), which was designed based on the enhanced version of the long-term generation expansion plan (LTGEP 2015-2034), the divisional medium-voltage distribution plans, and the demand forecast.

Specifically, in the five phases of 2015, 2018, 2020, 2022, 2024, the plan is developed to fulfill each of the network system criteria including voltage, thermal, N-1, security, stability, and short-circuit.

As mentioned above, in the five phases, the transmission development plan is proposed and, if this plan is implemented as scheduled, the planning criteria mentioned in 8.2 will be satisfied so that there would not be any great challenges up until 2024 at least.

Furthermore, CEB uses PSS/E as a tool for the power network system analysis. The JICA study team also uses PSS/E in investigating the master plan.

In the development plan for the long-term transmission network system of CEB, the following is the major transmission system reinforcement plan for 400kV and 220kV, proposed for the year 2018 and beyond.

Table 8-1 Major Development Plan for the 400kV and 220kV System

Year	Description
2018	**Transmission Lines & Underground Cables** Kelanitissa = Port 220kV cable 6.5km Kerawalapitiya = Port 220kV cable 13.5km Port = Port City 2×220kV cable New Polpitiya = Padukka = Pannipitiya 2×220kV transmission line New Habarana = Veyangoda 2×220kV transmission line Mannar = New Anuradhapura 2×220kV transmission line 125km Nadukuda = Mannar 2×220kV transmission line 30km **New Grid Substations** New Habarana 2×250MVA 220/132/33kV New Polpitiya 2×250MVA 220/132kV Mannar 1×45MVA 220/33kV Nadukuda 2×63MVA 220/33kV
2019	**Transmission Lines & Underground Cables** Kirindiwela = Padukka 2×400kV transmission line (initially 220kV operation) 20km
2020	**Transmission Lines & Underground Cables** New Polpitiya = Hambantota 2×220kV transmission line Veyangoda = Kirindiwela 2×220kV transmission line Kotmale = New-Polpitiya 2×220kV transmission line New Polpitiya ＝Hambantota (via Embilipitiya) 2×220kV transmission line Pannipitiya = Wellawatta (SubK) 220kV cable Port = Wellawatta (SubK) 220kV cable Sampoor = New Habarana 2×400kV transmission line (initially 220kV operation) 95km **New Grid Substations** Kerawalapitiya 2×45MVA 220/33kV Kirindiwela 2×250MVA 220/132/33kV Hambantota 2×250MVA 220/132/33kV
2022	**Transmission Lines & Underground Cables** Sampoor = New Habarana 2×400kV transmission line (400kV operation) 95km **New Grid Substations** Sampoor 2×500MVA 400/220kV **Grid Augmentations** New Habarana 2×800MVA 400/220kV
2034 (reference)	**Transmission Lines & Underground Cables** Kirindiwela = Padukka 2×400kV transmission line (400kV operation) Padukka = Ambalangoda = Hambantota 2×400kV transmission line

(Source: LTTDP 2015-2024)

8.3 The Future Plan for the Trunk Transmission Network System

In general, the power plant and the consumers are less likely to be located in the same area. Thus, transmission lines become essential as the facilities to transport electricity to all the consumers so that imbalance of power demand and supply can be eliminated. For this, the basic method of the trunk transmission network development plan is to understand the imbalanced volumes of the demand and supply per region and to examine efficient methods of transporting surplus electricity to the regions with an electricity shortage. However, it is vital to draft the future plan for the trunk transmission network considering a sustainability of over 20 years from the perspective of avoiding redundant investment, as it is usually the case that transmission lines are maintained for over 20 years after construction. Thus, the study was conducted considering the year 2040, which is the final year of this master plan.

8.3.1 Criteria of Transmission System Plan

The following are the currently adopted criteria in the CEB plan:

- Frequency: 50Hz±1%
- Voltage: 400, 220kV Within ±5%
  132kV within ±10%
- Fault current: 40kA (220kV and more)
- Overload: No overload at N-1 contingency

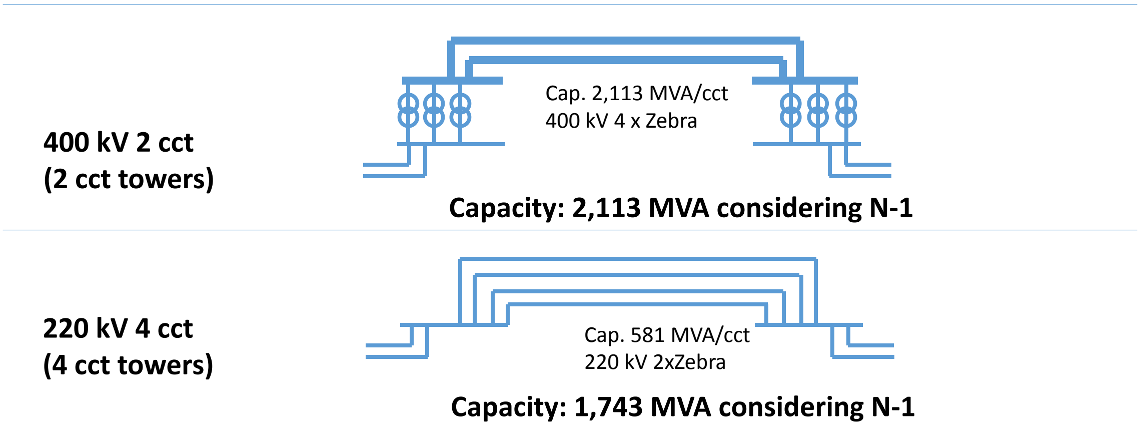
Moreover, the following have been confirmed in the consultation with the transmission network systems planning division of CEB:

- Rating Capacity: Normal Operation 100%
  N-1 Contingency 100%
- Operational goal for voltage: 0.9-1.1 of standard voltage
- Fault Current: upgrading to 63kA in case of surpassing ≥220kV transmission system and 40kA
- Dynamic Stability: Permit generator shedding if dynamic stability cannot be kept

Thus, this study will be based on the above criteria.

8.3.2 Adoption of 400kV Transmission Line

The JICA Survey Team examined the voltage of the transmission line between Sampoor - New Habarana, which is necessary when constructing a coal-fired power plant in Sampoor.
The distance between the two substations was about 100 km, and the case where a 400kV transmission line is constructed via a two-circuit tower and the case where a 220kV transmission line is constructed via a four-circuit tower are compared. The reason for adopting the four-circuit tower is based on CEB's opinion that the land width of the transmission line should be as small as possible.
Figure 8-3 shows the equipment configurations for the cases compared.



(Source: JICA Survey Team)

Figure 8-3 Equipment Configurations for the Cases compared

Table 8-2 shows the conditions such as resistance value, power transmission distance, unit price of loss, power transmission power factor, etc. of the transmission line used for the study. Costs of power transmission lines, circuit breakers, transformers, etc. used for the study are shown in the same table. The unit price of loss is based on the fuel costs and maintenance costs for the LNG thermal power plant, which is calculated in anticipation of the price rise in 2030, and the cost of the equipment is based on the data obtained from CEB. The cost per circuit when adopting the 4-circuit tower is set to 1.125 times' the cost when adopting the 2-circuit tower.

Table 8-2 Conditions used for Comparison Study

Conditions				
Conductor Resistance at 70℃ (Zebra)	0.0700623	ohm/km		
Distance	100	km		
Loss Price	8.93	Usc/kWh		
Power Factor	0.9			
Load Loss Factor (0.85*0.7^2+0.15*0.7)	0.5215			
Equipment Cost	FC(LKR)	LC(LKR)	LKR	million USD
400 4x Zebra, double circuit	109.34	25.44	135	0.88
220 2x Zebra, double circuit	40.47	16.81	57	0.37
400kV Line Bay DB	106.54	11.02	118	0.76
220 kV Line Bay DB	66.53	4.97	72	0.46
400kV TR Bay DB	89.44	9.25	99	0.64
220 kV TR Bay DB	51.99	5.06	57	0.37
Common Items for 400/220/33kV 2x300 MVA (Out do	368.34	192.09	560	3.64
Transformers 400/220kV 800MVA & E.Tr. & Aux. Tr	555.25	64.15	619	4.02
Exchange rate	0.006496	USD		
Cost factor for T/L 4cct towers	1.125			

(Source: JICA Survey Team)

The results are shown in Table 8-3. If the transmission power is about 600MW or more, the cost including transmission loss becomes smaller for 400kV than 220kV. Therefore, it is more economical to adopt 400kV if there is a transmission power of about 600MW or more and a power transmission distance of about 100km.

In the plan to develop the Sampoor thermal power plant, the output is over 600MW, so the JICA Survey Team decided to adopt 400kV between Sampoor and New Habarana.

Table 8-3 Comparison between 400kV and 220kV Transmission Lines

	Condition						Loss Calculation			Cost (million USD)							
Cases	Peak P. (MW)	Voltage Class (kV)	cct	No. of 800 MVA Tr. per S/S	R. per phase (ohm)	Amp. per phase (A)	Loss (kW)	Loss (MWh/y)	Loss (million USD/y)	Loss for 10 years	Cost of T/L	Cost of Tr.	Cost of Bays	Common for S/S	Total Cost excl. Loss	Total Cost excl. Loss (4cct)	Total Cost inc. Loss
	600	400	2	2	1.752	481	2,433	11,113	0.992	10	88	8.0	7.1	7.3	110.0	110.0	120
	600	220	4		3.503	437	8,042	36,739	3.281	33	74		3.7		78.1	87.9	121
	800	400	2	2	1.752	642	4,325	19,757	1.764	18	88	8.0	7.1	7.3	110.0	110.0	128
	800	220	4		3.503	583	14,297	65,313	5.832	58	74		3.7		78.1	87.9	146
	1000	400	2	3	1.752	802	6,758	30,871	2.757	28	88	12.1	9.1	7.3	116.0	116.0	144
	1000	220	4		3.503	729	22,339	102,052	9.113	91	74		3.7		78.1	87.9	179
	1200	400	2	3	1.752	962	9,731	44,454	3.970	40	88	12.1	9.1	7.3	116.0	116.0	156
	1200	220	4		3.503	875	32,168	146,955	13.123	131	74		3.7		78.1	87.9	219
	1500	400	2	3	1.752	1,203	15,204	69,459	6.203	62	88	12.1	9.1	7.3	116.0	116.0	178
	1500	220	4		3.503	1,093	50,263	229,617	20.505	205	74		3.7		78.1	87.9	293

(Source: JICA Survey Team)

8.3.3 Plan for Distribution Substations and estimated Load

(1) Plan for distribution substations

CEB supplies electricity from a 220kV or 132kV substation to a 33kV (MV) distribution system. In consultation with CEB, existing and new substations of 220kV/MV and 132kV/MV are set as follows.

Table 8-4 Distribution Substations (Existing and Planned)

Division	Province	Grid Substation	Transformer Capacity (MVA)	Remark
1	CC	Kelanitissa	120	
		Kolonnawa (Indoor)	94.5	
		Sub A (Havelock Town)	94.5	
		Sub A2 (Havelock Town)	90	New
		Sub B (Pettah)	94.5	
		Sub C (Kotahena)	94.5	
		Sub E (Kollupitiya)	90	
		Sub F (Fort)	90	
		Sub I (Maradana)	94.5	
		Sub I2 (Maradana)	90	New
		Sub K (Wellawatta)	135	
		Sub L (Port) L1	90	
		Sub L (Port) L2	90	
		Sub M (Slave Island)	90	
		Sub N (Hunupitiya)	90	
		Sub P (Narahenpita)	135	New
		Sub Q (Town Hall)	135	
		Sub R (Port City) R1	189	
		Sub R (Port City) R2	189	
		Sub S (Madampitiya)	135	New

Division	Province	Grid Substation	Transformer Capacity (MVA)	Remark
	NCP	Anuradhapura	94.5	
		Anuradhapura West	135	New
		Habarana	94.5	
		New Anuradhapura	60	
		Polonnaruwa	94.5	
		Polonnaruwa East	63	New
	NP	Chemmani	94.5	
		Chunnakam	94.5	
		Kilinochchi	94.5	
		Mannar	45	
		Vavuniya	63	
2	NWP	Bolawatta	94.5	
		Dummalasuriya	135	New
		Kurunegala	94.5	
		Kurunegala West	135	New
		Madampe	94.5	
		Maho	94.5	
		Pannala	94.5	
		Puttalama	94.5	
		Wariyapola	135	
	CP	Kandy City	94.5	
		Kegalle	94.5	
		Kiribath Kumbura	126	
		Naula	63	
		Nawalapitiya	94.5	
		Nuwara Eliya	94.5	
		Pallekele	63	
		Pallekele East	94.5	New
		Ragala	63	
		Thulhiriya	94.5	
		Thulhiriya East	63	New
		Ukuwela	94.5	
		Wimalasurendra	94.5	
	EP	Ampara	94.5	
		Echalampattu	63	
		Oluvil	63	New
		Kappalthurei	189	
		Kappalthurei North	189	New
		Pottuvil	63	
		Trincomalee	63	
		Valachchenai	63	
		Vavunathivu	63	
	WPN	Aniyakanda	94.5	

Division	Province	Grid Substation	Transformer Capacity (MVA)	Remark
		Biyagama	126	
		Biyagama IPZ	135	New
		Gampaha	135	New
		Katunayaka	94.5	
		Katunayaka 2	135	New
		Kelaniya	63	
		Kerawalapitiya	90	
		Kerawalapitiya North	126	New
		Kirindiwela	94.5	
		Kotugoda	120	
		Kotugoda New	135	
		Meerigama 1	135	New
		Meerigama 2	135	New
		Negombo	135	
		Sapugaskanda	94.5	
		Veyangoda	94.5	
		Yakkala	135	
3	SBP	Balangoda	94.5	
		Embilipitiya	63	
		Kalawana	63	
		Maliboda	63	
		Rathnapura	94.5	
		Wewalwatta	63	
	UP	Badulla	94.5	
		Mahiyanganaya	94.5	
		Monaragala	63	
		Wellawaya	63	
	WPS II	Athurugiriya	94.5	
		Kaduwela	94.5	New
		Battaramulla	135	
		Horana	94.5	
		Horana West 1	135	New
		Horana West 2	135	New
		Kesbewa	94.5	
		Kollonnawa (Outdoor)	63	
		Kosgama	63	
		Oruwala	6.3	
		Padukka	135	
		Pannipitiya	94.5	
		Seethawaka	94.5	
		Sri Jayawardanapura	94.5	
		Udahamulla	189	
4	SP	Ambalangoda	94.5	

Division	Province	Grid Substation	Transformer Capacity (MVA)	Remark
		Baddegama	135	
		Beliatta	63	
		Deniyaya	94.5	
		Galle	94.5	
		Hikkaduwa	135	New
		Hambantota	94.5	
		Hambantota Port	135	
		Hambantota Port 2	189	New
		Hambantota Port 3	189	New
		Matara	94.5	
		Suriyawewa	94.5	
		Tissamaharama	63	
		Weligama	135	
	WPS I	Dehiwala	94.5	
		Mathugama	94.5	
		Mathugama West	135	New
		Moratuwa	135	New
		Kalutara	94.5	
		Panadura	94.5	
		Piliyandala	135	New
		Ratmalana	94.5	
Total Demand				

(Source: JICA Survey Team)

(2) Estimated load of each substation

Based on the load of the substation modeled in the 2037 PSSE data received from CEB, the loads of the 132kV system for 2025, 2030, 2035 and 2040 are estimated by adjusting to the total demand in each year respectively. The estimated load of each substation is shown in Table 8-5.

Table 8-5 Estimated Load of each Substation

Bus Number	Bus Name	2037PSSE base		2025 Day 3.6GW		2025 Night 3.7GW		2030 Day 4.5GW		2030 Night 4.5GW		2035 Day 5.4GW		2035 Night 5.2GW		2040 Day 6.2GW		2040 Night 5.9GW	
		Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)
2027	PS 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2028	PS 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2029	PS 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3010	NEGOMBO-3	110.3	52.1	66.9	31.6	68.6	32.4	82.9	39.1	82.3	38.8	98.7	46.6	95.6	45.1	114.4	54.0	108.7	51.3
3020	MALIBODA-3	6.0	2.8	3.6	1.7	3.7	1.7	4.5	2.1	4.5	2.1	5.4	2.5	5.2	2.4	6.2	2.9	5.9	2.8
3030	WEWALWA-1	17.4	14.1	10.6	8.5	10.8	8.8	13.1	10.6	13.0	10.5	15.6	12.6	15.1	12.2	18.1	14.6	17.2	13.9
3040	MALABE-3	54.6	26.4	33.1	16.0	33.9	16.4	41.0	19.8	40.7	19.7	48.8	23.6	47.3	22.8	56.6	27.4	53.8	26.0
3050	KESBEWA-3	50.2	28.5	30.4	17.3	31.2	17.7	37.7	21.4	37.4	21.2	44.9	25.5	43.5	24.7	52.1	29.5	49.5	28.0
3060	TISSA-3	20.7	4.2	12.5	2.5	12.9	2.6	15.5	3.2	15.4	3.1	18.5	3.8	17.9	3.6	21.5	4.4	20.4	4.1
3120	WIMAL-3	66.0	8.3	40.0	5.0	41.0	5.1	49.6	6.2	49.2	6.2	59.0	7.4	57.2	7.1	68.4	8.6	65.0	8.1
3150	AMPA-3	48.3	46.2	29.3	28.0	30.1	28.7	36.3	34.7	36.0	34.4	43.2	41.3	41.9	40.0	50.1	47.9	47.6	45.5
3155	KALMUNAI-3	18.2	17.2	11.0	10.4	11.3	10.7	13.7	12.9	13.6	12.8	16.3	15.4	15.7	14.9	18.9	17.8	17.9	16.9
3200	UKUWE-3	53.1	20.8	32.2	12.6	33.0	13.0	39.9	15.6	39.6	15.5	47.5	18.6	46.0	18.0	55.1	21.6	52.4	20.5
3220	CHEMMUNI-3	48.4	16.1	29.3	9.8	30.1	10.0	36.3	12.1	36.1	12.0	43.2	14.4	41.9	14.0	50.2	16.7	47.7	15.9
3230	ELUWANKU-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3240	VAVUN-33	31.6	7.9	19.1	4.8	19.6	4.9	23.7	6.0	23.5	5.9	28.2	7.1	27.3	6.9	32.7	8.2	31.1	7.8
3280	MANNAR	19.8	5.0	12.0	3.0	12.3	3.1	14.9	3.7	14.8	3.7	17.7	4.5	17.2	4.3	20.6	5.2	19.5	4.9
3290	KALUT-3	53.7	30.0	32.5	18.2	33.4	18.7	40.3	22.6	40.0	22.4	48.0	26.9	46.5	26.0	55.7	31.2	52.9	29.6
3301	KELAN-3A	40.4	15.8	24.5	9.6	25.1	9.8	30.4	11.9	30.1	11.8	36.1	14.1	35.0	13.7	41.9	16.4	39.8	15.6
3302	KELAN-3B	40.4	15.8	24.5	9.6	25.1	9.8	30.4	11.9	30.1	11.8	36.1	14.1	35.0	13.7	41.9	16.4	39.8	15.6
3305	KERA-3	129.7	62.8	78.6	38.1	80.6	39.1	97.4	47.2	96.7	46.8	116.0	56.2	112.3	54.4	134.5	65.1	127.8	61.9
3320	NAULA-3	7.1	2.9	4.3	1.7	4.4	1.8	5.3	2.2	5.3	2.1	6.3	2.6	6.1	2.5	7.3	3.0	7.0	2.8
3325	DAMBULLA-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3330	MONARA-3	19.6	3.8	11.9	2.3	12.2	2.4	14.7	2.9	14.6	2.8	17.5	3.4	16.9	3.3	20.3	4.0	19.3	3.8
3340	BELIAT-3	50.7	24.8	30.7	15.0	31.5	15.4	38.1	18.6	37.8	18.5	45.4	22.2	43.9	21.5	52.6	25.7	50.0	24.4
3370	WARIYA-1	69.0	30.7	41.8	18.6	42.9	19.1	51.8	23.0	51.5	22.9	61.7	27.4	59.8	26.6	71.6	31.8	68.0	30.2
3380	NAWALAP-1	21.1	11.2	12.8	6.8	13.1	7.0	15.8	8.4	15.7	8.4	18.8	10.0	18.2	9.7	21.8	11.6	20.7	11.1
3390	RAGALA-3	3.8	1.1	2.3	0.7	2.4	0.7	2.9	0.8	2.8	0.8	3.4	1.0	3.3	0.9	4.0	1.1	3.8	1.1
3400	HAMBA-33	67.3	28.8	40.8	17.5	41.9	17.9	50.6	21.6	50.2	21.5	60.2	25.7	58.3	24.9	69.8	29.9	66.4	28.4
3405	HAMB PORT	34.5	18.6	20.9	11.3	21.4	11.6	25.9	14.0	25.7	13.9	30.8	16.6	29.8	16.1	35.7	19.3	34.0	18.3
3411	KALAWANA-3	19.8	15.6	12.0	9.4	12.3	9.7	14.9	11.7	14.8	11.6	17.7	13.9	17.2	13.5	20.6	16.1	19.5	15.3
3420	HORANA_3	60.6	26.3	36.7	16.0	37.7	16.4	45.5	19.8	45.2	19.6	54.2	23.5	52.5	22.8	62.9	27.3	59.7	25.9
3440	KATUNA-3	69.8	33.3	42.3	20.2	43.4	20.7	52.4	25.0	52.0	24.8	62.4	29.7	60.4	28.8	72.4	34.5	68.8	32.8
3450	MAHO-3	47.2	13.5	28.6	8.2	29.3	8.4	35.4	10.1	35.2	10.1	42.2	12.1	40.9	11.7	48.9	14.0	46.5	13.3
3460	POLON-3	45.4	20.3	27.5	12.3	28.2	12.6	34.1	15.3	33.8	15.2	40.6	18.2	39.3	17.6	47.1	21.1	44.7	20.0
3470	VAUNAT-3	58.1	20.5	35.2	12.4	36.1	12.7	43.7	15.4	43.3	15.3	52.0	18.3	50.4	17.7	60.3	21.3	57.3	20.2
3480	KAPPAL-3	64.6	15.4	39.2	9.3	40.2	9.6	48.5	11.5	48.2	11.5	57.8	13.7	56.0	13.3	67.0	15.9	63.7	15.1
3490	PALLEK-3	57.0	27.6	34.5	16.8	35.4	17.2	42.8	20.8	42.5	20.6	50.9	24.7	49.3	23.9	59.1	28.7	56.1	27.2
3500	KOSGA-3	38.8	19.9	23.5	12.0	24.2	12.4	29.2	14.9	29.0	14.8	34.7	17.8	33.6	17.2	40.3	20.6	38.3	19.6
3510	SITHA-33	53.3	25.2	32.3	15.3	33.1	15.7	40.0	18.9	39.7	18.8	47.7	22.5	46.2	21.8	55.3	26.1	52.5	24.8
3520	NUWAR-3	22.2	6.6	13.4	4.0	13.8	4.1	16.7	4.9	16.5	4.9	19.8	5.9	19.2	5.7	23.0	6.8	21.9	6.5
3525	WELIMADA-3	2.0	0.6	1.2	0.3	1.2	0.4	1.5	0.4	1.5	0.4	1.8	0.5	1.7	0.5	2.1	0.6	2.0	0.6
3530	THULH-3	71.6	40.0	43.4	24.3	44.5	24.9	53.8	30.1	53.4	29.8	64.0	35.8	62.0	34.7	74.3	41.5	70.6	39.4
3535	KEGA-3	67.1	39.2	40.7	23.7	41.7	24.4	50.4	29.4	50.0	29.2	60.0	35.0	58.1	33.9	69.6	40.6	66.1	38.6
3540	ORUWA-3	6.2	1.3	3.8	0.8	3.9	0.8	4.7	0.9	4.6	0.9	5.6	1.1	5.4	1.1	6.4	1.3	6.1	1.2
3550	KOLON-3A	70.3	31.0	42.6	18.8	43.7	19.3	52.8	23.3	52.4	23.1	62.9	27.8	60.9	26.9	72.9	32.2	69.3	30.6
3551	KOLON-3B	35.7	22.2	21.6	13.4	22.2	13.8	26.8	16.6	26.6	16.5	31.9	19.8	30.9	19.2	37.0	23.0	35.2	21.8
3560	PANNI-3	52.2	40.9	31.6	24.8	32.5	25.5	39.2	30.7	38.9	30.5	46.7	36.6	45.2	35.5	54.1	42.5	51.4	40.3
3571	BIYAG-33-2	73.3	40.1	44.4	24.3	45.6	24.9	55.1	30.1	54.7	29.9	65.6	35.9	63.5	34.7	76.0	41.6	72.2	39.5
3575	BIYAG_ZONE-	64.1	42.1	38.9	25.5	39.9	26.2	48.2	31.6	47.8	31.4	57.4	37.6	55.5	36.4	66.5	43.6	63.2	41.5
3581	KOTU_NEW_3	42.3	27.9	25.6	16.9	26.3	17.4	31.8	21.0	31.5	20.8	37.8	25.0	36.6	24.2	43.9	29.0	41.7	27.5
3582	KOTUG-33-3	88.5	55.9	53.6	33.9	55.0	34.7	66.5	42.0	66.0	41.7	79.1	50.0	76.6	48.4	91.8	58.0	87.2	55.1
3590	SAPUG-3A	72.8	48.0	44.1	29.1	45.2	29.9	54.6	36.1	54.2	35.8	65.1	43.0	63.0	41.6	75.5	49.8	71.7	47.3
3600	BOLAW-3	73.4	32.0	44.5	19.4	45.6	19.9	55.1	24.0	54.7	23.8	65.6	28.6	63.6	27.7	76.1	33.1	72.3	31.5
3610	POTTUVIL-3	17.9	16.9	10.8	10.2	11.1	10.5	13.4	12.7	13.3	12.6	16.0	15.1	15.5	14.6	18.6	17.5	17.6	16.7
3620	BADUL-3	27.1	5.3	16.4	3.2	16.9	3.3	20.4	4.0	20.2	3.9	24.2	4.7	23.5	4.6	28.1	5.5	26.7	5.2
3630	BALAN-3	33.0	27.5	20.0	16.7	20.5	17.1	24.8	20.6	24.6	20.5	29.5	24.6	28.6	23.8	34.2	28.5	32.5	27.1
3635	KAHAWATTA	6.0	5.0	3.6	3.0	3.7	3.1	4.5	3.7	4.4	3.7	5.3	4.4	5.2	4.3	6.2	5.1	5.9	4.9
3640	DENIY-3	63.1	22.7	38.2	13.8	39.2	14.1	47.4	17.1	47.0	16.9	56.4	20.3	54.6	19.7	65.4	23.6	62.2	22.4
3650	GALLE-3	62.4	46.4	37.8	28.1	38.8	28.8	46.8	34.8	46.5	34.6	55.8	41.5	54.0	40.2	64.7	48.1	61.5	45.7
3655	WELI-3	64.8	39.7	39.2	24.1	40.3	24.7	48.6	29.8	48.3	29.6	57.9	35.5	56.1	34.4	67.2	41.2	63.8	39.1

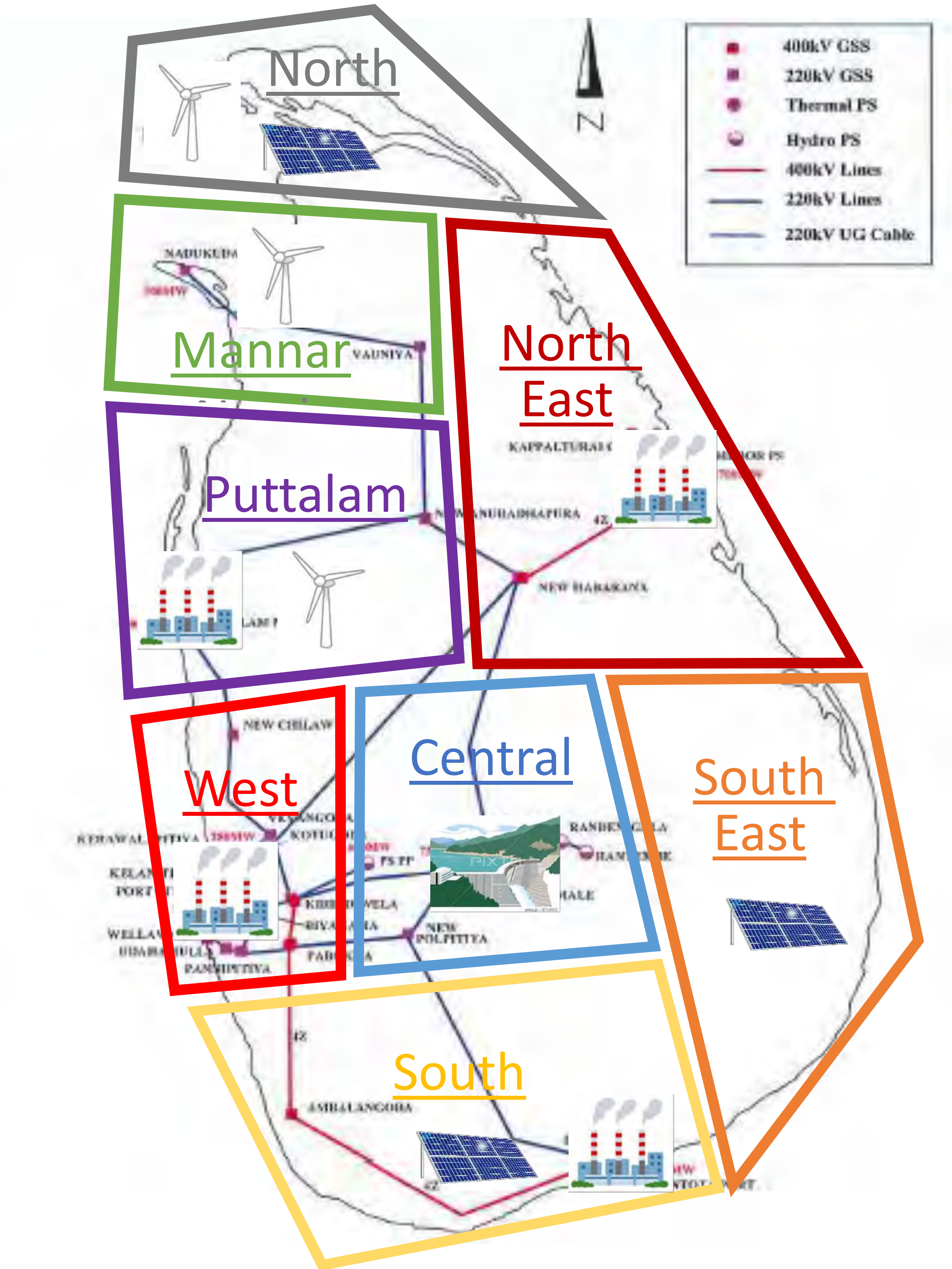
Bus Number	Bus Name	2037PSSE base		2025				2030				2035				2040			
				Day 3.6GW		Night 3.7GW		Day 4.5GW		Night 4.5GW		Day 5.4GW		Night 5.2GW		Day 6.2GW		Night 5.9GW	
		Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)	Pload (MW)	Qload (Mvar)
3660	EMBIL-3	47.9	21.3	29.1	12.9	29.8	13.2	36.0	16.0	35.7	15.9	42.9	19.0	41.5	18.4	49.7	22.1	47.2	21.0
3670	MATARA-3	70.8	36.3	42.9	22.0	44.0	22.6	53.2	27.2	52.8	27.0	63.4	32.4	61.4	31.4	73.5	37.6	69.8	35.8
3680	KURUN-3	68.7	31.0	41.6	18.8	42.7	19.3	51.6	23.3	51.2	23.1	61.4	27.8	59.5	26.9	71.2	32.2	67.7	30.6
3690	HABAR-3	62.7	28.3	38.0	17.2	39.0	17.6	47.1	21.3	46.7	21.1	56.0	25.3	54.3	24.5	65.0	29.4	61.7	27.9
3700	ANURA-3A	53.2	13.5	32.2	8.2	33.1	8.4	39.9	10.1	39.6	10.0	47.5	12.0	46.0	11.7	55.1	14.0	52.4	13.3
3705	NEWANU-3	41.9	10.6	25.4	6.4	26.0	6.6	31.5	8.0	31.2	7.9	37.5	9.5	36.3	9.2	43.4	11.0	41.3	10.5
3710	TRINC-3	36.4	8.2	22.0	5.0	22.6	5.1	27.3	6.2	27.1	6.1	32.5	7.4	31.5	7.1	37.7	8.5	35.8	8.1
3711	SERUNUWAR/	5.0	1.2	3.1	0.7	3.1	0.7	3.8	0.9	3.8	0.9	4.5	1.1	4.4	1.0	5.2	1.2	5.0	1.2
3720	KILINOCH_3	31.8	33.4	19.3	20.3	19.8	20.8	23.9	25.1	23.7	24.9	28.5	29.9	27.6	29.0	33.0	34.7	31.4	32.9
3730	CHUNNAKAM	33.4	11.8	20.3	7.1	20.8	7.3	25.1	8.8	24.9	8.8	29.9	10.5	28.9	10.2	34.7	12.2	32.9	11.6
3740	RATNAP-3	28.0	23.3	17.0	14.1	17.4	14.5	21.0	17.5	20.9	17.4	25.0	20.8	24.2	20.2	29.0	24.2	27.6	23.0
3770	KIRIB-3	93.1	50.5	56.4	30.6	57.9	31.4	69.9	38.0	69.4	37.7	83.2	45.2	80.6	43.8	96.5	52.4	91.7	49.8
3780	VALACH_3	54.2	19.1	32.8	11.6	33.7	11.9	40.7	14.3	40.4	14.2	48.4	17.1	46.9	16.5	56.2	19.8	53.4	18.8
3790	RATMA-3A	64.2	33.8	38.9	20.5	39.9	21.0	48.2	25.4	47.9	25.2	57.4	30.2	55.6	29.3	66.6	35.1	63.3	33.3
3800	MATUG-3	47.8	23.4	29.0	14.2	29.7	14.5	35.9	17.5	35.6	17.4	42.7	20.9	41.4	20.2	49.5	24.2	47.1	23.0
3810	PUTTA-3	43.3	19.8	26.3	12.0	26.9	12.3	32.5	14.8	32.3	14.7	38.8	17.7	37.5	17.1	44.9	20.5	42.7	19.5
3820	ATURU-3	70.2	34.0	42.6	20.6	43.7	21.1	52.7	25.5	52.4	25.4	62.8	30.4	60.8	29.5	72.8	35.3	69.2	33.5
3825	KOTADENIY-3	47.2	28.2	28.6	17.1	29.4	17.5	35.5	21.2	35.2	21.0	42.2	25.2	40.9	24.4	49.0	29.3	46.5	27.8
3830	VEYAN-33	70.4	31.2	42.6	18.9	43.8	19.4	52.8	23.4	52.5	23.3	62.9	27.9	60.9	27.0	73.0	32.4	69.3	30.7
3835	MIRIGAMA-3	59.6	26.2	36.1	15.9	37.0	16.3	44.7	19.7	44.4	19.5	53.3	23.4	51.6	22.7	61.8	27.2	58.7	25.8
3840	JPURA_3	60.7	36.1	36.8	21.9	37.8	22.5	45.6	27.1	45.3	26.9	54.3	32.3	52.6	31.3	63.0	37.5	59.8	35.6
3841	UDAHA-33	57.8	39.4	35.1	23.9	36.0	24.5	43.4	29.6	43.1	29.4	51.7	35.3	50.1	34.2	60.0	40.9	57.0	38.9
3850	PANAD-3	65.9	37.0	40.0	22.4	41.0	23.0	49.5	27.8	49.1	27.6	58.9	33.1	57.1	32.0	68.4	38.4	65.0	36.4
3860	MADAM-3	66.0	29.5	40.0	17.9	41.0	18.4	49.6	22.2	49.2	22.0	59.0	26.4	57.2	25.6	68.5	30.6	65.1	29.1
3865	KIRIYANKAL-	57.6	26.2	34.9	15.9	35.8	16.3	43.2	19.7	42.9	19.5	51.5	23.4	49.9	22.7	59.7	27.1	56.7	25.8
3870	K-NIYA-3	45.4	23.3	27.5	14.1	28.2	14.5	34.1	17.5	33.8	17.4	40.6	20.9	39.3	20.2	47.0	24.2	44.7	23.0
3880	AMBALA	45.9	31.2	27.8	18.9	28.5	19.4	34.4	23.4	34.2	23.2	41.0	27.9	39.7	27.0	47.6	32.3	45.2	30.7
3882	BADDE-33	85.2	62.4	51.6	37.8	53.0	38.8	64.0	46.9	63.5	46.5	76.2	55.8	73.8	54.1	88.3	64.7	83.9	61.5
3890	DEHIW_3	56.9	35.0	34.5	21.2	35.4	21.7	42.7	26.3	42.4	26.1	50.9	31.3	49.3	30.3	59.0	36.3	56.1	34.5
3900	PANNAL	68.0	41.4	41.2	25.1	42.3	25.7	51.1	31.1	50.7	30.8	60.8	37.0	58.9	35.8	70.5	42.9	67.0	40.7
3910	ANIYA	64.0	36.7	38.8	22.2	39.8	22.8	48.1	27.5	47.7	27.3	57.3	32.8	55.5	31.8	66.4	38.0	63.1	36.1
3930	SURI'WEWA-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3941	WELLAWA-3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3950	YAKKALA3	99.9	57.1	60.5	34.6	62.1	35.5	75.0	42.9	74.4	42.5	89.3	51.0	86.5	49.4	103.6	59.2	98.4	56.2
3960	MAHIYA-3	20.7	7.6	12.5	4.6	12.9	4.7	15.5	5.7	15.4	5.7	18.5	6.8	17.9	6.6	21.5	7.9	20.4	7.5
3971	HOMAGAMA-3	90.5	32.9	54.9	19.9	56.3	20.5	68.0	24.7	67.5	24.5	80.9	29.4	78.4	28.5	93.9	34.1	89.2	32.4
3975	MILLEWA-3	21.2	9.0	12.9	5.5	13.2	5.6	15.9	6.8	15.8	6.7	19.0	8.1	18.4	7.8	22.0	9.4	20.9	8.9
3976	MILLANIYA-3	22.9	9.7	13.9	5.9	14.2	6.0	17.2	7.3	17.0	7.2	20.4	8.7	19.8	8.4	23.7	10.1	22.5	9.6
3991	KIRIN-3	68.7	35.3	41.6	21.4	42.7	21.9	51.6	26.5	51.2	26.3	61.4	31.5	59.5	30.5	71.2	36.6	67.7	34.7
4190	COL_K_11	95.9	38.3	58.1	23.2	59.6	23.8	72.0	28.7	71.5	28.5	85.7	34.2	83.0	33.1	99.4	39.7	94.5	37.7
4260	COL-N-11	48.6	21.9	29.5	13.3	30.2	13.6	36.5	16.5	36.2	16.4	43.5	19.6	42.1	19.0	50.4	22.8	47.9	21.6
4270	COL-M-11	56.2	25.2	34.1	15.3	34.9	15.7	42.2	18.9	41.9	18.8	50.2	22.5	48.7	21.8	58.3	26.1	55.4	24.8
4351	COL-L1-11	54.4	33.7	33.0	20.4	33.8	21.0	40.9	25.3	40.6	25.1	48.7	30.2	47.1	29.2	56.4	35.0	53.6	33.2
4352	COL-L2-11	54.4	33.7	33.0	20.4	33.8	21.0	40.9	25.3	40.6	25.1	48.7	30.2	47.1	29.2	56.4	35.0	53.6	33.2
4356	PORT CITY R1	149.7	80.8	90.7	49.0	93.1	50.2	112.4	60.7	111.6	60.2	133.9	72.3	129.6	70.0	155.3	83.8	147.5	79.6
4357	PORT CITY R2	149.7	80.8	90.7	49.0	93.1	50.2	112.4	60.7	111.6	60.2	133.9	72.3	129.6	70.0	155.3	83.8	147.5	79.6
4360	COL-Q-11	64.7	27.6	39.2	16.8	40.2	17.2	48.6	20.8	48.2	20.6	57.9	24.7	56.0	23.9	67.1	28.7	63.8	27.2
4365	COL-P-11	98.2	40.7	59.5	24.6	61.1	25.3	73.8	30.5	73.2	30.3	87.8	36.4	85.1	35.2	101.9	42.2	96.8	40.1
4430	COL_I_11	69.4	27.5	42.1	16.7	43.1	17.1	52.1	20.7	51.7	20.5	62.0	24.6	60.1	23.8	72.0	28.5	68.4	27.1
4435	COL_A_11	62.9	25.8	38.1	15.6	39.1	16.0	47.2	19.4	46.9	19.2	56.2	23.0	54.5	22.3	65.2	26.7	62.0	25.4
4445	KATU_LECO-1	45.2	21.4	27.4	12.9	28.1	13.3	34.0	16.0	33.7	15.9	40.4	19.1	39.2	18.5	46.9	22.1	44.6	21.0
4750	COL_E-11	67.8	27.0	41.1	16.3	42.1	16.8	50.9	20.2	50.5	20.1	60.6	24.1	58.7	23.4	70.3	28.0	66.8	26.6
4760	COL_F-11	66.3	29.2	40.2	17.7	41.2	18.2	49.8	21.9	49.4	21.8	59.2	26.1	57.4	25.3	68.7	30.3	65.3	28.8
4771	KANDY CIT-1	28.0	14.9	17.0	9.1	17.4	9.3	21.0	11.2	20.9	11.1	25.0	13.4	24.3	12.9	29.0	15.5	27.6	14.7
4845	RAJAGIRIY-11	66.8	41.5	40.5	25.1	41.5	25.8	50.1	31.1	49.8	30.9	59.7	37.1	57.8	35.9	69.3	43.0	65.8	40.8
4875	JAELA_LECO	49.0	31.0	29.7	18.8	30.5	19.3	36.8	23.3	36.6	23.1	43.9	27.7	42.5	26.8	50.9	32.1	48.3	30.5
4920	COL-C-11	60.7	23.9	36.8	14.5	37.8	14.8	45.6	17.9	45.3	17.8	54.3	21.3	52.6	20.7	63.0	24.7	59.9	23.5
4980	COL_B_11	71.7	31.7	43.5	19.2	44.6	19.7	53.9	23.8	53.5	23.6	64.2	28.3	62.1	27.4	74.4	32.9	70.7	31.2
TOTAL		5999	2996	3636	1816	3730	1863	4505	2250	4472	2233	5365	2679	5196	2595	6222	3107	5911	2952

(Source: JICA Survey Team)

8.3.4 Feature of Power Sources to be developed in each Area

As indicated in Figure 8-4, according to the development plan, the areas are divided into eight, and each area has a distinctive feature of power source developed.

The north and north-western (Mannar, Puttalam) region is marked by strong wind. Thus, development of a renewable energy plant such as a wind farm is expected. In the Puttalam area of the north-western region, large-scale coal fired TPP has already been developed. In the north-eastern region, although the plan for the Sampoor coal-fired power plant is on hold, the potential is high as a candidate for a thermal power plant and it is a promising area. In the central region, many hydropower stations have already been developed, and development of a large-scale pumped-storage power plant is expected. In the southern region, there are expectations of not only a development plan for a thermal power plant in Hambantota, but also renewable energy generation such as biomass, and solar power. In addition, development of solar power generation is expected in the south-eastern region. In the western region, where Colombo is located, many oil-fired power plants have already been constructed, but there is a plan to develop a large-scale LNG thermal power plant. The load currents are flowing into Colombo, where electricity consumption is enormous, from the generators in each area.



(Source: JICA Survey Team)

Figure 8-4 Illustration of Power Generation Development

The area-wise installed capacity in 2025 and 2040 is shown below.

Table 8-6 Area-wise Installed Capacity (2025)

(Scenario A: 2025) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	26	0	0	84	45	0	155
Mannar	0	0	0	0	0	145	15	4	164
North East	1,200	0	0	0	0	15	30	9	1,253
Puttalam	900	0	0	0	0	158	15	7	1,080
West	0	1,200	105	0	75	0	30	4	1,415
Central	0	0	0	1,539	392	17	30	13	1,991
South	0	0	0	90	35	17	75	4	221
South East	0	0	0	11	0	0	60	2	73
Total	2,100	1,200	131	1,640	503	434	300	44	6,352

(Scenario B: 2025) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	26	0	0	122	75	0	223
Mannar	0	0	0	0	0	360	25	4	389
North East	0	0	0	0	0	34	50	9	93
Puttalam	900	0	0	0	0	246	25	7	1,178
West	0	1,800	105	0	75	0	50	4	2,035
Central	0	0	0	1,539	392	36	50	13	2,031
South	0	300	0	90	35	36	125	4	591
South East	0	0	0	11	0	0	100	2	113
Total	900	2,100	131	1,640	503	834	500	44	6,652

(Scenario C: 2025) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	26	0	0	85	75	0	186
Mannar	0	0	0	0	0	235	25	4	264
North East	900	0	0	0	0	22	50	9	980
Puttalam	900	0	0	0	0	186	25	7	1,118
West	0	1,500	105	0	75	0	50	4	1,735
Central	0	0	0	1,539	392	24	50	13	2,018
South	0	0	0	90	35	24	125	4	278
South East	0	0	0	11	0	0	100	2	113
Total	1,800	1,500	131	1,640	503	574	500	44	6,692

(Source: JICA Survey Team)

Table 8-7 Area-wise Installed Capacity (2040)

(Scenario A: 2040) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	0	0	0	172	225	0	397
Mannar	0	0	0	0	0	440	75	10	525
North East	1,800	0	0	0	0	44	150	21	2,015
Puttalam	900	0	0	0	0	276	75	16	1,267
West	0	1,200	105	0	105	0	150	10	1,571
Central	0	0	0	1,539	548	46	150	31	2,315
South	1,200	0	0	90	49	46	375	10	1,771
South East	0	0	0	11	0	0	300	5	316
Total	3,900	1,200	105	1,640	703	1,024	1,500	104	10,176

(Scenario B: 2040) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	0	0	0	602	300	0	902
Mannar	0	0	0	0	0	1,960	100	10	2,070
North East	0	0	0	0	0	194	200	21	415
Puttalam	900	0	0	0	0	886	100	16	1,902
West	0	2,100	105	0	105	0	200	10	2,521
Central	0	0	0	2,139	548	196	200	31	3,115
South	0	1,200	0	90	49	196	500	10	2,046
South East	0	0	0	11	0	0	400	5	416
Total	900	3,300	105	2,240	703	4,034	2,000	104	13,386

(Scenario C: 2040) (MW)

	Coal	LNG	Oil	Hydro	M-Hydro	Wind	Solar	Biomass	Total
North	0	0	0	0	0	302	300	0	602
Mannar	0	0	0	0	0	960	100	10	1,070
North East	1,200	0	0	0	0	94	200	21	1,515
Puttalam	900	0	0	0	0	476	100	16	1,492
West	0	1,500	105	0	105	0	200	10	1,921
Central	0	0	0	2,139	548	96	200	31	3,015
South	600	300	0	90	49	96	500	10	1,646
South East	0	0	0	11	0	0	400	5	416
Total	2,700	1,800	105	2,240	703	2,024	2,000	104	11,676

(Source: JICA Survey Team)

8.3.5 Area-wise Generated Electricity

Regarding the power development planning, as described in Chapter 7, there are three scenarios, Scenario A to C. Considering the power generation situation for renewable energy, the JICA Survey Team executes 2 cases of analysis on each scenario, where the amount of electricity generation is extremely small (cloudy and weak wind, April) and extremely large (sunny and strong wind, August). The JICA Survey Team examines the development plan for every five years from the year 2025.
The area-wise generated electricity in each scenario is shown below.

Table 8-8 Area-wise Generated Electricity

(Scenario A) (MW)

	2025			2030			2035			2040		
	Installed	April	August	Installed	April	August	Installed	April	August	Installed	April	August
North	155	31	116	215	43	164	311	65	241	397	76	318
Mannar	164	15	132	254	24	203	373	37	299	525	53	420
North East	1,133	989	1,015	1,170	1,000	1,044	1,228	1,017	1,091	1,835	1,522	1,468
Puttalam	1,005	760	886	1,050	768	840	1,114	779	891	1,192	791	953
West	1,385	592	623	1,427	766	709	1,445	981	633	1,505	1,191	592
Central	1,991	1,215	781	2,108	1,251	835	2,207	1,282	895	2,315	1,314	962
South	221	100	123	840	609	615	1,508	1,132	1,147	1,651	1,173	1,260
South East	73	27	54	124	43	95	215	71	168	316	102	249
Total	6,127	3,730	3,730	7,187	4,505	4,505	8,401	5,365	5,365	9,735	6,222	6,222

(Scenario B) (MW)

	2025			2030			2035			2040		
	Installed	April	August	Installed	April	August	Installed	April	August	Installed	April	August
North	223	42	171	448	72	351	673	102	531	902	120	722
Mannar	389	29	312	916	63	733	1,443	97	1,155	2,070	136	1,656
North East	93	24	74	197	44	157	301	65	241	415	86	332
Puttalam	1,103	768	965	1,331	787	817	1,559	807	999	1,827	829	1,214
West	1,981	1,095	1,130	2,048	935	843	1,783	1,122	573	2,419	1,770	652
Central	2,031	1,376	659	2,815	1,902	887	2,960	1,936	830	3,115	1,970	454
South	579	356	329	1,051	630	546	1,807	1,133	785	1,998	1,176	859
South East	113	41	91	214	71	171	315	102	252	416	133	333
Total	6,511	3,730	3,730	9,019	4,505	4,505	10,841	5,365	5,365	13,161	6,222	6,222

(Scenario C) (MW)

	2025			2030			2035			2040		
	Installed	April	August	Installed	April	August	Installed	April	August	Installed	April	August
North	186	40	141	328	66	242	478	92	362	602	105	482
Mannar	264	23	212	516	43	413	793	65	635	1,070	86	856
North East	890	752	793	967	771	854	1,316	1,034	945	1,395	1,053	1,008
Puttalam	1,043	765	917	1,161	779	846	1,289	794	948	1,417	809	1,051
West	1,693	774	734	1,760	872	723	1,783	1,058	580	1,843	1,268	716
Central	2,018	1,222	649	2,775	1,746	975	2,895	1,779	1,051	3,015	1,812	768
South	278	116	196	435	158	282	860	442	593	1,574	957	1,009
South East	113	39	89	214	70	170	315	101	251	416	132	332
Total	6,485	3,730	3,730	8,155	4,505	4,505	9,729	5,365	5,365	11,331	6,222	6,222

Note: Installed capacity of the thermal power plants excludes in-house consumption. (Source: JICA Survey Team)

8.3.6 Transmission Development Plan in 2040 corresponding to each Power Development Scenario

Based on the 2037 PSSE data provided by CEB, the JICA Survey Team set up the 2040 network system model corresponding to the power development scenarios A, B and C. The JICA Survey Team conducts power flow calculations and examined the system plan for each scenario up to 2040.

(1) Scenario A (High priority on cost)

The system configuration and power flow for 2040 in Scenario A is shown in Figure 8-5 (April with low renewable energy power generation) and Figure 8-6 (August with large amount of renewable energy generation). In Scenario A, the generation output from Sampoor coal-fired TPP is large. The main transmission lines required for the 400kV, 220kV system from 2017 to 2040 are as follows.

- In order to transmit power generated by Sampoor coal-fired TPP, a new 400kV transmission line is developed between Sampoor - New Habarana.
- A 400kV transmission line is newly developed between New Habarana - Kirindiwela depending on the increase in power flow from Sampoor coal-fired TPP.
  - For part of this section, New Habarana-Kotmale, it is expected to be difficult to secure the right of way for the route. In this case, it is necessary to consider that the route of the existing 220kV transmission line may be used for the new 400kV transmission line.
- In order to cope with increase in power flow due to the expansion of the Kerawalapitiya TPP, 1 circuit of 220kV cable from the Kerawalapitiya TPP to the center of Colombo city is added.
- A 220kV transmission line between Kerawalapitiya TPP - Kirindiwela is newly developed.

(2) Scenario B (High priority on renewable energy development with CO_2 reduction)

The system configuration and power flow for 2040 in Scenario B is shown in Figure 8-7 and Figure 8-8. In Scenario B, the generation output from windpower and solar power in the northern part of Sri Lanka is large. The main transmission lines required for the 400kV, 220kV system from 2017 to 2040 are as follows.

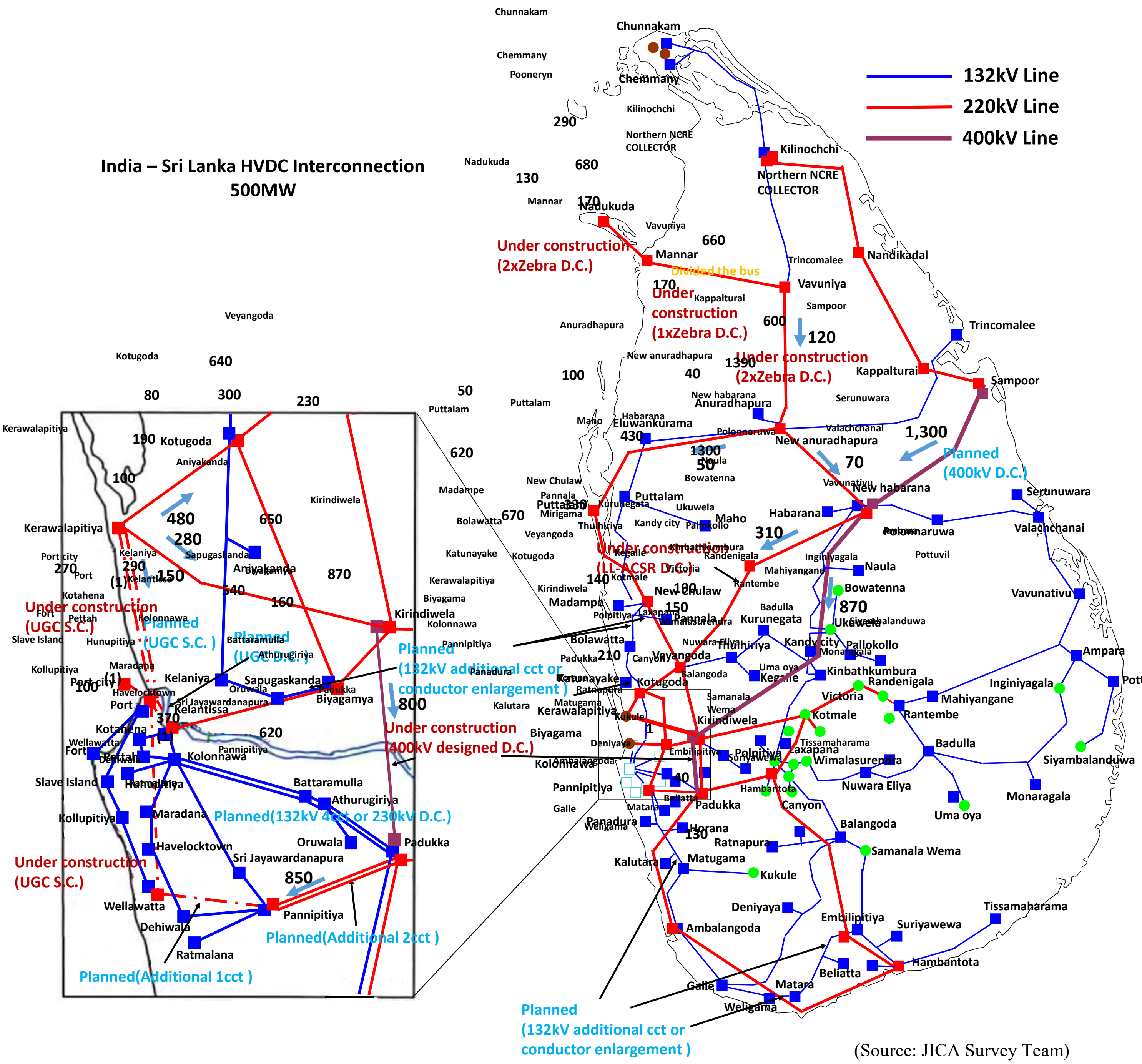
- Due to the increase in power flow due to the windpower and solar power in the northern area, four circuits of 220kV transmission lines between Vavuniya-New Anuradhapura-New Habarana are added.
- A 400kV transmission line is newly developed between New Habarana – Kirindiwela.
- 2 circuits of 220kV transmission line between Euwnkurama-Puttalam-New Chulaw-Veyangoda-Kelanitissa are added
- In order to cope with increase in power flow due to the expansion of the Kerawalapitiya TPP, 1 circuit of 220kV cable from the Kerawalapitiya TPP to the center of Colombo city is added.
- A 220kV or 400kV transmission line between Kerawalapitiya TPP - Kirindiwela is newly developed.

(3) Scenario C (Mixed power supply development)

The system configuration and power flow for 2040 in Scenario C is shown in Figure 8-9 and Figure 8-10. The main transmission lines required for the 400kV, 220kV system from 2017 to 2040 are as follows.

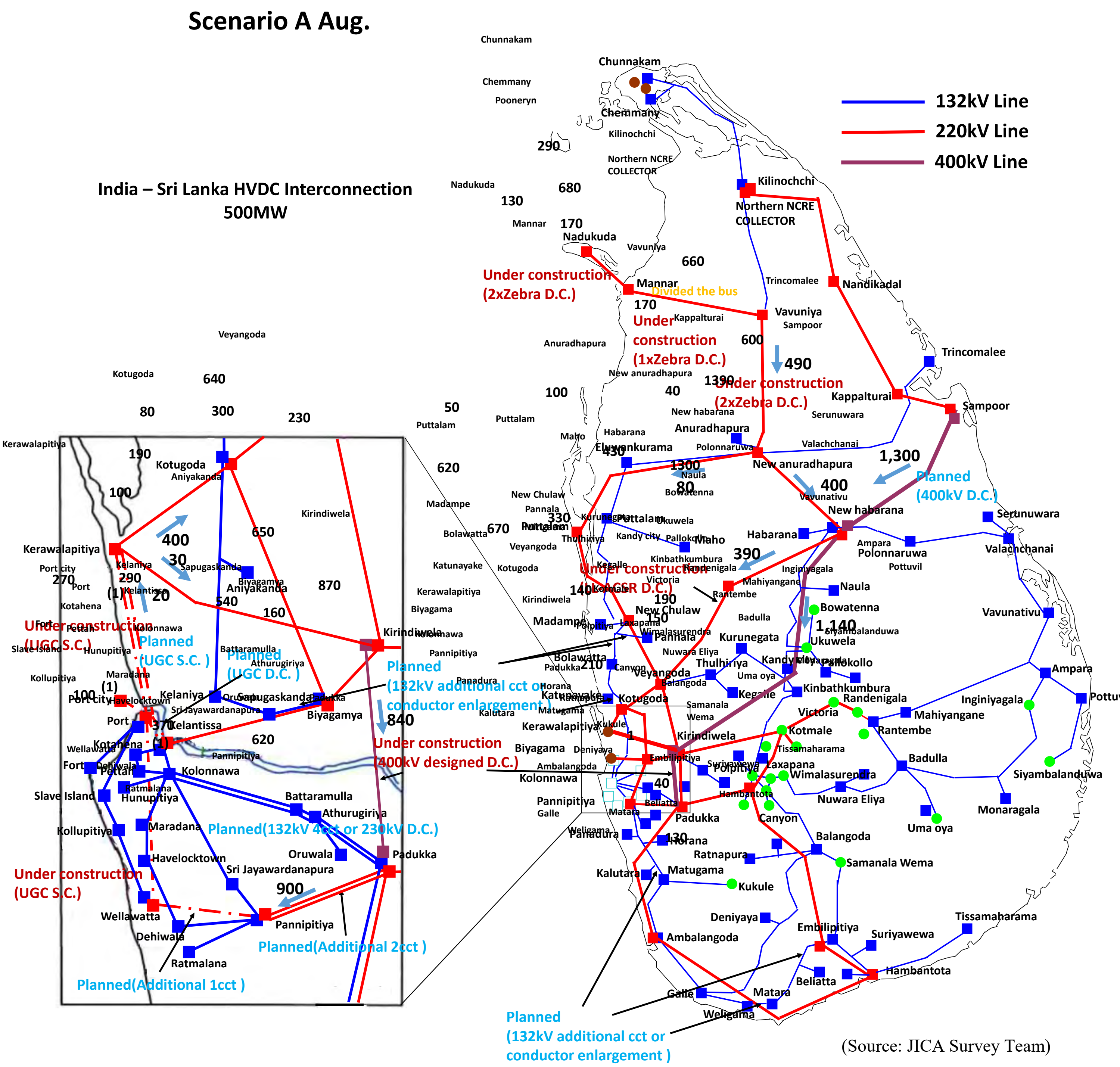
- In order to transmit power generated by Sampoor coal-fired TPP, a new 400kV transmission line is developed between Sampoor - New Habarana.
- A 400kV transmission line is newly developed between New Habarana - Kirindiwela depending on the increase in power flow from Sampoor coal-fired TPP and renewable energies in the northern area.
- In order to cope with increase in power flow due to the expansion of the Kerawalapitiya TPP, 1 circuit of 220kV cable from the Kerawalapitiya TPP to the center of Colombo city is added.
- A 220kV transmission line between Kerawalapitiya TPP - Kirindiwela is newly developed.

Scenario A Apr.



(Source: JICA Survey Team)

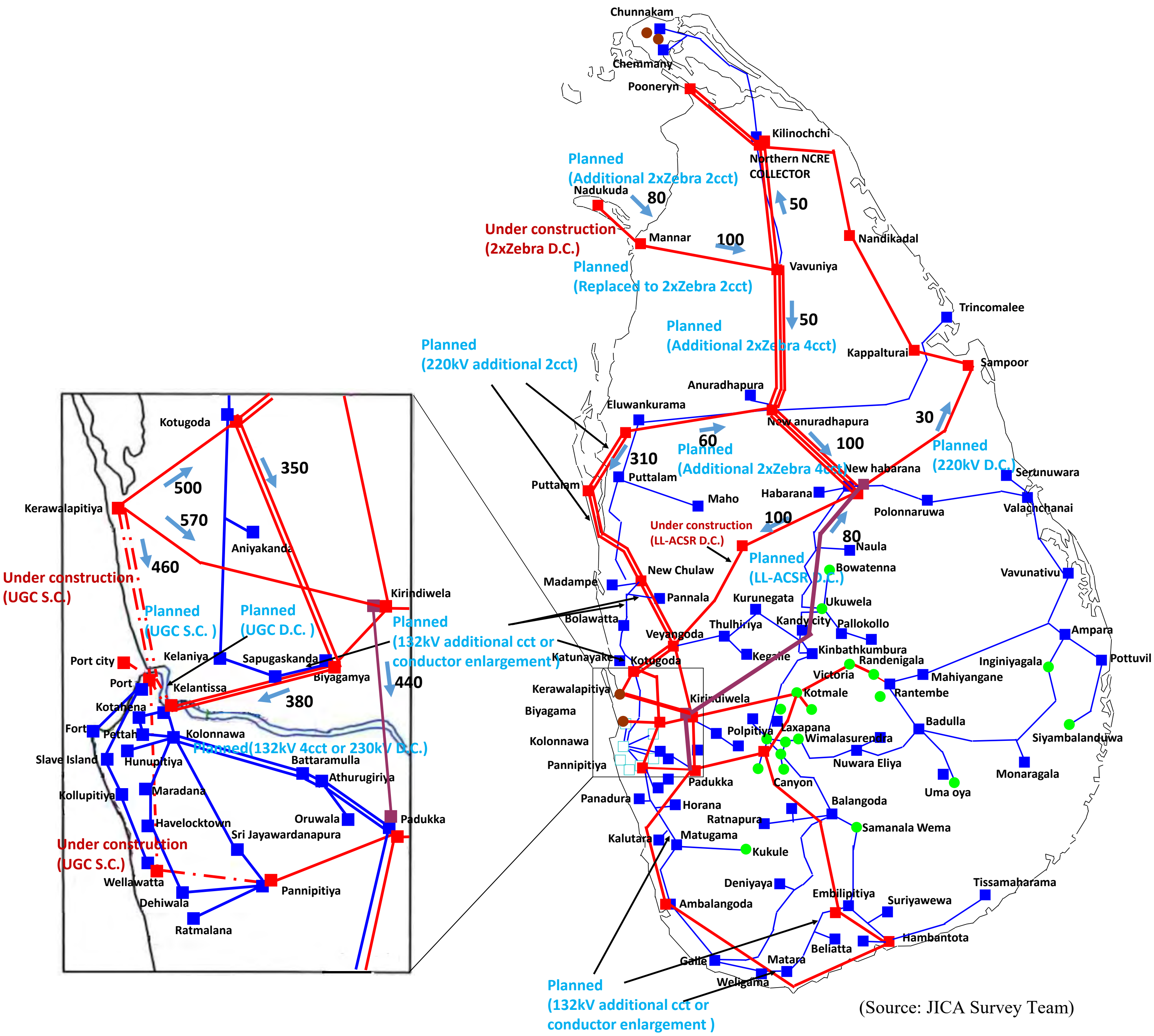
Figure 8-5 System Configuration in Scenario A (Power Flow in April 2040)



(Source: JICA Survey Team)

Figure 8-6 System Configuration in Scenario A (Power Flow in August 2040)

Scenario B Apr.



(Source: JICA Survey Team)

Figure 8-7 System Configuration in Scenario B (Power Flow in April 2040)

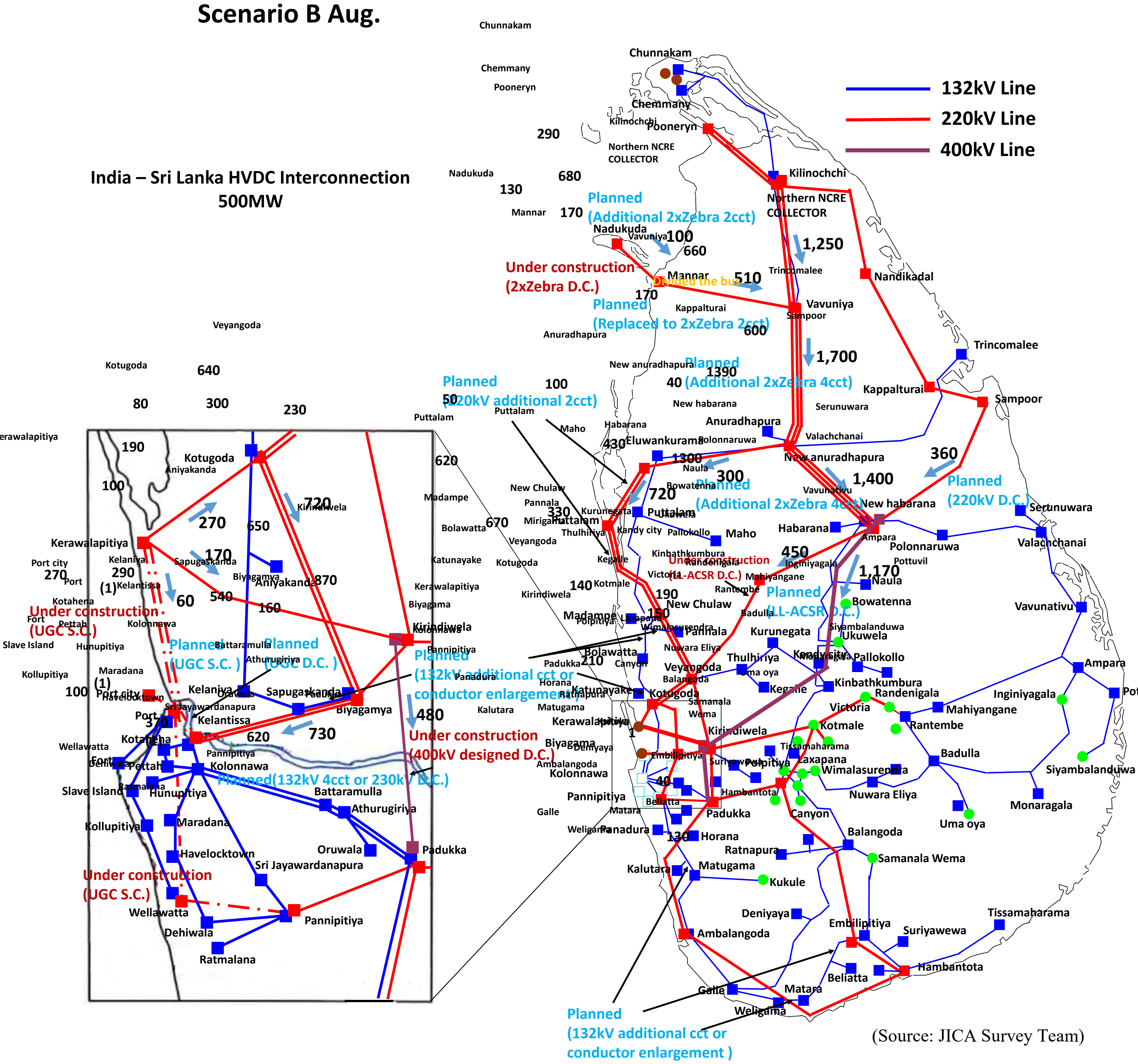
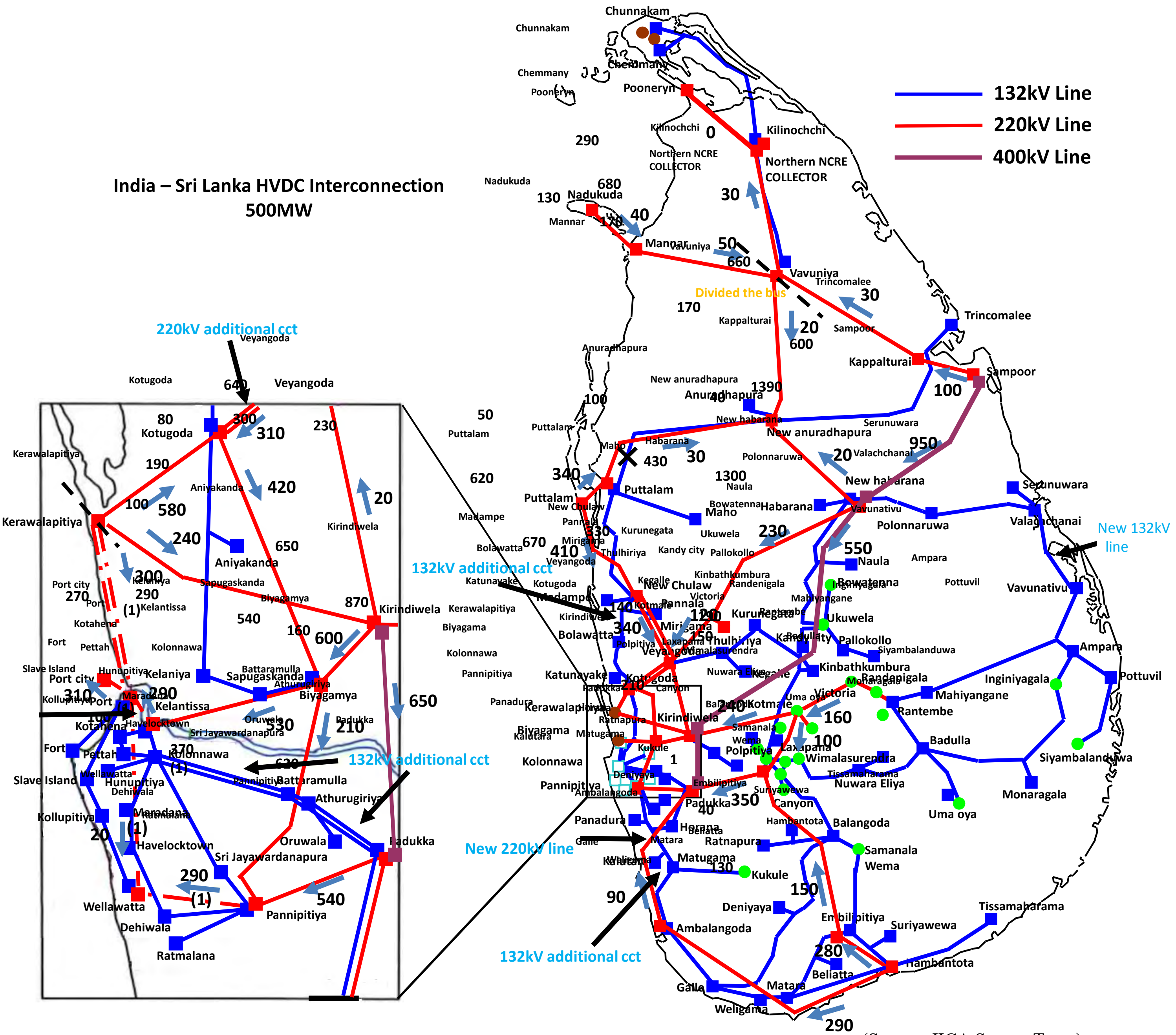


Figure 8-8 System Configuration in Scenario B (Power Flow in August 2040)

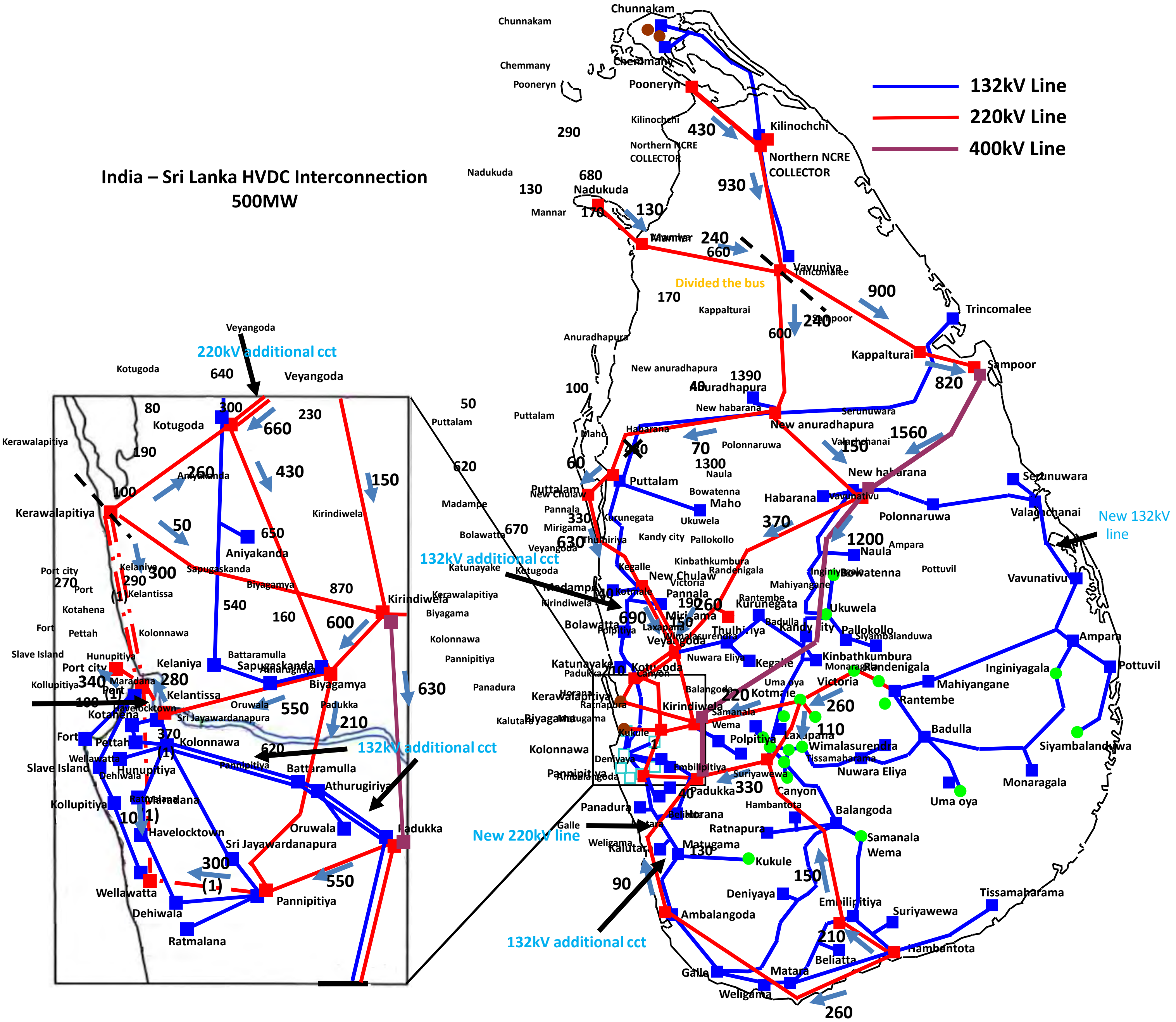
Scenario C Apr.



(Source: JICA Survey Team)

Figure 8-9 System Configuration in Scenario C (Power Flow in April 2040)

Scenario C Aug.



(Source: JICA Survey Team)

Figure 8-10 System Configuration in Scenario C (Power Flow in August 2040)

8.4 Proposed Basic Transmission System Development Plan

In consultation with CEB, a power transmission development plan for every 5 years from 2025 to 2035 is examined based on Scenario C.
The development plan for large thermal power plants is as follows. In consideration of the test operation period, it is necessary to start operation of the transmission line one year before the power generation operation starts.

Table 8-9 Development Plan for large TPP

	Kerawalapitiya	Sampoor	Hambantota
Existing	300MW	-	-
By the year 2025	300MW x 3	300MW x 3	-
By the year 2030	-	300MW x 1	-
By the year 2035	300MW x 1	-	300MW x 2
By the year 2040	-	-	300MW x 1

(Source: JICA Survey Team)

Renewable energies are developed gradually across the whole country, for example in the northern part of Kilinochchi.

8.4.1 Power Transmission Development Plan for every 5 Year

(1) By the year 2025

- In order to transmit power generated by Sampoor coal-fired TPP, a new 400kV transmission line is developed between Sampoor - New Habarana.
- To transmit power from renewable energy, such as windpower developed in the north of Kilinochchi, a 220kV transmission line using a large capacity wire between Pooneryn - Kilinochchi - Vavuniya is developed.

(2) By the year 2030

- In order to transmit the power from renewable energy developed in the north of Kilinochchi via the 400kV Sampoor - New Habarana transmission line, a 220kV transmission line using a large capacity wire between Vavuniya - Kappalturai is developed. In addition, when windpower development in Mannar increases, it will be necessary to examine rewiring of the 220kV transmission line between Mannar - Vavuniya.
- A 400kV transmission line is newly developed between New Habarana - Kirindiwela depending on the increase in power flow from Sampoor coal-fired TPP and renewable energies in the northern area.

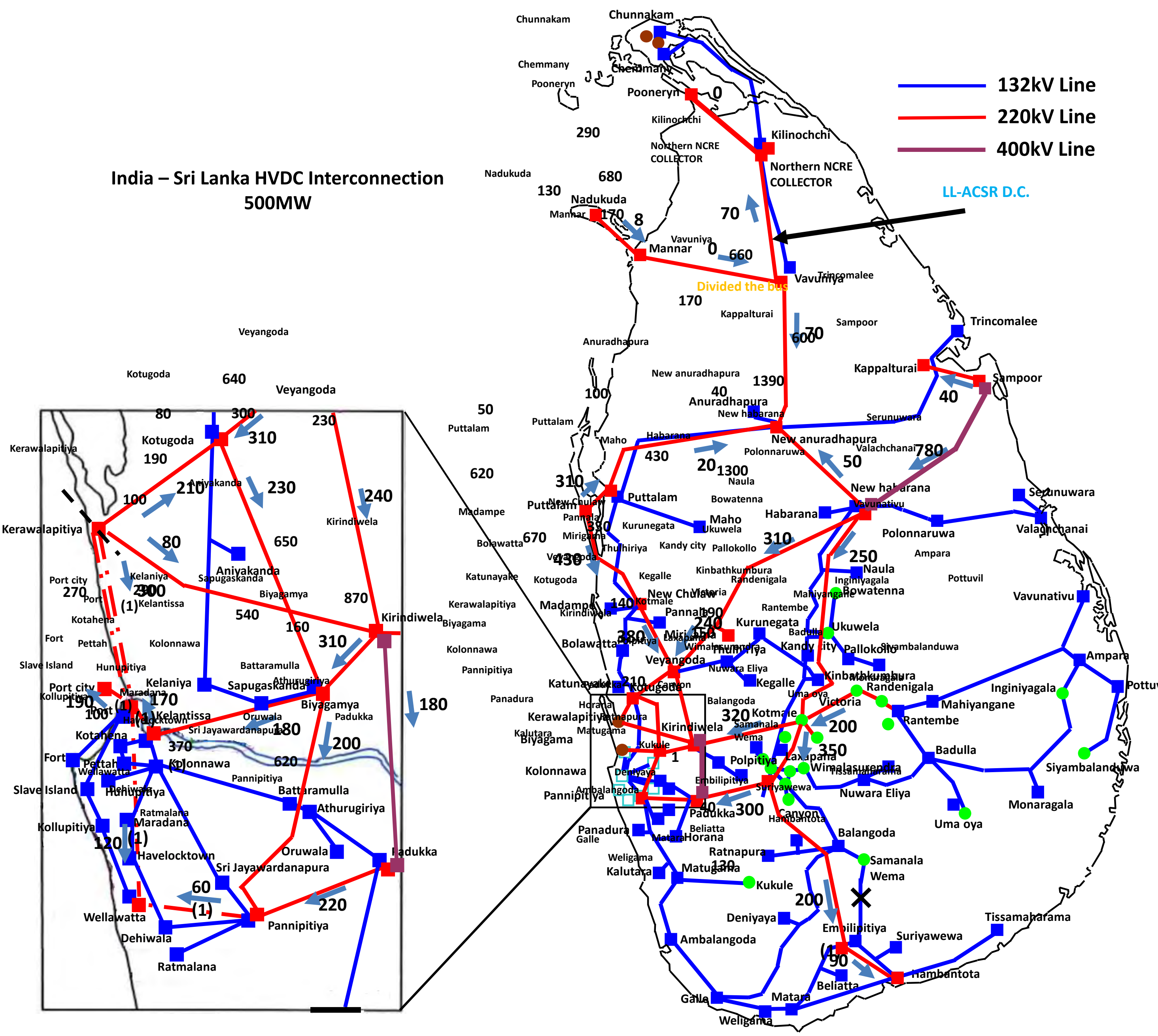
(3) By the year 2035

In order to transmit the power from renewable energy developed in the north of Kilinochchi, the capacity of the 220kV transmission line between Kappalturai - Sampoor is enlarged via rewiring or rebuilding.

In order to avoid a heavy current flow between Vavuniya-New Anuradhapura-New Habarana due to the increase in power transmitted from renewable energy in Kilinochchi, the busbar in Vavuniya is separated and the power from Kilinochchi is transmitted towards only Sampoor.

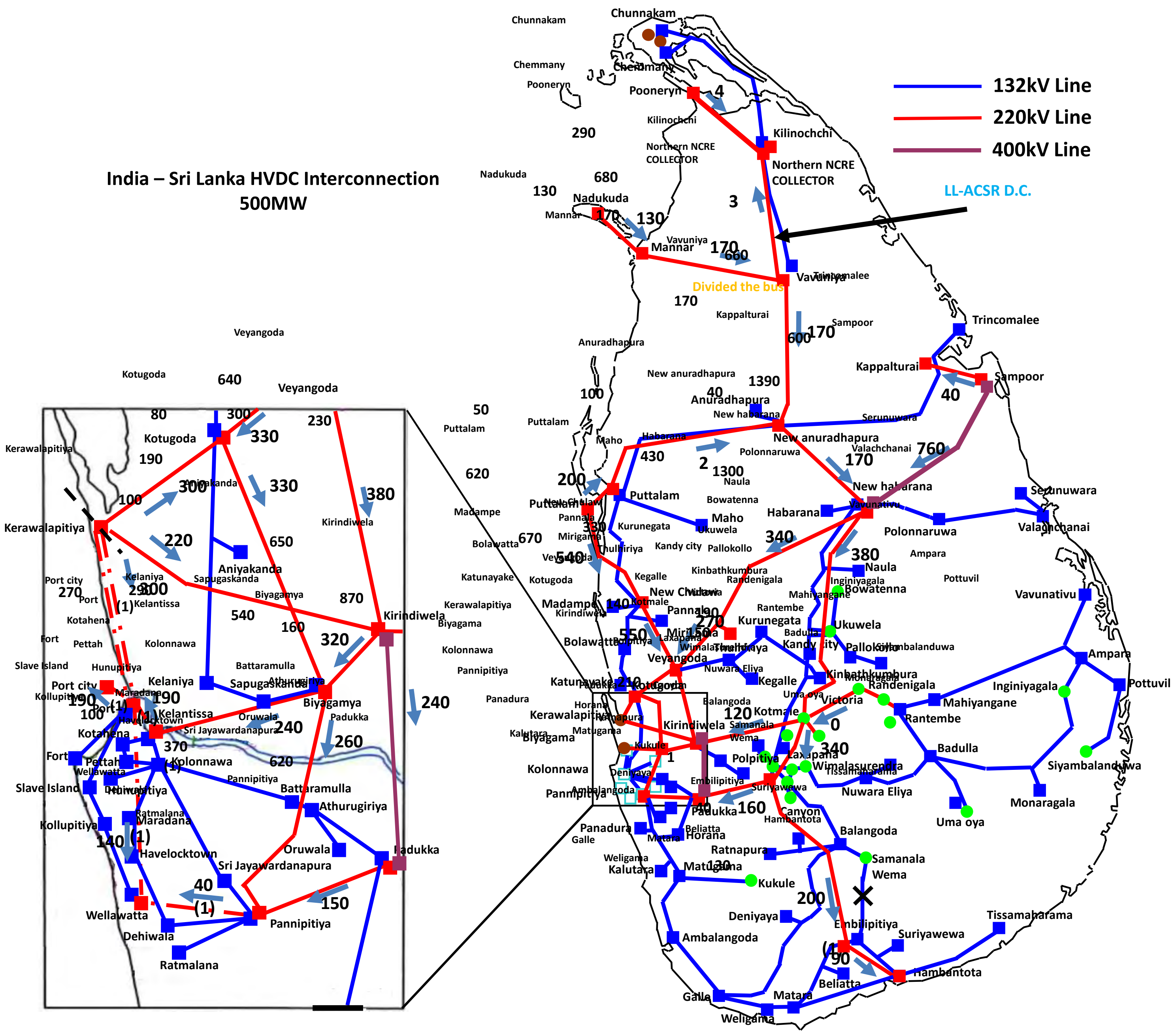
In addition, since the power flow supplied to the northern part from the Puttalam TPP decreases and the power flow towards the Colombo center increases, as a countermeasure, a line is added to the 220kV transmission line between New Chulaw-Veyangoda, or rewiring work is carried out.

The transmission line required due to the enhancement of the Kerawalapitiya TPP is described later.



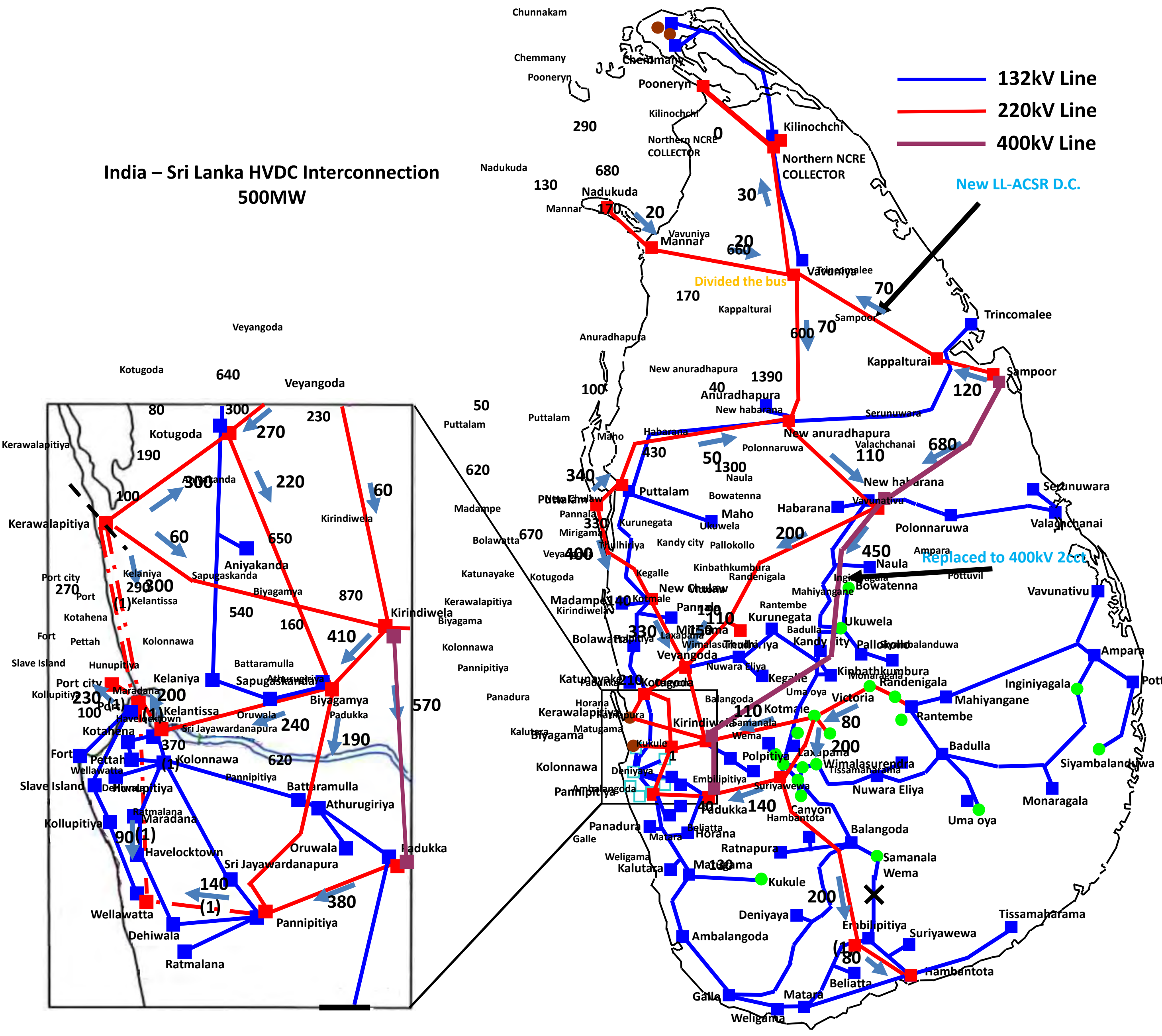
(Source: JICA Survey Team)

Figure 8-11 System Configuration in Scenario C (Power Flow in April 2025)



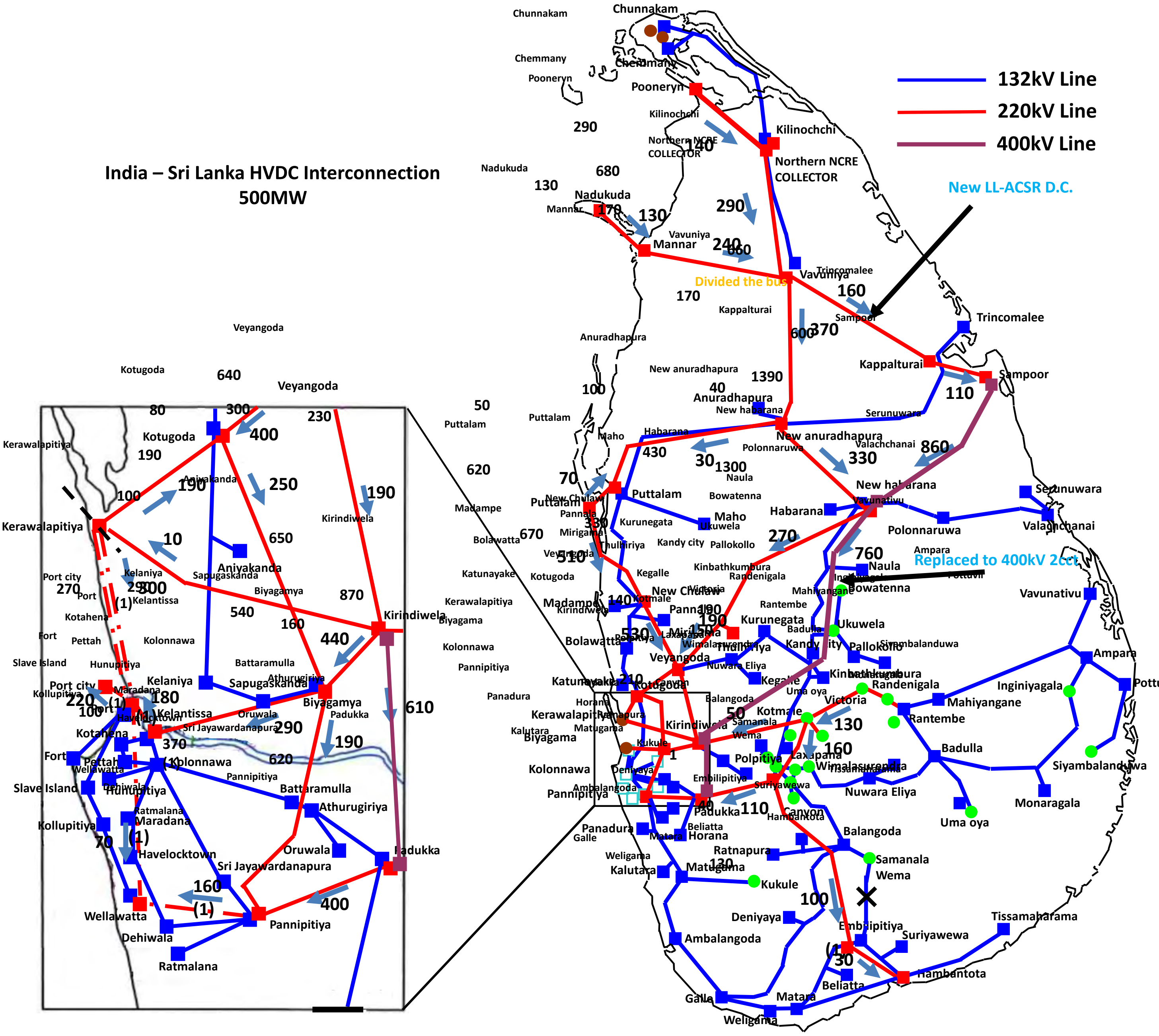
(Source: JICA Survey Team)

Figure 8-12 System Configuration in Scenario C (Power Flow in August 2025)



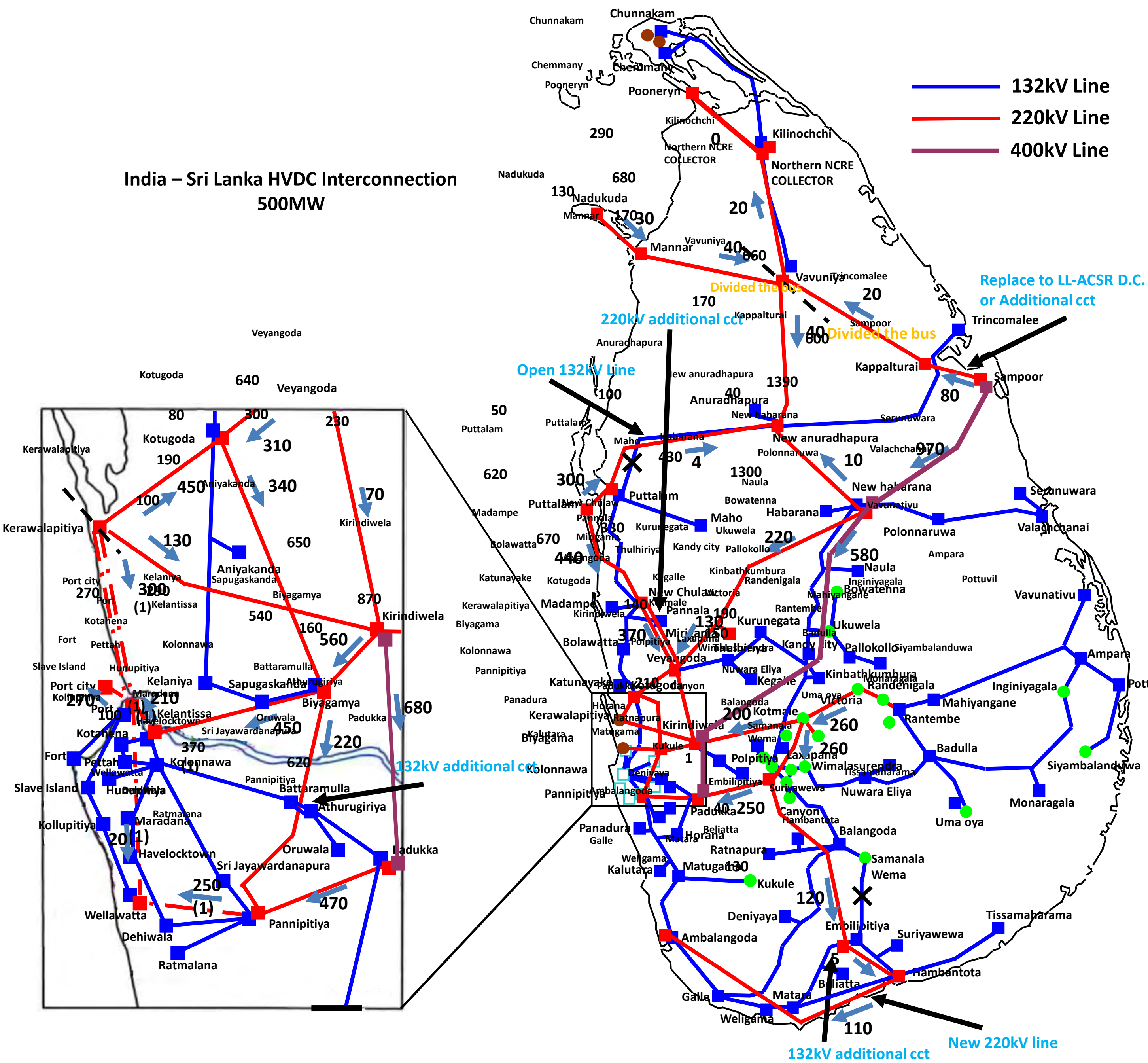
(Source: JICA Survey Team)

Figure 8-13 System Configuration in Scenario C (Power Flow in April 2030)



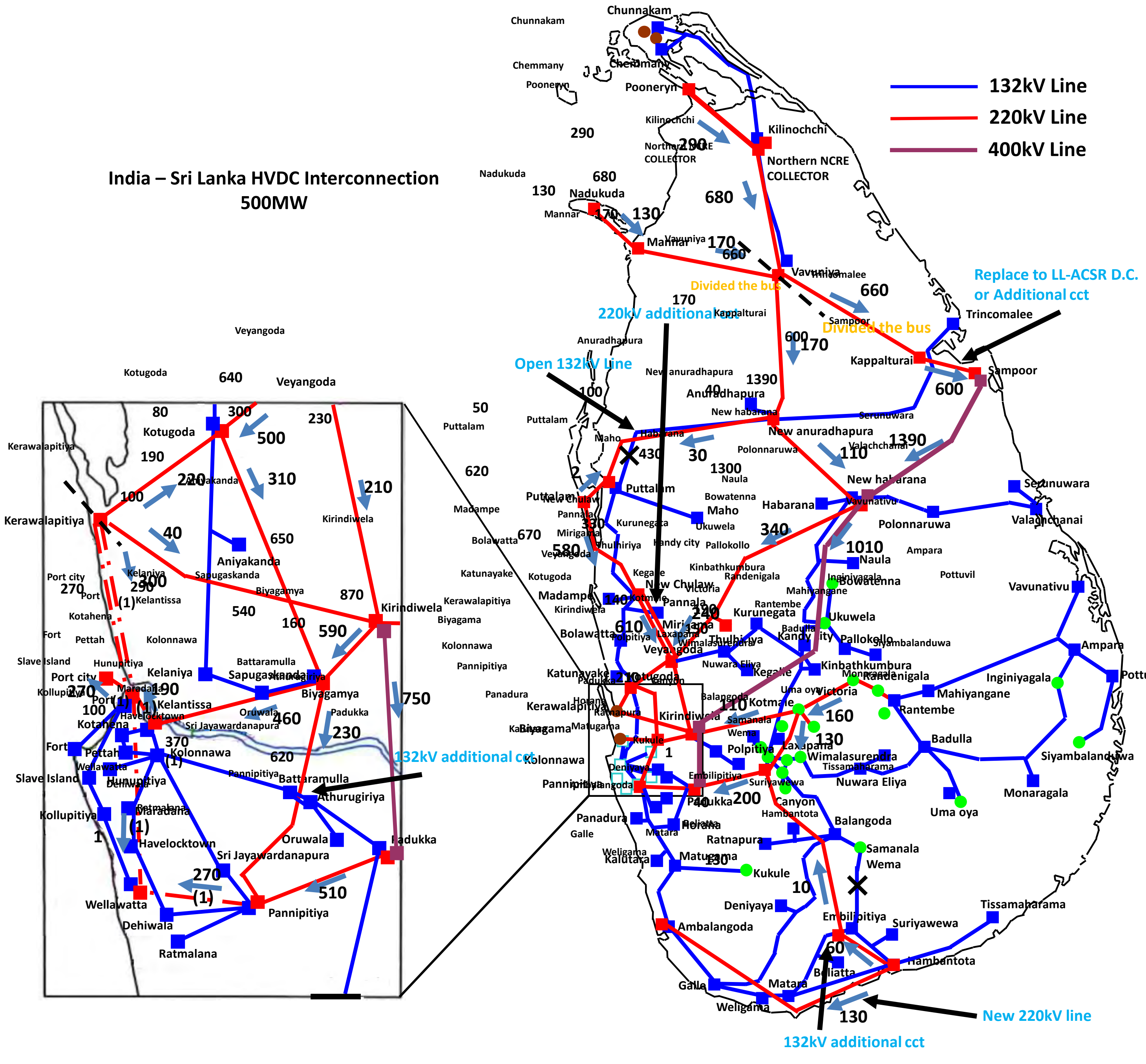
(Source: JICA urvey Team)

Figure 8-14 System Configuration in Scenario C (Power Flow in August 2030)



(Source: JICA Survey Team)

Figure 8-15 System Configuration in Scenario C (Power Flow in April 2035)



(Source: JICA Survey Team)

Figure 8-16 System Configuration in Scenario C (Power Flow in August 2035)

8.4.2 System Status when the Output of a large Power Plant is the Maximum

The power plants of Kerawalapitiya, Hambantota, and Sampoor are far away in the west, the south, and the east of the national land, and when their respective outputs are at maximum, the output of other power plants is suppressed, and the power flow changes dramatically. Therefore, the impact of the power flow on the whole system is examined in each case.
The simulation results are shown below.

Table 8-10 System Status when the Output of a large Power Plant is at Maximum

Impact Study (2040 Aug)

	case1	case2	case3
Kerewalapitiya	1500MW	1100MW	800MW
Puttalam	825MW	550MW	550MW
Hambantota	0MW	900MW	0MW
Sampoor	200MW	0MW	1200MW
overload T/L (normal condition)	Biyagama=Kotugoda (220kV)	Non	Non
overload T/L (n−1 contingency)	Biyagama=Kotugoda Kelantissa=Biyagama (220kV)	Weligama=Matara (132kV)	Kilantissa=Biyagama (220kV)

(Source: JICA Survey Team)

The place where the overloading under normal conditions occurs is between Biyagama and Kotugoda. As shown in the results of the examination of the transmission line around the Kerawalapitiya power station described later, it is possible to cope with this issue by increasing line capacity. In addition, 220kV Kelanitissa-Biyagama, and 132kV Weligama-Matara are overloaded at N-1 contingency. Regarding these sections, measures must be taken in terms of by increasing line capacity, constructing a new line, or operation by limiting the maximum output of the abovementioned power plants.

8.4.3 Fault Current

The three-phase short circuit fault currents of the 400kV and 220kV buses of the Sri Lanka electric power system in Scenario C are shown in Table 8-11.

Calculations are carried out under the following conditions.
- Automatic sequencing fault calculation function of PSSE is used.
- Impedance of the generator is set to the subtransient reactance Xd", and the voltage behind the generator is calculated at 1 PU.
- All generators installed in the system in each year are being operated.

In each year, the three phase short circuit fault current is within the specified 40kA or less. The maximum value is 39.9kA for the Kirindiwela 220kV bus in 2040, which is just under 40kA. However, in fact, since all of the installed generators do not operate at the same time, it is sufficiently below 40 kA, and there is no problem.
The maximum value of the three phase short circuit fault current of the 132kV bus is 27.6kA at the Kolonawa bus bar in 2030.

Therefore, the fault current for the Sri Lanka system is at a level where there is no problem.

Table 8-11 Three-Phase Short Circuit Fault Currents in the Sri Lanka System

Bus Name	Voltage (kV)	Year				Bus Name	Voltage (kV)	Year			
		2025	2030	2035	2040			2025	2030	2035	2040
KIRIND-4	400	10.4	16.7	18.5	19.4	MIRI-D1	220	18.3	21.3	23.0	24.0
NEWHAB	400	9.4	14.8	15.8	16.3	MIRIGAMA-2	220	18.5	21.5	23.2	24.2
PADUKKA	400	10.2	15.3	16.9	17.8	NADUKUDA-2	220	5.1	6.1	6.3	5.8
PSPP400	400	-	15.9	17.1	17.7	NCHILAW-2	220	16.2	21.8	23.4	24.3
SAMPOOR	400	8.8	12.5	14.0	14.2	N-COLLECT	220	5.4	8.4	12.2	11.5
AMBALANGODA	220	-	-	7.3	15.9	NEWANU-2	220	13.6	19.6	21.9	20.4
BIYAG-2	220	23.4	29.6	33.0	34.6	NEW-POLP 2	220	20.5	24.1	26.2	26.7
COL_K_220	220	19.4	23.5	25.4	27.1	NHAB-2	220	18.5	24.7	26.4	26.8
COL-L-2	220	20.2	24.4	26.3	28.6	PADUKKA-2	220	20.4	27.1	29.7	32.7
EMBILIPITIYA	220	6.6	9.9	14.0	15.9	PANNI-2	220	21.1	26.7	29.2	30.9
HAMBA-2	220	5.5	9.3	16.5	19.9	POONERYN	220	4.6	7.0	9.9	10.2
KALLADI	220	17.1	20.1	21.0	21.5	PORT CITY R1	220	19.9	24.0	25.9	28.1
KAPPAL-1	220	6.5	7.3	13.3	11.6	PUTTALAM-PS	220	18.4	21.4	22.3	22.7
KELAN-2	220	21.3	26.0	28.3	29.9	RAGALA_IB-2	220	17.7	19.2	20.1	20.5
KERAWALA_2	220	17.5	20.3	21.5	23.0	RANDE-2	220	13.1	14.2	14.7	15.0
KERAWALA_3	220	18.2	20.5	32.3	33.5	RANTE-2	220	13.2	14.3	14.8	15.1
KILINOCHCHI	220	5.4	8.4	12.2	11.5	SAMPOOR-1	220	10.0	12.2	16.0	17.5
KIRIND-2	220	24.0	32.2	38.4	39.9	UDAHA-2	220	19.9	24.5	26.6	28.1
KOTADENIY-2	220	12.9	14.3	15.1	15.5	UPPER-KOTH-2	220	14.9	15.7	16.4	16.5
KOTMA-2	220	23.4	25.6	27.6	28.1	VADAMARA	220	4.3	6.0	7.7	7.4
KOTUG-2	220	22.6	27.2	32.3	35.1	VAUNIYA-2	220	8.7	12.1	16.9	10.2
MANNAR S	220	4.7	5.6	5.8	5.3	VEYAN-2	220	24.0	29.9	33.6	36.0
MANNAR-2	220	5.7	7.1	7.5	6.6	VICTO-2	220	16.7	18.1	18.9	19.2

(Source: JICA Survey Team)

8.4.4 System Stability at major Transmission Line Accident

(1) Stability of power system

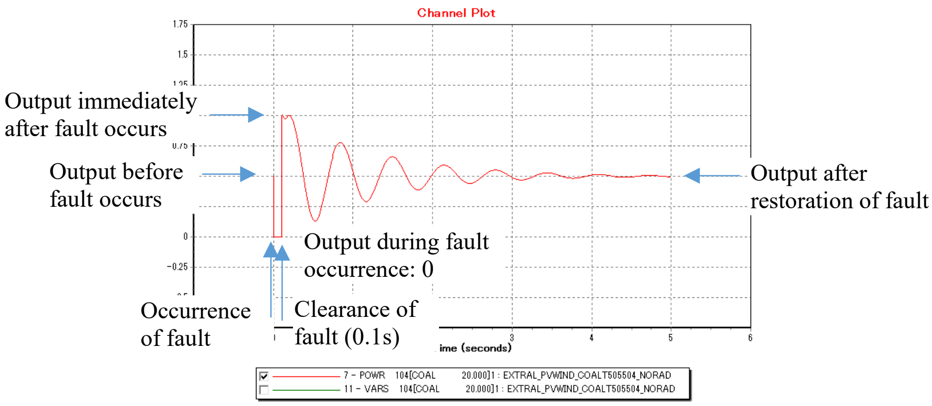
(a) Stability

An electric power system is required to be able to continue to supply stable power even if a disturbance such as a transmission line fault occurs in the system. Generators are required to continue operation while maintaining synchronization. After the clearance of the fault by the protection relay, the output and rotation speed of the generator, which will fluctuate due to the disturbance, usually converges to the value before the fault via the synchronizing power of the power system. However, for long-distance transmission lines that do not have a sufficient number of lines and voltage for the power flow, the reactance of the transmission line increases, the internal phase angle of the generator widens, and the synchronization power is not maintained. Even after the disturbance is stopped, the synchronous operation of the generator may not be recovered. In this case, the generator causes a step-out phenomenon and is separated from the electric power system in order to protect it.

In this section, the stability of the power system model in Sri Lanka is calculated. Stability analysis is generally carried out by simulating the situation after occurrence of a three-phase short circuit fault of a transmission line for a few seconds. Specifically, after releasing the fault transmission line and clearing the fault at a specified time, it is checked whether or not vibrations such as the active power output and the internal phase angle of the generator have been eliminated.

(b) General response of synchronous generators during a system failure

When a short circuit fault or a ground fault occurs in the transmission line near the generator, the surrounding voltage instantaneously drops and the active power output of the connected generator becomes almost zero. While the fault continues, the active power output becomes zero, but the generator is accelerated by the continuously supplied input energy. When the fault is cleared by the system's protection relays, the system voltage recovers instantaneously and power is again supplied from the generator. At this time, due to the acceleration of the generator, the internal phase angle of the generator widens, and active power that is larger than that before the occurrence of the fault is output. After the clearance of the fault, the fluctuation of the output continues, but usually it will fall within the output before the occurrence of the fault, due to the synchronizing power of the generator and the power system.



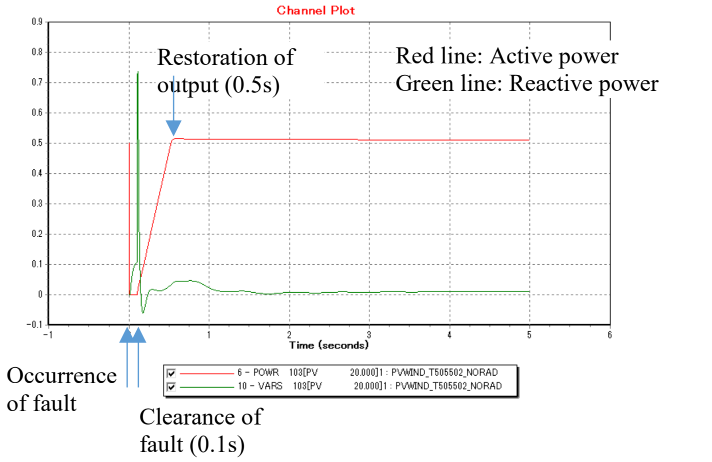
(Source: JICA Survey Team)

Figure 8-17 Response of Synchronous Generators during a System Failure

(c) General response of windpower and solar power generators during a system failure

Solar power generators and almost all windpower generators are connected to a system via an AC/DC converter. If the AC voltage drops to nearly zero due to a fault in the power system or the like, the AC/DC converter stops because it cannot convert the power. However, when the fault on the AC side is cleared and the voltage returns, the operation starts again and it normally returns to the original operation state.

The figure below shows examples of fluctuations in active power (red line) and reactive power (green line) for solar power generation during a system failure. The restoration of output power is carried out after some time to protect the AC/DC converter. Immediately after the system failure, the voltage approaches nearly zero and the active power output becomes zero, but after the clearance of the fault, the active power output is restored in about 0.3 to 0.4 seconds. In addition, the reactive power is close to zero during normal operation, but shows a large value immediately after recovery of the voltage of the power system, after the clearance of the failure.



(Source: JICA Survey Team)

Figure 8-18 Response of Solar Power Generators during a System Failure

(2) Conditions of the stability analysis for Sri Lankan power system

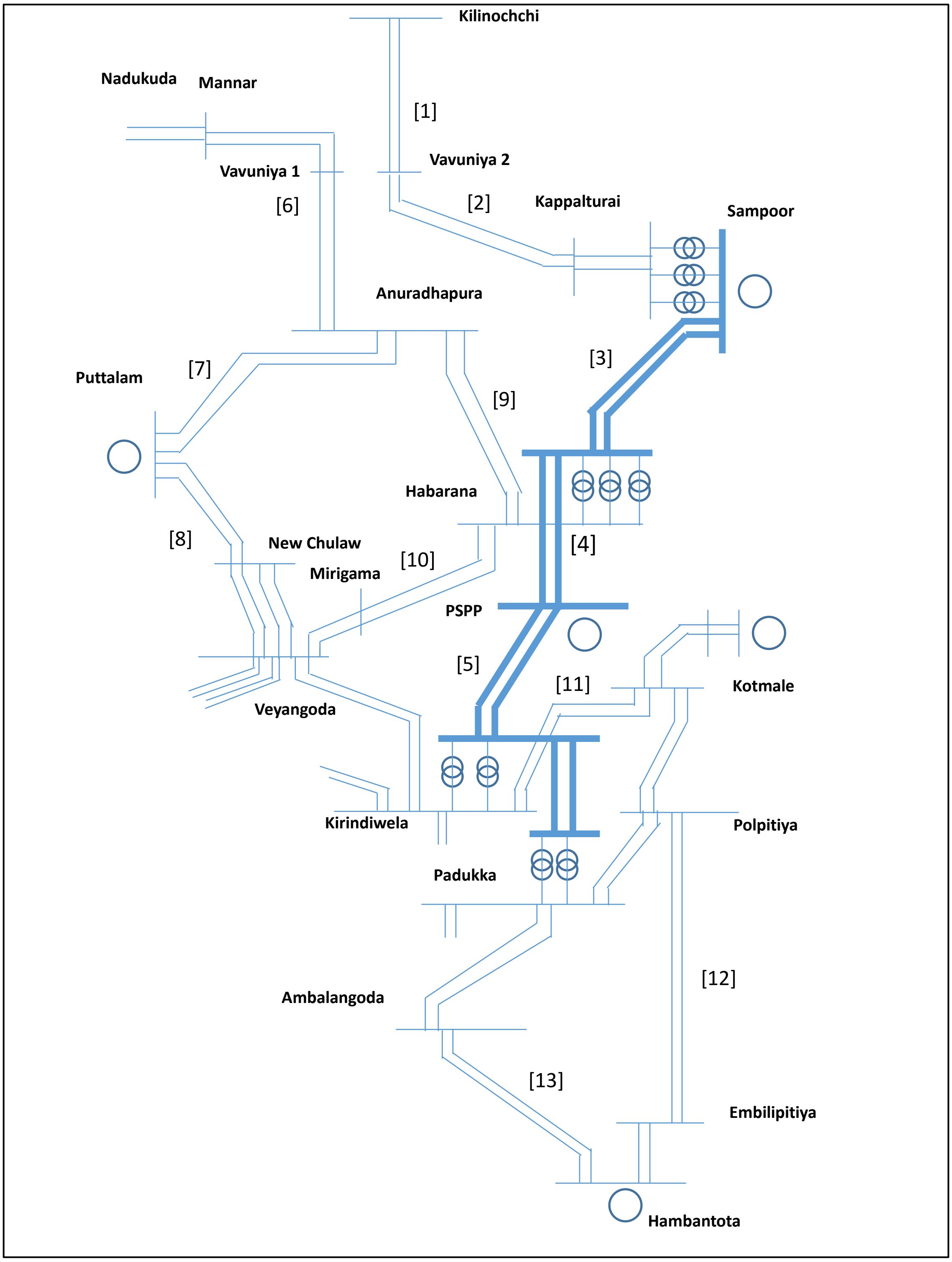
Stability analysis is carried out under the following conditions.

- Study scenario and year: Scenario C, the years of 2035 and 2040
- Status of fault: three-phase short circuit fault at a single circuit of a transmission line
- Clearance of fault: 1 circuit section opening, clearance time: 0.1 seconds, reclosing: none
- Duration of simulation: 5 seconds after occurrence of fault
- System analysis tool: PSS/E ver 33.5
- Generator models: The following models provided by CEB
    - Thermal unit: synchronous generator, cylindrical rotor model, AVR, Governor
    - Hydro unit: synchronous generator, salient pole rotor model, AVR, governor
    - Windpower, solar power: generator with AC/DC convertor

For a synchronous generator whose model is unknown, or biomass-fired TPP, a classical model using only inertial constants is used.

(3) Faulty section setting for the stability analysis

At the section of the 400kV and 220kV transmission line shown in the following figure, the fault shown under the above conditions is set and the stability in each case is evaluated.



(Source: JICA Survey Team)

Figure 8-19 Faulty Section setting for the Stability Analysis

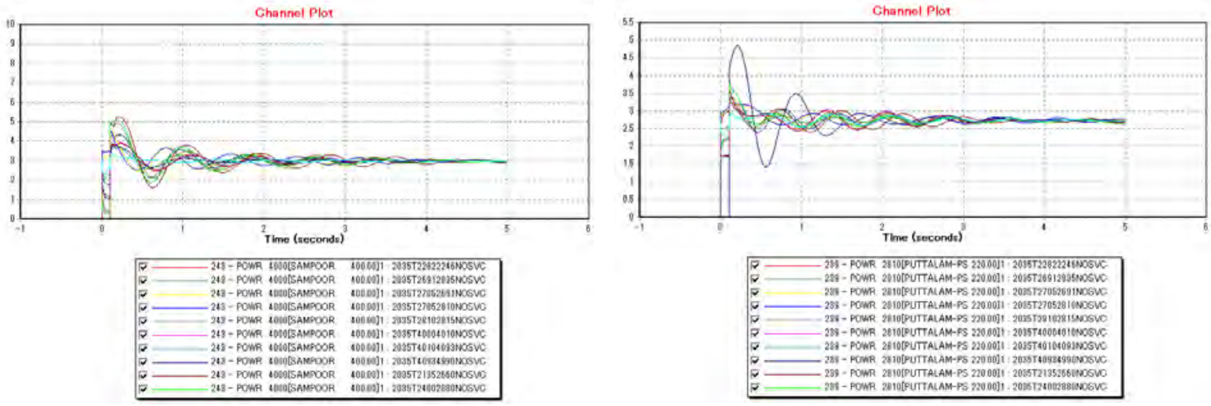
(4) Stability on the bulk power system in 2035

In each single contingency of sections [1] - [13], the stability of the system can be maintained in either case. Stability analysis results are shown in the table and the figure below.

Table 8-12 Stability on the Bulk Power System in 2035

No.	Voltage	From	To	Stability at single contingency
[1]	220	Kilinochchi	Vavuniya 2	Stable
[2]	220	Vavuniya 2	Kappalturai	Stable
[3]	400	Sampoor	Habarana	Stable
[4]	400	Habarana	PSPP	Stable
[5]	400	PSPP	Kirindiwela	Stable
[6]	220	Vavuniya 1	Anuradhapura	Stable
[7]	220	Anuradhapura	Puttalam	Stable
[8]	220	Puttalam	New Chulaw	Stable
[9]	220	Anuradhapura	Habarana	Stable
[10]	220	Habarana	Mirigama	Stable
[11]	220	Kotmale	Kirindiwela	Stable
[12]	220	Polpitiya	Embilipitiya	Stable
[13]	220	Hambantota	Ambalangoda	Stable

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 8-20 Fluctuation of Output at each single contingency of sections [1] - [13] in 2035 (Left: Sampoor TPP, Right: Puttalam TPP)

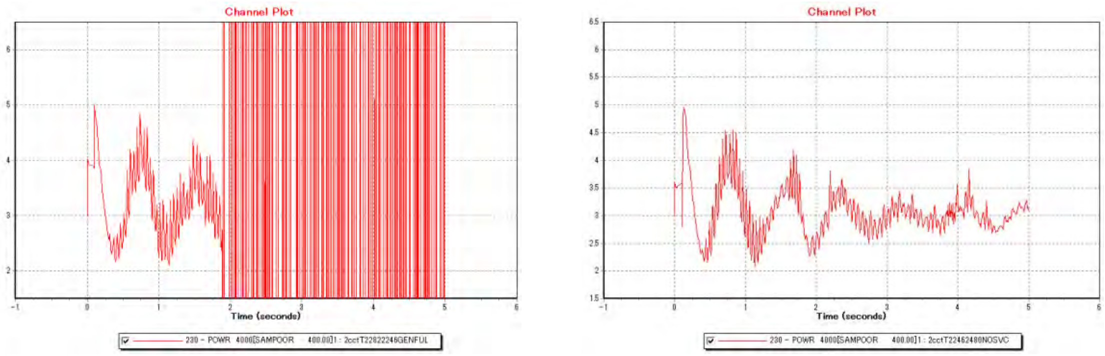
(5) Stability on the bulk power system in 2040

System stability cannot be maintained at a single contingency in section [1] or [2]. Stability analysis results are shown in the table and the figure below.

Table 8-13 Stability on the Bulk Power System in 2040

No.	Voltage	From	To	Stability at single contingency
[1]	220	Kilinochchi	Vavuniya 2	Unstable (Oscillation instability)
[2]	220	Vavuniya 2	Kappalturai	Short period oscillation continuation
[3]	400	Sampoor	Habarana	Stable
[4]	400	Habarana	PSPP	Stable
[5]	400	PSPP	Kirindiwela	Stable
[6]	220	Vavuniya 1	Anuradhapura	Stable
[7]	220	Anuradhapura	Puttalam	Stable
[8]	220	Puttalam	New Chulaw	Stable
[9]	220	Anuradhapura	Habarana	Stable
[10]	220	Habarana	Mirigama	Stable
[11]	220	Kotmale	Kirindiwela	Stable
[12]	220	Polpitiya	Embilipitiya	Stable
[13]	220	Hambantota	Ambalangoda	Stable

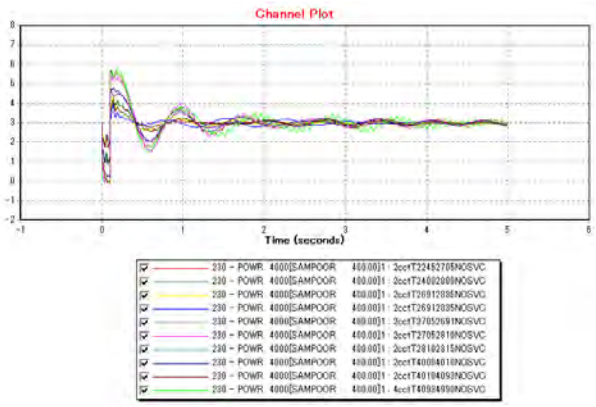
(Source: JICA Survey Team)



When fault occurs in Section [1]   When fault occurs in Section [2]

(Source: JICA Survey Team)

Figure 8-21 Stability when Fault occurs in Section [1] or [2] in 2040 (Output of Sampoor TPP, No. 1 Unit)



(Source: JICA Survey Team)

Figure 8-22 Stability when Fault occurs in Sections other than [1] or [2] in 2040 (Output of Sampoor TPP, No. 1 Unit)

If the power flow calculation is carried out under the conditions that one line of section [1] or [2] is disconnected, no convergent solution can be obtained in either case. For this reason, even if judged from the viewpoint of voltage stability, it is impossible to transmit power in this system at the time of a single contingency in section [1] or [2].

Therefore, as a countermeasure for improving the stability of sections [1] and [2], a synchronous condenser is installed on the Kilinochchi 132kV bus. When installed capacity is 1,000MVA, it is unstable, but when 1,500MVA, it becomes stable. The following table shows the stability analysis results when a 1,500MVA synchronous condenser is installed on a Kilinochchi 132kV bus.

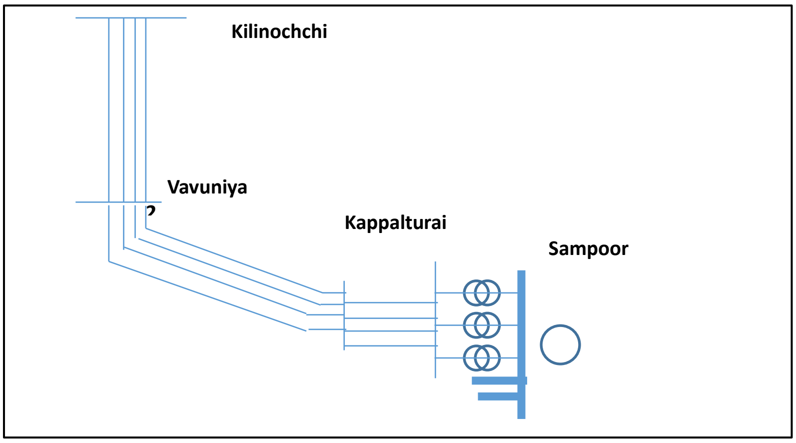
Table 8-14 Stability on the Bulk Power System in 2040 (with 1,500MVA synchronous condenser)

No.	Voltage	From	To	Stability at single contingency
[1]	220	Kilinochchi	Vavuniya 2	OK
[2]	220	Vavuniya 2	Kappalturai	OK
[3]	400	Sampoor	Habarana	OK
[4]	400	Habarana	PSPP	OK
[5]	400	PSPP	Kirindiwela	OK
[6]	220	Vavuniya 1	Anuradhapura	OK
[7]	220	Anuradhapura	Puttalam	OK
[8]	220	Puttalam	New Chulaw	OK
[9]	220	Anuradhapura	Habarana	OK
[10]	220	Habarana	Mirigama	OK
[11]	220	Kotmale	Kirindiwela	OK
[12]	220	Polpitiya	Embilipitiya	OK
[13]	220	Hambantota	Ambalangoda	OK

(Source: JICA Survey Team)

After installing a 1,500MVA synchronous condenser, if the power flow calculation is carried out under the conditions that one line of section [1] or [2] is disconnected, a convergent solution can be obtained in both cases. Even if judged from the viewpoint of voltage stability, it is possible to transmit power in this system at the time of a single contingency in section [1] or [2].

As another countermeasure, the stability of the case where Kilinochchi - Vavuniya - Kappalturai - Sampoor has 4 circuits is calculated.



(Source: JICA Survey Team)

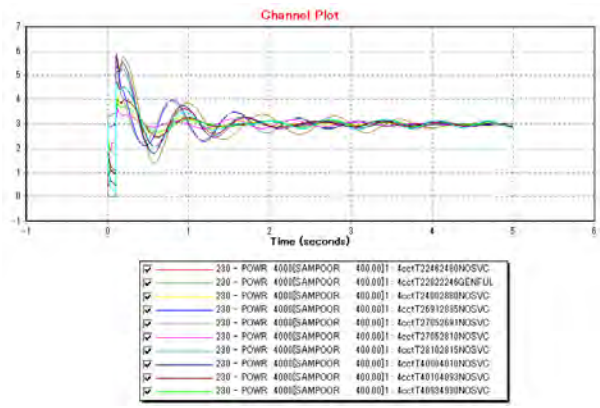
Figure 8-23 Kilinochchi-Vavuniya-Kappalturai-Sampoor 4 Circuits System

Stability analysis results are shown in the table and the figure below. It becomes stable at the time of single contingency in all sections, [1] to [13].

Table 8-15 Stability on the Bulk Power System in 2040
(with Kilinochchi-Vavuniya 2-Kappalturai-Sampoor 4 circuits)

No.	Voltage	From	To	Stability at single contingency
[1]	220	Kilinochchi	Vavuniya 2	OK
[2]	220	Vavuniya 2	Kappalturai	OK
[3]	400	Sampoor	Habarana	OK
[4]	400	Habarana	PSPP	OK
[5]	400	PSPP	Kirindiwela	OK
[6]	220	Vavuniya 1	Anuradhapura	OK
[7]	220	Anuradhapura	Puttalam	OK
[8]	220	Puttalam	New Chulaw	OK
[9]	220	Anuradhapura	Habarana	OK
[10]	220	Habarana	Mirigama	OK
[11]	220	Kotmale	Kirindiwela	OK
[12]	220	Polpitiya	Embilipitiya	OK
[13]	220	Hambantota	Ambalangoda	OK

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 8-24 Stability with Kilinochchi-Vavuniya 2-Kappalturai-Sampoor 4 Circuits in 2040 (Output of Sampoor TPP)

After installing an additional 2 circuits, if the power flow calculation is carried out under the conditions that one line of section [1] or [2] is disconnected, a convergent solution can be obtained in both cases. Even if judged from the viewpoint of voltage stability, it is possible to transmit power in this system at the time of a single contingency in section [1] or [2].

(6) Conclusion

- Stability of the power system until 2035 is maintained at the time of a single line fault.
- In 2040, the stability of the power system is maintained during a single line fault in sections other than the northern Kilinochchi-Vavuniya 2 and Vavuniya 2-Kappalturai.
- In 2040, power flow from the northern Kilinochchi area is large, and it becomes unstable during a single line fault at Kilinochchi-Vavuniya 2, or Vavuniya 2-Kappalturai.
- In 2040, it is necessary to improve the stability in the north of Kilinochchi, and the following measures are possible. With any of the following measures, the stability of the electric power

system in 2040 is maintained during a single line fault in all sections of the 400kV, 220kV transmission line.

- Two routes (4 circuits) of transmission line between Kilinochchi-Vavuniya 2-Kappalturai-Sampoor are installed.
- A 1,500MVA synchronous condenser is installed on a Kilinochchi 132kV bus.

Considering the system stability at the time of a transmission line fault, in the case of installing two routes of transmission line between Kilinochchi-Vavuniya 2-Kappalturai-Sampoor, the system diagram in 2040 in Scenario C is as follows.

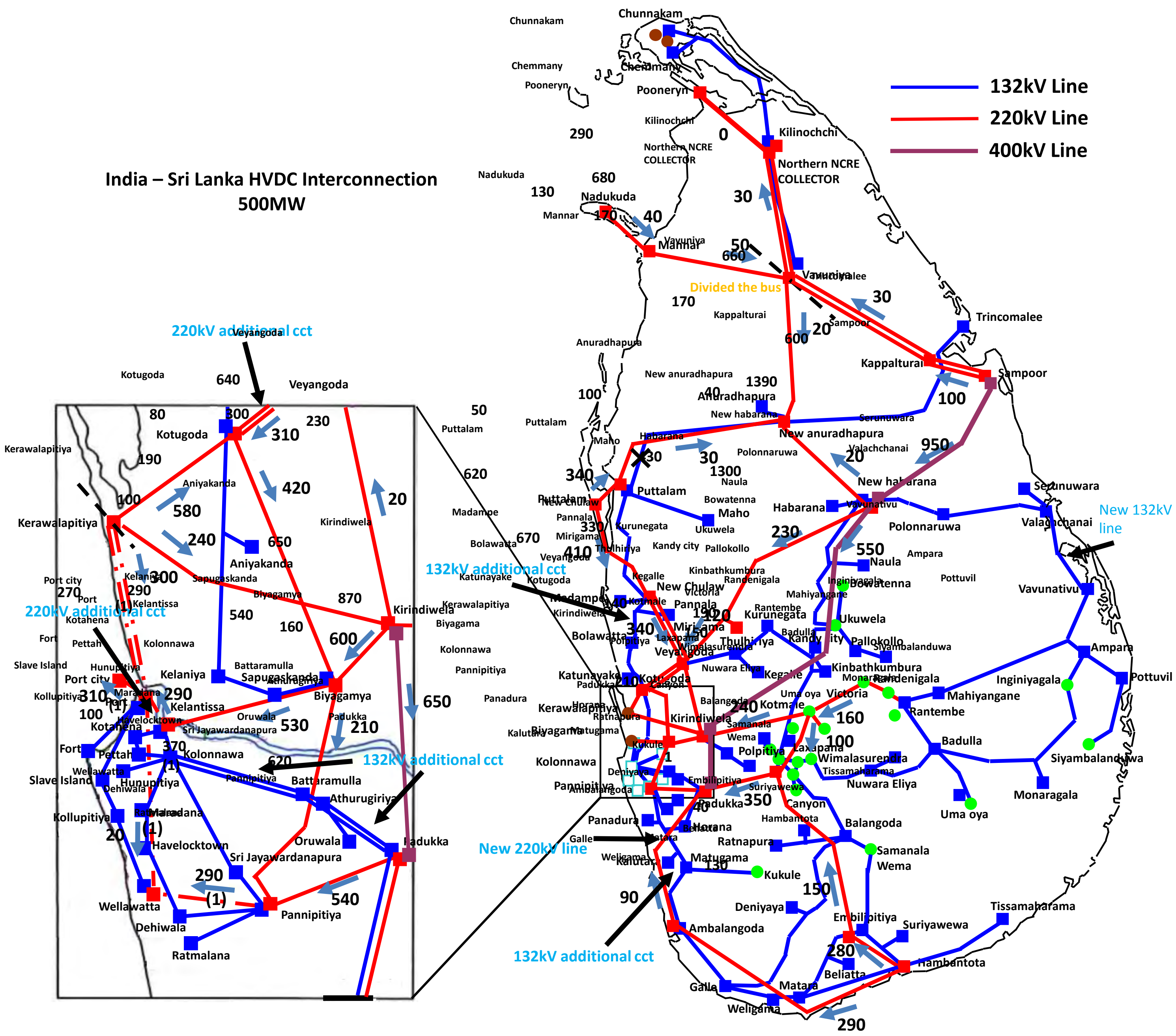
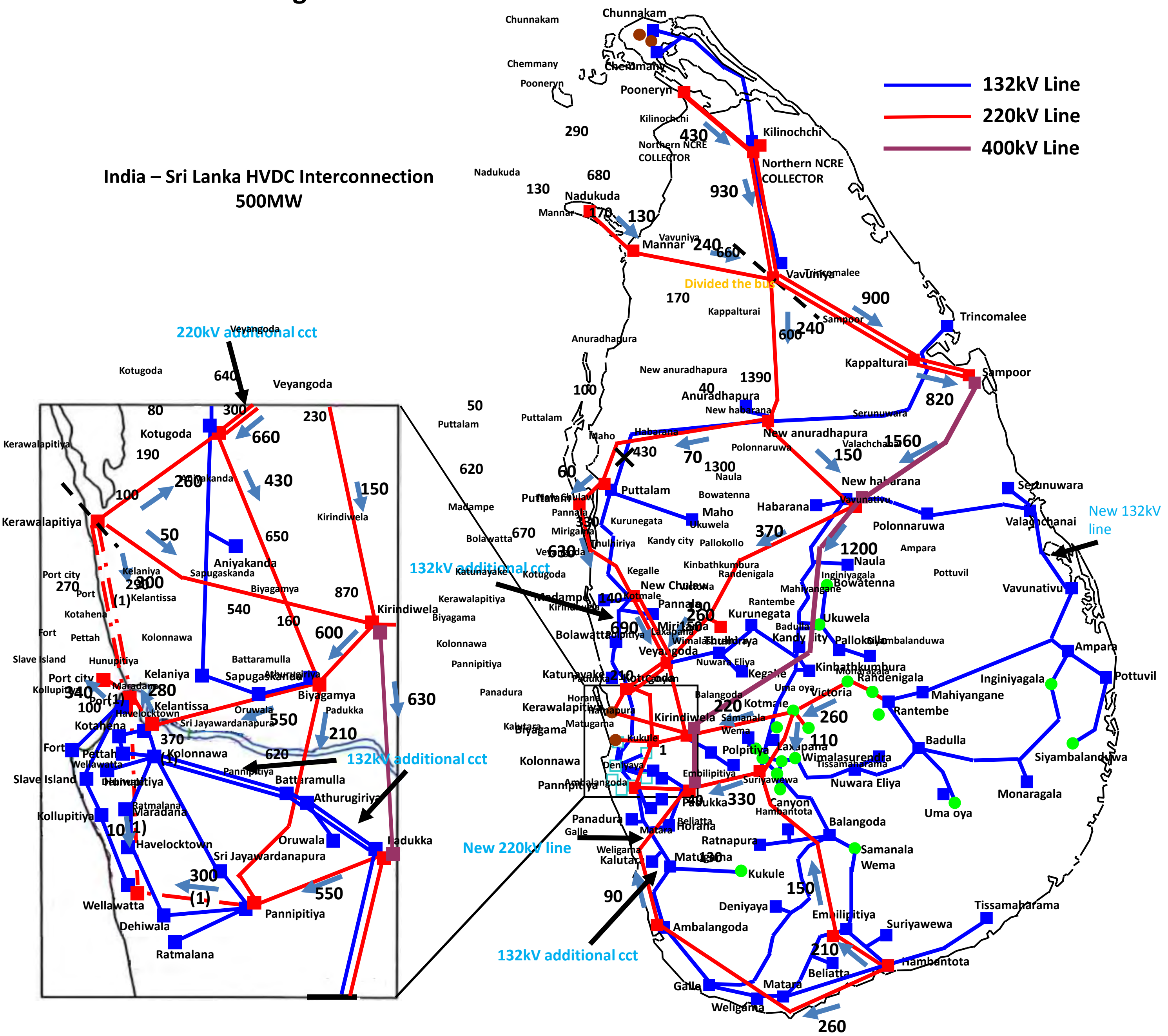


Figure 8-25 System Configuration in Scenario C after Consideration of System Stability (Power Flow in April 2040)

Scenario C Aug.



(Source: JICA Survey Team)

Figure 8-26 System Configuration in Scenario C after Consideration of System Stability (Power Flow in August 2040)

8.4.5 Required Reactive Power Compensation

(1) Objective of the reactive power compensation

The main objectives for introducing the reactive power compensator are "maintaining proper voltage" and "avoiding voltage instability phenomena".

Therefore, in this study, the JICA Survey Team shows the amount of reactive power compensators for maintaining the proper voltage and checks the voltage instability phenomenon via the P-V curve, and if there is a possibility of the voltage instability phenomenon occurring, the JICA Survey Team proposes an additional amount of reactive power compensators.

(2) Basic concept of voltage control

The basic concept in facility planning for reactive power compensators is to install reactive power compensators at an appropriate place to maintain the proper voltage. However, on the other hand, in order to reduce power transmission loss, it is also important for the reactive power not to flow to transmission lines. In other words, it is effective and economical to install reactive power compensators near the reactive power source.

Therefore, in this study, in order to maintain the voltage, the installation of reactive power compensators shall be planned via the following steps.

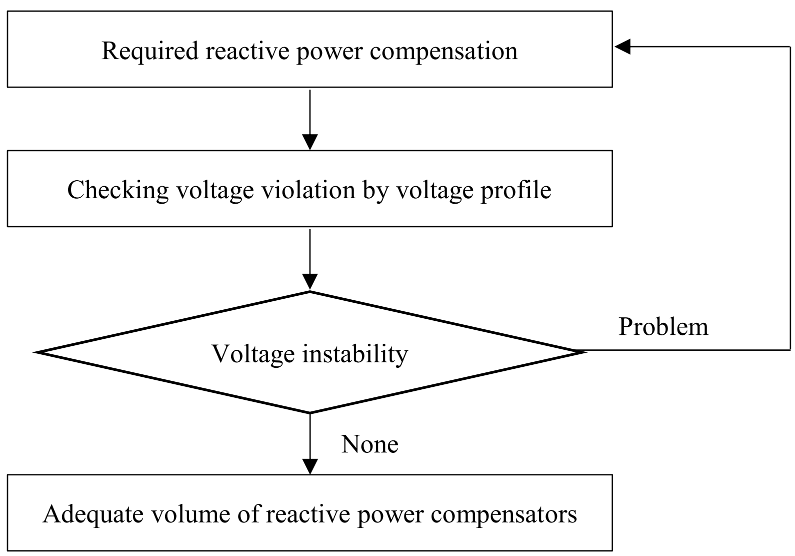
i) Install necessary amount at load end
ii) Only when the proper voltage cannot be maintained are the reactive power compensators installed at the upper voltage substation

In voltage regulation, not only voltage drop due to a heavy load but also voltage rise at light load must be taken into consideration, so the voltage condition is also checked at light load.

(3) Study procedure

The main objectives for the study are "proposal of adequate volume of reactive power compensators for maintaining proper voltage" and "confirmation of the voltage instability phenomena", as described above.

Therefore, in this study, the JICA Survey Team proceeds with the following steps.



(Source: JICA Survey Team)

Figure 8-27 Study Flow for Adequate Volume of Reactive Power Compensators

(4) Required volume of reactive power compensators

The required volume of reactive power compensators in each voltage class and the development plan for every five years are shown below.
For the study of the light load, it is assumed that the demand is about 45% of the heavy load.

Table 8-16 Required Volumes of Reactive Power Compensators

Voltage	2025	2030	2035	2040	Total	Light load (2040)
220kV	200 (SC) -105 (ShR)		560	1,030	1,790	-150 (ShR) 100 (SC)
132kV	100	240			340	100
33kV	575				575	515
22kV	160				160	60
Below 11kV	345				345	150
Total	1,380	240	560	1,030	3,210	-150 (ShR) 925 (SC)

(Source: JICA Survey Team)

Table 8-16 shows the required amount of reactive power compensators for the whole system by 2025 and the required amount additionally ever 5 years after 2025.

Table 8-17 Required Volume of Reactive Power Compensators in each Substation (at Heavy Load)

Substation	Voltage [kV]	2025	2030	2035	2040
COL	220	200	200	360	360
VAUNIYA	220	0	0	0	210
N-COLLECT	220	0	0	0	20
KELAN	220	0	0	200	0
PANNI	220	0	0	0	100
BIYAG	220	0	0	0	450
KOTUG	220	0	0	0	450
PADUKKA	220	0	0	200	200
KOLON	132	0	240	240	240
PANNI	132	100	100	100	100
AMPA	33	30	30	30	30
KERA	33	30	30	30	30
HAMB PORT	33	20	20	20	20
HORANA	33	15	15	15	15
KATUNA	33	20	20	20	20
POLON	33	20	20	20	20
PALLEK	33	20	20	20	20
THULH	33	10	10	10	10
KEGA	33	15	15	15	15
KOLON	33	40	40	40	40
BIYAG-33	33	30	30	30	30
KOTUG	33	50	50	50	50
SAPUG	33	35	35	35	35
BOLAW	33	20	20	20	20
KURUN	33	10	10	10	10
HABAR	33	10	10	10	10
KIRIB	33	20	20	20	20
MATUG	33	20	20	20	20
PUTTA	33	20	20	20	20
ATURU	33	20	20	20	20

Substation	Voltage [kV]	2025	2030	2035	2040
PANAD	33	20	20	20	20
K-NIYA	33	20	20	20	20
AMBALA	33	10	10	10	10
PANNAL	33	20	20	20	20
ANIYA	33	20	20	20	20
GALLE	33	30	30	30	30
PORT CITY R	22	160	160	160	160
COL	11	305	305	305	305
GALLE	5.9	40	40	40	40
Total		1,380	1,620	2,180	3,210

(Source: JICA Survey Team)

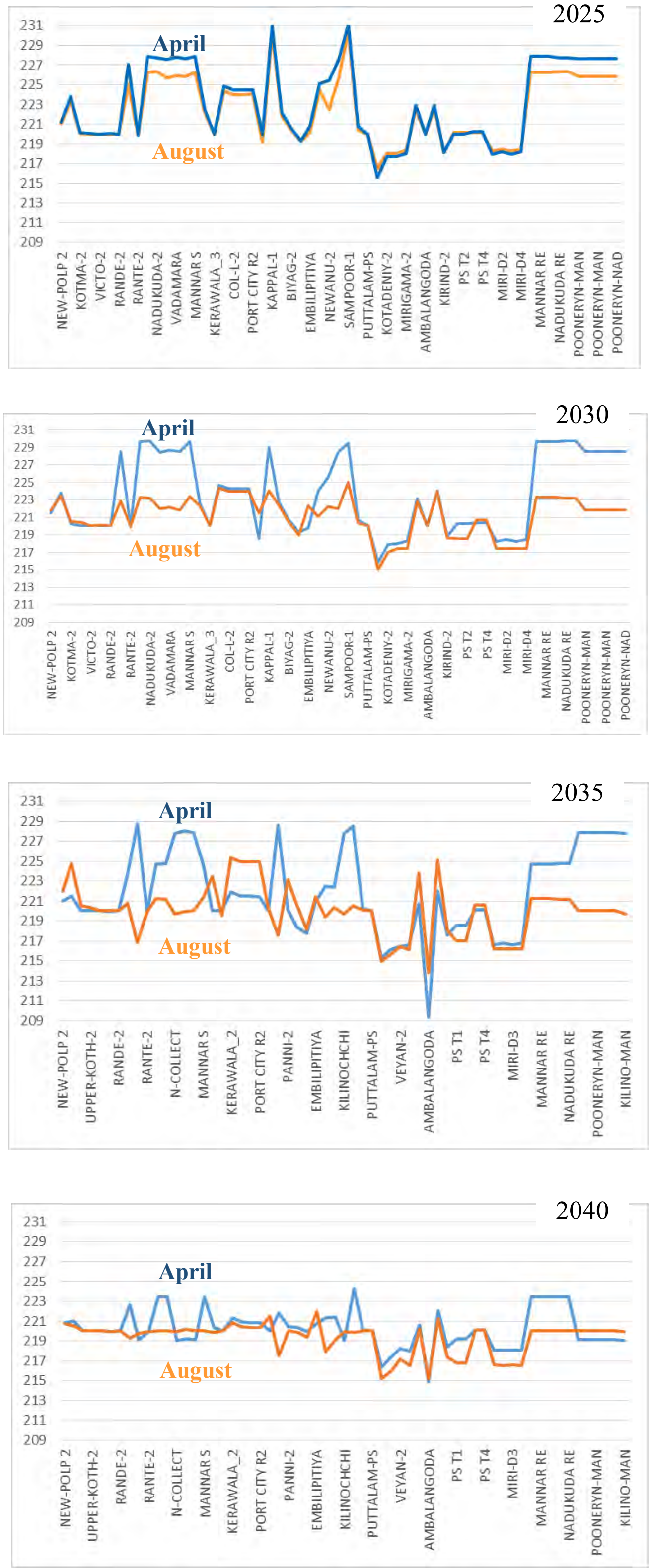
Table 8-18 Required Volume of Reactive Power Compensators in each Substation (at Light Load)

Substation	Voltage [kV]	2040
KOTMA	220	-150
VAUNIYA	220	90
N-COLLECT	220	10
PANNI	132	100
KERA	33	10
HAMB PORT	33	5
THULH	33	10
KURUN	33	10
HABAR	33	10
AMBALA	33	10
HORANA	33	15
POLON	33	15
KEGA	33	15
KATUNA	33	20
PALLEK	33	20
KOLON	33	40
KOTU_NEW	33	20
BOLAW	33	20
KIRIB	33	20
MATUG	33	20
PUTTA	33	20
ATURU	33	20
PANAD	33	20
K-NIYA	33	20
PANNAL	33	20
ANIYA	33	20
AMPA	33	25
BIYAG	33	20
KOTUG	33	30
GALLE	33	25
SAPUG	33	35
PORT CITY R1	22	30
PORT CITY R2	22	30
COL	11	150
Total		-150 (ShR), 925 (SC)

(Source: JICA Survey Team)

(5) Checking voltage violation by voltage profile

The voltage profiles of 220kV and 132kV substation buses in each year are shown below.



(Source: JICA Survey Team)

Figure 8-28 Voltage Profile of 220kV Substation Buses

(Source: JICA Survey Team)

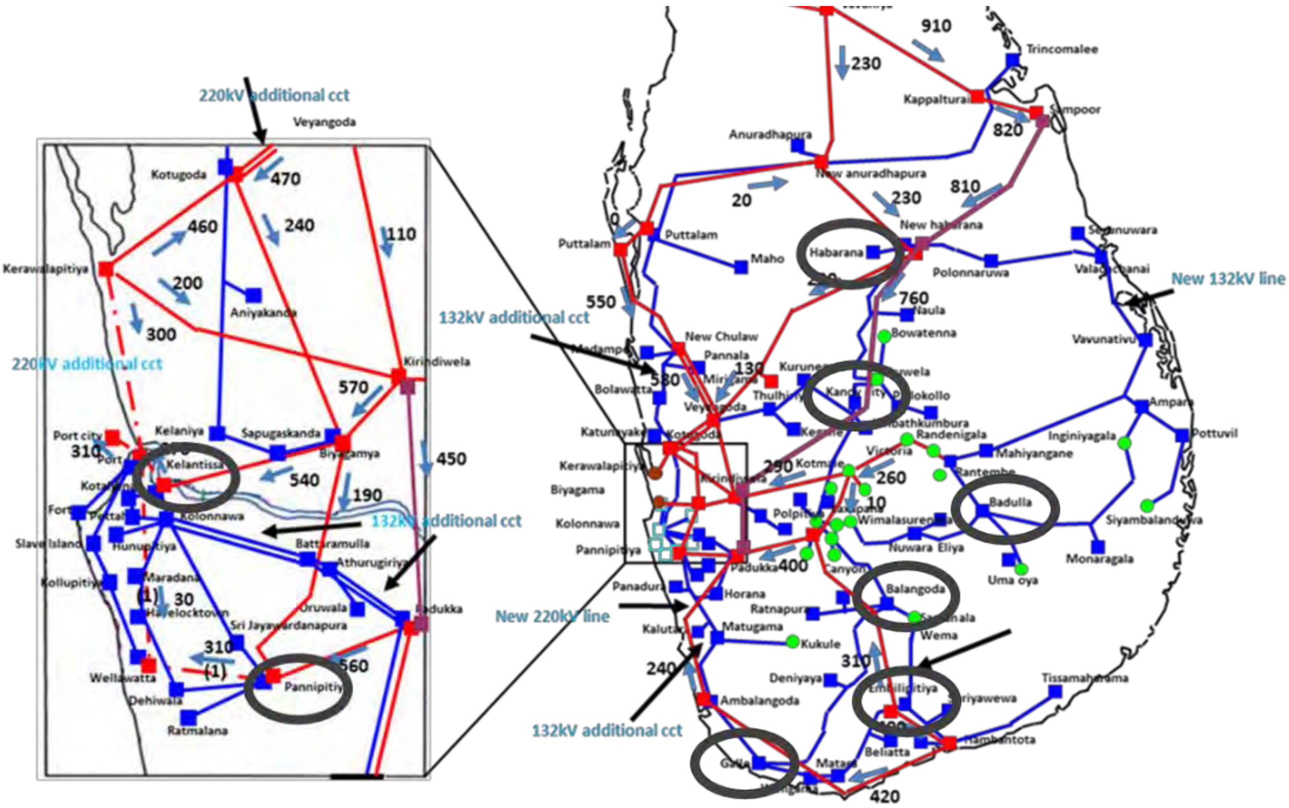
Figure 8-29 Voltage Profile of 132kV Substation Buses

(6) Confirmation of voltage instability phenomenon

Voltage instability phenomenon on a 132kV bus is analyzed via the P-V curve. In creating the P-V curve, a method to uniformly increase the total load being carried out at TEPCO is used.

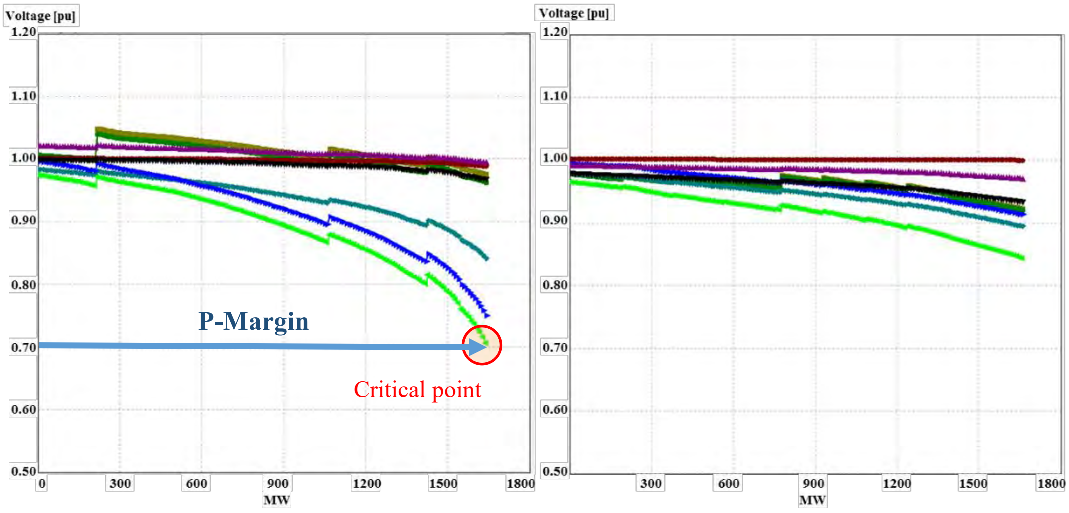
Here, the cases of a typical 132kV busbar in the Colombo, South and Central areas are studied as an example.

The voltage instability phenomenon occurs due to a rapid increase of demand in a short time (about several hours) with an insufficient amount of reactive power compensators, and voltage instability is evaluated by the P-margin. In this study, the P-margin in 2025 is smaller than in the other years, but even a substation with a small P-margin has a P-margin of about 1.6GW, which is 40% of the whole demand (4GW). In general, it can be considered that the maximum demand does not rise by as much as 40% in about several hours. Therefore, there is sufficient P-margin in 2025 and it can be considered that the voltage instability phenomenon will not occur.



(Source: JICA Survey Team)

Figure 8-30 Typical 132kV Substations



(a) 2025 (b) 2040

(Source: JICA Survey Team)

Figure 8-31 P-V curve at 132kV Busbar in each Substation

8.4.6 Switching Overvoltage

(1) Objective of the switching overvoltage study

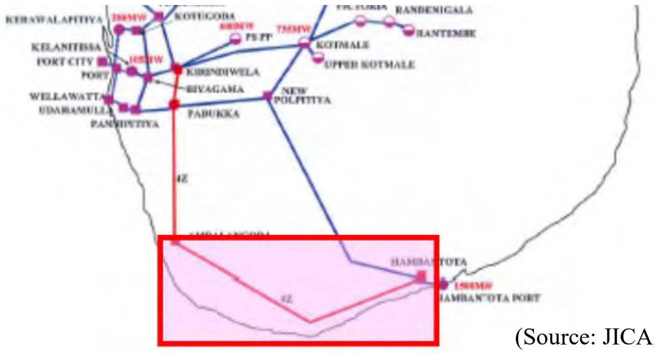
For extra high voltage transmission systems, flexible system configuration is required to counter various system phenomena. Particularly, how to suppress overvoltage is one of the most important factors in determining the specifications of equipment. Therefore, several overvoltage studies in the time domain of the order of several micro seconds are implemented as well as studies in the commercial frequency range.

In this study, the switching overvoltage analysis requested by CEB is implemented focusing on a representative overhead transmission line and underground cable. Moreover, recommendations and considerations are proposed.

(2) Targeted Equipment

The following transmission line and underground cable are selected for the switching overvoltage analysis based on the discussion with CEB.

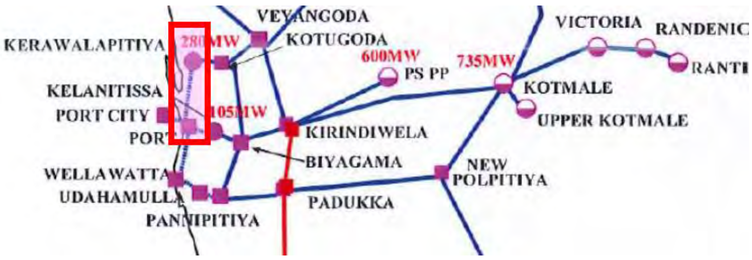
Overhead transmission line: Hambantota – Ambalangoda 400kV line



(Source: JICA Survey Team)

Figure 8-32 Hambantota – Ambalangoda 400kV Overhead Transmission Line

Underground cable: Kerawalapitiya – Port City 220kV cable



(Source: JICA Survey Team)

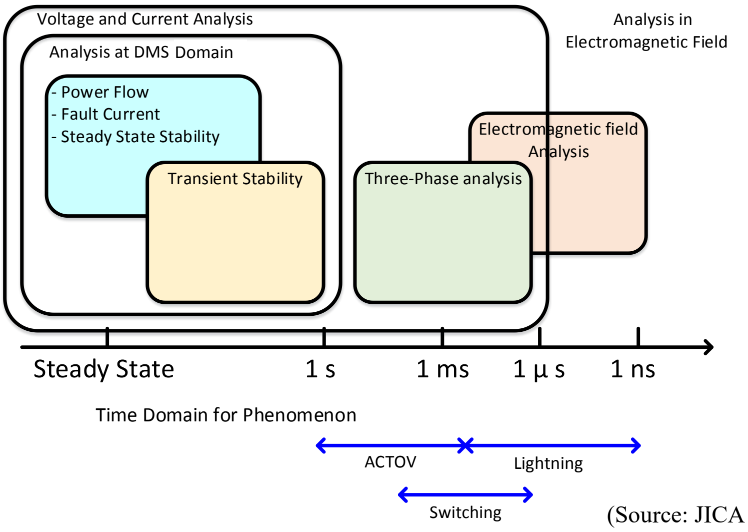
Figure 8-33 Kerawalapitiya – Port City 220kV Underground Cable

(3) Study Procedure

(a) Analytical Tool

As shown in Figure 8-34, there are several kinds of overvoltage according to the time domain. For the overvoltage analysis, it is very important to use the analytical program appropriate for the time domain. For analysis of switching overvoltage, it is necessary to use a program for transient analysis as shown Table 8-19.

In this study, EMTP, which is widely used worldwide and has high reliability of results, is used.



(Source: JICA Survey Team)

Figure 8-34 Overvoltage Analyses according to Time Domain

Table 8-19 Simulation Tools

System Phenomenon	Analytical Method	Program
Steady state check	Power flow analysis	PSS/E, EMTP, PSCAD
Surge	Overvoltage analysis	EMTP, PSCAD
Harmonics	Harmonic analysis	EMTP, PSCAD
ACTOV	ACTOV analysis	EMTP, PSCAD
Fault current	Fault current analysis	PSS/E
Subsynchronous Torsional Interaction (STI)	SSTI analysis	DAMP, EMTP, (PSCAD)
Dynamic stability	Stability analysis - Steady state - Transient	PSS/E, PSCAD
Voltage instability	Voltage stability analysis	PSS/E
Frequency fluctuation	Frequency fluctuation calculations	MATLAB

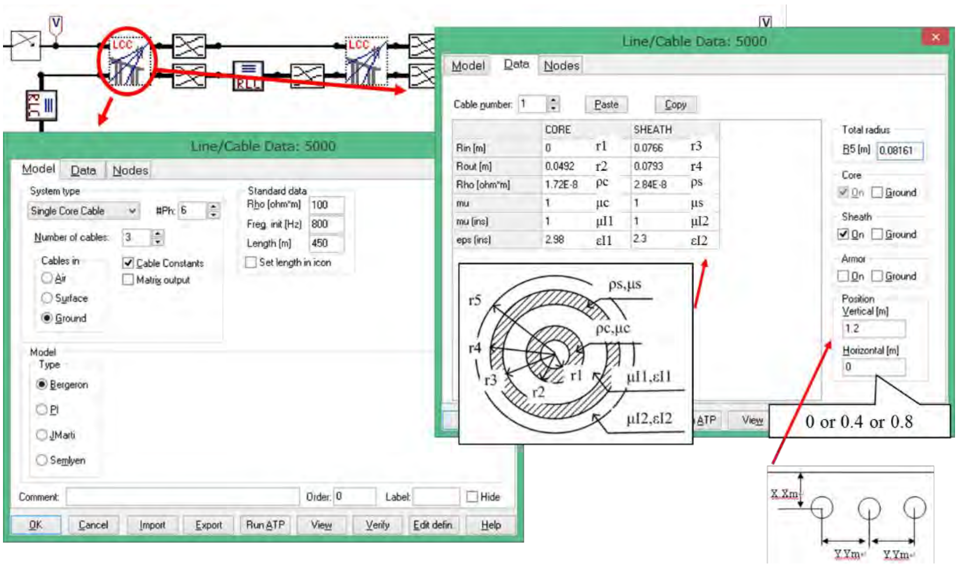
(Source: JICA Survey Team)

(b) Simulation model

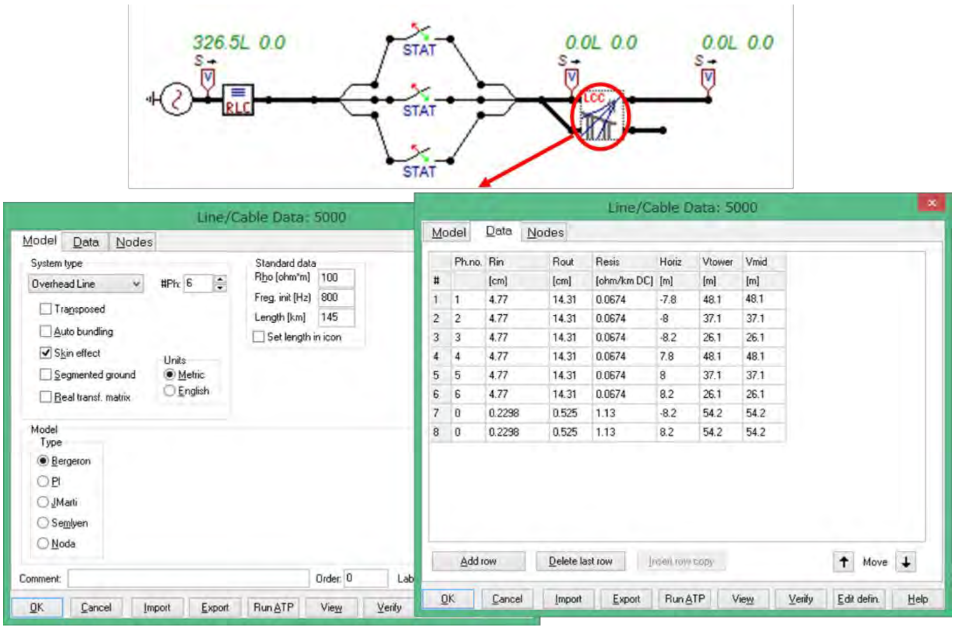
The simulation model is shown in Figure 8-35.

For the 400kV overhead power transmission line and 220kV underground cable, EMTP models were created based on data provided by CEB. For the 220kV underground cable, the cross-bonding is considered.

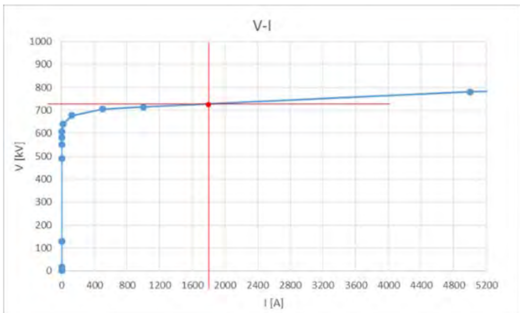
The 400kV surge arrester model was created based on our company data.



(a) 220kV Underground Cable Model (Kerawalapitiya – Port City)



(b) 400kV Overhead Transmission Line Model (Hambantota – Ambalangoda)



(c) V-I Characteristics of 400kV Surge Arrester

(Source: JICA Survey Team)

Figure 8-35 EMTP Simulation Models

(4) Analytical Results

Switching was done 100 times with a statistics switch.
The results are shown in Table 8-20.

Table 8-20 Switching Overvoltage

220kV Underground Cable (Kerawalapitiya – Port City)		400kV Overhead Transmission Line (Hambantota – Ambalangoda)	
Peak-voltage [V]	Frequency	Peak-voltage [V]	Frequency
216,000	0	Less than 963,175	37
225,000	1	979,500	0
234,000	1	995,825	2
243,000	0	1,012,150	0
252,000	0	1,028,475	2
261,000	1	1,044,800	2
270,000	0	1,061,125	1
279,000	1	1,077,450	1
288,000	1	1,093,775	1
297,000	4	1,110,100	3
306,000	1	1,126,425	7
315,000	1	1,142,750	16
324,000	5	1,159,075	10
333,000	4	1,175,400	6
342,000	9	1,191,725	3
351,000	11	1,208,050	0
360,000	26	1,224,375	4
369,000	15	1,240,700	2
378,000	9	1,257,025	1
387,000	4	1,273,350	0
396,000	3	1,289,675	1
405,000	1	1,306,000	0
414,000	2	1,322,325	1

(Source: JICA Survey Team)

The calculation results are evaluated based on the IEC standard. The required specifications of 220kV underground cable and 400kV overhead transmission line are 360/850 and 1,050/1,425 respectively (yellow part in the table).

Table 8-21 Required Specifications based on IEC Standard

(a) 220kV Underground Cables (Kerawalapitiya – Port City)

Study Result kV	IEC Standard	
	Standard rated short-duration power-frequency withstand voltage kV (r.m.s. value)	**Standard rated lightning impulse withstand voltage** kV (peak value)
414	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1050

(b) 400kV Overhead Transmission Line (Hambantota – Ambalangoda)

Study result kV	IEC Standard	
	Standard rated switching impulse withstand voltage Phase-to-earth kV (peak value)	**Standard rated lightning impulse withstand voltage kV (peak value)**
1,322	850	1,050
		1,175
	850	1,175
		1,300
	1,050	1,300
		1,425

(Source: IEC60071-1)

These results are based only on switching overvoltage analysis. In general, in the case of overhead transmission lines, lightning overvoltage is dominant. In the case of the corridores from power stations, the AC temporary overvoltage may become dominant. As the 220kV Kerawalapitiya – Port City underground cable corresponds to this case, it is necessary to pay attention to ACTOV.
Therefore, in practice, it is necessary to conduct multifaceted studies at the design stage.

8.5 Investment for Transmission Equipment

The 400kV and 220kV transmission lines scheduled to be completed by 2020 in CEB's Long Term Transmission Development Plan (2015 - 2024) are shown below.

・220kV Nadukuda-Mannar-New Anuradhapura (2 cct) 155km
・220kV New Habarana-Veyangoda (2 cct) 148km
・220kV Veyangoda-Kirindiwela (2 cct) 17.5km
・400kV Kirindiwela-Padukka (2 cct) 20km (initially 220kV operation)
・220kV Kotmale-New Polpitiya (2 cct) 23km
・220kV New Polpitiya-Padukka-Pannipitiya (2 cct) 70km
・220kV New Polpitiya-Hambantota (2 cct) 150km
・220kV Kerawalapitiya-Port-Wellawatta (UG cable 1cct) 22.5km
・220kV Kelanitissa-Port (UG cable 1cct) 6.5km
・220kV Pannipitiya-Wellawatta (UG cable 1cct) 14km
・220kV Port-Port City (UG cable 2cct) 1.0km

The above transmission lines are necessary for all power development scenarios. In addition to these, the transmission lines required for each power development scenario by 2040 are shown below.

Table 8-22 Transmission Lines required for each Power Development Scenario

	Length (km)	Scenario A	Scenario B	Scenario C
400kV Sampoor-New Habarana	95	Y (2 cct)	N	Y (2 cct)
400kV New Habarana-Kirindiwela	165	Y (2 cct)	Y (2 cct)	Y (2 cct)
400kV transmission line (2 cct) total length		260km	165km	260km
220kV Sampoor-New Habarana	95	N	Y (2 cct)	N
220kV Kerawalapitiya-Kirindiwela	30	Y (2 cct)	Y (2 cct)	Y (2 cct)
220kV Pooneryn-Northern NCRE collector	30	N	Y (4 cct)	Y (2 cct)
220kV Northern NCRE collector-Sampoor	180	Y (2 cct)	Y (2 cct)	N
220kV Northern NCRE collector- Vavuniya	75	N	Y (4 cct)	Y (4 cct)
220kV Vavuniya-Sampoor	100	N	N	Y (4 cct)
220kV Vavuniya-New Anuradhapura-New Habarana	105	N	Y (4 cct)	N
220kV New Anuradhapura -Puttalam-New Chulaw	174	N	Y (2 cct)	N
220kV New Chulaw-Veyangoda-Kotugoda	60	N	Y (2 cct)	Y (2 cct)
220kV Biyagama-Kelantissa	12.5	N	Y (2 cct)	N
220kV Padukka-Ambalangoda-Hambantota	220	Y (2 cct)	Y (2 cct)	Y (2 cct)
220kV transmission line (2 cct) total length		430km	1,192km	690km
220kV Kerawalapitiya-Port (UG)	13.5	Y (1 cct)	Y (1 cct)	Y (1 cct)

(Source: JICA Survey Team)

In Scenario B, the required length of the 400kV transmission line can be reduced by 95km, but the required length of the 220kV transmission line is about 500km more compared with other scenarios. The construction cost difference for power transmission facilities between Scenario B and Scenario C is about USD 280 million in total by 2040, and the difference in average cost during this period is about 0.04 USC/kWh (0.06 LKR/kWh).

Based on the above-mentioned conditions, investment for transmission equipment by each scenario is studied by using the unit price list shown in Table 8-23.

Table 8-23 Unit Price List

Equipment		Construction Cost	
Overhead Transmission Line	230kV D/C (Twin Conductor)	0.63	MUSD/km/2cct
	400kV D/C (Quad Conductor)	0.87	MUSD/km/2cct
Underground Cable	230kV	2	MUSD/km/1cct
	400kV	4	MUSD/km/1cct
Substation	400kV/230kV (3x 750MW, GIS)	80.3	MUSD
Reactive Power Compensation	230kV Shunt Capacitor	0.029	MUSD/Mvar

Reference: Final Report of JICA Research on revised Master Plan in Bangladesh

(Source: JICA Survey Team)

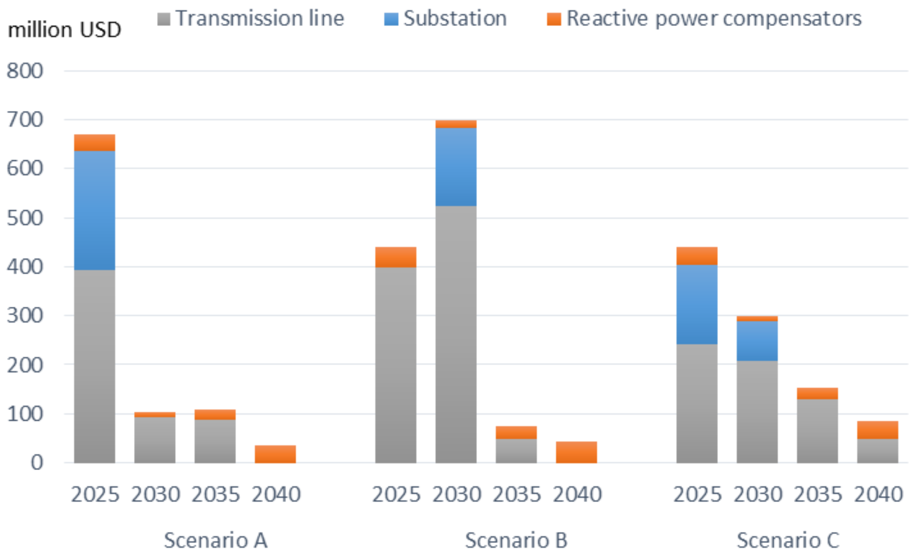
The results are shown in Table 8-24 and Figure 8-36.

Table 8-24 Trends of Capital Investment

	length	Scenario A				Scenario B				Scenario C			
	(km)	2025	2030	2035	2040	2025	2030	2035	2040	2025	2030	2035	2040
Substation		273.4	8.4	17.7	29.9	39.0	170.7	21.2	35.8	193.1	88.7	17.7	29.9
Kirindiwela 400kV S/S		80.3					80.3				80.3		
New Habarana 400kV S/S		80.3					80.3			80.3			
Sampoor 400kV S/S		80.3								80.3			
Reactive power compensators		32.5	8.4	17.7	29.9	39.0	10.1	21.2	35.8	32.5	8.4	17.7	29.9
Transmission line		393.6	91.4	86.7	0.0	399.0	522.5	47.3	0.0	242.3	206.6	129.2	157.5
400 Sampoor - New Habarana	95	82.7								82.7			
400 Kirindiwela - New Habarana	165	143.6					143.6				143.6		
220 Sampoor - New Habarana	95					59.9							
Kerawalapitiya - Kirindiwela	30			39.5		39.5				39.5			
Pooneryn - Northern NCRE	30					18.9	18.9			18.9			
Northern NCRE - Sampoor	180	113.4				113.4							
Northern NCRE - Vavuniya	75					47.3	47.3			47.3			47.3
Vavuniya - Sampoor	100										63.0		63.0
Vavuniya - New Habarana	105					66.2	66.2						
New Anuradhapur - New Chulaw	174						109.6						
New Chulaw - Kotugoda	60						37.8					37.8	
Biyagama - Kelantissa	12.5						7.9						
Padukka - Ambalangoda	75			47.3				47.3					47.3
Ambalangoda - Hambantota	145		91.4				91.4					91.4	
Kerawalapitiya - Port (UG)	13.5	54.0				54.0				54.0			
Total (million USD)		667.0	100.0	105.0	30.0	438.0	694.0	69.0	36.0	436.0	296.0	147.0	188.0

(Source: JICA Survey Team)

Regarding the power transmission route from Kirindiwela to Kerawalapitiya, from the viewpoint of economy, it is assumed that overhead transmission lines are used up to the suburbs of Colombo, and the inside of Colombo city is to be underground transmission lines.
In addition to this, it is necessary to install additional transformers at 220/132kV substations and extend the 132kV transmission lines/substations, but the necessary timing is almost the same for each scenario, because it depends on the increase in regional demand.



(Source: JICA Survey Team)

Figure 8-36 Illustration of the Capital Investment Trend

8.6 Transmission System from Kerawalapitiya TPP

At present, there is one 300MW Combined Cycle Generator unit in Kerawalapitiya TPP. There is a future expansion plan for a one unit generation facility in this TPP, and the transmission system from the Kerawalapitiya TPP is examined.

Currently, there are the following transmission lines and transformers.
Kerawalapitiya – Kotugoda 220kV Transmission lines 2 cct (Existing)
Kerawalapitiya – Port 220kV Underground cables 1cct (Under construction)
Kerawalapitiya 220/33kV Transformers 200MVA x1 (Under construction)

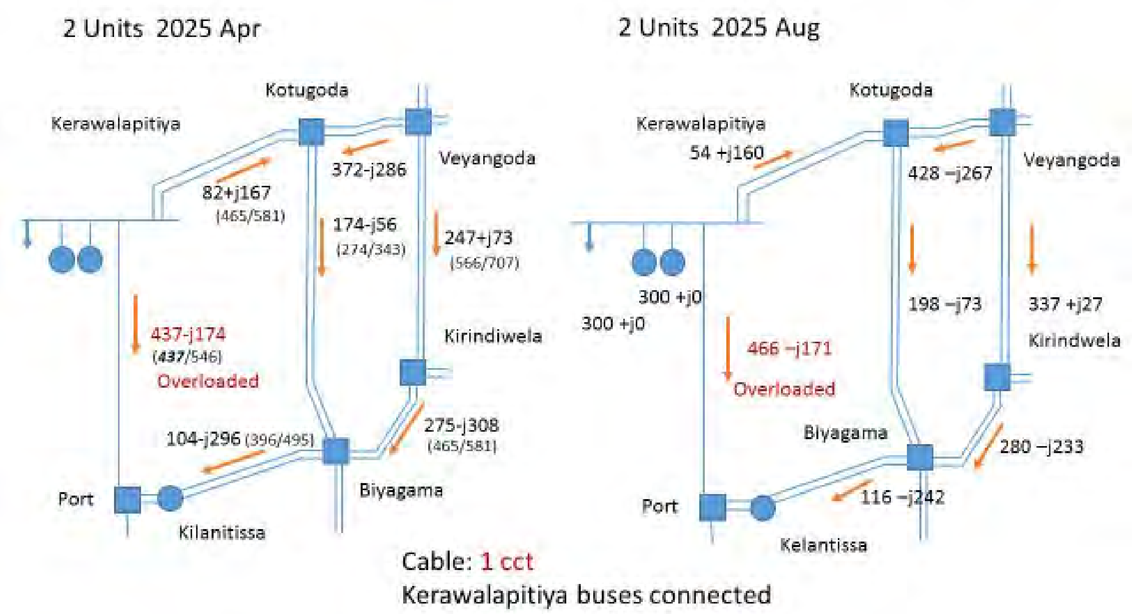
As of January 2018, one 220kV underground cable route from Kerawalapitiya TPP to Colombo city is under construction. With the expansion of Kerawalapitiya TPP in the future, power flow will increase on this route and capacity will be overloaded at single line contingency. For this reason, it is necessary to install an additional route. Therefore, two 220kV cable routes are examined in addition to the one route under construction.

In addition to the above, when installing additional underground cables, the additional route selected will be different from the underground cable route under construction, but it may not be possible to secure an appropriately sized route for the underground cables because the surrounding area is overcrowded. In this case, there is another plan to install the second route through the seabed outside the port. It is considered that the likelihood of a plan to install a submarine cable is fairly high, because a Japanese company has recently installed a 230kV AC undersea cable, which is almost the same capacity as that for the additional cable[33].

(1) In Case of Kerawalapitiya 300MW x 2 Units

An additional unit will be installed in 2019 and the total capacity will become 300MW x 2 units. At this time, Kerawalapitiya – Port 220kV underground cable and Kerawalapitiya 220/33kV transformer, which are under construction, will be completed. As shown in the following figure, Kerawalapitiya – Port 220kV underground cable 1 cct becomes overloaded due to power flow under normal operation when Kerawalapitiya – Kotugoda transmission line and Kerawalapitiya – Port underground cable are connected with Kerawalapitiya TPP and used at the same time.

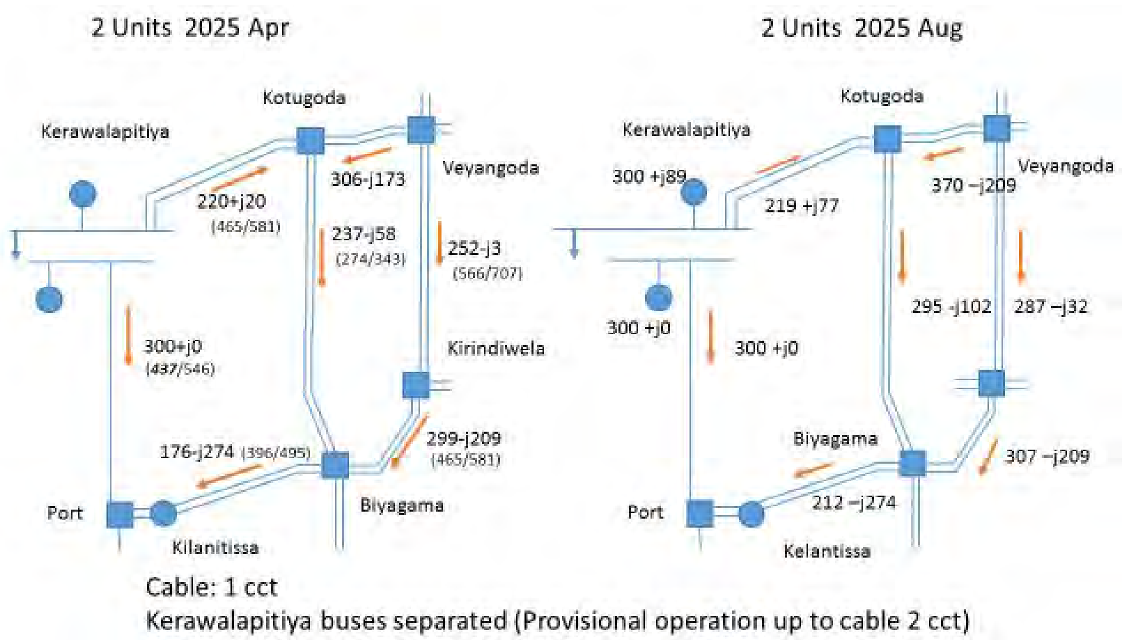
[33] Example: Installation of 230kV undersea cable which is the same capacity level
- AC 230kV undersea cable project in San Francisco bay in the US
- Total length 13.5km (Route length 4.5km)
- July in 2015



(Source: JICA Survey Team)

Figure 8-37 Power Flow in Case of 300MW x 2 units (Bus in Parallel Use)

For this reason, Kerawalapitiya – Kotugoda transmission line and Kerawalapitiya – Port underground cable are not used at the same time, and it is necessary to separate them at Kerawalapitiya TPP bus and manage them separately.



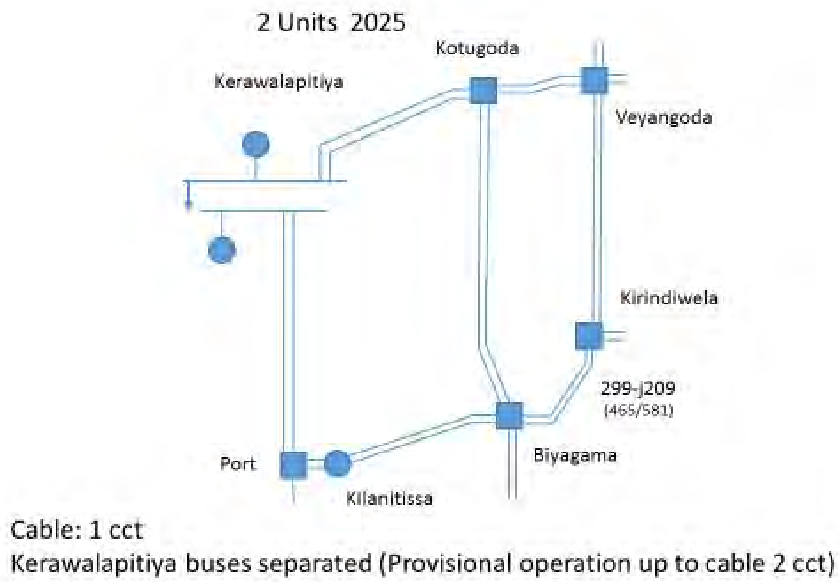
(Source: JICA Survey Team)

Figure 8-38 Power Flow in Case of 300MW x 2 units (Bus in Separated Use)

However, the generation unit connected with Kerawalapitiya – Port underground cable will be shut down[34] at single line contingency when Kerawalapitiya – Port underground is one route only.
It is necessary to install a new transmission line to avoid such a situation.

[34] CEB permits power shedding at one line underground cable failure until the second line of underground cable is installed, but it seems that this is a provisional form.

The transmission system in the case that Kerawalapitiya – Port underground cable becomes two routes by installing one additional route is shown below.



(Source: JICA Survey Team)

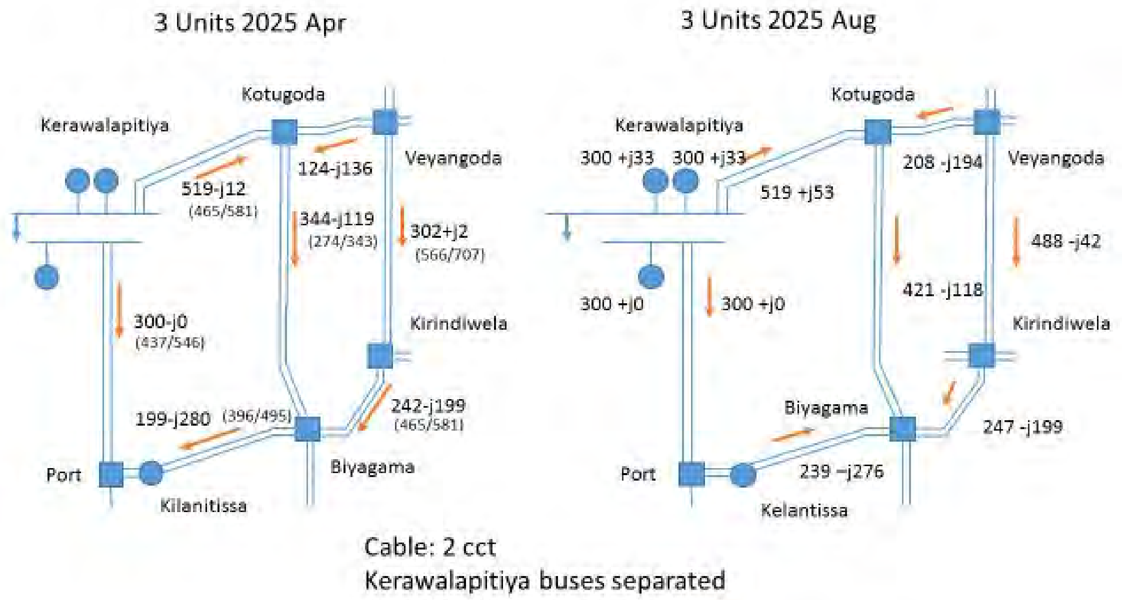
Figure 8-39 Transmission System in Two Routes of Underground Cables, Kerawalapitiya – Port

It is necessary to install the following new transmission line when Kerawalapitiya TPP becomes two units.

- Kerawalapitiya – Port 220kV Underground Cable 1 cct newly installed

(2) In Case of Kerawalapitiya 300MW x 3 units

An additional unit will be installed in around 2021 and the total capacity will become 300MW x 3 units. In this case, the transmission system for the abovementioned two units is available.

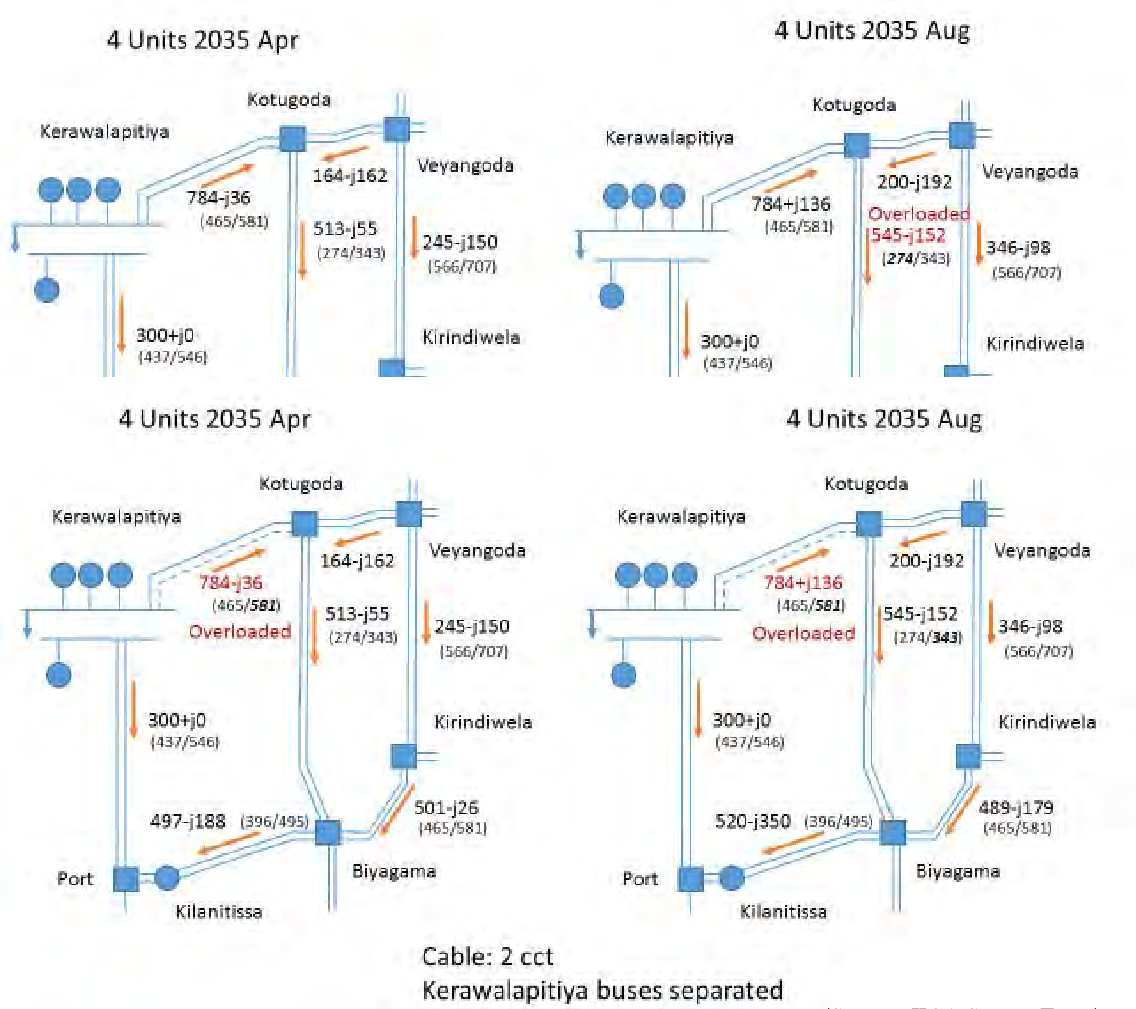


(Source: JICA Survey Team)

Figure 8-40 Power Flow in Case of 300MW x 3 units

(3) In Case of Kerawalapitiya 300MW x 4 units

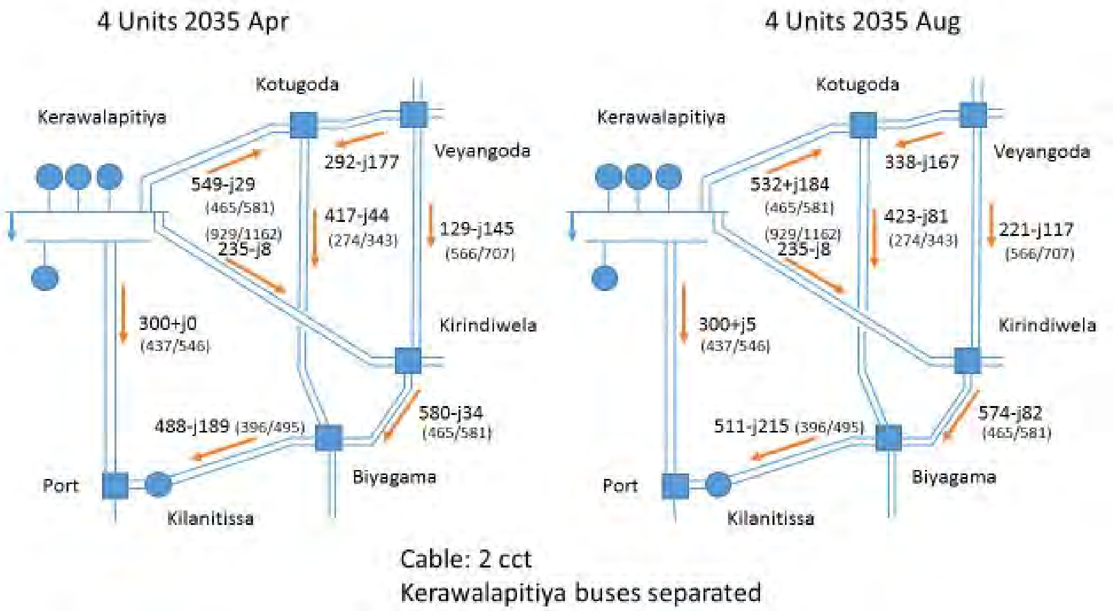
An additional unit will be installed in around 2024 and the total capacity will become 300MW x 4 units. In this case, the usual power flow at the Kotugoda-Biyagama transmission line exceeds the transmission capacity. In addition, the power flow in the other line exceeds the transmission capacity at a single line contingency of the Kerawalapitiya-Kotugoda line, and a healthy line is overloaded.



(Source: JICA Survey Team)

Figure 8-41 Power Flow in Case of 300MW x 4 units

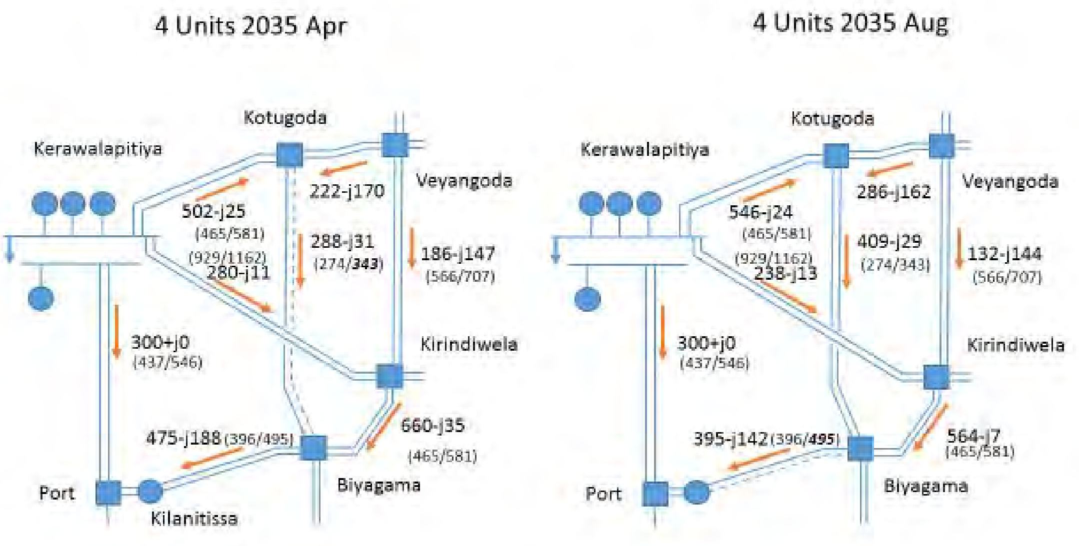
For this reason, two 220kV lines between Kerawalapitiya – Kirindiwela are installed because it is necessary to install a new transmission line from Kerawalapitiya.



(Source: JICA Survey Team)

Figure 8-42 Power Flow in Case of 300MW x 4 units (After Measures)

As shown below, the power flow around Kerawalapitiya is maintained within the capacity at single line contingency by installing new transmission lines.



(Source: JICA Survey Team)

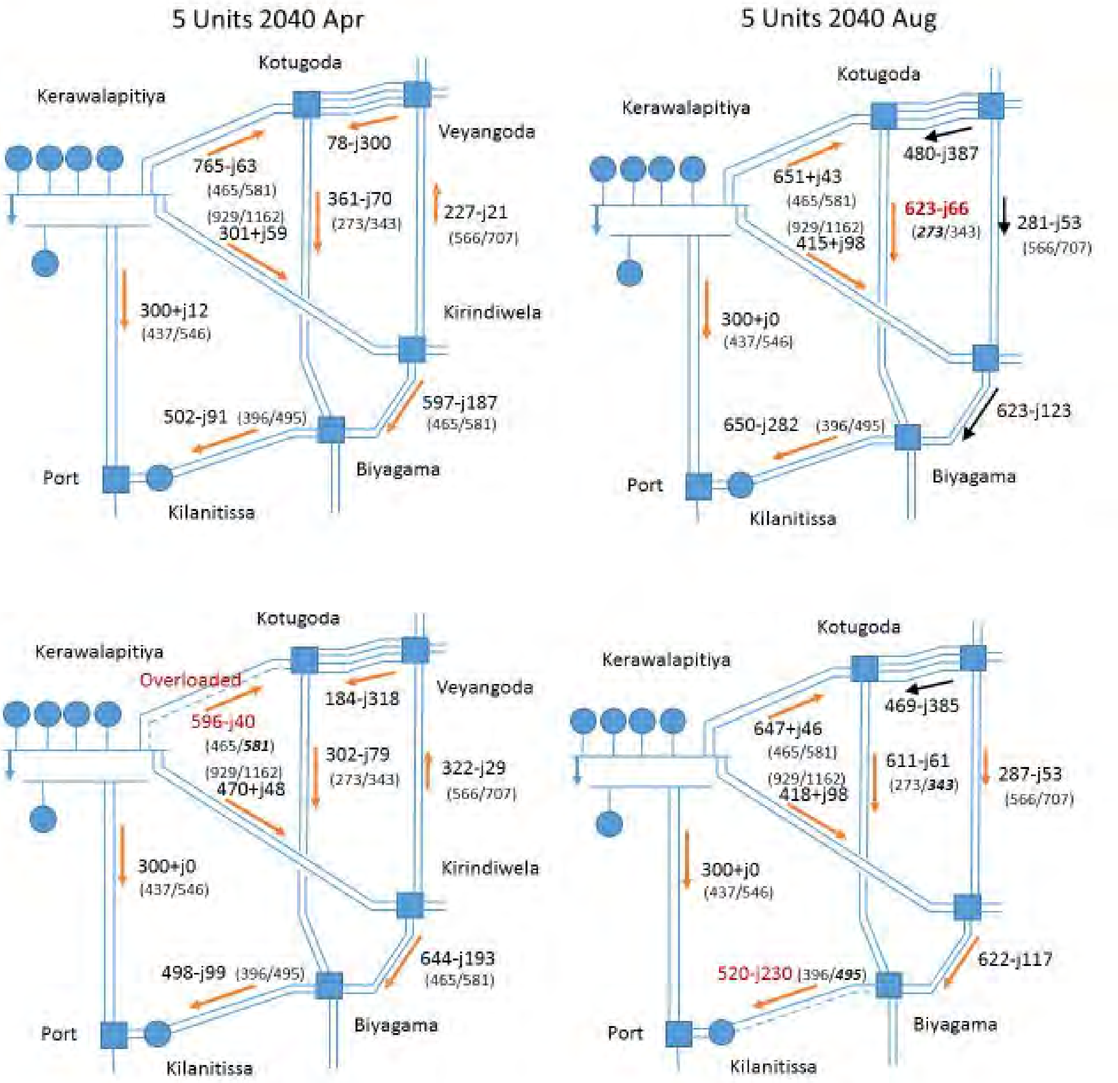
Figure 8-43 Power Flow in Case of 300MW x 4 units (After Measures, at N-1 Contingency)

Therefore, the following newly installed transmission line is necessary when Kerawalapitiya becomes 4 units.

- Kerawalapitiya – Kirindiwela transmission line 2 cct

(4) In Case of Kerawalapitiya 300MW x 5 units

An additional unit will be installed in around 2033 and the total capacity will become 300MW x 5 units. In this case, the usual power flow at the Kotugoda-Biyagama transmission line exceeds the transmission capacity. In addition, the power flow in the other line exceeds the transmission capacity at a single line contingency of Kerawalapitiya-Kotugoda and a healthy line is overloaded.



(Source: JICA Survey Team)

Figure 8-44 Power Flow in Case of 300MW x 5 units

This countermeasure is as follows:

- New transmission line from Kerawalapitiya is installed additionally.

Otherwise

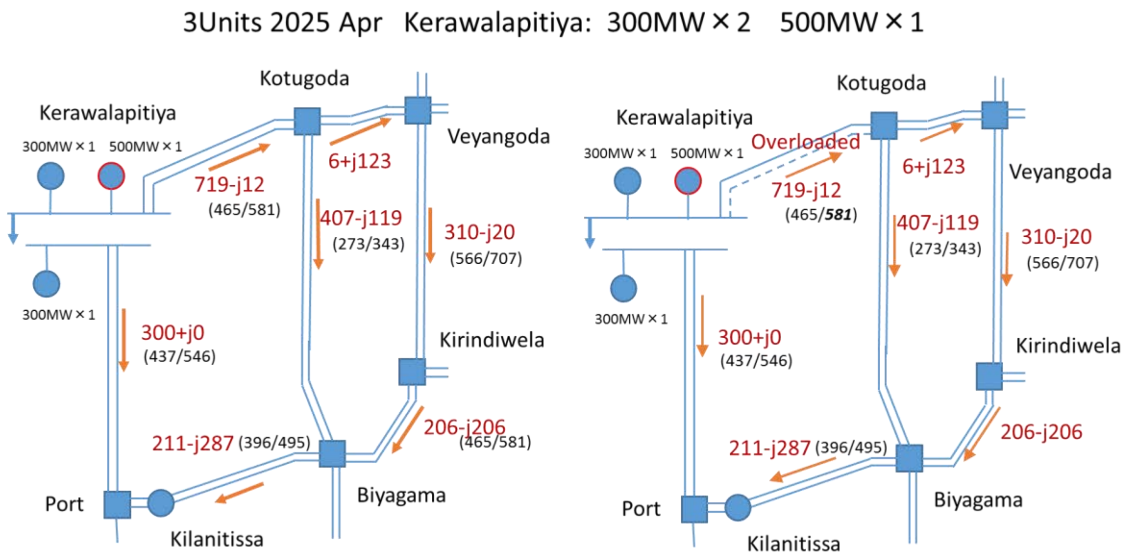
- Improvement of transmission capacity via replacement of the existing transmission lines or reconstruction.

It is considered that there is a fully possibility of reconstruction or replacement of transmission lines to improve the transmission capacity because three routes of 6 x 220kV transmission lines have already been connected to Kerawalapitiya in this phase.

For this reason, new transmission lines are not constructed anymore when the fifth unit starts operation, and it is proposed that transmission capacity for the 220kV transmission lines around Kerawalapitiya, such as Kerawalapitiya-Kotugoda, Biyagama-Kelanitissa, etc., should be increased.
However, it is a very rare case in which the power flow exceeds the transmission capacity and is overloaded at a single line contingency of Kerawalapitiya-Kotugoda, because 300MW x 5 units operate at full load and all units of Puttalam TPP stop in this situation. Therefore, a countermeasure at the operating side should be considered in order to refrain from the abovementioned extreme operation.

(5) In Case of Kerawalapitiya 300MW x 2 units, 500MW x 1 unit

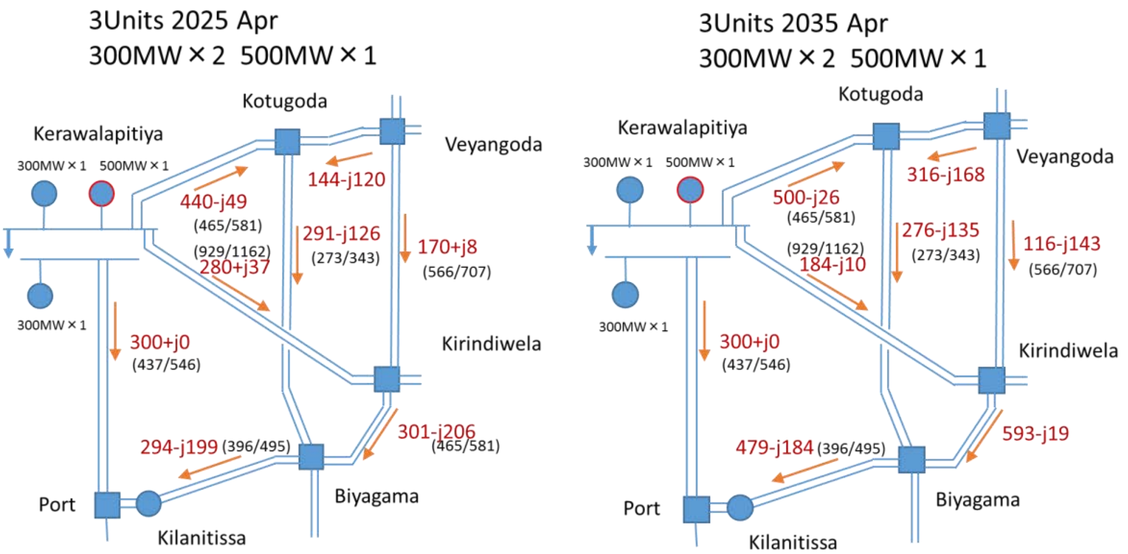
If one unit of 500MW is installed in around 2021, the total capacity will become 300MW x 2 units and 500MW x 1 unit. If all units operate at full load, the power flow at the other lines will exceed the transmission capacity and become overloaded at a single line contingency of Kerawalapitiya-Kotugoda. Therefore, it is necessary to install a new transmission line from Kerawalapitiya, and two 220kV transmission lines between Kerawalapitiya‐Kirindiwela.



(Source: JICA Survey Team)

Figure 8-45 Power Flow in Case of 300MW x 2 units and 500MW x 1 unit

However, when it is assumed that the maximum power system capacity is approximately 3,000MW and the minimum is approximately 1,200MW in 2021, and that the upper limitation of the 500MW unit operating range is 15% of power system capacity, the operating range becomes from 440MW to 180MW and the output should be suppressed in most of the time zones. For this reason, delaying the period for constructing two 220kV transmission lines between Kerawalapitiya‐Kirindiwela is considered by limiting the power flow in Kerawalapitiya-Kirindiwela to approximately 580MVA.

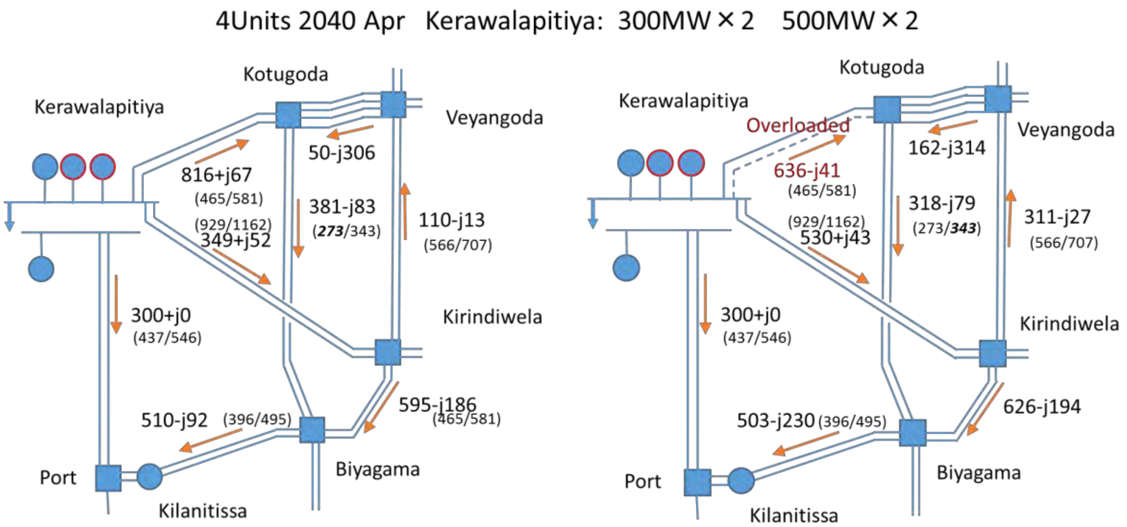


(Source: JICA Survey Team)

Figure 8-46 Power Flow in Case of 300MW x 2 units and 500MW x 1 unit (Output Suppression)

(6) In Case of Kerawalapitiya 300MW x 2 units and 500MW x 2 units

If one unit of 500MW is installed in around 2033, the total capacity will become 300MW x 2 units and 500MW x 2 units. In this case, the usual power flow between Kotugoda-Biyagama will exceed the transmission capacity.

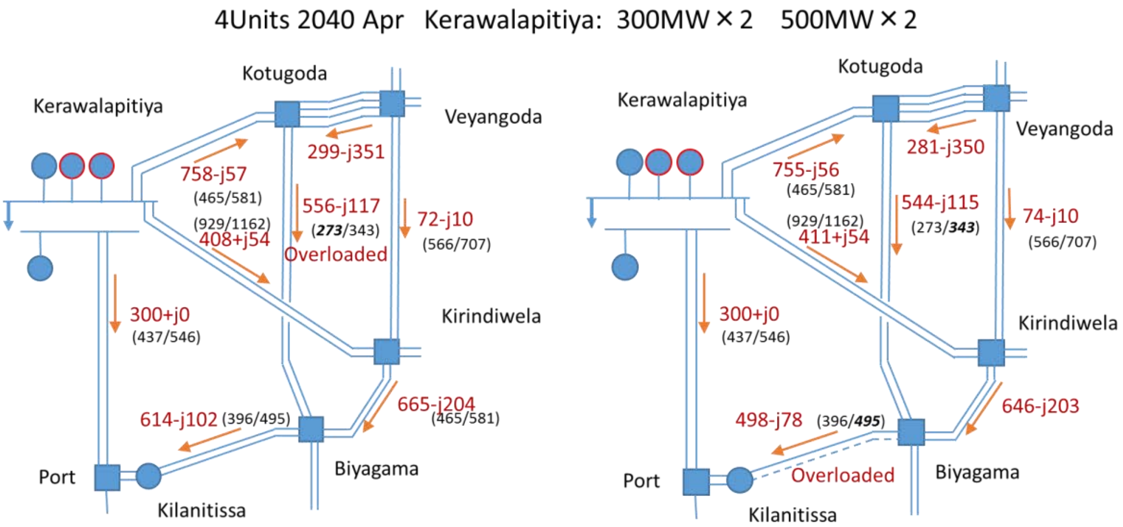


(Source: JICA Survey Team)

Figure 8-47 Power Flow in Case of 300MW x 2 units and 500MW x 2 units

Power flow under normal operation exceeds transmission capacity in the case where 300MW x 2 units and 500MW x 2 units operate at full load in Kerawalapitiya, and 275MW x 3 units operate at full load in Puttalam TPP. In addition, power flow in the other line exceeds transmission capacity and is overloaded at a single line contingency of Kerawalapitiya-Kotugoda. This situation is similar to the case of Kerawalapitiya TPP with 300MW x 5 units at full load operation.

For this reason, new transmission lines are not constructed anymore when the second 500MW unit starts operation, and it is proposed that transmission capacity for the 220kV transmission lines around Kerawalapitiya, such as Kerawalapitiya-Kotugoda, Biyagama-Kelanitissa, etc., should be increased.



(Source: JICA Survey Team)

Figure 8-48 Power Flow in Case of 300MW x 2 units and 500MW x 2 units (All Units at Full Load)

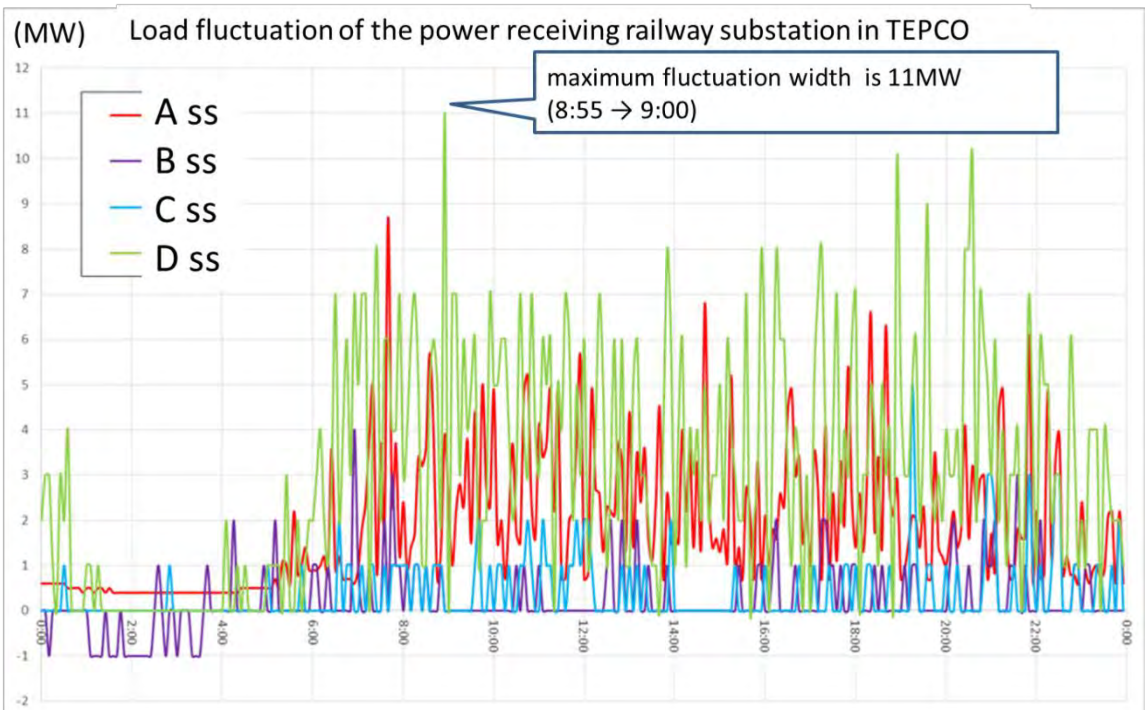
However, it is a very rare case in which the power flow exceeds the transmission capacity and is overloaded at a single line contingency of Kerawalapitiya-Kotugoda, because Kerawalapitiya TPP 300MW x 2 units and 500MW x 2 units operate at full load and all units of Puttalam TPP stop in this situation. Therefore, a countermeasure at the operating side should be considered in order to refrain from the abovementioned extreme operation.

8.7 Impact of the Fluctuating Load

8.7.1 Impact of the Fluctuating Load by the electrified Railway

Currently there are no railroads being electrified in Sri Lanka. Therefore, the JICA Survey Team examines the impact of the fluctuating load due to electrified railways in Sri Lanka, with reference to the case of Tokyo operating crowded vehicles on an overcrowded timetable.

Figure 8-49 shows the actual load fluctuation in a day at the four power receiving railway stations of J-Railway Company, which are connected to TEPCO's 66kV electric network system. According to this, it is understood that the maximum load fluctuation is 11MW.



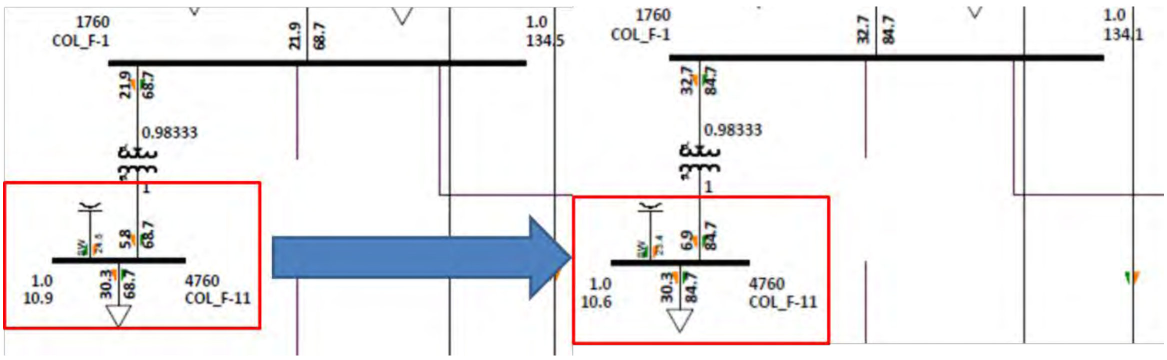
(Source: JICA Survey Team)

Figure 8-49 Actual Railway Load Fluctuation in a Day

As examples of load fluctuations other than J-Railway Company, K-Railway Company is 10.6MW and O-Railway Company is 16MW, and the power factor is almost 1.0 in either case. The maximum electricity load for a crowded 10-car train is about 6MW, and one power receiving station supplies power to three stations and a 4 to 5 km route distance on average.

As mentioned above, the maximum fluctuation range even at the power receiving station of a railroad that is operating very crowded trains on an overcrowded timetable is about 16MW (power factor 1.0), and there are no problems caused by these fluctuations.

Assuming that the maximum load fluctuation range is the same level even in Sri Lanka, the simulation results for the change in voltage at the FORT substation (COL F-11) are shown in Figure 8-50, when the load suddenly increases by 16MW at the FORT substation.



(Source: JICA Survey Team)

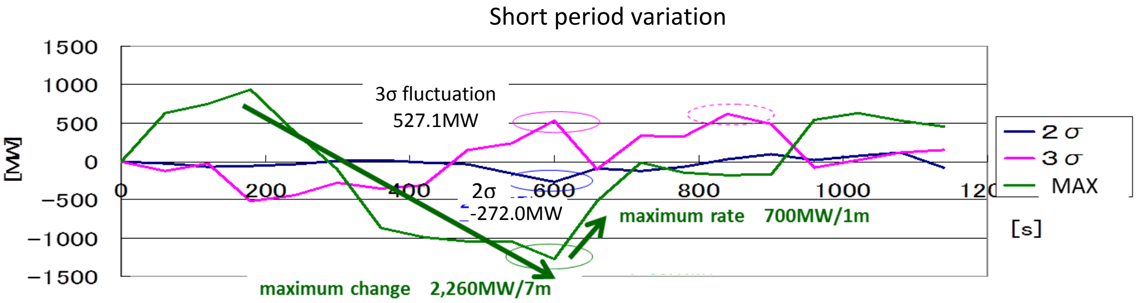
Figure 8-50 Impact of the Fluctuating Load due to the electrified Railway

It is thought that the voltage fluctuation is a drop of 0.3 kV (from 10.9 kV to 10.6 kV, 0.03 p.u.), which is not a serious problem level.

8.7.2 Impact of the Fluctuating Solar Power Output

The amount of solar power is still small in Sri Lanka. Therefore, as in the previous section, the JICA Survey Team examines the impact of solar power output fluctuation in Sri Lanka with reference to TEPCO's case, where a large amount of solar power has already been introduced.

TEPCO assumed the output of all solar power generation from the actual solar radiation performance for one year. Among this, the output fluctuation results for 600 seconds before and after the time when the maximum deviation occurred are shown in Figure 8-51. (Total electricity generation of solar power at this time is 14,200MW.)



(Source: JICA Survey Team)

Figure 8-51 Actual Solar Power Output Fluctuation (Example from TEPCO)

It is estimated that the maximum change is 2,260MW/7 minutes (16% of power generation per 7 minutes) and the maximum change rate is 700MW/1 minute (5% of power generation per 1 minute) from TEPCO's actual data.
The maximum value of solar power generation for Scenario B in 2040 is 1,600MW. Therefore, assuming that the same degree of change will also occur in Sri Lanka, the change amount is estimated as 256MW/7 minutes (= 1,600MW × 16%).

If there is a change of 5%/1 minute in the solar power generation, the solar power generation change amount for Scenario B in 2040 is 80MW/1 minute (= 1,600MW × 5%). The system scale in the daytime in 2040, which is a situation where solar power generation is close to full output, is around 6,000MW. In addition, since many hydro power plants are operating in the daytime, the power system characteristics are assumed to be 10%MW/Hz. Under such circumstances, even when a power generation fluctuation of 80MW occurs in a very short time of less than 1 second, the frequency change is about 0.13Hz (= 80MW/6000MW/10%MW/Hz) and this is well within the allowable range.

8.8 Inter-connected Transmission Line with India

Since 2000, USAID has actively supported the promotion of Cross-Border Energy Trade in the South Asia region (8 countries: India, Bangladesh, Nepal, Bhutan, Sri Lanka, Pakistan, Afghanistan, Maldives) through implementation of the South Asia Regional Initiative (SARI/EI). As part of this, the Inter-connected transmission line between Sri Lanka and India shown below is proposed.
The interconnection line capacity will ultimately be 1,000MW, with a distance of about 380 km, including a 50 km submarine cable.

(Source: 2nd Task Force 2 Meeting on "Advancement of Transmission Systems Interconnections")

Figure 8-52 Inter-connected Transmission Line between Sri Lanka and India

At the present stage, the concept for the plan is being proposed. In consideration of the future survey and implementation schedule, an economic evaluation is being carried out based on the forecasted situation around 2030.

8.8.1 Electric Power Situation in India (Tamil Nadu State)

Based on information such as the Tamil Nadu Transmission Corporation Limited (TANTRANSCO) web site, the electric power situation in Tamil Nadu State is surmised.

(1) Present situation

The maximum power demand in 2016 recorded 15,343MW on April 29. The annual power generation amount was 106,582 GWh, and the annual load factor was 79.1%. (The daily maximum power generation amount also recorded 345.617 GWh on April 29 and the daily load factor was 93.9 %.)
The recent growth in electricity demand has increased at an annual rate of 5% to 6%. If it continues to increase at an annual rate of around 5%, it is assumed that demand in 2030 will become about twice the current demand.

The status of the power plant facilities at the end of December 2016 is shown below.

Table 8-25 Electric Power Configuration in Tamil Nadu State

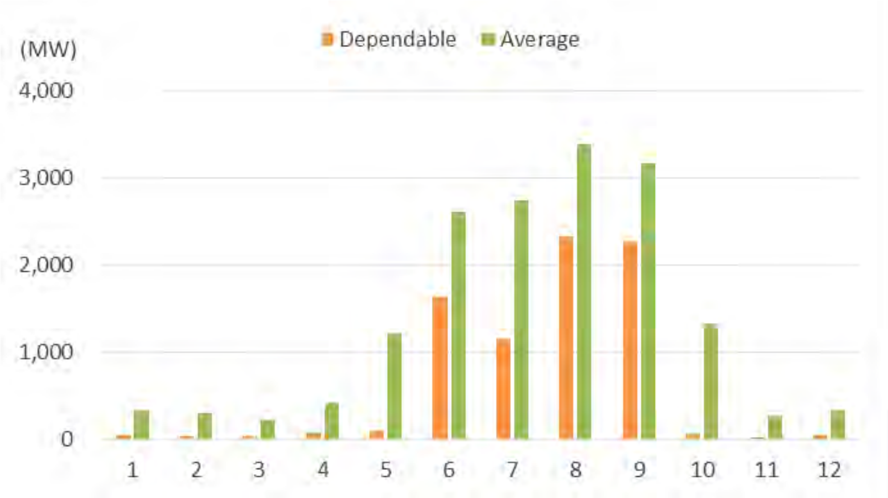
(GW, %)

	State	Private	Central	Total	
Thermal	5.2	3.9	4.3	13.3	48.6%
Coal	4.7	3.0	4.3	11.9	43.4%
Gas	0.5	0.5	0	1.0	3.7%
Diesel	0	0.4	0	0.4	1.5%
Nuclear	0	0	1.7	1.7	6.2%
Hydro	2.3	0	0	2.3	8.4%
NCRE		10.1	0	10.1	36.8%
Co-gen		0.7		0.7	2.4%
Biomass		0.2		0.2	0.8%
Wind		7.7		7.7	28.0%
Solar		1.5		1.5	5.5%
Total	7.5	13.9	6.0	27.4	100%

(Source: Created by JICA Survey Team based on the information on TANTRANSCO web site)

Installed capacity of coal-fired TPP is 11.9 GW, accounting for 43% in the configuration rate, but installed capacity of windpower is also 7.7 GW, accounting for 28% in the configuration rate.

The windpower generation results in 2016 are shown below.



(Source: Created by JICA Survey Team based on the information on TANTRANSCO web site)

Figure 8-53 Windpower Generation Results in 2016 in Tamil Nadu State

Wind power generation fluctuates seasonally and can be expected to provide a large supply of power from May to October, but from November to April, little can be expected. This situation closely resembles wind power in Sri Lanka.

(2) Future development plans

Details of future development plans in Tamil Nadu State are unknown. However, according to Vision 2023, announced in February 2014 by the state government of Tamil Nadu, the following contents are stated.

- Development of 20,000MW of thermal power plants
  Basically, coal-fired TPP (including supercritical equipment of a single unit capacity of 600MW or more) and gas-fired TPP (GT corresponding to peak)
- Development of 10,000MW of renewable energy
  Among this, 5,000MW is solar power

- Although there some conventional hydropower plans, it includes a plan for PSPP

Based on the contents of Vision 2023, the power supply configuration around 2030 is assumed as follows.

Table 8-26 Power Supply Configuration in Tamil Nadu State around 2030

(GW)

	2016	2017 - 2030	2030
Thermal	13.3	16.0	29.3
Coal	11.9	15.0	26.9
Gas	1.0	1.0	2.0
Diesel	0.4		0.4
Nuclear	1.7	1.7	3.4
Hydro	2.3	0.6	2.9
NCRE	10.1	9.2	19.3
Co-gen	0.7		0.7
Biomass	0.2	0.2	0.4
Wind	7.7	4.5	12.2
Solar	1.5	4.5	6.0
Total	27.4	27.5	54.9

(Source: JICA Survey Team)

8.8.2 Economic Evaluation of Inter-connected Line

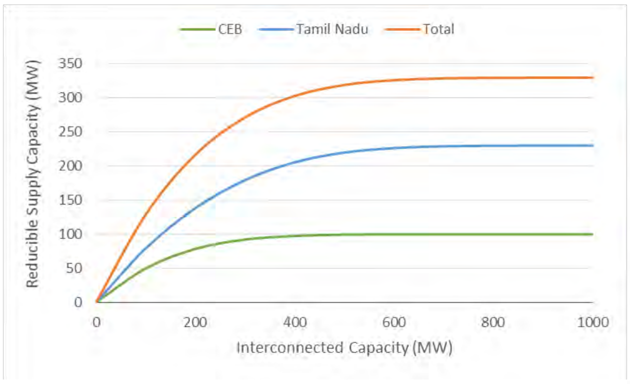
(1) Benefit

(a) Reserve capacity saving effect by interconnecting with each other

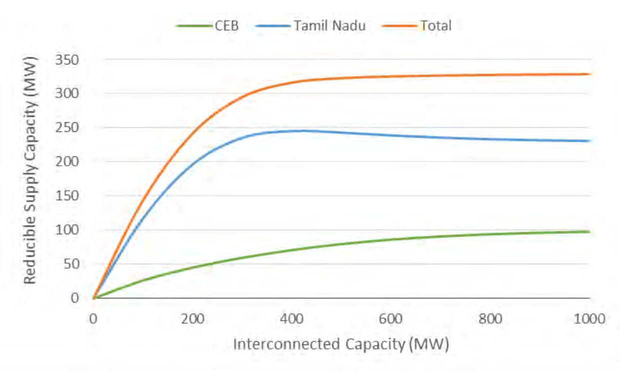
If the level of supply reliability is improved, the probability of occurrence of supply shortage is lowered accordingly, but the amount of installed capacity becomes large and the overall cost becomes high. In other words, suppressing the occurrence amount of supply shortages and suppressing the expenses necessary for the facility are utterly contradictory propositions. Construction of interconnection lines is one way to balance these two propositions.

As a measure to improve the level of supply reliability, simply increasing the amount of power generation facilities is the most effective means. However, it is possible to improve the supply reliability level of both systems with a relatively small investment by constructing interconnection lines with other systems and sharing reserve capacity. Based on the assumption that the same supply reliability (LOLE = 24 hours) is secured, the results of estimating the amount of the reserve capacity saving effect through the increase of interconnection line capacity are shown below.

When there is no constant power flow



When Sri Lanka constantly receives power equivalent to half of interconnection capacity



(Source: JICA Survey Team)

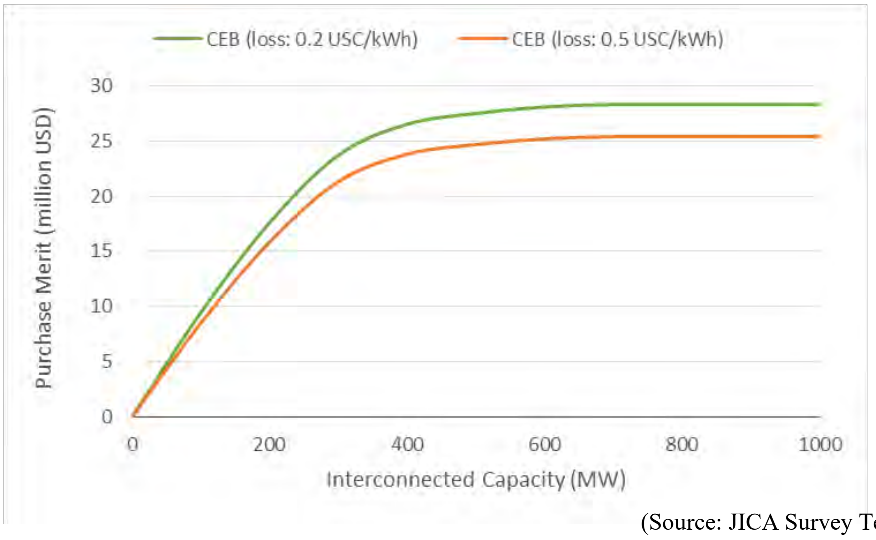
Figure 8-54 Reserve Capacity Saving Effect with Inter-connected Line

If interconnection capacity is 300MW or less, the total reserve capacity saving effect for both countries can be expected to be the same amount as the interconnect capacity. However, the effect is almost saturated when the interconnection capacity exceeds 400MW. Looking at the saving situation for each country, there is a big effect on the Indian system with its large system scale, but the effect on the Sri Lankan system is about half that of the Indian, about 100MW at most.

When there is no constant power flow, the reserve capacity saving effect for the interconnected capacity of 500MW is 318MW in total for both countries. In other words, by connecting the two countries, the same supply reliability can be secured without building such power generation facilities. This effect is evaluated as a benefit that can enable the construction of LNG-fired TPP to be avoided. The construction cost for LNG-fired TPP is 1108.8 USD/kW, and annual expenses are 122.2 USD/kW, as shown in Table 7-12. In other words, if it is possible to avoid the construction of 318MW of LNG-fired TPP, a benefit of 38.9 million USD per year can be obtained.

(b) Possibility of economic power trades

In Sri Lanka and India, there are differences in the power supply configuration and the peak occurrence time, and there is a difference in the marginal cost of each time. If there is an interconnection line, cheap electric power can be received mutually within the interconnection capacity to decrease the amount of expensive electric power, thereby bringing about the merits of fuel cost saving mutually. The results of estimating the amount of the fuel cost saving effect through the increase of interconnection line capacity are shown below.

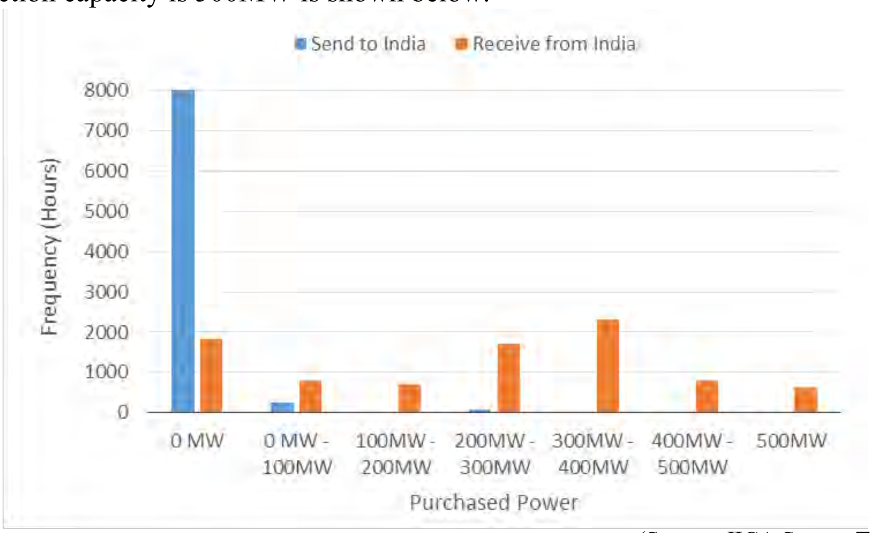


(Source: JICA Survey Team)

Figure 8-55 Fuel Cost Saving Effect with Inter-connected Line

Although the above graph only describes CEB, similar benefits are also generated on the Indian side, as it is calculated that the benefits arising from the fuel cost saving effect will be divided into both systems evenly. This effect also shows the same tendency as the reserve capacity saving effect, and when the interconnection capacity exceeds 400MW, the effect is almost saturated. If the loss is large, there is no merit in power interchange unless there is a difference in fuel cost considering losses. Therefore, as the loss increases, the amount of power trade decreases and the benefit also decreases.

The frequency distribution of power trades (case where the loss is 0.2 USC/kWh) when the interconnection capacity is 500MW is shown below.



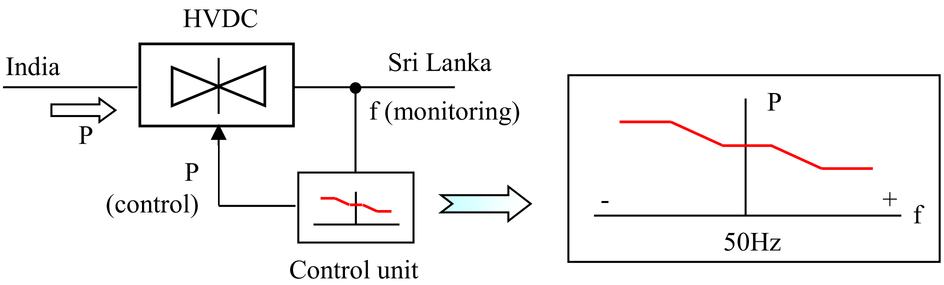
(Source: JICA Survey Team)

Figure 8-56 Frequency Distribution of Power Trades (Interconnection Capacity: 500MW)

Basically, the marginal cost on the Indian side is cheaper than that on the Sri Lankan side, so the time for electricity sending to the Indian side is very small, and the time for purchasing electricity from the Indian side is very large.

(c) Frequency Adjustment with the Use of AC/DC Convertor

An AC/DC convertor easily and rapidly controls power flow. Thus, by monitoring frequency on one side of the grid and quickly adjusting the power flow according to the variance between the monitored frequency and the defined frequency standard, frequency stabilization can be very easily achieved. A specific illustration of control is given in the following figure.



(Source: JICA Survey Team)

Figure 8-57 Illustration of Frequency Control with HVDC

When frequency rises in Sri Lanka due to the surplus in supply capacity, the supply capacity from India shall be lowered. When the frequency drops due to the lack of supply capacity, the supply capacity from India shall be increased. To avoid fluctuation of the receiving capacity, as long as the monitored frequency stays within a certain dead band near the 50 Hz standard, the receiving capacity stays constant.

Because this is a very simple controlling module, only small additional investment is required. However, in order to accommodate this controlling module, the following points should be taken into consideration.

- Fluctuation in power flow at the AC/DC convertor induces frequency fluctuation in India. Therefore, Sri Lanka needs India's consent for the controlling scheme. As applicable conditions, the size of the other network is sufficiently large and frequency fluctuation due to the fluctuation of power flow at the convertor would be rather small. In this case, the size of the Indian South grid is more than 5 times that of the Sri Lankan grid. As long as the upper limitation of fluctuation is clearly defined, it is possible to regulate the frequency fluctuation in relation to the power flow fluctuation at the convertor.
- Because it is not possible to receive more power than the HVDC capacity, the operational capacity has already got some margin for adjustment in the case of frequency drop to boost receiving capacity from India.
- When receiving capacity varies due to frequency fluctuation, the actual energy received faces deviation from the contracted capacity, and hence incurs a penalty. To avoid the penalty payment, within the contracted time zone (15 minutes), some manipulation to balance actual and contracted capacity is required.

(d) CO_2 emission reduction effect

By constantly receiving electricity from India, it is possible to reduce CO_2 emissions per unit of electricity demand in Sri Lanka. For example, when constantly receiving 270MW of electricity from India in 2030 as per the Scenario C development proposal shown in Figure 7-39, the CO_2 emissions per kWh will decrease from 0.44 kg-CO_2/kWh to 0.37 kg-CO_2/kWh. If the amount of electricity received from India is electric power via a surplus in renewable energy, reduction can be achieved on a global scale, but if it is electric power from coal-fired TPP, considering the loss at the interconnecting transmission lines, CO_2 emissions will increase on a global scale.

(2) Expenses

(a) Construction costs

According to the 2nd Task Force 2 Meeting on "Advancement of Transmission Systems Interconnections" document, the construction cost for the 500MW interconnection is expected to be 554 million USD. The adequacy of this cost is evaluated based on the construction costs of the Java-Sumatra interconnection line project in Indonesia shown below.

Capacity	3,000MW
500kV HVDC T/L	510km x 2 routes
500kV Undersea Cable	40km x 2 routes

(Source: http://hvdcsumatrajava.com/)

Figure 8-58 Conceptual Diagram of Java-Sumatra Interconnection Line Project

Table 8-27 Construction Costs of Java-Sumatra Interconnection Line

Item	Quantity	Construction cost (million USD)
AC/DC convertor station (Muara Enim)	3,000MW	324.0
500/150kV Substation (Muara Enim)	1,000MVA	54.3
500kV DC T/L (Muara Enim – Ketapang)	800km	268.8
500kV Undersea cable (Ketapang - Tanjung Pucut)	80km	352.8
500kV DC T/L (Bogor X - Tanjung Pucut)	220km	77.0
AC/DC convertor station (Bogor X)	3,000MW	726.3
500/150kV Substation (Bogor X)	1,000MVA	
Total		1,803.2

(Source: RUPTL 2011-2020)

Referring to the above construction costs, estimated construction costs for the Sri Lanka - India interconnection line project are calculated as follows.

Table 8-28 Rough Estimation of Construction Costs for Sri Lanka-India Interconnection Line

Item	Unit Construction cost	Quantity	Construction cost (million USD)
AC/DC convertor station	150 USD/kW	500MW x 2	150
400/220kV substation	60 USD/kVA	500MVA x 2	60
500kV DC T/L	0.34 million USD/km	330km	112
500kV Undersea cable	4.4 million USD/km	50km	220
Total			542

(Source: JICA Survey Team)

As a result, 554 million USD, which is estimated as the construction cost for a 500MW interconnection, is generally considered to be reasonable.

(b) Annual expenses

Using this construction cost, the annual expenses are calculated as follows.

Table 8-29 Rough Estimation of Annual Expenses for Sri Lanka-India Interconnection Line

	Item	Total	Sri Lanka	India
Construction cost (million USD)	AC/DC convertor station	150	75	75
	400/220kV substation	60	30	30
	500kV DC T/L	112	48	64
	500kV Undersea cable	220	110	110
	Total	542	263	279
Annual expenses (million USD/year)		62.9	30.5	32.4

Note: The service life of transmission and transformation equipment is 30 years, the interest rate is 10%, and the O&M cost is 1% of construction cost

(Source: JICA Survey Team)

(3) Benefits and Expenses

The results comparing the benefits and costs for the 500MW interconnection are as follows.

Table 8-30 Comparison between Benefits and Costs for the 500MW Interconnection

(Unit: million USD/year)

		Sri Lanka	India	Total
Benefit	Reserve capacity saving	12.1	26.8	38.9
	Fuel cost saving	24.7	24.7	49.4
	Total	36.8	51.5	88.3
Expense		30.5	32.4	62.9
Benefit - Expense		6.3	19.1	25.4

(Source: JICA Survey Team)

Benefits for the 500MW interconnection are larger than the costs so it is economical. However, when the interconnection capacity is further increased by 500MW to make a 1,000MW interconnection, it is uneconomical because almost no incremental benefit can be expected.

When constructing an interconnection transmission line for the purpose of constantly receiving 450MW of India's cheap power as an alternative to developing thermal power in Sri Lanka, the cost of this interconnection line is an expense of 2.0 USC/kWh. In other words, considering losses, if it is possible to procure a power source in India that is 2.5 USC/kWh or more lower than the power generation cost in Sri Lanka, it is also economical to increase the interconnection capacity to 1,000MW. Specifically, as shown in Figure 7-41, since the cost of electricity generation after 2030 is about 8.8 USC/kWh, it is necessary that power can be secured with a selling price of about 6.3 USC/kWh in India.

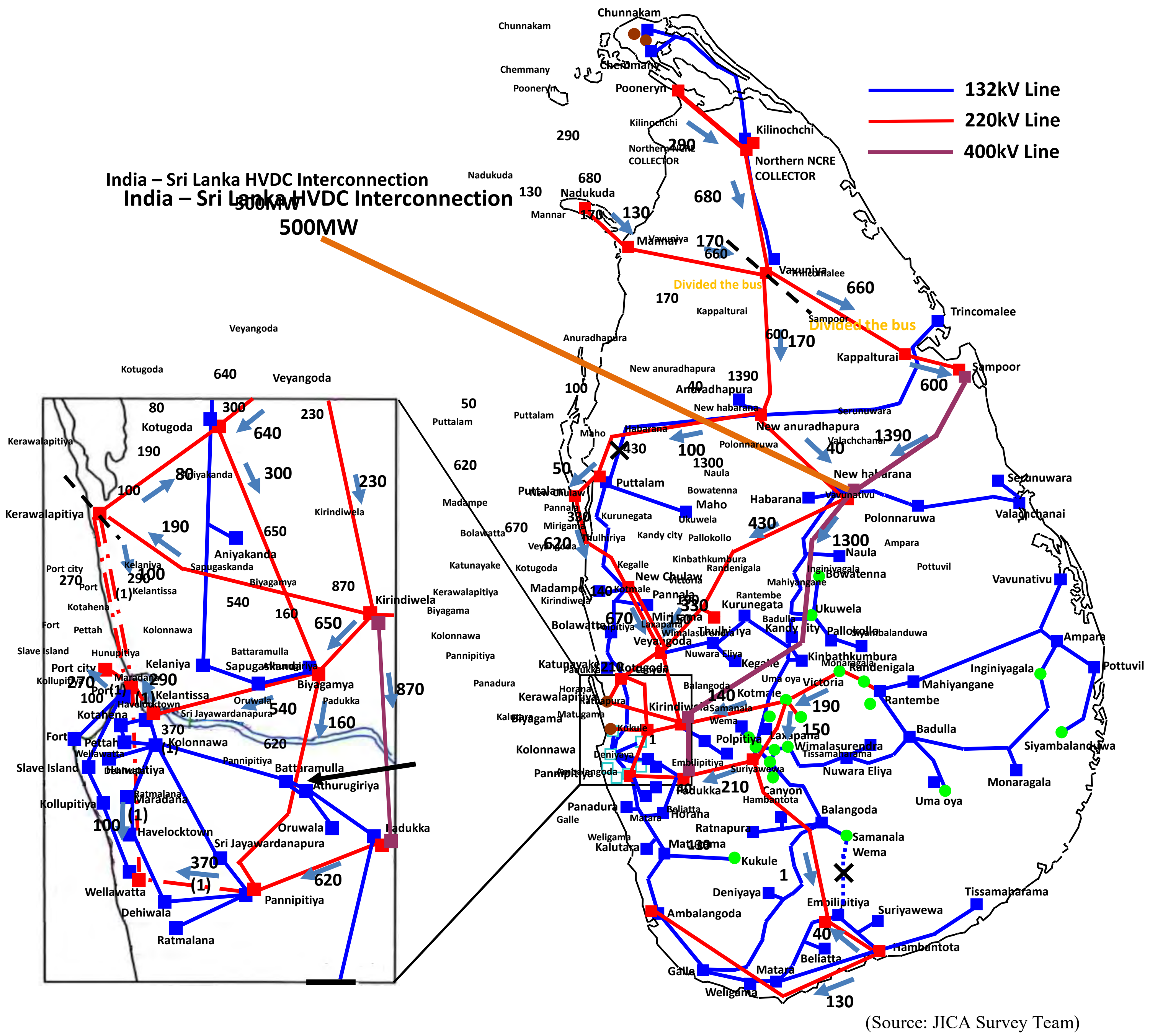
8.8.3 Necessity of Reinforcing Domestic Transmission Lines in Sri Lanka

The electric power flow analysis is carried out and the transmission line required within the domestic network of Sri Lanka is examined in the case that the Sri Lanka-India interconnection line is connected to New Habarana substation and 500MW of electricity is imported from India in the year 2035 in Scenario C. In this case, due to the electricity imported from India, the output of Kerawalapitiya TPP is decreased.

As a result, some 132kV transmission lines in the southern part of Colombo become overloaded at the time of a one-line accident, so countermeasures are necessary. However, other countermeasures are not necessary, as the system can accommodate 500MW of imports from India with only the transmission lines required by 2035 in Scenario C. Because of the reduction in the amount of power generated by the Kerawalapitiya TPP along with the importing of electricity from India, it is possible to avoid an overload at the time of a one-line accident by implementing operational measures.

2035

(In the case of importing 500MW via Sri Lanka - India Interconnection line.)



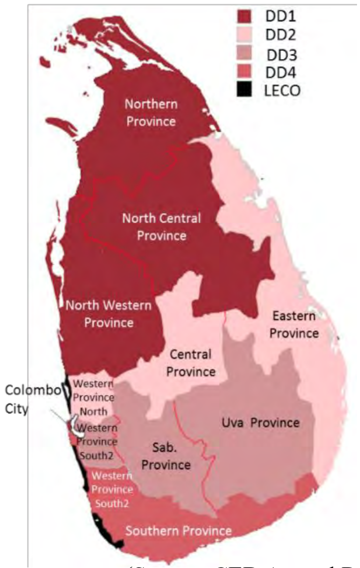
(Source: JICA Survey Team)

Figure 8-59 Power Flow Situation in case of Importing 500MW via Sri Lanka - India Interconnection Line

Chapter 9. Distribution Development Plan

9.1 Present Distribution System Situation in Sri Lanka

The survey team investigated the operational results (System loss rate, reliability indices, etc.) of each distribution company and review improvement schemes for them. Based upon the findings, we review the distribution master plan for each district and make suggestions about the planning and operation methods. Furthermore, we investigated the possibility of introducing smart grid technologies in the future.
In Sri Lanka, CEB's distribution division (DDs: Distribution Division 1 to 4) and LECO (Lanka Electricity Company (Private) Limited) are registered as the distribution licensees. Since each company operates independently, we conducted surveys for each through interviews and site surveys.
The supply areas and general characteristics of each company are shown below.



(Source: CEB Annual Report 2013)

Figure 9-1 Supply Area of Each Company

Table 9-1 General Characteristics of Each Company

Company - Province	Area (km2)	Load Density (Kwh/km2)	Electrification Rate (%)
DD1	26,810	121	92
CC	37	35,919	99
NWP	7,756	150	95
NCP	10,472	42	92
NP	8,545	35	79
DD2	17,639	204	96
WPN	1,387	1,377	100
CP	6,472	175	98
EP	9,780	57	88
DD3	14,215	138	96
WPS2	1,200	1003	99
Sab.	4,465	67	99
Uva	8,550	53	95
DD4	6,870	225	100
WPS1	1,230	502	100
SP	5,640	165	100
LECO	396	3446	100

(Source: CEB and LECO data as of 2015)

As shown in Table 9-1, electricity demand in Sri Lanka is concentrated around Colombo city, while the density is small in the northern and eastern areas of the country. Moreover, since the governmental policy has been focused on rural electrification in recent years, the electrification rate is approaching 100% in most areas. However, the rate is not so high in the Northern Province and Eastern Province due to the civil war that ended in 2009.

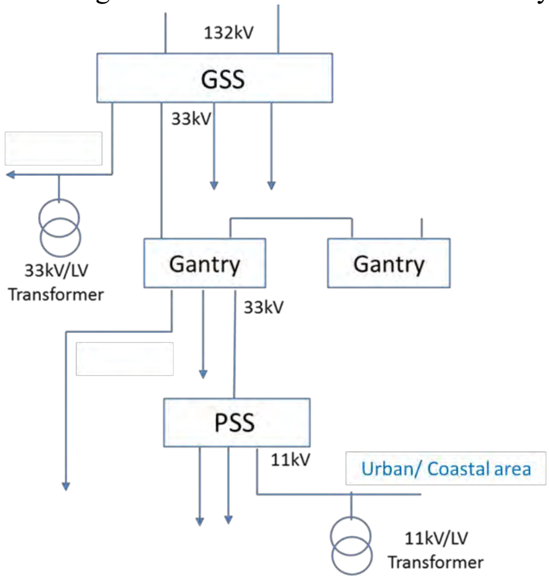
As indicated in Figure 9-1, whereas CEB supplies a wide area of the country, LECO supplies a limited area in the southwest of country. Since the load density and electrification rate of LECO is higher than CEB, LECO operates under a relatively better business environment.
The distribution system assets of each company are shown below.

Table 9-2 Distribution System Assets

Description	Unit	DD1	DD2	DD3	DD4	LECO
33kV Distribution Lines	km	8,390	8,489	6,447	4,529	0
11kV Distribution Lines	km	762	650	40	293	1,017
11kV Underground Cables	km	620	112	4	22	66
33/11kV Primary Substations	No	31	42	14	33	0
230/400V Distribution Lines	km	31,734	34,162	26,824	23,117	3,336
230/400V Underground Cables	km	562	63	0	3	
LV Distribution Substations	No	8,345	7,950	4,889	4,268	3,590
Customers (×1000)	No	1,432	1,808	1,063	908	538

(Source: CEB Annual Report 2013, LECO Statistical Digest 2015)

As shown in Table 9-2, the distribution line area is composed of Medium-Voltage (MV) lines of 33kV or 11kV and Low-Voltage (LV) lines of 230V or 400V. 33kV is mainly used for MV distribution lines, and 11kV is used for some of the urban areas and coastal areas which are affected by salt damage. Although Colombo city in DD1 is fully undergrounded and a loop system of ring main unit is installed, most areas in the county are supplied by an overhead radial system and are not as sophisticated as Colombo. The typical network configuration of an overhead distribution system is shown below.



(Source: CEB data)

Figure 9-2 Typical Network Configuration of Overhead Distribution System

The 33kV distribution feeder which emanates from GSS supplies loads to demand areas directly or after passing through the Gantry. In the 11kV supply area, the voltage is stepped down in PSS and outgoing feeders supply loads for urban areas or coastal areas. Regarding industrial parks and important facilities, a more reliable network has been installed with interconnection lines between gantries or via a primary selective system.
Although bare conductors are normally used for overhead distribution lines, the distribution companies promote the conversion of LV lines from bare conductors to covered conductors in order to reduce the number of feeder faults caused by tree contacts. Moreover, as a result of the implementation of rural electrification, the 33kV distribution lines and LV lines in remote areas tend to be long distance.

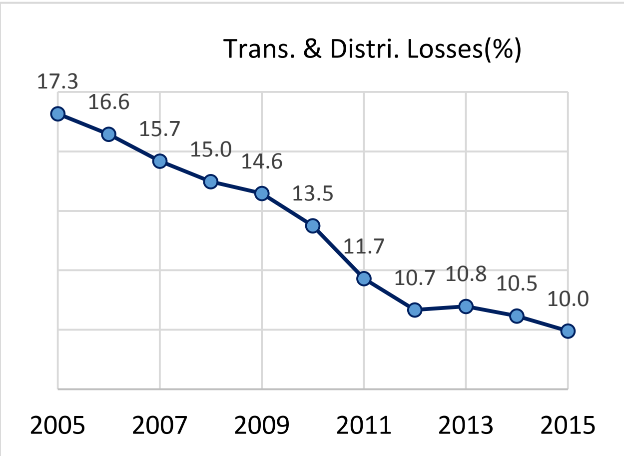
LECO is supplied from PSS of CEB and 11kV distribution lines are used for MV. Since its supply area is mainly located in southwestern coastal cities, problems such as long distance feeders do not occur.

9.2 Basic policy for distribution system enhancement

We investigated the operational results (System loss rate, reliability indices, etc.) of distribution companies and reviewed the basic policy for system loss reduction and reliability improvement.

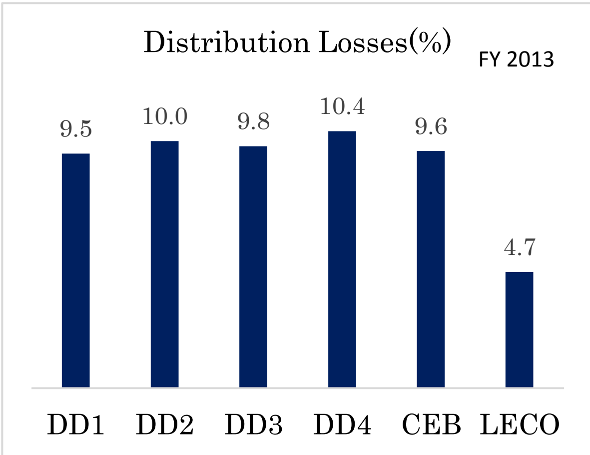
9.2.1 Present policy for system loss reduction

The trends in the transmission and distribution losses of CEB and distribution losses in each company area are shown below.



(Source: CEB Statistical Digest 2005-2015)

Figure 9-3 Trend in Trans. & Distri. Losses



(Source: CEB & LECO data)

Figure 9-4 Distribution Losses

As shown in Figure 9-3, power system losses have dramatically reduced in the last ten years. Moreover, these figures show that the majority of system loss occurs in the distribution system (e.g. 9.6% out of 10.8% were distribution losses in 2013).
Each distribution company analyzes MV system losses by using system analysis software (SynerGEE, PSS/ADPT) and has identified its value as roughly 2%. From this analysis, most losses are caused by LV distribution losses and non-technical losses. Although some distribution companies have estimated these values, they have not been quantitatively analyzed.

The countermeasures which are required, from interviews with each company, are shown below.

<DD1>

- Distribution loss is about 9% in total (2015). The breakdown is that the loss in the MV system (33 kV, 11 kV) is about 2%, the loss in the LV system is about 5%, and the non-technical loss is about 2%.
- In the LV system, voltage drops and system losses have not yet been analyzed with analysis software.
- As a measure against non-technical loss, automatic meter reading with a communication function (AMR) has been conducted for large-scale customers and each meter is regularly checked. In addition, DD1 plans to install meters to all distribution transformers (DT) over the next three years with ADB funds. It is currently in the phase of bidding. DD1 specifies transformers with larger losses than customer meters, and there is a policy to reduce non-technical losses.
- In NP and NCP, the voltage drop is relatively large because MV and LV distribution lines are quite long. In these provinces, voltage improvement via automatic voltage regulators (SVR) is implemented. However, there are only three places in DD1, one of which has not yet started

operation.

- For the city and surrounding areas, MV loss reduction by upgrading 11kV to 33kV has been planned.

<DD2>

- Distribution loss was 11% in 2015. In terms of technical breakdown, the technical loss is 2% for MV distribution lines and 5% for LV distribution lines, and the non-technical loss is around 4%. Of the non-technical losses, the ratio of theft is about 1%, which is not so high.
- To reduce the loss in LV distribution lines, it is planned to eliminate long-distance power distribution lines by making three-phase LV single-phase wires and installing new transformers. However, due to a lack of budget, the plan has not been fully implemented.
- As for the LV distribution lines, investigation using system analysis software has not been conducted. Therefore, there are plans to make use of SynerGEE, which is currently used in the MV distribution system, for the LV system analysis.
- For the urban areas of 11kV, where the power demand is growing, there are plans to boost medium voltage from 11 kV to 33 kV in order to improve system loss.

<DD3>

- Distribution loss has been improved to about 8% in total. Among this, the loss in MV distribution lines is 2.3%, the technical loss in LV distribution lines is 3%, and the non-technical loss is also about 3%.
- As measures against technical loss, new expansion of GSS and PSS, increase in capacity of overload distribution transformers, and new split distribution lines are normally planned. In addition, it is also planned to make the electric wire thicker. There is another plan to properly deal with long-distance LV distribution loss by rearranging the transformers in an appropriate manner.
- The non-technical loss issue receives support from the Energy Management Team. Meters with a communication function are installed at large customers, and the condition of the instruments and the amount of usage are checked to see if there is any fraud.
- For the purpose of load management of pole transformers and loss reduction, there are plans to install meters with a communication function at all secondary DTs.

<DD4>

- The distribution loss in 2014 was 9.2%. There is a goal to reduce distribution losses to 6% within 10 years. Of the losses, MV system loss is 2%, and LV and non-technical losses are 7%. However, the breakdown of the 7% has not yet been analyzed.
- As measures to reduce the technical loss, three-phase LV single-phase distribution lines and new substations are planned. For the non-technical loss, automatic meter reading for large customers and periodic inspection of meters are carried out. In addition, in order to prevent theft, seals for meters are being implemented.
- In order to reduce loss by implementing load control for the distribution transformers, DD4 started to install DT meters experimentally at two or three places. However, the meters do not have a communication function.

<LECO>

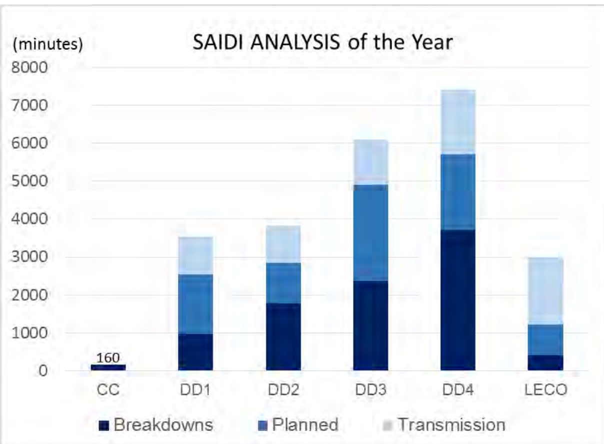
- In LECO, distribution loss is 3.76% (2015). Loss is smaller compared with the DDs.
- Energy loss is calculated by attaching a meter to the distribution transformer in order to improve the distribution losses. When the loss is large, checking the meters at each customer makes it possible to discover faults or theft.
- LECO wants to reduce the distribution loss by boosting the MV distribution line from 11 kV to 33 kV. However, as the received voltage from CEB has been determined, the plan has not been realized as of now.
- Countermeasures are being considered for when the operation rate of distribution transformers exceeds 65%. Control is being carried out under stricter conditions than the regulation stipulated

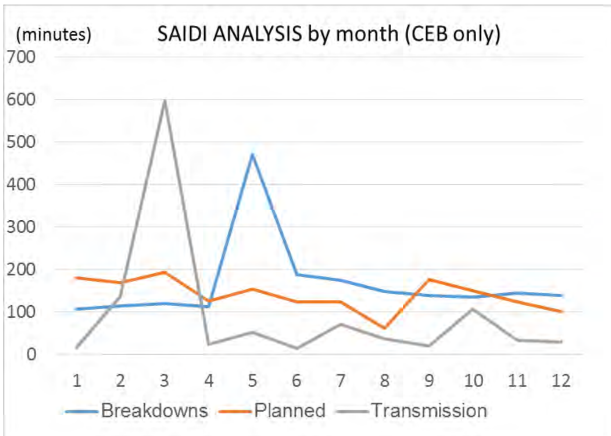
by the regulatory authority (PUCSL), which is 80%. This is aimed at reducing distribution loss.

Figure 9-5 DT Meter for Energy Management

9.2.2 Present policy for reliability improvement

SAIDI is used as a supply reliability index for each company. CEB began to take accurate SAIDI statistics in January 2016, and this is the first time that annual indicators have been developed. LECO has taken SAIDI statistics for several years. The results for each company are shown below.





(Source: JICA Survey Team based on CEB data in 2016 and LECO Statistical Digest 2015)

Figure 9-6 Yearly SAIDI by Company **Figure 9-7 Monthly SAIDI in CEB**

Outage time is classified by reasons such as LV & MV equipment breakdowns, planned interruption (e.g. maintenance or construction work) and transmission failures. For our analysis, breakdowns and planned outages in 33kV for LECO are included in the transmission because LECO is not responsible for the 33kV distribution system.

Looking at the indices for each company, DD1, DD2 and LECO are relatively reliable, but reliability is low in DD3 and DD4. Considering that about 60% of LECO outages are caused by the transmission system, it can be said that operation with the highest reliability is performed. Although Colombo City is in DD1's area, it is operating with a high degree of reliability in comparison with other areas. This is the result of setting all the distribution lines underground in a loop system, and performing supervisory control by SCADA.

Looking at Fig. 9-7, it can be seen that power outage in the power transmission system in March and the equipment trouble in May have a great influence. In the March power outage, two outages occurred in the power transmission system, and distribution companies were greatly affected. In May, large-scale blackouts occurred due to natural disasters, mainly in DD2 and DD4.

In order to reduce the power outage time, measures for each target factor are necessary. For example, in order to reduce power outages in the event of equipment trouble, effective measures are to introduce distribution automation systems and fault indicators for early recovery of accidents, and to improve aspects of the equipment to reduce some kinds of equipment failure. In order to reduce the effect of planned outages, networking of the power grid that reduces the outage area/section is effective as well.

The countermeasures which are required from interviews with each company are shown below.

<DD1>

- Covering of LV naked wires is 10% complete as of present. All new LV distribution lines are covered conductors.
- The overhead distribution system in CEB is basically radial. In the industrial areas, power supply by dedicated line or by main and reserve lines are employed based on the requests from large customers. In this case, additional necessary expenses are borne by the customer.
- Auto Reclosers are installed on the Gantry and 33 kV distribution lines. The reclosers and relays of GSS are coordinated in protection. When a distribution accident occurs, the recloser on the power supply side of the accident point opens, and the accident point is separated. The maximum number of reclosers to be installed in one feeder is three, and beyond that, protection coordination becomes difficult.

Figure 9-8 Auto Recloser Installed on the Gantry

- Regarding overhead MV lines, accident current passing indicators (FI: Fault indicator) of pole mounted type are installed on utility poles. However, they are susceptible to the influence of magnetic fields from the low voltage line and the transformer, so the detection accuracy is low.
- Fault detection for a distribution accident is roughly performed via customer calls and the fault indicator (FI) which is attached to the overhead distribution line. After that, a visual inspection is done. As for underground cable, a fault point exploration device is used to find the accident point.
- The above device detects the fault point based on the time difference between the magnetic field generated by the surge and the arc sound of the fault point. Since it is difficult to detect the arc sound during the daytime due to the considerable noise in towns, fault point searching is generally conducted at night.

- For a distribution line accident, there is one engineer in charge of each area in all 30 areas. Accident causes are normally categorized into 17 categories. However, detailed analyses of failures and countermeasures have not been made.
- As a countermeasure against salt damage in the coastal areas, DD1 is conducting 11 kV distribution utilizing 33 kV insulators. However, DD1 recognize that this is not a fundamental solution. For this reason, countermeasures such as replacement with salt resistant insulators, periodic cleaning of insulators, and special painting are planned.
- In order to reduce construction interruptions, DD1 performs hot-line work using hot sticks only for 33kV steel tower maintenance work (the tool is manufactured by A. B. Chance, USA).

<DD2>

- Currently, the overhead MV system is basically radial. However, there is a policy to increase the loop system according to the importance of the supply area. Industrial parks and major cities are designated as important areas, and reliability is decided according to the area's needs.
- An auto recloser is installed on the overhead 33 kV distribution lines, with at most two units per feeder.
- In many cases, accident points at distribution lines are recognized by power interruption notifications from customers. The call center operates on a 24-hour basis. After receiving a customer's call, the call center informs the area office and the restoration group located at each local office performs the restoration work.
- Detecting the accident point is done by visual inspection. When an accident point is found, the accident section is separated by the line switch on the power supply side of the accident point, and power restoration is carried out in the healthy section. Depending on the length of the distribution line, it can take a long time to find the accident point.
- FIs (NortRoll made) are installed at 15 to 20% of the overhead power distribution lines. Both conductor-attached type and pole-mounted type are used. Some FIs have a communication function and it is possible to remotely monitor the status.

Figure 9-9 Fault indicator for overhead distribution lines

<DD3>

- As an improvement for power supply reliability, expansion of the installation of FIs and auto reclosers is planned. FIs are conductor-attached type. Some FIs have a communication function and can monitor the status remotely.
- Since the auto recloser needs protection coordination with the substation CB, it is normally installed in one place on the Gantry. As for the long-distance feeders, up to two reclosers are installed per feeder.

- LV distribution lines are planned to be replaced with covered wires, and all newly installed wires are covered conductor.
- FIs are preferentially installed at some places where tree contacts are frequent and distances of distribution lines are long.
- Regarding causes of accidents, tree contacts with bare conductors are dominant; other causes are blown fuses and bad weather (heavy rain due to the monsoon from May to September, equipment failure due to strong winds and thunder in the central mountain area throughout the year).
- As a measure against lightning strikes, Arresters are installed on the primary side of each transformer (DT) and on the pull-in pole of large customers. In some cases, due to lightning strikes of IKL 100, equipment failures may occur.
- DD3 does not perform direct live line work by hot stick. Therefore, when maintenance or new power supply work is conducted, distribution lines at the site are stopped and construction work is carried out during an outage.

Figure 9-10 Distribution Transformer (DT) and Arrester

- To improve reliability, Vegetation Management (tree cutting) is carried out. Depending on the growth of trees, they are cut about three times a year. The separation from trees is set to 5 feet at LV lines and 15 feet at MV lines.
- For large-scale customers such as some big factories, power supply reliability is increased by supply from a main & reserve line (by two parallel lines) due to customer requests.

<DD4>

- In a distribution accident, the target distribution line is identified by customer calls. The call center then contacts the area office. The recovery team normally detects accident points by visual inspection.
- The main reason for distribution line accidents is tree contacts, which are a problem especially in rural areas where the length of distribution lines is long. For this reason, according to the patrol provision of PUCSL, tree patrols are conducted twice to four times a year.
- DD4 is working on replacing LV bare conductors with covered ones to reduce the number of outages due to trees. There are plans to replace every bare conductor with covered wires within five years.
- Measures for grid side enhancement, installing grid interconnections, have not been carried out because they are expensive. We are taking measures on the equipment side mainly by installing an auto recloser or a manual load break switch. These devices do not have a communication function, and are operated in a standalone manner.

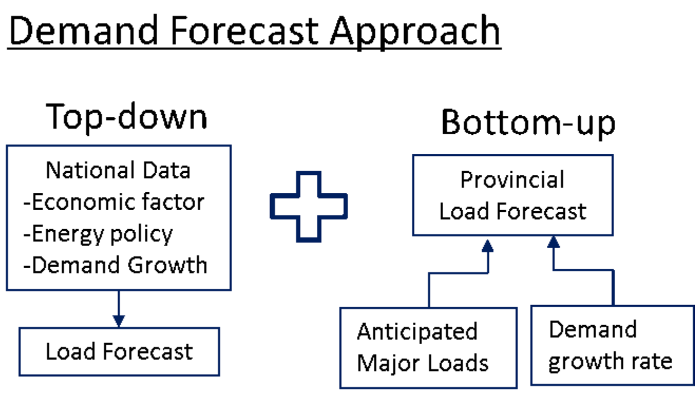
- Installation places for auto reclosers are determined by the length of the distribution line and the frequency of accidents. Up to two are installed in total, one for the Gantry and one for the distribution line. GSS relays and reclosers are set to be coordinated.

<LECO>

- SAIDI/SAIFI statistics are well managed. In the results for 2015, SAIDI is 50.55h and SAIFI is 91 times. Of these, about 60% are outages due to the CEB system with a higher voltage level.
- The overhead distribution system is an open loop system interconnected with other distribution lines. MV distribution lines are operated at 50% of normal occupancy rate. However, since the operation rate of the higher voltage system is already large, it is sometimes impossible to switch the load.
- The length of the distribution lines is generally about 3 km. A manual LBS is installed every 1 km, and 3 to 6 are installed per distribution line. In the event of a power outage, the accident section is separated and power is transmitted in the healthy section. Although an auto recloser is installed on the 33 kV Gantry, one is not installed in the 11 kV distribution line.
- An FI is installed in the distribution line, and information is sent to the control center via wireless communication.
- When distribution line faults are reported by customer calls, field-workers look for the fault point using FI and visual inspections. Although fault points are relatively easily found due to the short length of distribution lines, it takes a long time to reach the site because they don’t use emergency vehicles to avoid traffic congestion.
- The major causes of distribution line accidents are vehicle collisions with utility poles, third party causes (contact with heavy machinery at construction sites, etc.), and animal and tree contacts with the overhead wires.

9.3 Review of Distribution System Master Plan

Each distribution company formulates a “Medium Voltage Distribution System Development Plan”, which is expected to be reviewed once every two years as a 10 year rolling plan. The reviews are carried out at Provincial level by computer modelling and network analysis using computer software such as SynerGEE, and by load forecasting methodology based on a combination of two approaches (Top down and Bottom up) as below. After the computer software identifies future violation points (voltage drop, overloading, etc.) in the distribution system, countermeasures are planned.



(Source: JICA Survey Team)

Figure 9-11 Demand Forecasting Methodology

With regard to the demand forecast, their forecasting methodology is properly developed. Each company has adopted a combination of requirement-based forecasting and historical trend analysis in provincial level forecasting, in addition to National level forecasting. Moreover, in order to achieve the planned objectives, many kinds of options are studied in detail and the most economical and sustainable solutions are selected; as a result, the investment plan is designed to be optimized.

The condition of the future MV distribution system is analyzed based on the Voltage and Equipment loading criteria which are regulated by PUCSL. However, system reliability criteria have not been studied and the criteria are not regulated yet.

Table 9-3 Voltage Criteria

Nominal/Maximum Working Voltages	Normal		Contingency	
	Min	Max	Min	Max
	%	%	%	%
33kV/36kV	- 6%	+ 6%	- 10%	+ 10%
11kV/12kV	- 6%	+ 6%	- 10%	+ 10%
230V/400V	- 6%	+ 6%	-10%	+ 10%

(Source: CEB data)

Table 9-4 Equipment Loading Criteria

ITEM	CRITERIA
Distribution Lines	Economic Loading, 70% of thermal rating Emergency Loading, 125% of thermal capacity
Primary Substation	Firm capacity with 25% Overloading
Distribution Substation	80% of transformer capacity

(Source: CEB data)

Table 9-5 Reliability Criteria

Index	Norm
SAIDI	yet to be decided/published by PUCSL
SAIFI	yet to be decided/published by PUCSL
CAIDI	yet to be decided/published by PUCSL

(Source: JICA Survey Team based on CEB data)

As the study is mainly focused on the load flow analysis of the MV distribution system, LV systems are not studied in the plan and the reliability improvement effects are not evaluated in detail. Moreover, the reinforcement project related to increasing NCRE is not considered in the study.

MV development proposals are categorized as short term, medium term and long term proposals according to the total project cost. Short term proposals are carried out using CEB system augmentation funds. Medium and long term proposals are carried out using CEB funds and foreign funds such as ADB.

Based on reviews of MV development plans and interviews with each company, we have summarized their challenges regarding the existing system as below.

(a) Inadequate capacity in substations and distribution lines
In the supply areas of each distribution company, distribution facilities are approaching overload and their systems do not have enough flexibility for reliable operation. For this reason, it is necessary to reinforce each facility in the appropriate year without deferral.

(b) Low voltage situation in distribution lines
Low voltage is caused by the long distance of 33kV and LV distribution lines without voltage compensation devices. This situation has been confirmed in rural areas of the country. As a result of

rural electrification, which has been promoted by the electric power policy of Sri Lanka, the ratio is approaching 100%. However, this has caused the low voltage situation as above. From now on, it is necessary to construct new substations and install SVR in order to improve the low voltage situation.

(c) Installation of Distribution SCADA System
In Colombo City, Distribution Control Centers (DCC) equipped with fully functioning SCADA systems for the underground MV network were implemented in 2012. However, DCCs equipped with SCADA functions were installed in only 5 districts of the whole country, and power failure information in the other districts is confirmed only after telephone contact from the customers.

Figure 9-12 Distribution Control Center in LECO

(d) Breakdowns caused by vegetation, and fault location methods
The main cause of power failures is tree contacts, mainly in rural areas where the MV feeders are long distance. Effective solutions for vegetation management are periodic patrol of lines and conversion from bare conductors to fully insulated conductors. Moreover, when a power failure occurs, the fault point is identified mainly by a patrol of the lines. This takes hours for the long MV feeders, and a more efficient fault location method is desirable.

(e) Identification of LV system losses and non-technical losses
Each company analyzes the MV network using power system analysis software and monitors the system losses by metering feeder load, but the LV system is not analyzed in the same way. Distribution Transformer (DT) meters are useful for monitoring LV system losses and non-technical losses. Some companies have started to install these on a trial basis, but the installation rate is not adequate in the current situation.

9.4 Proposals for distribution planning

9.4.1 System loss reduction

There are two types of system loss. One is the Technical Loss, which is technically caused in distribution feeders, and the other is the Non-technical Loss, which is caused by tapping, defective meters and so on. For countermeasures to reduce these losses, we propose the following options as an interim report.

(1) Technical Loss reduction
As countermeasures to reduce MV system losses, construction of new GSS and optimization of network power flow are effective and each distribution company has already implemented these solutions by identifying the violation points via analysis software. Therefore, it is appropriate to implement the same

methodology for the LV system. As countermeasures to reduce LV system loss, conversion of single phase to three phase and construction of new distribution transformers in long LV lines are effective.

(2) Non-technical Loss reduction

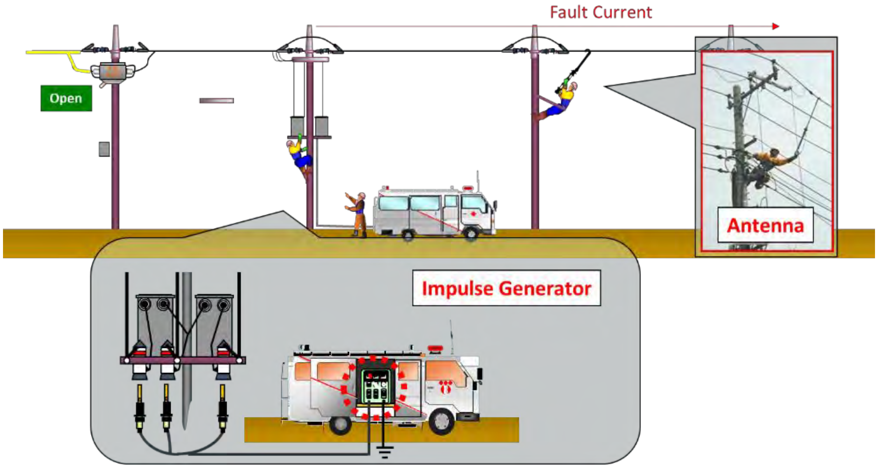
In order to identify the non-technical losses in LV feeders, DT meters are effective. We confirmed that some of the DDs and LECO have already installed them on a trial basis. By evaluating the values of DT meters and customers' meters, tampering and defective meters are identified. Moreover, installation of smart meter equipment with remote monitoring and reading functions is effective for promoting load management in an LV system. Each company has already installed this for the bulk customers. Therefore, we propose to expand the installation to DT meters.

9.4.2 System Reliability Improvement

For countermeasures to improve system reliability, we propose the following options.

(1) Distribution line fault detection method for overhead MV lines

In order to reduce the outage duration in the short term, fault detection devices are effective for reducing the time needed to locate fault points. At present, each distribution company uses a fault indicator which detects the fault current to effectively patrol the MV feeders. However, as it is fixed at a specific point on the MV feeders, it is not effectively utilized in some situations. Therefore, we recommend a fault detection method using a portable generator and antenna. This method will contribute to the quick detection of fault points and some DDs and LECO have an interest in it. The fault detection method is as follows.



(Source: JICA Survey Team)

Figure 9-13 Fault point detection method in TEPCO

In this method, the fault current is generated by applying a DC voltage up to 15kV with a portable generator to the outage line. Then, field crews put an antenna, which is equipped with a highly sensitive current transformer, to the line and find the direction and the phase of the fault point. This method can identify invisible fault points such as insulator cracks and internal faults in lightning arresters.

Since this method greatly interests CEB and LECO, the survey team conducted a demonstration program in CEB's training center in February 2017. In the first session of the program, we explained the operating procedure, including safety instructions, in the Lecture hall. After that, fault detection methods were demonstrated on the training MV line by using actual devices.

Figure 9-14 Workshop in Lecture hall

Figure 9-15 Demonstration in Training Field

In addition, in this demonstration, together with the charging device, technical introductions on overcurrent indicators and enclosed cutouts made in Japan were also introduced. Questionnaires were given to the participants and the following results were obtained. The participants of the workshop were engineers from the planning and development department of each company.

Table 9-6 Questionnaire for the Workshop & Demonstration

Question	Device	Score
Q.1 How interested are you in each device? (low = 1, high = 5)	Fault Point Detector	4.0
	Fault Indicator	3.7
	Enclosed Cutout	4.3
Q.2 What was the most impressive device/tool?	Fault Point Detector	14/38
	Enclosed Cutout	10/38
Q.3 How did you understand the fault detection method in Japan? (poorly = 1, fully understood = 5)		4.2
Q.4 Is it possible to introduce the fault point detection in Sri Lanka at the moment? (not possible = 1, possible = 5)		3.8

Total Participants: 58, Effective Replies: 38

(Source: JICA Survey Team)

As shown in Table 9-6, participants evaluated the fault point detector highly. However, some participants pointed out the insufficiency of the applied voltage for the 33kV system, which might result in undetectable situations with regard to high resistance ground faults and internal faults in lightning arresters.
In order to introduce this device, it is necessary to verify the technical issues which may arise from using this equipment.

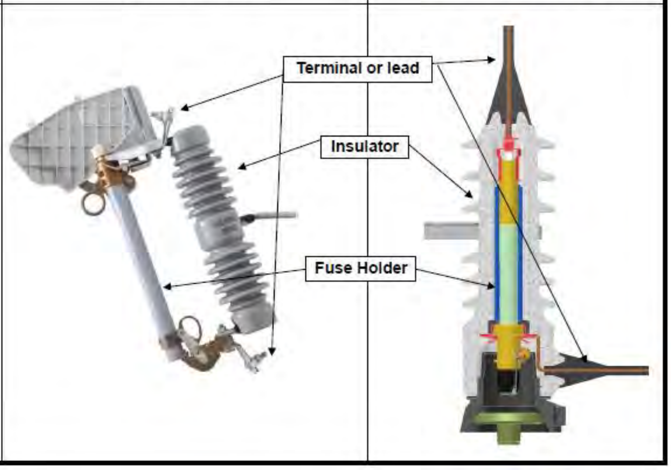
First, DC 15kV is less than the rated voltage of 33kV distribution lines. In general, the cause of distribution line faults comes from a permanent ground fault in which the electrical circuit is connected to ground through fault points such as tree contacts, equipment failure, salt contamination, etc. In this case, the fault current depends on the resistance of the fault point, so the detection capacity of fault locators does not depend on the distribution voltage. Therefore, it is highly likely that this equipment can be applied for a permanent ground fault at a 33kV distribution line, but verification on real lines is also required.

Second, the detectable range of this ground fault detector is approximately 30 km from the DC pulse injection point. In the CEB's 33kV distribution lines, there are some long lines that are over 100km. In such cases, it is necessary to take countermeasures which divide such feeders into 30km or less by installing some section switches. For distribution lines with high frequency of accidents, it is effective to use the fault current indicator (FCI) that can detect the fault current together with the fault detection device for more actual location to be detected as well.
Third, safety concerns was raised by CEB because the LV side of distribution lines is also energized through a distribution transformer when applying DC voltage to an MV line. In Japan, we do not take safety measures such as opening the transformer primary side when applying pulse into the MV line. This is because it is the DC pulse, and the apply time is very short from 10 to 500 ms, and also the secondary current is very small due to the internal resistance of the transformer. Therefore, there is no adverse effect on the transformer and the secondary side.

In order to introduce this device, it is necessary to implement a pilot project with cost-benefit analysis in the actual field in order to identify the suitable DC voltage to be applied, ground fault detection range, safety measures and other issues.

(2) Introduction of Enclosed Cutouts
Generally, a cutout is installed on the primary side of a distribution transformer in order to disconnect it from the MV distribution line. In Sri Lanka, open type is adopted for cutouts, and the structure of the fuse holder is exposed as below. An enclosed cutout is adopted in Japan, and the structure of the fuse holder is concealed with the insulator. The main benefit of an enclosed cutout is a reduction in the number of equipment breakdowns by preventing tree contacts and salt contamination. Since there are many coastal and forest areas in Sri Lanka, the introduction of enclosed cutouts would be effective. However, since this product isn't currently manufactured for 33kV, we propose to focus on 11kV distribution lines. In addition, a detailed study should be carried out with CEB regarding the installation, maintenance and operation before adopting these devices in the field. Moreover, a comparative study should also be implemented to assess other devices such as a polymer fuse cutout.

No.	Item	Open Cutouts	Enclosed Cutouts
	Appearance		



(Source: JICA Survey Team)

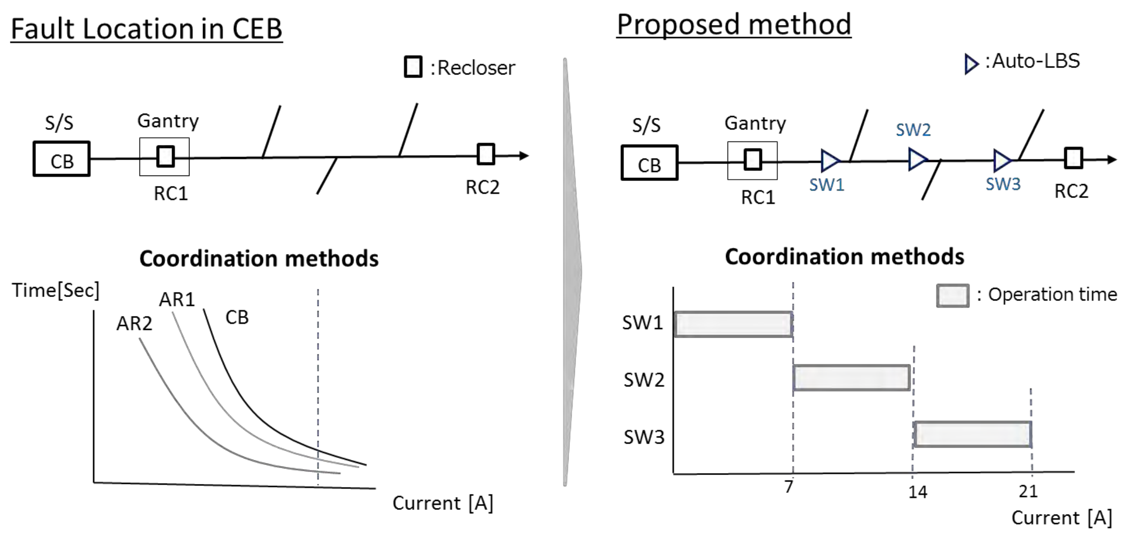
Figure 9-16 Comparison of Cutout Structures

(3) Distribution automation with sequential fault location methods
As a measure for improving reliability, it is considered desirable to introduce Japan's timed delivery method in accordance with the Western-style reclose method. This is a method where the automatic switchgear controls are based on the following logic.

(a) When the power supply is lost, all of the switches open automatically.
(b) When a switch detects voltage in its supply side after (a), it counts 7 seconds and closes automatically.
(c) If a fault occurs again within 5 seconds of (b), the switch regards its load side as a fault area and remains open (lockout).

In this method, protection coordination is characterized by simple time setting alone. It is more effective in connecting a plurality of automatic switches in series and has high expandability for long distance distribution lines. However, since reclosers have already been installed in most of the Gantries, by applying this method on the load side of the recloser, it will be a more effective facility configuration method as it utilizes the existing facilities.

Moreover, by applying this method on the load side of the recloser, the number of operation times for the circuit breaker at the substation is the same as before the introduction of the proposed method. Therefore, it has no effect on the lifetime of the circuit breaker.



(Source: JICA Survey Team)

Figure 9-17 Fault Location Methods

When applying this to CEB distribution lines, it is also necessary to establish a time setting related to the length of the distribution line and to verify its effects, such as proper operation. Confirmation of the coordination verification is also important for practical application in protection relays at substations with the proposed system.

(4) Upgrade to Multi-Divided and Multi-Connected distribution network

Distribution networks in Sri Lanka are normally composed of a radial system. In order to improve system reliability, it is effective to upgrade to a loop system. However, double the capacity of new feeders is required because a loop system needs to ensure enough capacity to support tie feeders in a contingency situation. This leads to an increase in investment.

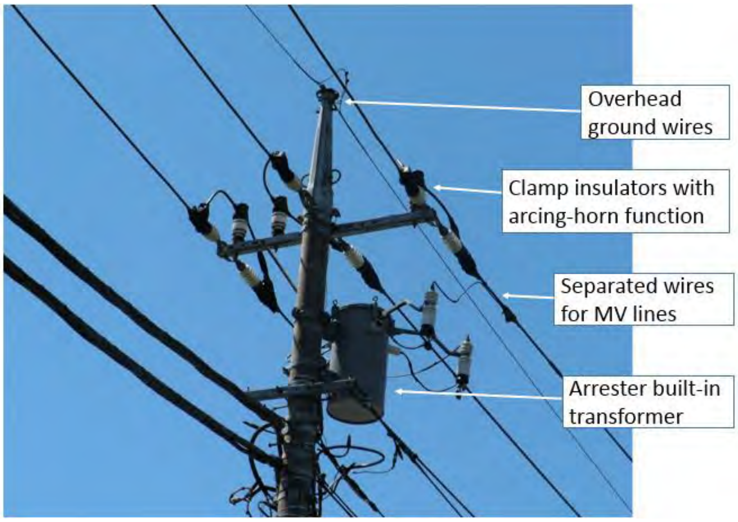
As a measure to solve this problem, we recommend the Multi-Divided and Multi-Connected network, which is widely adopted in Japan. In it, MV feeders are divided into 3 sections. The normal operation rate is 75% and it is more efficient than a loop system. Therefore, this leads to system reliability improvements with moderate investment.

However, as a result of interviews with DDs, it was confirmed that there are cases in which land acquisition and tree cutting are rejected by landowners when planning interconnection lines. For this reason, it is necessary to carefully examine the routes of distribution lines.

(5) Conversion from bare to covered conductors in MV lines

For reduction of failures caused by vegetation, it is effective to convert bare conductors to insulated conductors in the MV systems of mountainous areas because power outages in the MV system affect a large number of customers. Recently, in the forest reserve areas where cleaning of ay leaves is restricted in DD4, an MV line of about 5km has been constructed with partially insulated conductors for the first time in Sri Lanka. However, some technical issues should be considered before it is introduced.

First, CEB uses aerial bundled cables for insulated conductors, and this gives rise to some technical issues such as the need for special connection materials and construction methods, and inductive interference on tele-communication lines due to the large slack of wires. In Japan, we use covered electric wires separated one by one, and we do not have much difference in construction and materials from bare electric wires, so we would like to propose this method. Second, insulated conductors tend to be torn off by lightning due to their high insulation level. Therefore, some countermeasures should be applied such as installation of clamp insulators with an arcing-horn function, and arrester built-in transformers and overhead ground wires. Third, when insulated conductors are installed in coastal areas, they tend to deteriorate due to the saline effect. This issue can be solved by introducing salt resistant-type insulated wires or limiting the conversion area to non-coastal areas.

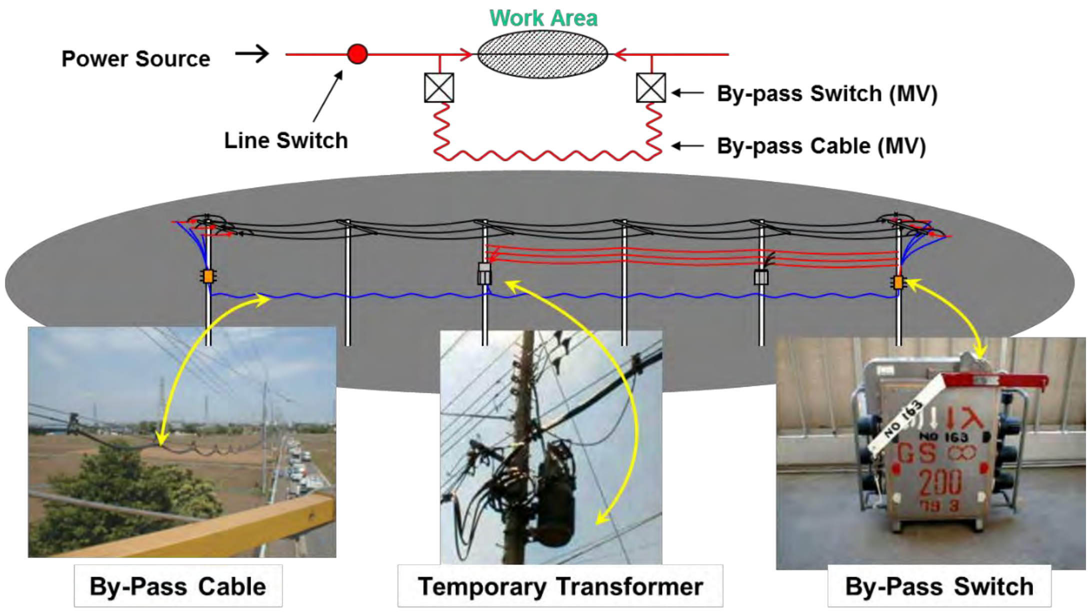


(Source: JICA Survey Team)

Figure 9-18 Typical distribution line in Japan

(6) Indirect hot-line work to reduce planned outages

In the long term, a reduction in planned outages caused by construction and maintenance work at MV lines is required to improve system reliability. In Japan, most distribution work for MV lines is implemented by indirect hot-line work to reduce planned outages while securing the safety of workers. Although some companies have already adopted this method only for maintenance work at distribution towers, it is necessary to expand adoption to other distribution work. Therefore, it is required to introduce tools such as hot sticks for 11kV and 33kV overhead lines, bypass cables, temporary transformers and bypass switches for hot-line work. Furthermore, it is necessary to standardize the design of hot-line work and the construction method, and to develop an operation manual that includes a safety policy and inspection standards. An example of non-interruption work in Japan is shown below.



(Source: JICA Survey Team)

Figure 9-19 Example of non-interruption distribution work method in Japan

9.4.3 Study on the installation of smart grid technology

For smart grid technology, our survey focuses on SCADA, Smart meters and EMS (Energy Management System), and investigates the current situation for each technology and future possibilities for introduction.

As for the development of SCADA and smart meters, CEB is requesting cooperation from other countries on technical and financial aspects. Currently, CEB is requesting financial support from AFD (Agence Française de Développement = France Development Agency).

(1) SCADA

(a) Current Situation

In Sri Lanka, a Distribution Control Center (DCC) equipped with fully functioning SCADA systems was introduced for the first time in 2009. At that time, micro SCADA, which is a software product by NortRoll, was introduced to DD1's North Western Province, North Central Province and North Province. Each DCC has a separate installation of NortRoll SCADA software, and they operate as three independent systems. However, as the SCADA system does not support industry standards such as IEC protocols, DCCs perform only remote operation and monitoring of Load Break Switches (LBS), which is provided by the specific manufacturers. Auto Reclosers and other LBS in the network are not directly connected to the SCADA. Conversely, Colombo city in DD1 and Kandy city in DD2, which introduced DCCs in recent years, are designed with high versatility and all the remote devices such as switches and FIs are directly connected to the SCADA system.

The present status of DCC development as of 2016 is shown in the table below.

Table 9-7 Existing DCCs in Each Company

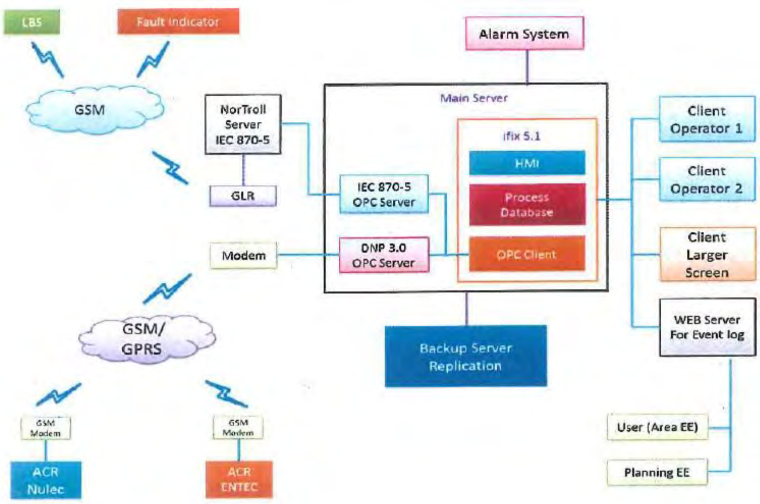
Company	Province	Present Status of DCC Development	SCADA System
DD1	NWP	Fully functioning	NortRoll, micro-SCADA
	NCP	Fully functioning	"
	NP	Fully functioning	"
	CC	Fully functioning	Siemens, Spectrum Power 4.5
	WPN	Fully functioning	ICONICS, Genisis64

DD2	CP	Fully functioning (Kandy) At development stage (Others)	GE, ifix
	EP	At design stage	ICONICS, Genisis64
DD3	WPS2	Fully functioning	GE, ifix
	Sab	Fully functioning	NortRoll, micro-SCADA
	Uva	At design stage	GE, ifix
DD4	WPS1	At design stage	
	SP	At study stage	
LECO		At development stage	

(Source: CEB document)

(b) Proposal

As shown in Table 9-7, SCADA systems from different manufacturers are used in each distribution company, and the functions and extensibility of the systems differ. For example, WPS2 in DD3 have built a highly scalable system with ifix, and it supports multiple protocols. However, EP in DD2 have developed a system with WSOS version 5, which supports only a specific vendor's switch. The SCADA architecture in WPS 2 is shown below.



(Source: CEB document)

Figure 9-20 SCADA Architecture in WPS2

From the above reasons, it is necessary to study optimum SCADA systems, communication methods and automation equipment in the whole of Sri Lanka. The following points need to be considered.

- Replacement of existing protocols which do not directly support the industry standards.
- Designing of SCADA with open platform communication (OPC) that cables the exchange of data between multi-vendor devices and controls applications without proprietary restrictions.

(2) Smart Meters

(a) Current Situation

Electricity customers are basically categorized into retail customers, whose contract demand is less than 42kVA, and bulk customers, whose contract demand is more than 42kVA. Distribution companies have installed Static Meters for remote meter reading for bulk customers, but the meters for retail customers are the electro-mechanical type, which are not equipped with a remote communication facility. Although distribution companies plan to replace the meters of retail customers with the Static Meters, there are big differences in the development of smart meters between CEB and LECO.

CEB is currently conducting a demonstration for general customers in DD2 and DD4. As for DD2, about 2,000 smart meters (HEXING, China) are set up to communicate by a wireless multi-hop system. In the DD4 demonstration, around 25,000 single phase meters are planned to be replaced by smart meters. Either way, the development of smart meters is still at the demonstration stage.

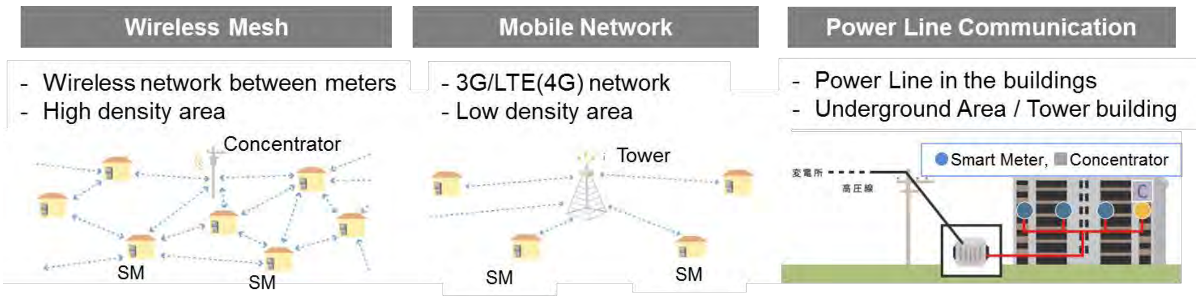
LECO has been installing smart meters using portable communications (GPRS) for some customers since 2009. In addition, LECO has been conducting demonstrations with 100 meters using a wireless multi-hop system (Zigbee) since 2014. Regarding meter procurement, although the main body is procured from overseas enterprises, the built-in software and accessories are developed in-house.

In addition, in January 2017, a subsidiary, Ante LECO Metering Company (a joint venture company with a Chinese company, Ante Meter Company Ltd., 70% owned by LECO) has established a meter manufacturing plant in Sri Lanka. The annual production volume is expected to be 1 million. Production meters are not only for customers in the company's area but also for CEB and foreign companies in the future. The development status of smart meters in LECO is very advanced.

Figure 9-21 Ante-LECO Smart Meter Factory

(b) Proposal

Technical problems with smart meters include communication methods and functions. In TEPCO, we started installing smart meters in 2014 and plan to install them in 27 million households by 2020. The meter selects the communication method suitable for the place according to the installation environment. Specifically, by combining a wireless multi-hop scheme, cellular network scheme, and PLC scheme, with each used in the appropriate place, we have realized a high recovery rate and early area development. The characteristics of each communication method are as follows.



(Source: TEPCO PG website)

Figure 9-22 Smart meter communication methods for each region

The most commonly used method is the wireless multi-hop method. In this method, a plurality of meter information is aggregated into concentrators by radio communication between meters and then communicated to a data center. The advantage of this method is that it can aggregate up to 100 data points. By reducing the number of communication points, communication cost can be reduced.
The next common method is a cellular network, and it is applied in suburbs and mountainous areas. Although this method has good communication conditions, communication is one by one, so the number of communication points increases and the cost increases accordingly.
According to an interview conducted by the JICA survey team, in the case of the wireless multi-hop scheme (Zigbee), the initial cost is about 6,000 LKR and the monthly usage fee is about 0.5 LKR. In contrast, in the case of the cellular network, the initial cost is about 3,000 LKR and the monthly usage fee is about 5 LKR. For this reason, although the initial cost is higher for the wireless system, the total amount of initial and running costs will be higher for the cellular network system after five years have passed.
A power line carrier system has not been introduced in Sri Lanka at this time. However, this scheme is effective for places where multiple smart meters are concentrated, like high-rise apartments. Currently, construction of high-rise apartments is proceeding mainly in the area around Colombo, so application of a PLC scheme may be effective in these areas.
In terms of the functions of a smart meter, the following three points are desirable.

- Sending of periodic amounts of electric energy to the server
- Remote control of built-in switchgear & limitation of usage according to contract capacity
- Monitoring of voltage, current, and switch conditions

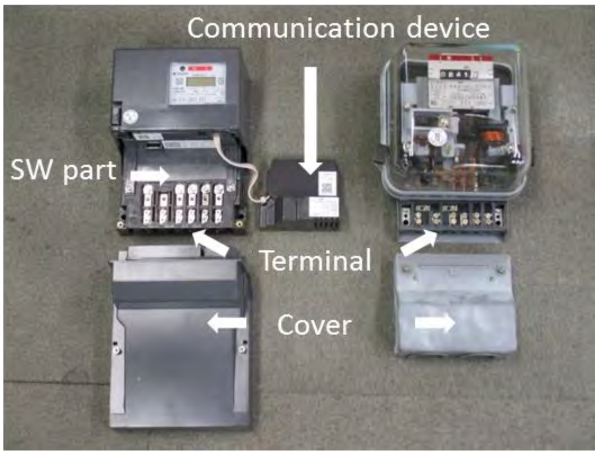


Figure 9-23 Smart Meter and Conventional meter

(3) EMS

(a) Current Situation

When renewable energy is connected at a high ratio to the system capacity, the frequency of the entire system fluctuates due to output fluctuation from the renewable energy. There is also the problem that the power quality deteriorates. EMS is a system that can maximize the output of renewable energy while maintaining power quality by controlling wind power and solar power generation, and storage batteries. The government of Sri Lanka is planning to drastically increase renewable energy capacity by 2040 with NCREs such as mini-hydro, solar and wind. As NCREs of 10MW or less are directly connected to the distribution system, EMS is required for the system.

Table 9-8 Wind-Solar Hybrid Systems in Jaffna

Number of Customers	800 persons
Wind Turbines	20kW
Solar PV system	46kW

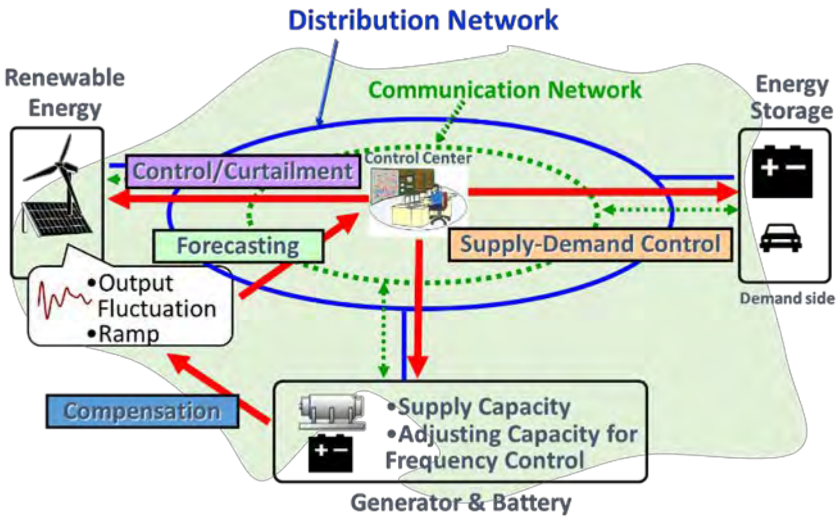
Battery system	110kWh/52kW
Diesel generator	30kW

(Source: CEB Document)

Currently, no commercial EMS system has been installed in Sri Lanka, but CEB has great interest in the system.

(b) Proposal

In Japan, an EMS demonstration using an independent small network is being carried out in island areas. An outline of the demonstration system currently being conducted in Niijima is shown below.



(Source: JICA Survey Team)

Figure 9-24 EMS demonstration system on Niijima Island

Since Sri Lanka has few island areas, there is little need to apply the above system as it is. However, there is a demand for improving reliability by constructing a micro grid for some customers. Although supply reliability in Sri Lanka is still not of a particularly high standard, reliable power supply is required for military facilities, hospitals, large commercial facilities, and so on.

Moreover, in recent years, solar power generation has been rapidly increasing at customers' premises on the basis of a governmental promotion policy for renewable energy. For this reason, an independent operation system using renewable energy is required at times of grid power failure.

Chapter 10. System Operation

10.1 Present Power System Situation

The JICA Survey Team visited the system control center in Colombo belonging to CEB and checked the present system operation situation based on provided documents, data and interviews. Below are photos of the system control center.

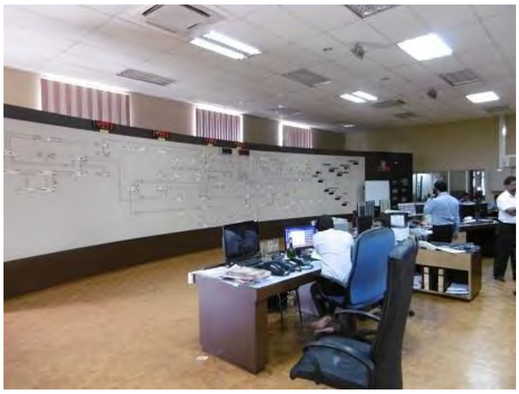


Figure 10-1 Building and inside operator room of system control center

10.1.1 Demand and Supply Operation

(1) Demand Records

Annual peak demands for the most recent three years are shown below. All of them were recorded at lighting time.

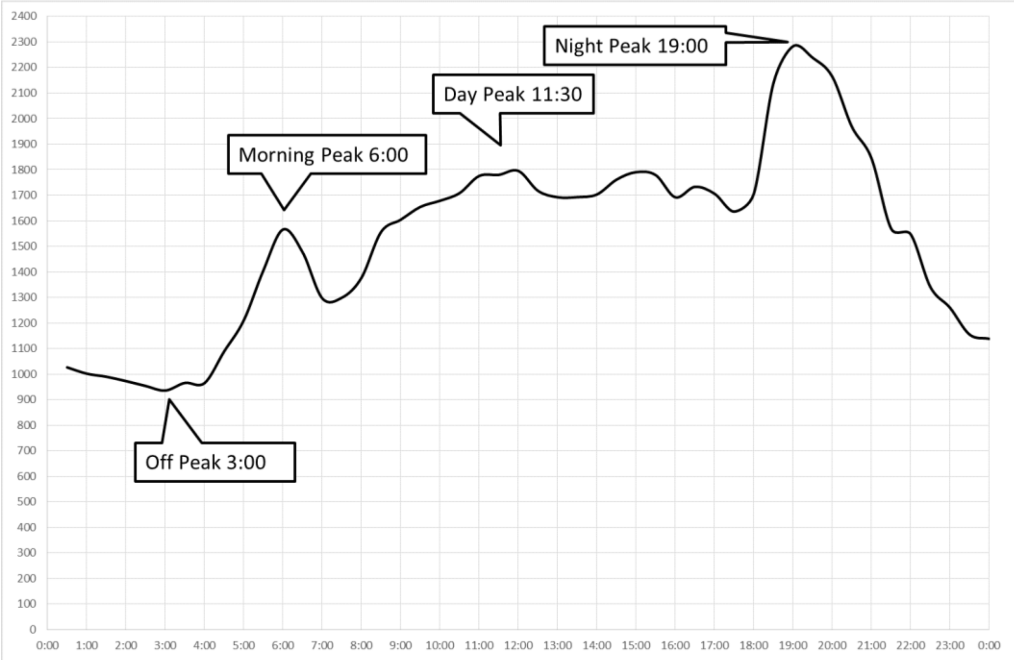
Table 10-1 Annual peak demands of most recent three years and date and time of occurrence

Year	Month	Date	Time	Total
2013	April	8th	19:00	2164.2 MW
2014	May	19th	19:30	2151.7 MW
2015	September	22th	19:00	2283.4 MW

(Source: CEB data)

Daily load curves for one day at peak demand last year are shown below.
Features of a typical daily load curve are the following:

- Around 3:00 Minimum demand in the day
- 4:30 to 6:00 Increasing massively until the peak in the morning
- Around 11:30 Peak demand in the daytime
- 12:00 to 13:00 A small drop during lunch time
- Around 15:00 A small rise to about the same demand as the peak in the daytime
- 16:00 to 16:30 After working hours, demand drops temporarily
- 19:00 to 19:30 Peak demand in the day during lighting time
- Around 20:00 Decreasing massively after the peak



(Source: CEB data)

Figure 10-2 Daily load curve for one day at peak demand last year (22nd Sep in 2015)

(2) Frequency Records

Frequency records around the peak demand last year are shown below. Demand during this period from 6pm to 10pm fluctuated from 1700MW to 2300MW and then to 1500MW.

(Source: CEB data)

Figure 10-3 Frequency records around peak demand last year (from 6pm to 10pm on 22nd Sep in 2015)

Frequency stayed within 0.2Hz for almost all of this period and definitely within 0.5Hz with sufficient margin.

The criteria for frequency is as follows:
- The statutory frequency limits are + or – 1% of 50Hz. i.e. from 49.5Hz to 50.5Hz

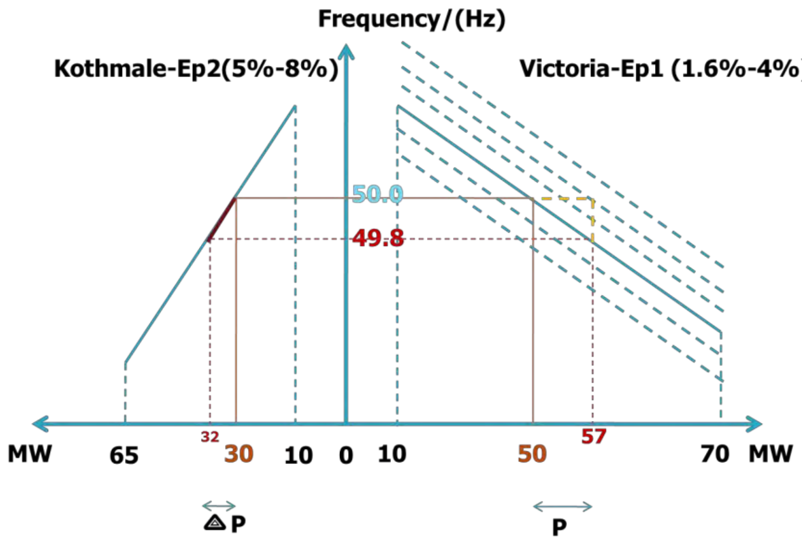
Frequency in Sri Lanka is of a very high quality compared to other Asian countries. The reasons for this are as follows:

- IPP generators which follow scheduled operation make up about 10% of the whole installed capacity and 90% of them are generators of CEB. Therefore, they can be supportively controlled according to instructions by the system control center.

- There are many hydro power plants with good frequency control ability.

(3) Frequency Control

Frequency control is done by one of six power plants, which are Victoria, New Laxapana, Samanalawewa, Kotmale, Upper Kotmale, and KPS (Kelanitissa). The actual setting of the droop speed control is shown below. One of them, set as Ep1, controls frequency proactively and others, set as Ep2 or by manual operation, control it moderately. Usually, three hydro power plants are set in droop mode as Ep1 or Ep2 and the others operate at a constant output.
In addition, most of the generators operate in free governor mode.
At present, all instructions to generators are not by SCADA but by phone.



(Source: CEB data)

Figure 10-4 Actual setting of droop speed control at power plants in charge of frequency control

(4) Generators

The following are items about generators related to demand and supply operation and frequency control.

- The maximum load of any generation unit shall be less than 25% of gross generation. However, for the purpose of maximizing thermal generation, this could be increased to 30%. The present maximum for a single unit is 300MW, at Lakvijaya coal power plant (300MWx3). Therefore, operators should decrease the output to less than 300MW when total demand is less than 1000MW.
- Outputs of hydro power plants vary greatly between dry and rainy seasons. Since outputs are huge during the rainy season, some thermal power plants should be stopped.
- Water usage priorities are as follows:
  1. Water service and drainage
  2. Environment
  3. Irrigation
  4. Power

  In many cases, water usage for power is limited because of other prioritized areas.
- Mini hydro and wind are available as renewable energy sources. As the state of operation cannot currently be checked online, it is checked by phone and input to SCADA.

(5) Under Frequency Load Shedding (UFLS)

For when a generator trips and frequency goes down significantly, under frequency load shedding (UFLS) schemes are installed to shed loads quickly and automatically in order to prevent total system failures. In Sri Lanka, the quality of frequency is always kept high before accidents; however, the risk of total system failures is high when a large scale generator trips and frequency fluctuates because total demand is not so large.

The following are items regarding UFLS.

- Two methods are adopted for UFLS setting. One is the value of frequency for 5 steps and the other is the rate of change for the frequency (df/dt).
- Each setting is shown below.
- 47% of total demand is set from stage 1 to stage 5 and 18% is set for df/dt. 60.5% is controllable by UFLS.
- Many UFLS relays are installed at substations near Colombo city as it is the load center.

Table 10-2 Actual settings for under frequency load shedding (UFLS)

Stage	Load Shedding Criteria	Load per Stage	Reconnection Criteria	Reconnecting Load
I	48.75 Hz + 100 ms	7.50%		
II	48.50 Hz + 500 ms	7.50%		
III	48.25 Hz + 500ms	11%	51 Hz + 500 ms AND df/dt > 0.2 Hz/s	2%
IV	48.00 Hz + 500mss	11%	51 Hz + 500 ms AND df/dt > 0.2 Hz/s	2%
V	47.5 Hz instantaneous	5.50%		
	47.5 Hz instantaneous **OR** 49 Hz AND df/dt > −0.85 Hz/s + 100 ms	4.50%		
df/dt	49 Hz AND df/dt > −0.85 s/Hz + 100 ms	13.5 % and 4.5% embedded in V		
Total	df/dt	18 % (4.5 % embedded with V)		
	Fre only	42.50%		

(Source: CEB data)

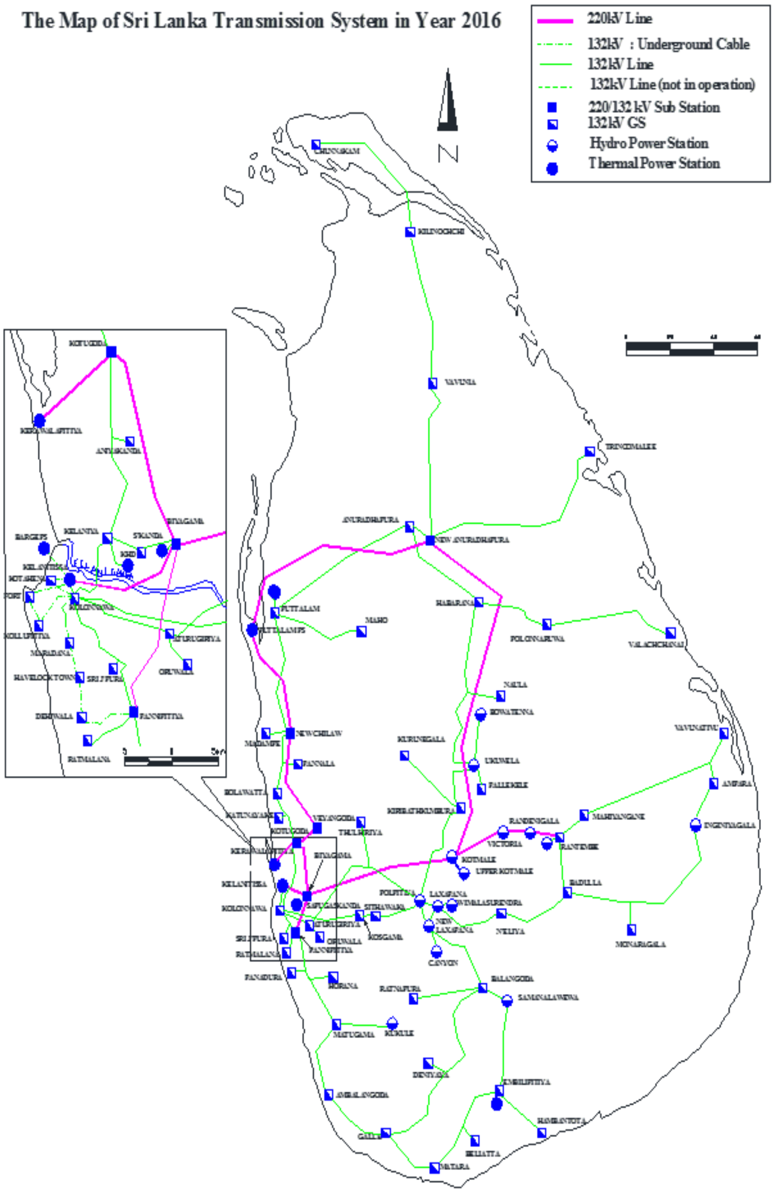
(6) SCADA

The following are items regarding SCADA.

- At present, all instructions to generators are not by SCADA but by phone.
- Facilities which can be monitored remotely by the system control center are as follows:
  40 substations among 65 in total
  18 power plants among 29 in total
- A new SCADA is currently being prepared, made by GE, though the present SCADA is made by Alstom. The system control center will be moved to Sri Jayawardenapura, near the parliament, within six months. The new system will enable remote control of substations and has LED screens.

10.1.2 System Operation

The present transmission system is shown below. Severe points for system operation are mainly described in this section.



(Source: CEB data)

Figure 10-5 Present transmission system in Sri Lanka

(1) Criteria for system operation

The following are items for policies and criteria.

- System operation priority is shown below.
  1. Safety of Persons
  2. Protection of Equipment
  3. Availability of Supply
  4. Quality of Supply
  5. Economics of System Operation
- The criteria for system voltage are shown below.

As normal	220kV(+/- 10%)	242kV to 198kV
	132kV (+/- 10%)	145.2kV to 118.8kV
	33kV (+/- 10%)	33.66kV to 32.34kV
Under emergency	220kV (+/- 10%)	242kV to 198kV
	132kV (+/- 10%)	145.2kV to 118.8kV

- The policy for system configuration is shown below.
  In general, a loop configuration is adopted; however, some points in the 132kV system are opened to prevent overloading under N-1 accidents due to there being many generators or low capacities of transmission lines or transformers. Since there are some cases of islanding or system separation under severe N-1 accidents at 132kV lines, there are 4 frequency meters in the system control center.

(2) Overloading for 132kV Transmission Lines

- Two 132kV lines in the southern part, Matugama - Pannipitiya and Balangoda - New Laxapana are very low capacity and a circuit breaker at New Galle on the Ambalangoda side is opened to prevent overloading under N-1. During peak load, run-of-river hydro at Kukule, thermal at Embilipitiya and hydro at Samanalawewa should be operated.
- Some 132kV lines near Colombo city, Biya - Sapugaskanda – Kelaniya – Kolonnawa – Panp, become overloaded under N-1 accidents when Laxapana complex and Kukule do not operate. This could become severe especially in the dry season. High cost gas turbine, KPS (Kelanitissa), is needed according to the situation.
- The circuit breaker at Ukuwela on the Habarana side is opened to prevent cascading under N-1 accidents at a 132kV line, Polipitiya – Kiribatkubura and New Anuradhapura – Old Anuradhapura. Then, if N-1 accidents happen, 4 substations (Kiribatkubura, Kurunegala, Ukuwela and Pallekele) or 5 substations (Habarana, Polonnaruwa, Valachchenam, Naula and Ukuwela) are stopped because they are not loop but radial configuration. Ukuwela and Bowatenna are hydro, mainly for irrigation.
- There are many hydro power stations in the 220kV system, i.e. Kotmale, Upper Kotmale, Victoria, Randenigala, and Rantembe. Total capacity is 820MW and power flow from these is as follows:
  Kotmale (220) – Biyagama (220) – Biya (132) – Kolonnawa (132) – Polipitiya (132) – Kiribatkubura (132)
  However, there are few hydros in the 132kV system. If the connection between Kotmale (220) and Kiribatkubura (132) within 1km is realized, many problems will be solved.
- N-1 accident at a 132kV line, New Anuradhapura – Anuradhapura, causes overloading.
- When LPS (Lakvijaya, 900MW) operates, the circuit breaker at Katunayake on the Kotugoda side should be opened to prevent overloading in the case of 132kV N-1 accidents. Transmission capacity is 80MW for each line.

(3) Voltage Drop

- Countermeasures for voltage drop near the load center, Colombo city, are required.
- When thermal power plants near Colombo city stop in the wet season and supply no reactive power compensation, the most severe voltage drop happens.
- The voltage drop record is 115kV in the 132kV system and 198kV in the 220kV system.

- Reactive power is supplied mainly by generators, not by facilities.
- There are some shunt capacitors around Colombo city and more shunt capacitors are needed, not only for near loads but also 132 and 220kV transmission levels.
- Capacitor banks are installed at Ampara with its huge industry in the south east area; however, they are not so useful to the grid. They are not installed near Colombo city, such as at Biya, Kolonnawa, Panp, Sapugaskanda, Kosgawa, Ratmalana etc.
- Capacitor banks operate automatically only for power factor improvement, not for voltage control, so shift operators operate them manually for voltage drops. Voltage control mode is necessary.

(4) Voltage Rise

- Some long northern 132kV lines, New Anuradhapura – Vavuniya – Kilinochchi – Chunnakam, cause voltage rises at all surrounding substations during off-peak periods. Countermeasures are required at New Anuradhapura - for example, 100MVar shunt reactors with 5MVar steps. 24MW power plants at Chunnakam should be stopped manually because of voltage rise.
- When LPS stops during off-peak periods, there is a voltage rise around New Chulaw.

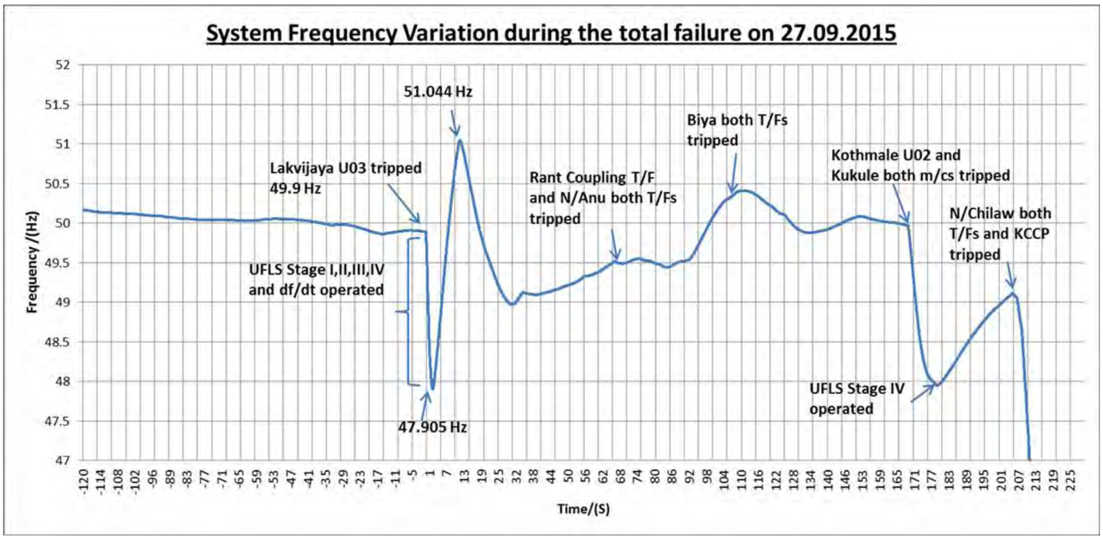
(5) Overloading for 220/132kV Transformers

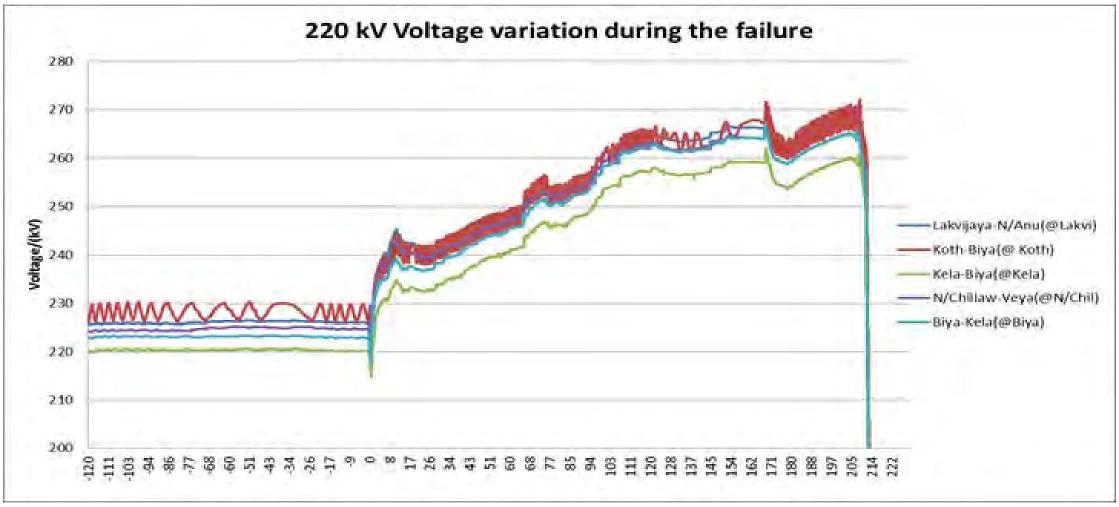
- When an N-1 accident at the transformer of Pannipitiya happens, another transformer becomes overloaded and hydro at Kukule should operate, but Kukule can’t operate in the dry season.
- There is only one 220/132kV transformer (105MW) at Rantambe and it became overloaded during the night peak period in normal conditions. Operators should open the circuit breaker between Badulla – Old Laxapana. There is a 50MW (25MW x2) hydro power plant at Rantambe, mainly for irrigation.

(6) Total System Failure

Maximum risk in Sri Lanka grid at present presents high possibility of total system failure.

- Total system failure is caused by generator trip or generator stopping due to transmission line trip.
- When a generator trips, frequency fluctuation becomes moderate temporarily due to load shedding by UFLS; however, voltage rise occurs because of a shortage of reactive power compensation by generators and this could lead to total system failure.
- An example of the above is shown below from 27th Sep 2015, which is an actual record of total system failure.





(Source: CEB data)

Figure 10-6 Frequency and voltage records after the accident causing total system failure (27th Sep in 2015)

- Installation of Static Var Compensators (SVC) is now being studied for countermeasures.
- Recently, there have been some cases of total system failure: 27th Sep in 2015, 25th Feb in 2016, 13th Mar in 2016 and 27th Mar in 2016.
- There is a manual for total system failure restoration and operators perform good operation during the actual accidents. They provide full restoration within 3 hours.

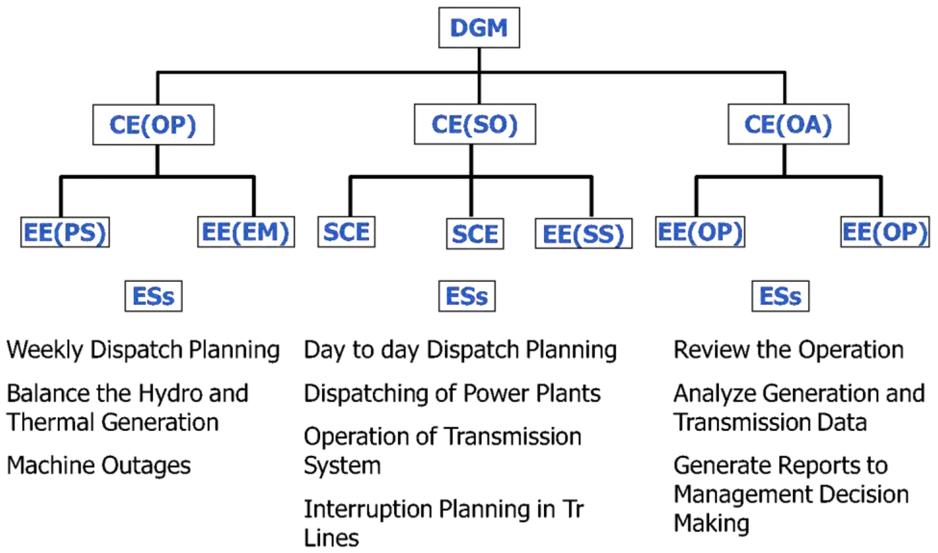
- Black start generators are shown below. They are tested once a month and can be started up within 15 minutes after the accident.
  1. Kelanitissa GT 16MW x4
  2. New Laxapana
  3. Victoria, Kotmale, Mahaweli
  4. Samanalawewa

10.1.3 Personnel in System Control Center

The head of the system control center is the Deputy General Manager (DGM) and there are three groups. Each of their roles are shown below. Each group has one chief engineer (CE) and two or three electrical engineers (EE). There are 25 members in total including 16 shift operators.

- Operations Planning Group (OP)
  Weekly dispatch planning
- System Operations Group (SO)
  Day to day dispatch planning
  Interruption planning in transmission lines
  Operation of transmission system
  Dispatching of power plants (operators belong to this group)
- Operation Audit Group (CE)
  Review of the operation
  Analysis of generation and transmission data
  Documentation for management decision making

Each squad of shift operators consists of two electrical engineers and two assistants. There are five squads and three shifts. There are 10 electrical engineers and six assistants in total.
The structure of the system control center is shown below.



(Source: CEB data)

Figure 10-7 Structure of system control center

10.2 Recommendations for improvements regarding system operation

An evaluation of the current power system operation from all the information above is given below.

- The quality of frequency is kept at a high level compared to other developing Asian countries.
- There are clearly many voltage control issues, especially for low voltage around Colombo city and high voltage around the northern part with its long transmission lines. Because reactive power supply is mainly from generators in service, when important generators are stopped there could be severe voltage issues. In the worst cases there have been total system blackouts when generators tripped.
- Routes of transmission lines and numbers of transformers are small and capacities are also insufficient, so there is a high possibility of overloading of facilities when normal or N-1 contingencies happen.
- System operation for contingencies, including total blackouts, is quick and accurate. There is little room for improvement.
- The biggest risk is total system failure because of overloading and/or voltage uncontrollability.

Recommendations for fundamental improvements regarding system operation are shown below, considering the opinion of the System Control Center.

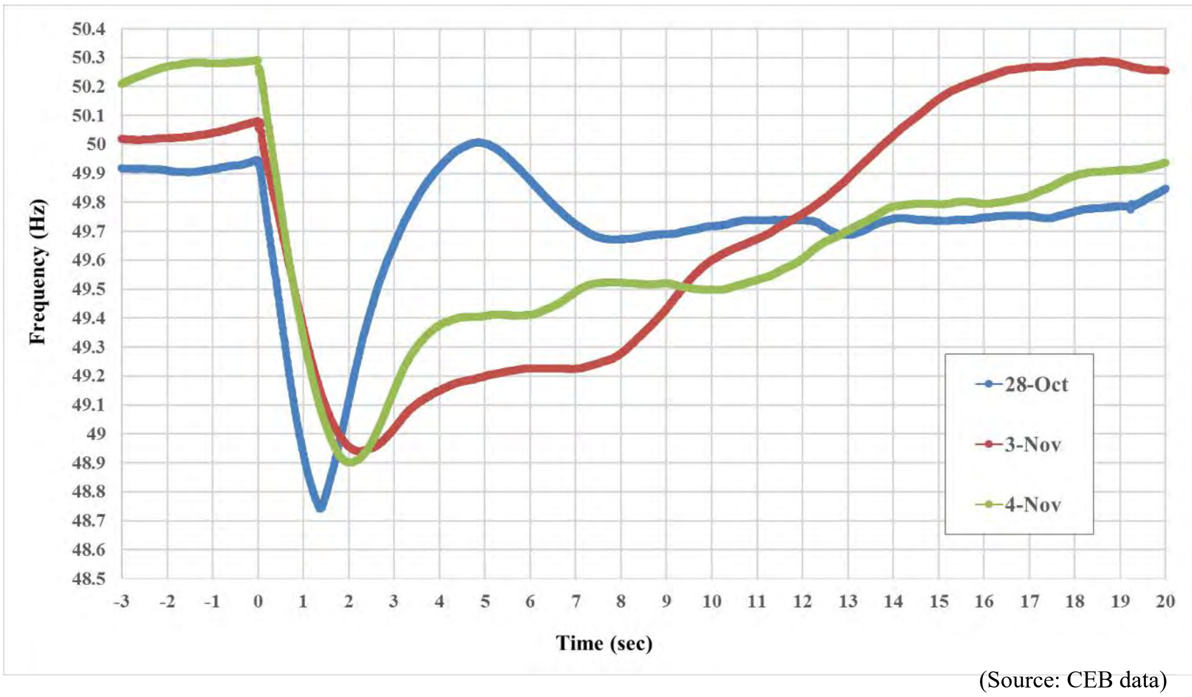
- Installation of new transmission lines and transformers with sufficient capacity, properly based on an accurate demand forecast when the transmission development plan is created.
- Installation of reactive power supply facilities such as shunt capacitors, shunt reactors, SVC and STATCOM based on a study of voltage control to change the current situation, which depends heavily on generators, when the transmission development plan is created.

These studies are considered and reflected in Chapter 8 “Transmission Development Plan”.

10.3 Maximum Output Capacity for Single Generator Unit

(1) Calculation of Power System Characteristics

Power system characteristics are calculated based on actual frequency records when a generator trips. The frequency records provided are shown below. When load shedding by UFLS occurs with a generator trip, understanding the phenomenon is complicated. Therefore, unit generator trip cases are chosen for the calculation of power system characteristics.



(Source: CEB data)

Figure 10-8 System Frequency Variation for One Unit Trip in Oct. and Nov. 2016

- Around 23:30 on 28th October in 2016
  Total demand before incident 1265MW
  GT 7 of Kelanitissa 80MW generator trip 49.946 → 48.741Hz
  Power system characteristics calculated:
  K1 = 80 / 1265 / (49.946 – 48.741) = 5.248 %MW/Hz

- Around 17:00 on 3rd November in 2016
  Total demand before incident 1741MW
  GT 7 of Kelanitissa 100MW generator trip 50.080 → 48.941Hz
  Power system characteristics calculated:
  K1 = 100 / 1741 / (50.080 – 48.941) = 5.0438 %MW/Hz

- Around 17:00 on 4th November in 2016
  Total demand before incident 1500MW
  GT 7 of Kelanitissa 115MW generator trip 50.292 → 48.901Hz
  Power system characteristics calculated:
  K1 = 115 / 1500 / (50.292 – 48.901) = 5.512 %MW/Hz

Current value of power system characteristics is 5.3%MW/Hz, which is the average value of the 3 cases.

10%MW/Hz is adopted for the future system considering the two reasons below.

- Load characteristics will change in the near future as more inverter equipment is installed.
- 8%MW/Hz is adopted in the 50Hz system in Japan and around 10%MW/Hz is adopted in developed countries.

(2) Maximum Capacity of Allowable Generator Trip

The following are described in the grid code in of Sri Lanka.

49.5Hz to 50.5Hz	As normal
47.5Hz to 52.5Hz	Frequency may vary under emergency conditions

Characteristics of generators to frequency are shown below according to the technical requirements for grid connection in TEPCO.

48.5Hz to 50.5Hz	Available for continuous operation
47.5Hz to 51.5Hz	Available for operation
48.5Hz	Available for more than ten minutes or so
48.0Hz	Available for more than one minute or so
47.5Hz	Unavailable for operation to protect machines

All generators should be tripped and total system failure is caused

Based on the above values, 1.5Hz is the allowable range since frequency should be kept at over 48.5Hz when a generator trips. Frequency must not stay at more than 1.5Hz for the safety margin. It is considered that frequency is usually over 50Hz before accidents when the total demand is small.
Therefore, power system characteristics are 10%MW/Hz and allowable frequency range is 1.5Hz. So, the maximum capacity of allowable generator trip is calculated to be 15% of total demand.

(3) Maximum output capacity of single generator unit

The maximum capacity of allowable generator trip or maximum output capacity of a single generator unit is 15% of total demand. Maximum demand for 2040 in Sri Lanka is about 6.2GW. Therefore, minimum demand is about 40% of this, or 2.5GW. So, maximum output capacity of a single generator unit is 15% of 2.5GW, or 370MW.

Table 10-3 Maximum output capacity of single generator unit

Item	Amount
Maximum demand in 2040	6.2GW
Minimum demand in 2040	2.5GW
Maximum output capacity of single generator unit in 2040	370MW

(Source: JICA Survey Team)

It may be possible to install generators with over 370MW installed capacity to consider operation in service with output of less than 15% for the maximum during off-peak hours.
When a unit of 600MW generator is installed in the grid, it is necessary to operate it with PSPP in pumping mode during off-peak periods to avoid a big impact on the grid. If a 600MW generator suddenly stops, the PSPP should be shed at once by the protection relay in order to avoid a huge frequency drop.

Chapter 11. Long-term Investment Planning

11.1 Premises for Capital Raising

The power industry in Sri Lanka needs capital investment for the power generating sector and transmission and distribution sector.
Assuming that there will be no large-scale sector reform and that CEB will remain as it is now, CEB will have the responsibility for investment in transmission and distribution facilities. ~~(~~Some states and regions in the United States of America adopt notions of Independent System Operator or Regional Transmission Organization, but these will not apply to Sri Lanka.~~)~~
There are some choices regarding capital sources for power generating facilities such as CEB itself, Independent Power Producers (IPP), and Joint Ventures (JV). In this chapter, the merits and demerits of these forms of organization and capital sources are examined.
As its basic policy for financing, Public Utilities Commission of Sri Lanka (PUCSL) says in its General Policy Guidelines (2009), "Private sector participation will be welcome in generation projects, but the major source of funds for all transmission and distribution development will be from international/bilateral donor agencies. Major hydro power generation will be under the auspices of the GOSL." For hydro power generation, it is assumed that major dams will be used not only for power generation but also for irrigation, forestry, and other purposes.)

11.1.1 Transmission and Distribution System

(1) Transmission

The Transmission sector is under the monopoly of CEB, and CEB should be responsible for investment in transmission facilities. It is desirable that CEB possesses all the facilities as it will operate and manage the assets. Since CEB's current financial status makes it difficult to raise the necessary funds within its budget for the moment, it will have to rely for most of the funds on assistance from governmental budget or support from donor institutions. The Asian Development Bank (ADB) and JICA have already provided loans. While maintenance and improvement work for the transmission system are financed by CEB internally, CEB relies on donors for the construction of new transmission lines.
LTTDP 2015-2024 shows the total investment requirements by foreign and domestic currencies. Most of these funds will be loaned from the Government, with most relying on loans from international/bilateral donors.

(2) Distribution

The Distribution sector is operated and managed by CEB's four distribution sectors, i.e., DD1-4, and CEB's subsidiary, Lanka Electricity Company (LECO). Similar to the transmission system, investment in the distribution sector will be made by CEB and LECO.
LECO is a 100% subsidiary of LECO and manages its accounting independently. It raises funds by itself.
DD1-4, CEB's distribution sectors, manage small and short-term repair work with CEB's internal funds; their fund for long-term and large-scale investments is loaned from governmental budget or donor institutions since CEB's current financial status makes it difficult to raise the necessary funds within its budget for the moment as PUCSL mentions in the above General Policy Guidelines that the major source of funds for all transmission and distribution development will be from international/bilateral donor agencies..
Since Sri Lanka's electrification is near 100%, no new major distribution line project is currently planned. Most of the distribution work is for maintenance or improvements.
Costs for Low Voltage (LV) distribution lines are borne by CEB. Only 20% of the necessary amount has been secured, and thus the work is delayed. Costs for Middle Voltage (MV) lines are usually financed by donor institutions. CEB recently relies on ADB for finance.

11.1.2 Generation System

In contrast to the transmission and distribution systems, CEB will be required to explore fund raising to minimize its own funds, or governmental assistance. (Again, PUCSL says, “Private sector participation will be welcome in generation projects.”)
For hydro power generation, the GOSL will provide the funds for investment as CEB will own and operate the generating facilities. It is not financially viable for IPPs, as large-scale dams are multi-purposed and pumped storage power plants are for load adjustment during on- and off- peak times.
Mini-hydro power generation is regarded as a renewable energy source like biomass, wind power and solar, and is subject to a feed-in-tariff (FIT). Regarding renewable energy projects with more than 10MW capacity, to which FIT is not applied, private investors/operators will evaluate the profitability based on generating costs, and will develop them as IPP if profitability is expected.
For thermal power generating facilities that are comparatively larger in capacity and require larger capital investment, there are a few financing options, including CEB’s own funds (= Assistance from GOSL), independent power producers (IPP), joint ventures (JV), and public-private partnerships (PPP). The following section examines the characteristics of these business types.

11.2 Financial Support by Other Donors

Japan, the World Bank, and the ADB are the main ODA suppliers to Sri Lanka. Japan’s ODA to Sri Lanka was 323 million USD, followed by IDAs (mainly WB) at 174, ADB Special Fund at 109, Korea at 52, the US at 49, EU institutes at 41, and Australia at 40, in 2013.

11.2.1 ADB

(1) Policy Assistance

For policy assistance, ADB evaluates the 5-year Country Partner Strategy (CPS), but the main issues have shifted from infrastructure (expansion of transmission & distribution system) to i) clean and sustainable generation (renewables) and ii) energy efficiency (conservation, introduction of smart meters etc.).
ADB provided support through technical assistance (TA) on “Renewable Energy Master Plan” in 2014, but the report has not been made public due to a change of governmental administration.

(2) Distribution Project

ADB currently provides loans directly to CEB on a distribution project and renewables project.
For the distribution project, ADB provides support for the project to increase the electrification rate from 98% to 100%, and provided a loan of 115 million USD directly to CEB in July 2016 with GOSL’s guarantee. Since the financial situation of CEB has worsened, ADB requested the setting of financial targets in the financial covenant. In the loan for the Electricity Supply Reliability Improvement Project, CEB exercised debt restructuring in 2014. With this as the background, ADB set Financial Targets as below for CEB in the financial covenant of the Loan Agreement for the above project. The Ministry of Finance of Sri Lanka also set an upper limit for loans to CEB.

Table 11-1 Financial Targets in ADB Loan Project

Indicator	Target
Current ratio	2018: 90%, 2019: 95%, 2020: 100%
Debt to Equity Ratio	100%

(Source: Information provided by the ADB)

As described in 9.4.3, ADB has been sponsoring DD-1’s demonstration project of an island micro-grid system using a simple EMS (battery inverter system by SMA, Germany) in Eluvaitive Island, Jaffna.

This demonstration research was a grant-type cooperation. As a next step, ADB plans to introduce a hybrid system using wind, solar, battery and diesel generation in surrounding three islands, i.e., Delft, Analaitivu, and Nainativu. Out of 6 MUD for this system, 2 MUSD will be a grant from Japan Fund for Poverty Reduction (JFPR) while the other 4 MUSD will be a loan from ADB.

(3) Generation Project

For support for renewable energy, ADB has provided a loan for Mannar Wind Farm. ADB approved a USD200 million loan to support the project in order to construct a total of 375MW of wind power generating facilities. CEB informed ADB of its intention to own the first 100MW, which will consist of four areas of 25MW, and the project will enjoy the merits of a feed-in-tariff with a cap amount of 12 cents/kWh.
According to ADB, the Bank will not support generation projects that are financially viable. The above loan to Mannar wind Firm is regarded exceptional as this is the first large-scale renewable energy project. (ADB will see to what extent CEB can absorb the cost in a project as large as 100MW.)

ADB in general will not provide finance to future LNG-fired TPP; however, there remains possibility of providing loans for fuel supply facilities and for fuel conversion of existing oil-fired TPPs.

(4) International Transmission Line between Sri Lanka and India

ADB has reached agreement with the governments of Sri Lanka and India on 10 MUSD loan to the detailed design of this project. While this work will be carried out using GOSL's loaned money, ADB will provide loan to both governments for construction work. Sri Lanka's representative party is MPRE and Indian counterpart will be Power Grid Co. of India. The consultant is not yet procured now, but the procurement of the consultant will start in 2018. Upon the detailed design is completed, ADB plans to provide loan for construction to both countries for unless serious problems arise.

(5) Loan Conditions

ADB's loan conditions will differ by fund. Its general loan conditions are a 20-25 year repayment period with grace period of 5 years, with the interest rate of LIBOR+40bps+10bps. The other type will use an ADB Special Fund and its loan conditions are a 25-year repayment period with an interest rate of 2% (fixed). Under the current financial market situation, where 6-monthly JPY and USD LIBOR are about 0.01% and 1.29% respectively, the former loans seem preferable.
While ADB loans have preferable conditions, ADB has requested a governmental guarantee when they are given to CEB directly. ADB also has a policy to limit its loans in the generation field to renewable energy, with no more going to thermal power. The main target of ADB loans will be transmission and distribution in future.

11.2.2 World Bank

The World Bank has been supporting the power sector policy making, for example by evaluating the LTGEP 2015-2034. As a part of this type of support, the World Bank develops the training program for operators of OPTGEN, which is an alternative power development planning tool replacing WASP.

The World Bank will not, in principle, provide direct loan to individual projects in Sri Lanka. However, CEB expects the Bank's loan to be provided for infrastructure (land reclamation, construction of access transmission line etc.) for the Solar Farm (100MW) in Siyambalanduwa, the south-east part of the country.

11.3 Business Formation for Generating System (Ownership)

The Sri Lankan electric power system adopts the single buyer model, monopolized by CEB, but the generation sector has been liberalized. In addition to CEB, the major operator, the sector accepts generation by IPPs. Furthermore, a joint venture (JV) in which CEB and another corporation jointly invest has recently been established.

11.3.1 CEB Ownership

Until recently, CEB has constructed, owned, and operated all the generating facilities. There is an option for CEB to continue to do so for some generating facilities in future.

The most serious issue for CEB in financing generating facilities by itself is the lack of funds and thus it has to rely on assistance from the GOSL. GOSL will also rely on international/bilateral donor agencies as the governmental budget is limited. As CEB itself is to receive loans from donors or governmental assistance, its debt will increase on its balance sheet. Although these ODA loan conditions are much more preferable than loans from commercial banks, ODA loans will be a burden to CEB's finance. Therefore, GOSL places a priority on hydro generation, which is not financially viable for the private sector, and leaves thermal power generation to the private sector.

Apart from ODA loans, there is an option to use an export credit scheme provided by Export Credit Agencies (ECA). The interest rate is higher than for ODA loans, but ECA enables earlier decisions on financing.

Some critics say that it will be more costly if CEB constructs the plant. However, if part of the ODA loan is used to hire an independent and neutral consultant, the consultant will monitor all the processes of designing, bidding and construction supervision, which will avoid unreasonably high construction costs.

11.3.2 Independent Power Producer (IPP)

As PUCSL welcomes private sector participation in generation projects, IPP projects will increase or will become a major business pattern.

Since IPP projects are developed, financed and operated by private businesses, CEB will have only to bear the cost of power purchase.

CEB has so far signed power purchase agreements (PPA) for 11 projects with IPPs. (One of them is a 15MW diesel generator with a 2 year contract period.) The list of these IPP projects is shown in Table 11-2. The seven IPP projects for which a PPA contract has been completed adopted a contract pattern based on Minimum Guaranteed Energy Amount (MGEA). For these projects, CEB had to pay the minimum amount (in kWh) as contracted, even if the actual generation was less than the contracted amount because its operation/dispatching orders. Most of these projects were small, up to 15MW, and their availability was assumed at around 80%.

Currently, four (4) IPP projects are ongoing. Out of them, three (3) projects, for which the PPA agreements have been rather recently signed, are not based on MGEA but on availability. Since an availability-based contract is for keeping the plant ready to operate at full capacity, the capacity charge is set at a higher rate than that for an MGEA-based contract. This pattern of PPA is applied to CCGT with larger unit capacity, and the plants are expected to work as base-load generation. Availability is usually set at 90%. According to CEB, future IPP projects will be larger scale with availability-based PPA.

Table 11-2 IPP Projects in Sri Lanka

	Lakdhanavi	ASIA Power	Colombo Power	ACE Matara	ACE Horana	ACE Embilipitiy	Haladhanavi	Northern Power	AES	West Coast	Aggreko
Commercial Operation Date	Nov. 1997	Jun 1998	Jul 2000	Mar 2002	Dec 2002	Apr 2016	Dec 2004	Dec 2007	Oct 2003	May 2010	Jan 2010
End Date	Nov. 2012	Jun 2018	Jul 2015	Mar 2012	Dec 2012	Apf 2017	Dec 2014	Dec 2019	Oct 2023	May 2035	Dec 2012
Contract Period (years)	15	20	15	12	10	1	10	10	20	25	2
Location	Sapugaskanda	Sapugaskanda	Colombo Port	Matara	Horana	Embilipitiya	Puttalam	Chunnakam	Kelanitissa	Kerawalapitiya	Chunnakam
Free Start/Stops per Year	No charges on Start &	240 Starts	80 Start/Stops	160 Stops	160 Stops	200 Stops	50 Stops	No start/Stop	No	No	n.a.
Guaranteed/Installed Capacity (MW)	22.5	51	60	20	20	100	100	6.5	163.5	270	15
MGEA (per year) (GWh)	156	330	420	167	167	698	698	n.a.	n.a.	n.a.	n.a.
Efficiency	37.30%										
Fuel	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Hvy Furnace Oil	Auto Diesel	Hvy Furnace Oil	Auto Diesel
Availability Factor (%) (Note 1)	79%	74%	80%	95%	95%	80%	80%	n.z.	n.a.	n.a.	n.a.

(Source: Information provided by the CEB)

(4 ongoing IPP projects are: ASIA Power, Northern Power, AES, and West Coast.)

Among many thermal projects to be constructed in future, the project of "1x 300MW Natural gas fired combined cycle power plant – Western Region" is scheduled to start operation in 2019. For this project, the Ministry of Power & Renewable Energy (MPRE) published a Request for Proposals for international competitive bidding on 15 November 2016. This plant will be a multi-fuel combined cycle plant. The fuel will be heavy oil etc. for the time being and will be switched to natural gas when Sri Lanka's first LNG terminal becomes available in the Colombo area.

For CEB, one of the major merits of introducing IPP is to evade a huge amount of initial capital investment. CEB does not have to increase its assets on the balance sheet either. (The investment can be "Off-Balanced".)

However, CEB will have to make regular payments according to the PPA. In general, the business risks that the private sector can take are different from those that the governmental capital can bear. Since CEB will be required to purchase power at a price that includes IPP's business risk, it may cost much depending on the contract conditions, particularly if the competition during the bidding process does not work effectively.

When larger thermal plants are developed as IPPs, CEB and the IPP operator will sign the PPA based on availability. If renewable energy generation grows at a high rate as examined in Scenario B, these IPP's generation will be restricted by dispatch orders, and the merits of base-load IPP will not be achieved. Despite a high capacity charge (according to the PPA), CEB may receive less energy generated.

Regarding renewable energy power generation, most of the projects will be developed by IPPs. Power from renewable energy will be purchased based on Standard Power Purchase Agreement (SPPA) set by PUCSL depending on renewable energy sources. The long-term feed-in tariff and its price are advantageous for IPP.

11.3.3 Joint Venture (JV)

Sri Lanka's Electricity Act 2009 stipulates in Article 9 that either CEB or a local authority, or a company incorporated under the Companies Act, is eligible to apply for the issue of a generation license over and above the generation capacity of 25MW and that the number of governmental shares for such a company shall be determined by the Secretary to the Treasury with the concurrence of the Ministry (of Power). (For reference, IPP is a case in which the government holds a zero percent share.) The JV is a special purpose company (SPC) that CEB sets up with private companies to generate electricity. According to CEB, the governmental share will be at least 50% because CEB may naturally wish to control management of the JV.

The first and the only JV is Trincomalee Power Company (TPC). This company is a special purpose company (SPC) established by CEB and Indian NTPC with equal equity portions in the contract and it operates a thermal power plant in Sampur, Trincomalee Bay. The original plan was to construct two 250MW coal-fired power plants, starting operation in 2021 and 2022 respectively. Out of the total cost of TPC, the equity will be 30%, and the remaining 70% is financed by loans. The Sri Lankan and Indian governments had agreed that CEB's equity (15% of total cost) was to be financed by the Indian government. As a result of Sri Lanka's Supreme Court judgment, the Sampur coal-fired power plant project was canceled in September 2016. Therefore, the treatment of TPC seems ambiguous.

CEB expects to introduce a similar pattern in future JV projects. Namely, CEB's capital investment in SPC will be financed by a loan from a (bilateral) donor agency. Furthermore, private enterprises who join the EPC contract should bring their own financial aid schemes. (For example, if a Japanese trading company manufacturer joins the EPC, they are expected to organize the buyer's credit of JBIC etc.) Through this scheme, even if a JV cannot benefit from a pure type of ODA, it will be able to use a soft loan from export credit agencies in each donor country.

The JV is invested in by a Sri Lankan governmental organization (CEB) and foreign company, but the organization is a special purpose company (SPC) for power generation. The SPC will set the selling price so it is profitable. In this regard, JV and IPP are quite similar. A PA will be signed between the JV and CEB and it will have two portions, i.e., fixed/capacity charge and energy/variable charge.

Since the SPC is to be operated based on non/limited-recourse project finance, it will have no impact on CEB's balance sheet. The main financial burden for CEB is investment in the SPC.

In power wholesale, CEB exists on both sides, seller and purchaser. CEB thinks the past IPP price too high, but the purchase price from the JV will be influenced by fuel prices and availability of the plant. Since there is no precedent case for JV and the project team could not obtain detailed information on TPC, the progress of TPC and the PPA with CEB is yet to be seen. However, it is considered that TPC will reimburse the loans with power sales revenue. CEB will also need to repay the loan from the Indian government for CEB equity, and its source will be the dividend from SPC. In any case, the JV is a kind of IPP, and thus the merits and demerits of IPP will apply to JV while the extent of impact may vary.

11.3.4 Public Private Partnership (PPP)

PPP is a scheme to target the efficient and effective management of public works/enterprises via partnership between public and private sectors. It utilizes the funds and know-how of the private sector to fulfill public services. (Private Finance Initiative (PFI), which is mainly led by the private sector in the design, construction and operation of public infrastructure, is a typical PPP form. Other options include DBO (Design-build-operate) and comprehensive assignment to private sector.)

The Finance Commission of Sri Lanka (which supervises the finances of the national and local governments) classifies PPP in its "Public Private Partnership Approach: Theory and Practice". IPP, including BOT and BOO, is regarded as a PPP because the private sector develops the generation which the government and CEB need. The JV mentioned above is a type of PPP because CEB (public) and the private sector co-invest in the JV company.

Another possible PPP case would be infrastructure for an LNG project. In the case of building an LNG power plant in Sri Lanka, the private sector will be responsible for constructing and operating the power plant, but basic infrastructure like an LNG terminal (jetty, tank, gasification, pipeline etc.) could be developed by PPP. Since the LNG infrastructure will be used not only by one power plant but also other plants that will be fueled by the LNG facility, the related IPPs, CEB, and Ceylon Petroleum Corporation (CPC), which is responsible for LNG imports and thus should play a core role in the project, would join the PPP.

Some LNG-based natural gas-fired power plants already exist and more are planned near Colombo. While they will burn heavy oil and other petroleum-based fuel for the time being, they will switch the fuel to LNG (natural gas) when the LNG infrastructure facilities become available in the near future. These power plants will be owned by IPP or JV, or even possibly by CEB, but LNG infrastructure such as the jetty at Colombo port, LNG gasification facilities, and natural gas pipelines to each power plant,

will be operated by PPP, the equity for which will be capitalized by CEB, IPPs, CPC and other related organizations.
The major merit for IPP operators is that IPPs will not be required to possess LNG receiving facilities themselves. (It is not reasonable to request existing generators to bear a part of the costs of infrastructure for fuel conversion.)

ODA agencies have come to consider supporting PPP-based infrastructure projects. For example, JICA develops such programs as Viability Gap Funding, Contingent Credit Enhancement Facility for PPP Infrastructure Development (CCEF-PPP), and Equity Back Finance (EBF). In particular, with EBF framework, JICA loan will cover the capital investment by developing country's government or governmentally-owned corporation that co-invest in a SPC for PPP infrastructure business with a Japanese company if the Japanese company takes part in operation of the SPC. For the loan to be provided in Sri Lanka, for example, the infrastructure business needs to be invested both by a Japanese company and by Sri Lanka Government or governmental organization, and the back finance by commercial banks cannot be organized because of Sri Lanka's country risk etc. The loan condition of EBF is the same as the general JICA loan in terms of interest rate and repayment and grace periods.

11.4 Possible Fund Sources for CEB Ownership

When CEB needs to invest in generating and transmission & distribution facilities, it will depend on assistance from GOSL. GOSL will also rely on donor agencies.

Depending on the business patterns described in 11.3, the available funding options may differ. Major fund sources are explained below. These types of ODA assistance can be applied to CEB/GOSL investments in transmission & distribution projects as well as power plant projects.

11.4.1 Use of Loans by ODA Agencies

ODA Agencies include multi-national/international development banks like the World Bank and ADB and each DAC country's agencies, like Japan's JICA.

The majority of loans to Sri Lanka were provided through bilateral ODA. In particular, the country's power sector has relied greatly on Japanese ODA. It is thought that Japanese loans will continue to be utilized.

As an example of bilateral ODA assistance, if GOSL relies on a Japanese ODA loan for future generation fund sources, the following conditions will apply according to "Major Terms and Conditions of the Japanese ODA Loans" (JICA) as of March 2017.

+ Loan Amount: 85% of the total project cost. Remaining 15% will be CEB equity.
+ Currency: Japanese Yen (JPY)
+ Interest Rate: 1.40% (Fixed Rate) for Middle-Income Country, Standard
+ Repayment Period: 25 years (Grace Period: 7 years)
+ Repayment Method: Equal Principal Payment (every 6 months)
+ Options for Variable Interest Rates: JPY LIBOR+15bp (30 year repayment with 10 year grace period) etc.
+ Procurement: Untied.

JPY Loans to the Sri Lankan power sector in the recent past include the following projects:

+ National Transmission and Distribution Network Development and Efficiency Improvement Project: Approved amount of 24,930million yen, date of E/N on 19 June 2015;
+ Greater Colombo Transmission and Distribution Loss Reduction Project: 15,941 million yen, 14 March 2013; and,

+ Habarana Veyangoda Transmission Line Project: 9,573 million yen, 28 March 2012.

For the above three projects, "Preferential Terms (fixed rate)" in the Japanese ODA Loans Terms & Conditions Table were applied: Repayment period of 40 years, Grace period of 10 years, interest rate of 0.3%.

Even if the Preferential Terms may not apply to the future power projects, the above loan conditions are still very advantageous compared with commercial banks' interest, which is around 12%.
While the JICA loan is received by GOSL and transferred to CEB. During this process, additional interest may be imposed; however, since CEB's financial conditions are weak, GOSL has not imposed such additional interest for the moment.

In applying for ODA Loans, the following issues should be considered:

+ It is GOSL's policy to minimize external debt. GOSL will need to consider the limit of the country's loan amounts. Furthermore, a direct loan to CEB will require GOSL's guarantee.
+ As PUCSL intends to utilize donor funds in the transmission and distribution field while expecting IPPs in the generation field, priority for future ODA loans will be given to transmission and distribution.
+ Some donor countries may be reluctant to provide loans for coal-fired power plants. (On the other hand, ECA's buyer's credit states that a sub-critical coal-fired plant up to 300MW is eligible according to OECA Arrangement.)
+ Bilateral ODA Loans need the agreement of both donor and recipient countries. First, GOSL engages the donor country, then an Exchange Note will be signed, then the loan agreement will be signed by GOSL's Ministry of Finance and the Donor's ODA agency. If no feasibility study (FS) was done for the project, it could take as many as two years for the period of FS study and the period from the recipient country's request through signing of loan agreement. It is necessary to have enough time before construction starts.

11.4.2 Utilization of Export Credit Agency's Financial Assistance

As mentioned above, an ODA loan needs rather complicated process and much time. If CEB cannot wait for an OEA loan, or if by some reason an ODA loan cannot be provided, CEB may consider utilizing ECA export loans. If CEB decides to import power equipment from one of the donor countries, it may be possible to receive an export loan from the donor country's ECA. (For example, if a Japanese manufacturer is selected as a machinery and equipment provider, Japan's JBIC will provide export credit with commercial banks on condition that Nippon Export and Investment Insurance (NEXI)'s Buyer's Credit Insurance is carried.)

Conditions for export credit (e.g. Interest and eligibility) are the same as far as the donor country is a member of the OECD because for these countries, ECA support is based on the Arrangement on Officially Supported Export Credits. It is noted that the Chinese Exim's conditions may differ because China is not an OECD member.

Taking the example of Japanese ECA, which is the Japan Bank of International Cooperation (JBIC), JBIC's conditions on Buyer's Credit are shown below. JBIC does not provide loans alone but co-finances with commercial banks. In receiving the buyer's credit, the importer (CEB) must also bear the cost of buyer's credit insurance for Japan's NEXI on the portion of commercial banks' loans.

Outlines of JBIC's Buyer's Credit and NEXI's Buyer's Credit Insurance are shown below:

(1) JBIC's Buyer's Credit

+ Loan Amount: To be determined based on the OECD Arrangement for Officially Supported Export Credits. Should not exceed the value of an export contract.
+ Loan Structure: Co-finance with commercial banks (JBIC/Commercial Bank = 60/40)

+ Currency: USD
+ Interest Rate: 5.70 % (USD CIRR 3.11% + Risk Premium 2.59%, as of June 2017) (Risk Premium is calculated by JBIC Risk premium calculation sheet based on the category of the recipient country, and buyers etc.)
+ Repayment Period: 12 years (10 years for sub-critical coal-fired plant)
+ Repayment Method: Equal Principal Payment (every 6 months).
+ Other: Commercial Bank loan to be covered by NEXI Buyer's Credit Insurance. JBIC will require GOSL's governmental guarantee as a pre-condition upon providing buyer's credit.

(2) NEXI's Buyer's Credit Insurance (for Commercial Bank Loan)

+ Insurance Amount: Political risk = 97.5% of commercial bank loan amount; Commercial Risk = 95% of commercial bank loan amount.
+ Insurance Premium: Commercial bank loan amount x 13.107% (Insurance premium rate is calculated by NEXI premium rate calculation URL. As of June 2017)
+ Payment Method: Lump-sum payment at first drawdown.

In general, once the exporter (manufacturer) is determined, GOSL's governmental guarantee is issued and the co-finance scheme is set up, and the Buyer's Credit is provided in a shorter time than ODA loans.

11.5 Comparison of Finance for Generation Facility

11.5.1 Comparative Case Study

It is assumed that IPP, private operators, will own most of the thermal power generation facilities and sell the generated power to CEB. However, relying wholly on IPP may lead to the concern of power shortage because there is no guarantee that the generation facility is constructed when CEB needs. Therefore, JICA Survey Team considered a possibility that CEB will own and operate coal-fired TPP, and developed a comparison study of CEB's cost bearing for the following cases.

Table 11-3 Comparative Case Study for Financing

Case	Conditions
Case 1	CEB will own and construct the plant. CEB will borrow the full amount of construction cost from commercial banks.
(Reference)	CEB will use such a high concessionality level as ODA loan for 85% of the construction cost.
Case 2	A SPC will be established as JV entity, in which CEB will invest 50% of the capital. The SPC will own and operate the plant. CEB will pay the capacity charge to the SPC for 20 years after the commencement of operation. 15% of the construction cost will be invested by CEB. The capital for the investment will be fully loaned. The amount of the capacity charge will be set at a level to assure that the SPC's IRR will be 11.5%.[35] As a BOT contract, the facility will be transferred to CEB after 20 years of operation.
(Reference)	The portion of CEB's investment in the above case will be loaned by Equity Back Finance.
Case 3	IPP will own and operate the plant. CEB will pay the capacity charge to the IPP for 20 years after the commencement of operation. The amount of the capacity charge will be set at a level to assure that the IPP's IRR will be 11.5%. As a BOT contract, the facility will be transferred to CEB after 20 years of operation.

(Source: JICA Survey Team)

11.5.2 Conditions of Examination

The comparative study assumes that the following coal-fired TPP (300MW unit) will be constructed.

Table 11-4 Conditions of Examination

Construction Cost	536.4 million USD	Construction cost per kW: 1,788 USD/kW
Construction Period	4 years	Cost Allocation: 20% for the first year, 30% for the second year, 30% for the third year, and 20% for the fourth year.
Operating Years	30 years	

(Source: JICA Survey Team)

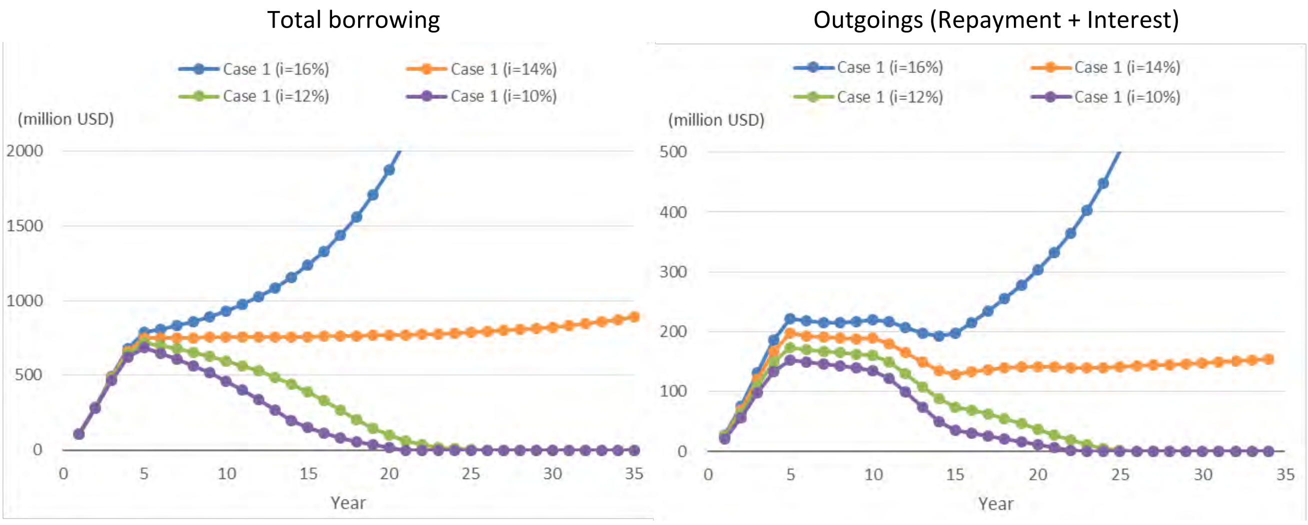
[35] Average value of Average Weighted Prime Lending Rate from January to March 2017 (Central Bank of Sri Lanka)

11.5.3 Result of Comparative Study

(1) Case 1: CEB will own and construct the plant.

CEB will construct the power plant by borrowing all the construction cost from commercial banks and so on. Since no revenue is expected for 4 years of construction period, the interest and capital repayment during this period will be covered by the added borrowings of the same interest rate. After the fifth year when the plant starts operation, CEB can expect revenue from operating sales. The revenue is assumed to be the same as the payment to IPP (in later case) without return portion, which is 104 MUSD/year. Therefore, if the revenue exceeds the expenses after fifth years, no additional borrowing is needed, but if the expense exceeds the revenue, the difference needs to be covered by the additional loan at the same interest

The following figures show the total annual borrowings and expenses (interest and capital repayment) with interest rates of 16%, 14%, 12% and 10%.



(Source: JICA Survey Team)

Figure 11-1 Annual Borrowings and Expenses (interest and capital repayment) (Case 1)

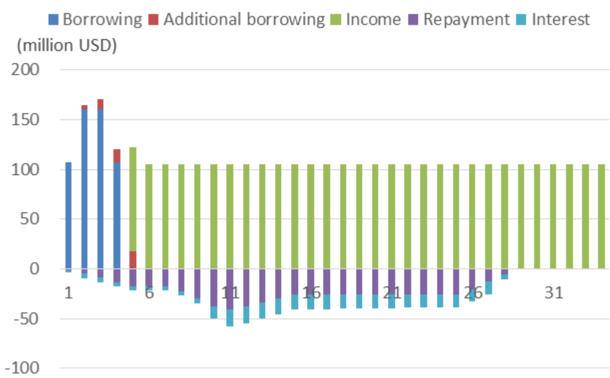
If the interest rate for the borrowing is 16%, the burden for interest is large and the net borrowing will continue to increase, which will lead to a complete failure of the business. If the interest rate is 14%, the borrowings will not increase but not decrease, which will result in the failure of business. At 12%, the borrowings will be fully repaid after 17 years of operation, and at 10%, after 13 years of operation.

The following figures show the situation of cash flow for each case. The plus side indicates the revenue (cash-in) and the minus side indicates the expense (cash-out).

(Source: JICA Survey Team)

Figure 11-2 Comparison of Cash Flow (Case 1)

For reference, the following figure show the cash flow when 85% of the construction cost is covered by ODA loan etc. with high concessionality level (interest rate 2%, repayment period of 25 years, and grace period of 7 years). The remaining 15% will be financed by commercial loan at 16% interest rate.



(Source: JICA Survey Team)

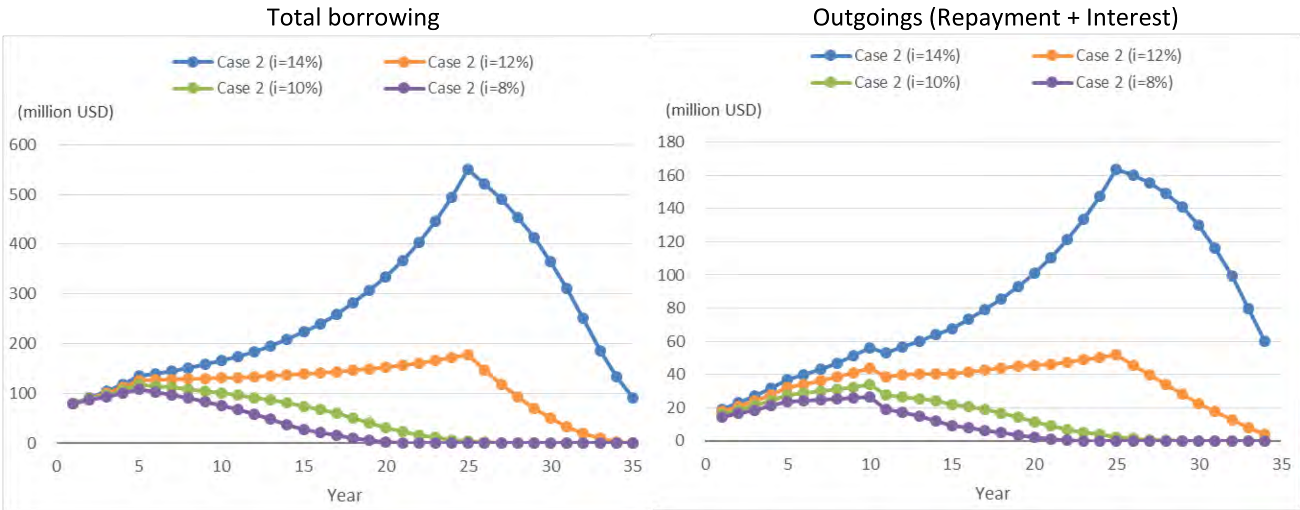
Figure 11-3 Cash Flow (Case 1: ODA loan case)

Since the interest rate is low and 7 years are given for grace period, it will be rather easy for CEB to repay the loan even if the remaining 15% of the construction cost is financed by commercial banks at an interest rate of 16%.

(2) Case 2: CEB will establish a SPC with other business entity, and the SPC will own and construct the plant.

CEB will establish an SPC with other business entity, and the SPC will own and construct a power plant. When establishing the SPC, CEB will borrow from commercial banks etc. for the full portion of its capital investment, i.e. 15% of the total construction cost, which is 50% of total equity of 30%. Since no revenue is expected for 4 years of construction period, the interest and capital repayment during this period will be covered by the added borrowings of the same interest rate. After the fifth year when the plant starts operation, CEB will pay to the SPC for power purchase, which amounts to 133.7 MUSD per year. (The SPC is treated similar to an IPP in the latter case.) The return on investment will be set at 5.4% of the construction cost. (If 30% of the equity is invested, ROE will be 18%.) The proportional portion of the return on investment will be CEB's income. After 20 years of operation, the power plant facility will be transferred to and owned by CEB.

The following figures show the total annual borrowings and expenses (interest and capital repayment) with interest rates of 16%, 14%, 12%, 10% and 8%.

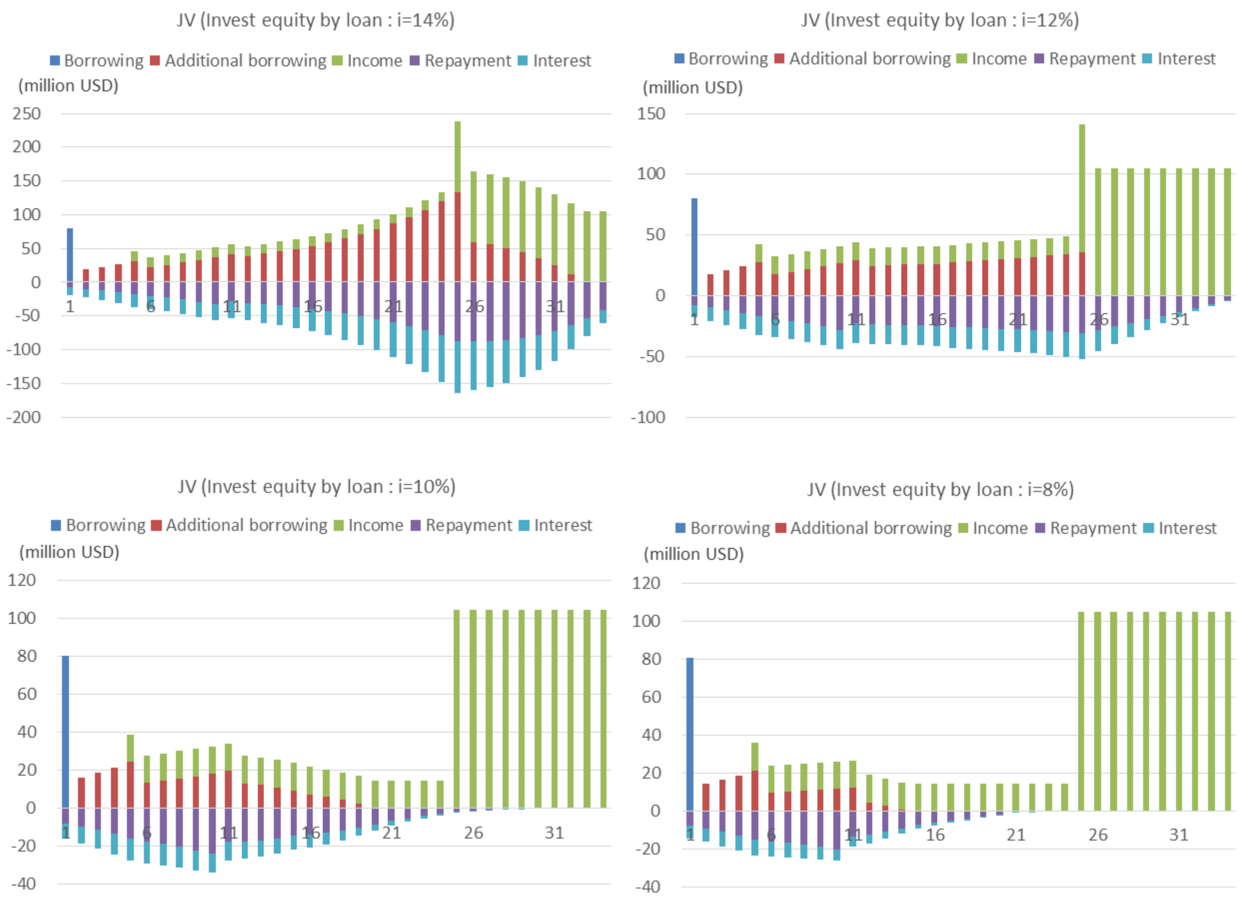


(Source: JICA Survey Team)

Figure 11-4 Annual Borrowings and Expenses (Interest and Capital Repayment) (Case 2)

If the interest rate is 14%, CEB will not be able to repay the borrowed money even after the operation period is over. At 12%, the borrowings will be repaid after 30 years of operation. At 10%, it will take 19 years, and at 8%, it will take 14 years.

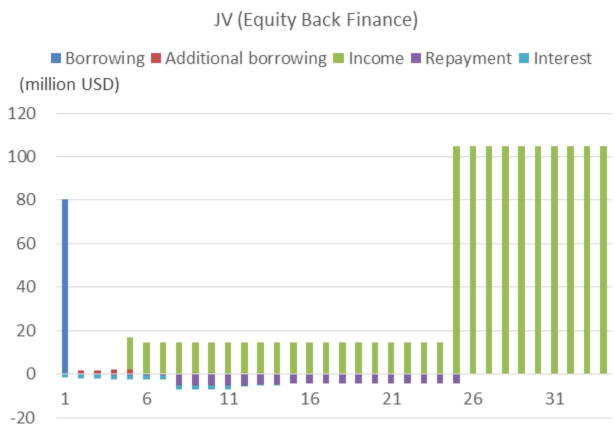
Cash flow comparison for each case is shown below:



(Source: JICA Survey Team)

Figure 11-5 Comparison of Cash Flow (Case 2)

For reference, the following figure shows the cash flow situation when Equity Back Finance with high concessionality (interest rate 2%, repayment period of 25 years, and grace period of 7 years) is applied to CEB's capital investment in the SPC. As a prerequisite for EBF application, Co-investor of the SPC must be a Japanese company.



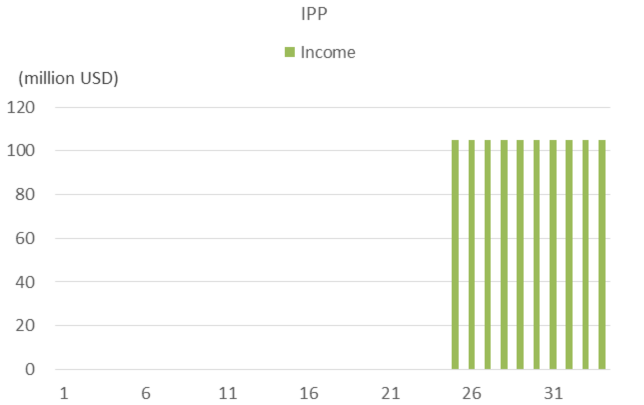
(Source: JICA Survey Team)

Figure 11-6 Cash flow (Case 2 with EBF Loan)

Since the interest rate is low and 7 years of grace period are given, the repayment of borrowing is rather easy.

(3) Case 3: CEB to purchase power from IPP

After the fifth year when the plant commences operation, CEB will have to pay the power purchase cost to IPP at 133.7 MUSD per year. The power purchase cost will be set at the level which enables IPP to retain 11.5% of IRR (104.8 MUSD per year) and to achieve appropriate return (28.9MUSD per year), i.e., 5.4% in return for construction cost. (If equity is 30% of construction cost, ROE will be 18%) After 20 years of operation, the power plant will be transferred to and owned by CEB. Similar to Cases 1 and 2, the cash flow for each year is shown below:



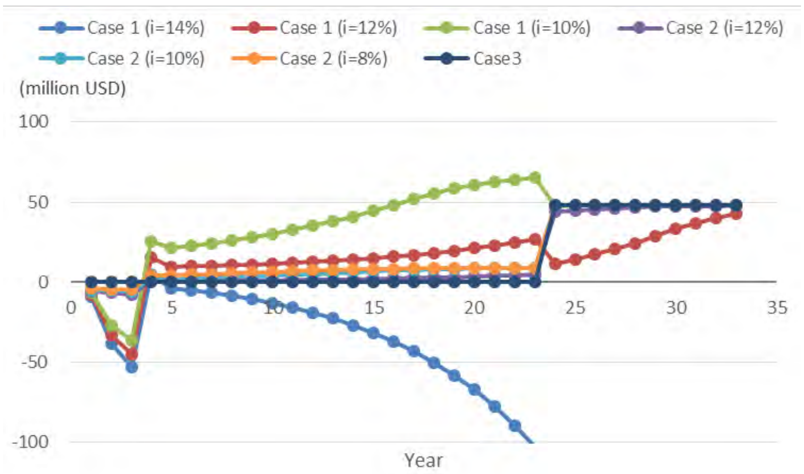
(Source: JICA Survey Team)

Figure 11-7 Cash Flow (Case 3)

In this case, because there is no borrowings, CEB is not required to repay interest and capital, and thus no cash-out flow arises. After 25 years, CEB will own the plant and will get cash-in.

(4) Comparison of Profit

The following figure shows the comparison of profit (difference of income and cost) of each case. The cost denotes interest and depreciation (if CEB owns the facility) while the income denotes power sales revenue (if CEB owns the facility) plus dividends (if CEB invests in SPC).



(Source: JICA Survey Team)

Figure 11-8 Comparison of Profit in each case

The following table shows the net present value (NPV) of the profit of each case.

Table 11-5 Comparison of NPV of Profit

(million USD)

	Discount rate	10%	5%	0%
Case 1 (i=14%)	CEB	-120	-152	-311
Case 1 (i=12%)	CEB	242	693	2,098
Case 1 (i=10%)	CEB	394	936	2,523
Case 1 (ODA)	CEB	652	1,254	2,882
Case 2 (i=12%)	JV	1	122	684
Case 2 (i=10%)	JV	58	241	980
Case 2 (i=8%)	JV	86	287	1,061
Case 2 (EBF)	JV	127	343	1,140
Case 3	IPP	54	208	869

(Source: JICA Survey Team)

The highest NPV is achieved in the Case 1 when CEB receives ODA loan. However, considering the current situation that ODA application is very difficult, CEB will be most profitable when it owns and construct the plant by procuring the necessary fund with 10% loan.

(5) Comparison of Unit Generation Cost

Following Table 11-6 shows the unit generation cost (per kWh) based on the plant factor at 80%. Each case includes the fuel cost of 3.3 USC/kWh and O&M cost of 1.4 USC/kWh for the year 2030.

Table 11-6 Comparison of Unit Generation Cost

(USC/kWh)

	Discount rate	10%	5%	0%
Case 1 (i=14%)	CEB	11.7	11.3	11.0
Case 1 (i=12%)	CEB	9.1	8.1	7.2
Case 1 (i=10%)	CEB	7.9	7.2	6.5
Case 1 (ODA)	CEB	6.1	6.0	5.9
Case 2 (i=12%)	JV	10.8	10.3	9.4
Case 2 (i=10%)	JV	10.4	9.8	9.0
Case 2 (i=8%)	JV	10.2	9.6	8.8
Case 2 (EBF)	JV	9.9	9.4	8.7
Case 3	IPP	10.4	9.9	9.1

(Source: JICA Survey Team)

Except the Case 1 (ODA Loan), the lowest unit generation cost can be achieved when CEB constructs the plant procuring the construction cost at borrowing interest at 10%. However, in all options in Cases 2 and 3, it is assumed that CEB will purchase power from SPC or IPP at the price that guarantee IPP=11.5% plus profit which guarantee ROI=5.4%. Therefore, if the SPC or IPP can get a comparatively advantageous loan from JBIC etc. and can lower the generation cost, CEB may expect lower purchase cost. For example, if the generating cost guarantees IRR=10%, the generation cost can be lower by 0.6 USC/kWh.

In case when CEB construct the plant by itself, using JBIC's Buyer's Credit can be an option. The Loan Conditions for JBIC Buyer's Credit is shown in 11.4.2. While the interest rate is around 5.7%, Buyer's Credit is applicable only to about 50% of the total cost; the repayment period is 10 years, and there is no grace period. Furthermore, NEXI insurance payment, about 13.1% on private sector loan, needs to be made in advance. In this regard, the generation cost can vary much depending on the rate of interest for the portion excluding Buyer's Credit. For example, if CEB can borrow at 12%, the unit generation cost will be 8.6 USC/kWh, which is about 0.5USC/kWh lower than the case without using Buyer's Credit.

(Reference) Examination in case of LNG Power Plant

The JICA Survey Team made a comparison study also for LNG-fired TPP. The construction cost of LNG-fired TPP is 332.6 MUSD, and the construction period is 3 years. The following Table 11-7 shows the unit generation cost (USC per kWh) when the plant is operated at plant factor at 80%. Each case includes the fuel cost of 8.4 USC/kWh and O&M cost of 0.6 USC/kWh for the year 2030.

Table 11-7 Comparison of Unit Generation Cost (LNG-fired TPP)

(USC/kWh)

	Discount rate	10%	5%	0%
Case 1 (i=14%)	CEB	15.0	16.0	17.6
Case 1 (i=12%)	CEB	12.3	12.0	11.6
Case 1 (i=10%)	CEB	11.2	10.8	10.4
Case 1 (ODA)	CEB	9.7	9.7	9.6
Case 2 (i=12%)	JV	12.4	12.1	11.6
Case 2 (i=10%)	JV	12.2	11.9	11.4
Case 2 (i=8%)	JV	12.1	11.8	11.4
Case 2 (EBF)	JV	12.0	11.7	11.3
Case 3	IPP	12.3	12.1	11.6

(Source: JICA Survey Team)

The same tendency is observed: Except for the Case 1 (ODA Loan), the lowest unit generating cost can be achieved when CEB construct the plant by itself procuring the necessary funds at interest rate at 10%.

11.6 Long-term Investment Plan

This section examines the factors of capital investment: transmission, distribution, and generation. The results will be integrated to each Scenario and explained in 11.6.4. Generation projects except hydro and back-up gas-turbine will be constructed and operated by IPP. Therefore CEB will not bear the capital investment for these generation facilities.

11.6.1 Transmission Planning (This section will be reconsidered later)

It is necessary to examine the investment for transmission in two patterns; (1) capital investment in proportion to incremental power demand (2) capital investment required for the specific projects examined.
According to PUCSL, capital investment in transmission facility will rely on ODA loan. While each loan agreement will be signed between GOSL and donors such as ADB and JICA, we here examine the amount necessary to disburse each year.

(1) Capital Investment in proportion to incremental power demand

Capital investment for transmission system at or lower than 132kV is assumed to increase in proportion to the power demand increase. Based on the capital investment of transmission system listed in LTTDP 2015-2024, excluding the investment amount for 220kV or higher voltage and considering the power demand increase, the capital investment per incremental power demand is calculated at 0.29 MUSD/MW. By multiplying this amount by annual demand increase that is led by Table 5-15 Peak Demand Estimate in Chapter 5, the annual capital investment in transmission is estimated in Table 11-8.

Table 11-8 Investment in Transmission System

Year	Peak Demand (MW) Base case	Incremental Demand (MW)	Annual Investment Cost (MUSD)
2016	2,369	---	
2017	2,491	122	35
2018	2,639	148	43
2019	2,798	159	46
2020	2,955	157	46
2021	3,112	157	46
2022	3,267	155	45
2023	3,422	155	45
2024	3,577	155	45
2025	3,730	153	44
2026	3,883	153	44
2027	4,035	152	44
2028	4,187	152	44
2029	4,333	146	42
2030	4,505	172	50
2031	4,677	172	50
2032	4,849	172	50
2033	5,021	172	50
2034	5,193	172	50
2035	5,365	172	50
2036	5,536	171	50
2037	5,708	172	50
2038	5,879	171	50
2039	6,051	172	50
2040	6,222	171	50

(Source: JICA Survey Team)

(2) Capital Investment Required for the Specific Projects Examined

This Master Plan Study examines several transmission facilities, including substation, reactive power capacitors, and transmission lines which should be constructed in and after 2025. This Study estimates the construction cost is divided in three years (construction period) for transmission lines and substations, in five years for reactive power capacitors. The investment amount for these specific projects is shown in Table 11-9.

Table 11-9 Investment in Specific Projects Examined

(in MUSD)

Scenario A		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
[SUBSTATIONS]																										
Kirindiwela 400kV S/S	2025							16	56	8																80
New Habarana 400kV S/S	2021			16	56	8																				80
Sampoor 400kV S/S	2021			16	56	8																				80
[REACTIVE POWER COMPENSATORS]						6	6	6	6	6	2	2	2	2	2	4	4	4	4	4	6	6	6	6	6	88
[TRANSMISSION LINES]																										
400kV Sampoor-New Habarana	2021			12	42	6																				60
400kV New Habarana-Kirindiwela	2025							21	73	10																104
220kV Kerawalapitiya-Kirindiwela	2032														8	28	4									39
220kV Northern NCRE collector-Sampoor	2025							23	79	11																113
220kV Padukka-Ambalangoda	2035																	9	33	5						47
220kV Ambalangoda-Hambantota	2030												18	64	9											91
220kV Kerawalapitiya-Port (UG)	2020		5	19	3																					27
[ADJUSTMENT WITH LTTDP2015-2024]		220	141	141	95	48																				646
[TOTAL]		220	146	204	252	77	6	66	215	36	2	2	20	66	19	31	7	13	37	8	6	6	6	6	6	1,457

Scenario B		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
[SUBSTATIONS]																										0
Kirindiwala 400kV S/S	2030												16	56	8											80
New Habarana 400kV S/S	2030												16	56	8											80
[REACTIVE POWER COMPENSATORS]						8	8	8	8	8	2	2	2	2	2	4	4	4	4	4	7	7	7	7	7	106
[TRANSMISSION LINES]																										0
400kV New Habarana-Kirindiwela	2030												29	100	14											144
220kV Sampoor-New Habarana	2025							12	42	6																60
220kV Kerawalapitiya-Kirindiwela	2021			8	28	4																				39
220kV Pooneryn-Northern NCRE collector	2025							4	13	2																19
220kV Pooneryn-Northern NCRE collector	2030												4	13	2											19
220kV Northern NCRE collector-Sampoor	2025							23	79	11																113
220kV Northern NCRE collector- Vavuniya	2025							9	33	5																47
220kV Northern NCRE collector- Vavuniya	2030												9	33	5											47
220kV Vavuniya-New Anuradhapura-New Habaran	2025							13	46	7																66
220kV Vavuniya-New Anuradhapura-New Habaran	2030												13	46	7											66
220kV New Anuradhapura -Puttalam-New Chulaw	2030												22	77	11											110
220kV New Chulaw-Veyangoda-Kotugoda	2030												8	26	4											38
220kV Biyagama-Kelantissa	2030												2	6	1											8
220kV Padukka-Ambalangoda	2035																	9	33	5						47
220kV Ambalangoda-Hambantota	2030												18	64	9											91
220kV Kerawalapitiya-Port (UG)	2020		5	19	3																					27
[ADJUSTMENT WITH LTTDP2015-2024]		220	141	141	95	47																				644
[TOTAL]		220	146	168	125	59	8	69	222	38	2	2	139	480	70	4	4	14	37	9	7	7	7	7	7	1,853

Scenario C		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
[SUBSTATIONS]																										0
Kirindiwala 400kV S/S	2030												16	56	8											80
New Habarana 400kV S/S	2022				16	56	8																			80
Sampoor 400kV S/S	2022				16	56	8																			80
[REACTIVE POWER COMPENSATORS]						6	6	6	6	6	2	2	2	2	2	4	4	4	4	4	6	6	6	6	6	88
[TRANSMISSION LINES]																										0
400kV Sampoor-New Habarana	2021			17	58	8																				83
400kV New Habarana-Kirindiwela	2030												29	100	14											144
220kV Kerawalapitiya-Kirindiwela	2023					8	28	4																		39
220kV Pooneryn-Northern NCRE collector	2025							4	13	2																19
220kV Northern NCRE collector- Vavuniya	2025							9	33	5																47
220kV Northern NCRE collector- Vavuniya	2040																						9	33	5	47
220kV Vavuniya-Sampoor	2030												13	44	6											63
220kV Vavuniya-Sampoor	2040																						13	44	6	63
220kV New Chulaw-Veyangoda-Kotugoda	2035																	8	26	4						38
220kV Padukka-Ambalangoda	2040																						9	33	5	47
220kV Ambalangoda-Hambantota	2035																	18	64	9						91
220kV Kerawalapitiya-Port (UG)	2020		5	19	3																					27
[ADJUSTMENT WITH LTTDP2015-2024]		220	141	141	95	48																				646
[TOTAL]		220	146	177	188	183	50	24	53	13	2	2	59	202	30	4	4	29	94	16	6	6	37	116	22	1,683

(Source: JICA Survey Team)

Distribution Planning

This Study estimates CEB's whole capital investment in Distribution Facilities from the past capital investment of DD1. Out of the capital investment in 2014-2016, CEB's own fund and external funds are summarized in the following Table 11-10.

Table 11-10 Capital Investment of DD1

Description	2016	2015	2014
[CEB Own Funds]			
AREP	0	0	9
SYA	1,461	1,299	1,009
MV	670	338	92
Other-ABC	485	243	0
SMC-SYA	10	0	0
[Other Funds]			
SUB J	176	96	167
Uthuru Wasanthaya	750	2,276	5,439
IRAN	1,090	1,396	2,119
Lighting Sri Lanka/Western Province	89	723	1,295
Other (ADB, SIDA, DK)	643	1,150	576
[Total]	5,374	7,521	10,705

(Source: DD1 information)

DD1's portion in whole CEB distribution system is: 31.0% in terms of power purchased, 31.4% in terms of power sold, and 35.9% in terms of sales revenue. In average, 32.8% is regarded as the share of DD1 in CEB. Using the above table and this share, CEB's investment for 2014-2016 and its average unit cost are introduced as follow:

Table 11-11 CEB's Investment in Distribution System (3 year average)

Year	DD1 Investment (MLKR)	Total Investment (MLKR)	Peak Demand (MW)	Unit Cost (MLKR/MW)
2014	10,705	32,668	2,269	14.4
2015	7,521	22,952	2,294	10.0
2016	5,374	16,400	2,453	6.7
Average				10.4

(Source: JICA Survey Team)

By multiplying the CEB's peak demand by the above average unit cost of 10.4 MLKR/MW and by converting it in USD at exchange rate of 1USD= 133.37 LKR, the annual investment in distribution is estimated in the below Table 11-12.

Table 11-12 Investment in Distribution System

Year	Peak Demand (MW)	Annual Investment (MLKR)	Annual Investment (MUSD)
2016	2,369	---	
2017	2,491	25,817	194
2018	2,639	27,351	205
2019	2,798	28,999	217
2020	2,955	30,626	230
2021	3,112	32,253	242
2022	3,267	33,859	254
2023	3,422	35,466	266
2024	3,577	37,072	278
2025	3,730	38,658	290
2026	3,883	40,244	302
2027	4,035	41,819	314
2028	4,187	43,394	325
2029	4,333	44,908	337
2030	4,505	46,690	350
2031	4,677	48,473	363
2032	4,849	50,255	377
2033	5,021	52,038	390
2034	5,193	53,821	404
2035	5,365	55,603	417
2036	5,536	57,376	430
2037	5,708	59,158	444
2038	5,879	60,930	457
2039	6,051	62,713	470
2040	6,222	64,485	484

(Source: JICA Survey Team)

11.6.2 Power Plant Planning

The following Table 11-13 shows the unit construction cost (USD/kW) of coal-fired TPP, LNG-fired TPP, Back-up Gas Turbine, Pumped Storage Hydro Power Plant and Renewable energies as well as the construction cost of LNG terminal.

Table 11-13 Conditions for Capital Investment for Generation Facilities

	Construction cost	Share of construction cost						Remarks
		-1 yr	-2 yrs	-3 yrs	-4 yrs	-5 yrs	-6 yrs	
Coal-fired TPP	1,788 USD/kW	20%	30%	30%	20%			Table 7-9
LNG-fired TPP	1,109 USD/kW	10%	70%	20%				Table 7-9
LNG Facility	484 million USD	20%	30%	30%	20%			Table 4-14
Back-Up GT	501 USD/kW	100%						Table 7-9
PSPP	1,063 USD/kW	10%	20%	20%	20%	20%	10%	Chapter 7.2.1
Hydro	2,000 USD/kW	10%	70%	20%				
Mini-hydro	2,000 USD/kW	100%						
Wind	1,820 USD/kW	100%						Table 7-14
Solar	700 USD/kW	100%						Table 7-14
Biomass	1,685 USD/kW	100%						LTGEP

(Source: JICA Survey Team)

The capital investment for generation facilities based on the power development plan is calculated in the following Table 11-14.

Table 11-14 Capital Investment for Generation Facilities

(in MUSD)

Scenario A	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Coal-fired TPP	0	107	268	429	536	429	375	268	268	268	161	215	268	322	268	215	161	268	268	161	215	161	268	268	6,169
LNG-fired TPP	299	266	33	0	0	0	0	0	0	0	0	0	0	67	233	33	0	0	0	0	0	0	0	0	932
LNG Facility	98	146	146	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	488
Back-Up GT	18	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50	0	50	0	268
PSPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro	37	21	31	99	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	203
Mini-hydro	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20	20	20	20	20	20	740
Wind	91	91	55	55	55	55	55	55	55	55	55	55	55	55	55	55	91	91	91	91	91	91	91	91	1,674
Solar	14	14	14	28	28	28	28	28	35	35	35	35	35	35	70	70	70	70	70	70	70	70	70	70	1,092
Biomass	0	0	0	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	135
[TOTAL]	597	686	588	749	673	552	498	425	398	398	291	344	432	498	696	392	392	483	499	342	446	342	533	449	11,700

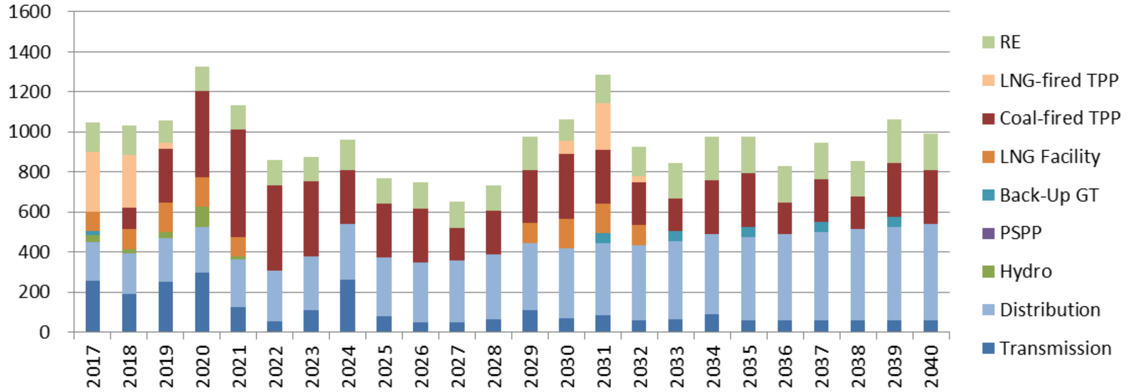
Scenario B	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
Coal-fired TPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LNG-fired TPP	299	266	100	299	266	100	299	266	33	0	0	0	0	67	299	266	100	233	33	67	233	100	233	100	3,660
LNG Facility	98	146	146	98	98	146	146	98	0	0	0	0	0	0	0	98	146	146	98	0	0	0	0	0	1,464
Back-Up GT	18	0	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	368
PSPP	0	0	0	0	21	64	106	128	128	106	64	21	0	0	0	0	0	0	0	0	0	0	0	0	638
Hydro	37	21	31	99	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	203
Mini-hydro	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20	20	20	20	20	20	740
Wind	91	91	127	182	182	182	182	182	364	364	364	364	364	364	364	364	364	364	364	364	364	546	546	546	7,589
Solar	35	35	35	35	35	35	42	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	1,442
Biomass	0	0	0	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	135
[TOTAL]	618	600	480	753	656	567	816	817	635	580	588	495	558	521	804	818	750	867	635	521	737	736	953	736	16,239

Scenario C	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
Coal-fired TPP	0	107	268	322	375	268	161	107	0	0	107	161	268	268	161	107	0	107	161	161	107	0	107	161	3,487
LNG-fired TPP	299	266	33	0	67	233	33	0	0	0	0	0	0	67	233	33	67	233	33	0	0	67	233	33	1,930
LNG Facility	98	146	146	98	0	0	0	0	0	0	0	0	0	0	0	98	146	146	98	0	0	0	0	0	976
Back-Up GT	18	0	0	0	0	0	0	0	0	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	368
PSPP	0	0	0	0	21	64	106	128	128	106	64	21	0	0	0	0	0	0	0	0	0	0	0	0	638
Hydro	37	21	31	99	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	203
Mini-hydro	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20	20	20	20	20	20	740
Wind	55	91	91	91	91	91	91	91	91	182	182	182	182	182	182	182	182	182	182	182	182	182	182	182	3,513
Solar	35	35	35	35	35	35	35	35	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	1,400
Biomass	0	0	0	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	0	0	0	34	0	135
[TOTAL]	581	600	377	363	268	463	306	327	329	398	406	313	376	339	555	403	535	685	453	272	322	339	589	305	9,902

(Source: JICA Survey Team)

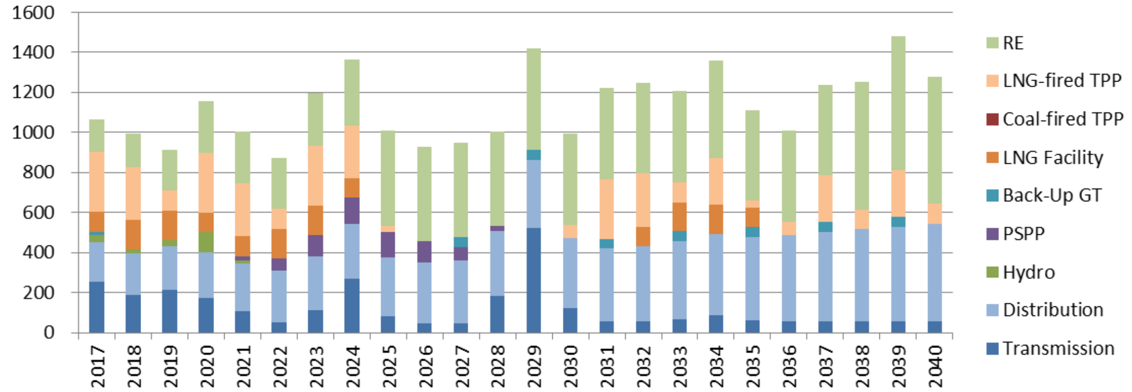
11.6.3 Whole Image of Long-term Investment Plan

In the previous sections in this Chapter 11, the JICA Survey Team estimated the capital investment up to 2040 by category of generation, transmission, and distribution. The following Figure 11-9 through Figure 11-11 show the whole image according to Scenarios A, B, and C.



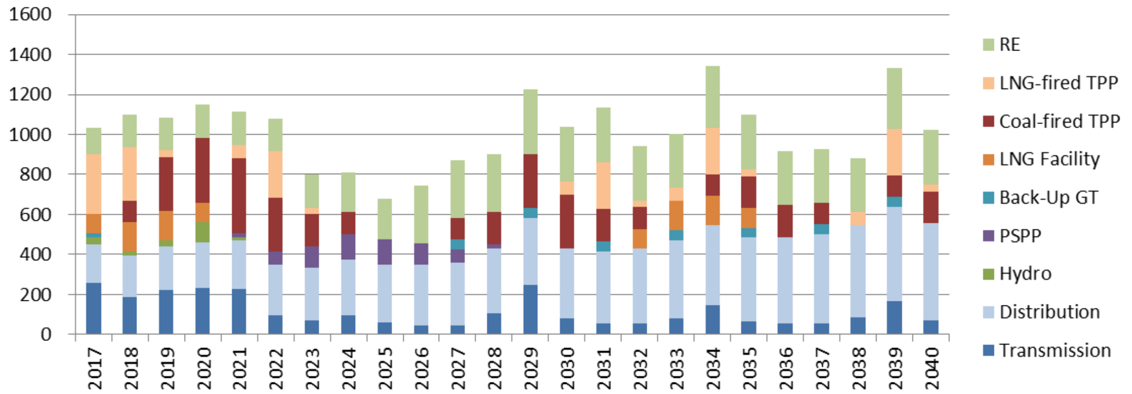
(Source: JICA Survey Team)

Figure 11-9 Capital Investment based on Scenario A



(Source: JICA Survey Team)

Figure 11-10 Capital Investment based on Scenario B



(Source: JICA Survey Team)

Figure 11-11 Capital Investment based on Scenario C

These capital investment deployments are the investment plan that the whole Sri Lanka's power sector should bear. Regarding the Scenario B, the total amount of investment from 2017 through 2040 is about 10% larger than other two Scenarios because the capital investment in renewable energies is larger.
Since the construction of renewable energies and thermal power plants will be owned and constructed by IPP, the construction cost is not included in CEB's capital investment. On the other hand, CEB will have to bear the cost of power purchase for long term, since CEB is required to purchase power from these generation facilities based on PPA.
CEB should bear the capital investment for transmission and distribution systems, PSPP, and back-up gas turbine, and the amount is about half of the total investment. For this portion, there is little difference among Scenarios.

Chapter 12. Economic and Financial Analysis

12.1 Review of Financial Position of CEB

The Study reviewed the financial conditions of CEB based on financial statements for the period from 2008 to the latest financial year. The items reviewed are as follows:

- Balance sheet analysis: analyzing financial stability, including liquidity, capital to asset ratio, debt ratio, debt capacity, etc.
- Income statement analysis: analyzing profitability, including balance between operating income and power supply cost, balance between tariff and unit cost of power supply (kWh), retained earnings for long-term investment

In Sri Lanka, the Sri Lanka Financial Reporting Standards (SLFRS) have been aligned with the International Financial Reporting Standard (IFRS) since 2012. The financial statements starting from January 1, 2012 needed to have applied the new SLFRS. Therefore, the financial statements of CEB from the financial year of 2012 have been prepared in accordance with the new SLFRS and the financial data before and after 2012 cannot be precisely compared. However, the computed figures for the year 2011 were restated as per the SLFRS convergence requests. CEB enjoyed exemptions of 1st time adoption, where the Assets are not at fair value; part of the Assets, such as vehicles, was recorded to the MG and other asset categories were considered deemed cost basis. The earlier indexing revaluation was stopped and the policy of the Property, Plan & Equipment was stood as cost base from the year 2012 onwards. The requirements of LKAS 19: Employee Benefits and LKAS 23: Borrowing Costs were also applied. In addition, the financial transactions and the financial assets and liabilities recognized after the beginning of 2011 have not been re-recognized. Hence, a certain tendency for the financial situation of CEB for the period from 2008 to 2015 can be indicated.

Table 12-1 shows the profitability of CEB based on their income statements for the period from 2008 to 2015. The sales revenue has increased by 2014 because of the increase in the sales volume of electricity and electricity sales amount. On the other hand, the cost of sales has fluctuated by year due to the fluctuation of fuel costs. Until 2014, the sales revenue has been below the cost of sales for most years and an operating loss and loss before tax including financial cost have been recorded almost every year. In 2013, a surplus was recorded because of the dramatic reduction of fuel costs and the revised electricity tariff.

Table 12-1 Profitability of CEB

(Rs. Million)

	2008	2009	2010	2011	2012	2013	2014	2015*
Revenue	111,287	110,518	121,862	132,460	163,513	194,147	202,645	188,684
Cost of Sales	-145,712	-118,186	-116,168	-151,448	-222,419	-165,509	-213,646	-168,308
Gross Profit/Loss	-34,425	-7,668	5,694	-18,988	-58,906	28,638	-11,001	20,376
Administrative Expenses	-1,487	-2,870	-1,851	-1,636	-2,997	-2,556	-3,146	-4,202
Other income	3,580	3,412	3,062	3,810	4,225	5,107	5,870	8,292
Operating Profit/Loss	-32,332	-7,126	6,905	-16,814	-57,678	31,189	-8,277	24,466
Financial Profit/Loss	-1,537	-2,212	-2,047	-3,371	-3,769	-8,924	-6,726	-4,700
Profit before Tax	-33,869	-9,338	4,858	-20,185	-61,447	22,265	-15,003	19,766

(Source: CEB, "Annual Report" (2008, 2009, 2010, 2011, 2012, 2013), Data provided by CEB)
Note: Figures for 2015 are provisional and can be confidential before officially approved.

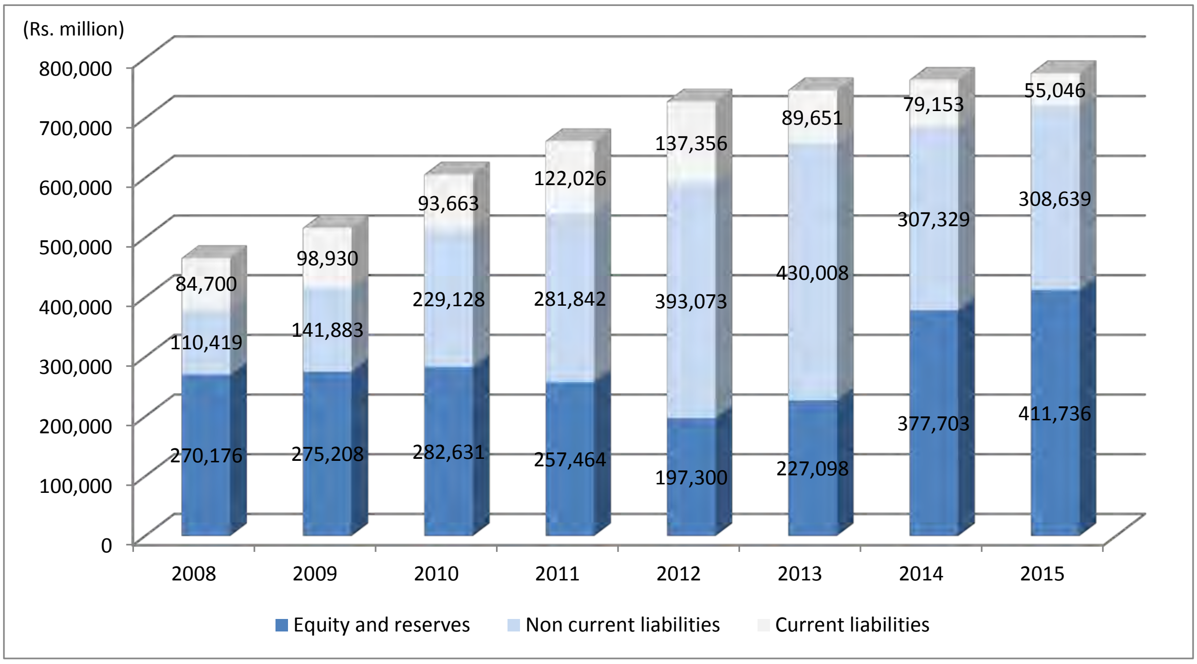
Table 12-2 shows the financial position of CEB for the period from 2008 to 2015. Non-current assets have accounted for the majority of CEB's total assets and have been mainly composed of power supply facilities. While the power demand has been growing, non-current assets have been increasing year by year due to the expansion of capital investment in power facilities. The capital investments have been financed by loans from international donors and domestic banks as well as CEB's own capital. However, it was difficult for CEB to accumulate retained earnings for capital investment due to the loss after tax. Therefore, capital injection from the government budget has covered for the necessary capital investments[36]. In addition, a debt equity swap was dealt in 2014. As a result, 161,707 million Rs. was capitalized. This means that the government has assumed CEB's long-term debts.

Table 12-2 Balance Sheet of CEB

(Rs. million)

	2008	2009	2010	2011	2012	2013	2014	2015*
Total Assets	465,296	516,021	605,422	661,333	727,728	746,759	764,185	775,420
Non-current assets	409,193	462,919	496,047	550,520	627,695	654,315	690,998	706,489
Current assets	56,102	53,337	109,319	110,812	101,295	91,423	72,163	67,906
Cash	774	585	1,547	1,479	2,571	2,043	1,543	675
Non-current liabilities	110,419	141,883	229,128	281,842	393,073	430,008	307,329	308,639
Current liabilities	84,700	98,930	93,663	122,026	137,356	89,651	79,153	55,046
Capital and reserves	270,176	275,208	282,631	257,464	197,300	227,098	377,703	411,736

(Source: CEB, "Annual Report" (2008, 2009, 2010, 2011, 2012, 2013), Data provided by CEB)
Note: Figures for 2015 are provisional and can be confidential before officially approved.



(Source: CEB, "Annual Report" (2008, 2009, 2010, 2011, 2012, 2013), Data provided by CEB)

Figure 12-1 Debts and equity of CEB

[36] The total amount of capital injection from the government budget is 1,063 million Rs. for 2016.

12.2 Preparation of Financial and Investment Strategy for CEB

The Survey Team analyzed the impacts of the alternatives of long-term development scenarios on the financial structure of CEB in order to prepare mid-term and long-term financial and investment strategies to ensure CEB's financial soundness (profitability and financial stability), based on the results of the financial sustainability analysis.

- Profitability through setting tariffs at cost recovery levels including future investment and long-run marginal costs
- Targeting of financial indicators for mid-term and long-term goals, including liquidity, debt capacity, and profitability
- Balance between debt and equity for long-term financial stability

12.2.1 Comparative analysis on power supply cost and electricity tariff

The Study made a comparison between the power supply cost by unit and the average electricity revenue as of November 2016. Table 12-3 shows the comparison between the power supply cost and the average electricity tariff. The power supply cost has been composed of power generation costs of more than 70%, transmission costs of around 3%, distribution costs of about 7% and system loss costs (opportunity loss) of around 8%.

The power generation cost fluctuated year by year because of the proportion of thermal power generation in the total power generation volume and the changes in fuel costs. The first coal fired power plant (Lakvijaya) was commissioned in December 2011 and has been operated as base load. However, in cases where the power demand could not be covered by hydropower generation due to drought, the power generation cost increased because of power purchases from the diesel power plants of Independent Power Producers (IPP) with very expensive fuel costs. On the other hand, in case where the sufficient power volume was generated by the existing hydropower plants, the power generation cost was ranged between 10-11 Rs/kWh.

Electricity tariffs are determined by the Public Utility Commission of Sri Lanka (PUCSL). PUCSL assesses and approves the electricity tariffs requested by CEB based on cost calculations by each division of CEB, such as generation, transmission and distribution (4 divisions). However, the actual power supply cost has been higher than the average electricity sales and CEB's electricity business has generated losses.

Table 12-3 Power Supply Costs and Electricity Tariffs (2011-June 2016)

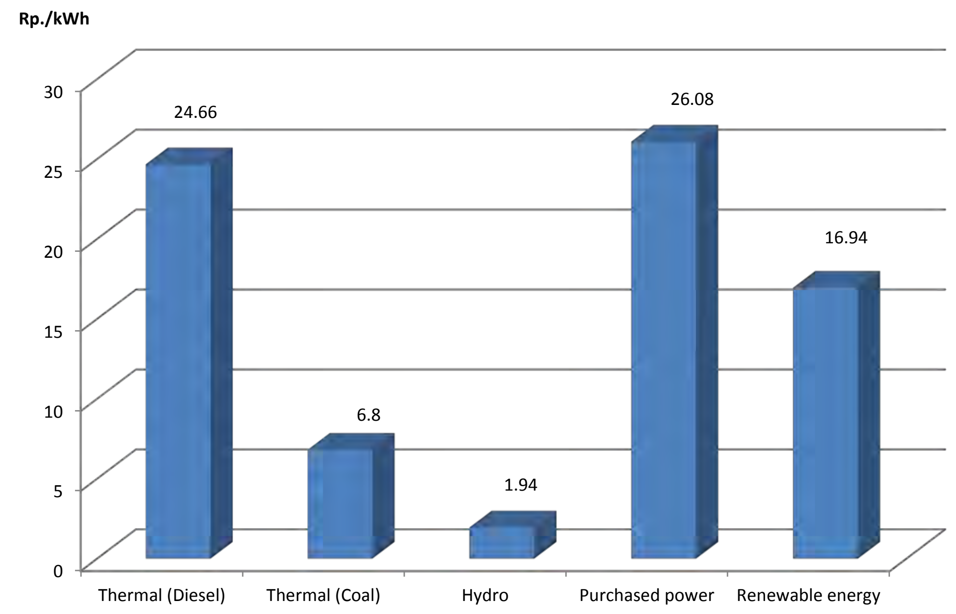
Rs/kWh	2011	2012	2013	2014	2015	2016.6
a) Generation*	11.32 (80%)	16.28 (76%)	11.38 (70%)	14.78 (74%)	10.30 (68%)	11.76 (72%)
b) Transmission*	8.00 (3%)	11.12 (3%)	7.50 (4%)	8.87 (2%)	5.46 (3%)	5.87 (3%)
c) Distribution*	2.40 (15%)	2.62 (12%)	2.80 (17%)	2.93 (15%)	3.08 (20%)	2.95 (17%)
d) System Loss	1.55 (10%)	2.01 (9%)	1.41 (9%)	1.77 (9%)	1.18 (8%)	1.36 (8%)
Total power supply cost*	15.68 (100%)	21.54 (100%)	16.19 (100%)	19.98 (100%)	15.07 (100%)	16.92 (100%)
Average electricity revenue	13.40	15.61	18.27	18.32	16.01	16.19
Difference	-2.28	-5.93	-2.09	-1.66	-0.94	-

(Source: Data provided by CEB)

Note 1: *Figures in ( ) are the proportion (%) in the total power supply cost.
Note 2: *The total power supply cost adds up a) generation cost, b) transmission cost, c) distribution cost) and d) system loss.

Figure 12-1 shows power generation costs, which account for more than 70% by power source. The costs of purchased power (IPP) and thermal power generation (diesel) are the most expensive at 26.08 Rs/kWh and 24.66 Rs/kWh respectively. Since IPPs generate electricity with diesel power plants, the costs for power generation are very high. On the other hand, the hydropower generation cost of 1.94

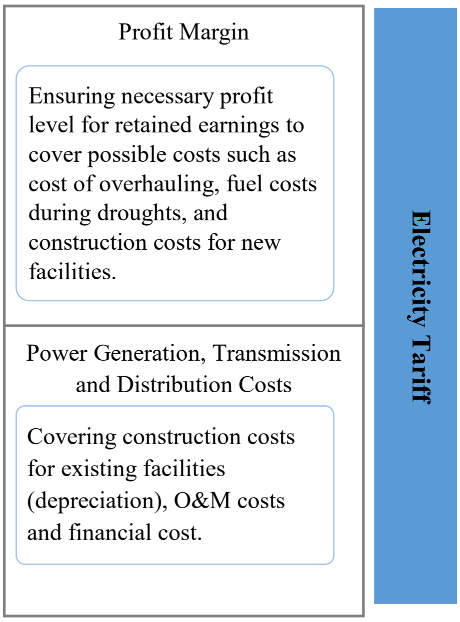
Rs/kWh which does not require fuel cost is the least and the power generation cost by coal fired power plant of 6.8 Rs/kWh is the second least. While the shares in the power generation volume by power source have fluctuated year by year, the share of diesel power generation by both CEB and IPPs is more than 40% as of December 2016. This high cost power generation of diesel power plants is a major factor in reducing the profitability of CEB. Although ensuring the power generation volume by hydropower plants at the lease cost can be essential to reduce and stabilize the power generation cost, the hydropower generation volume is affected by volume of rainfalls and is subordinated in water use than other purposes of drinking water and irrigation water. In addition, since there is no feasible plan for expansion of hydropower generation, the increase in the hydropower generation cannot be expected. Therefore, the issues in power development are introduction of coal-fired power generation at cheaper cost and reduction of power generation cost by renewable energies in order to stabilize and reduce the generation cost in future.



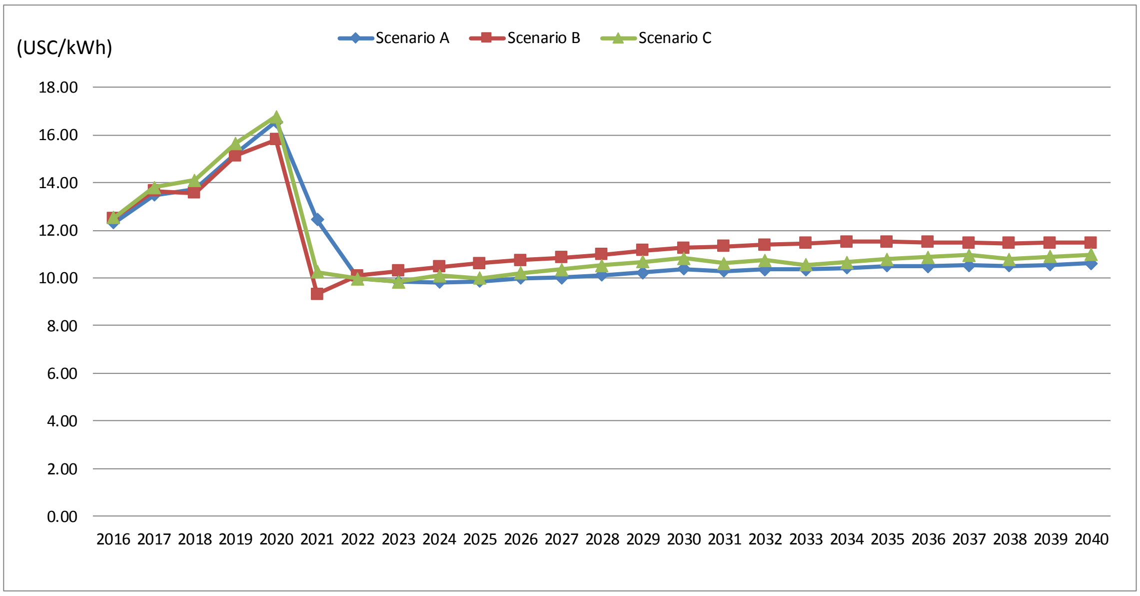
(Source: Data provided by CEB)

Figure 12-2 Power Generation Cost by Power Source

The Survey Team studied a financial strategy to ensure appropriate profitability (leveling of power supply cost and setting of appropriate profit margin). In this Study, financing cost for capital investment in power facilities and profit margin for future capital investment are considered. The financing cost is estimated based on the finance plan proposed in Chapter 11. The results of simulated power supply cost by proposed scenario and simulated power supply cost including financing cost and profit margin are shown below.



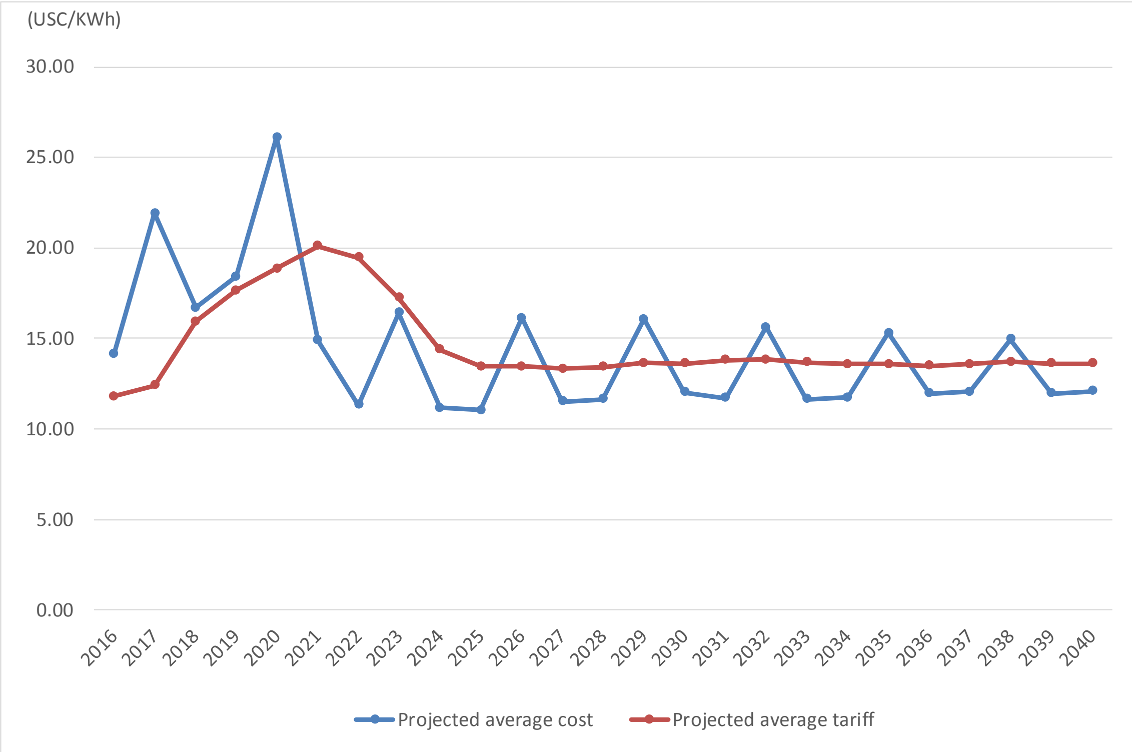
Simulation results for all scenarios indicate that the estimated power supply cost excluding financing cost and profit margin (USC/kWh) will not decrease by 2020 with no difference in the level of the cost by scenario. It is estimated that the power supply cost will sustain at high level of around 16-17 USC/kWh in 2020 from about 13 USC/kWh. However, the simulation results for scenario B, not including construction of new coal-fired power plants, indicates that the power supply cost will decrease to around 9.3 USC/kWh in 2021 and increase slightly to around 10.5-11.5 USC/kWh. Simulation results for scenarios A and C, including construction of new coal-fired power plants, indicate that the power supply cost will decrease to less than 10 USC/kWh in 2022 and remain at around 10-11 USC/kWh afterwards.



(Source: JICA Survey Team)

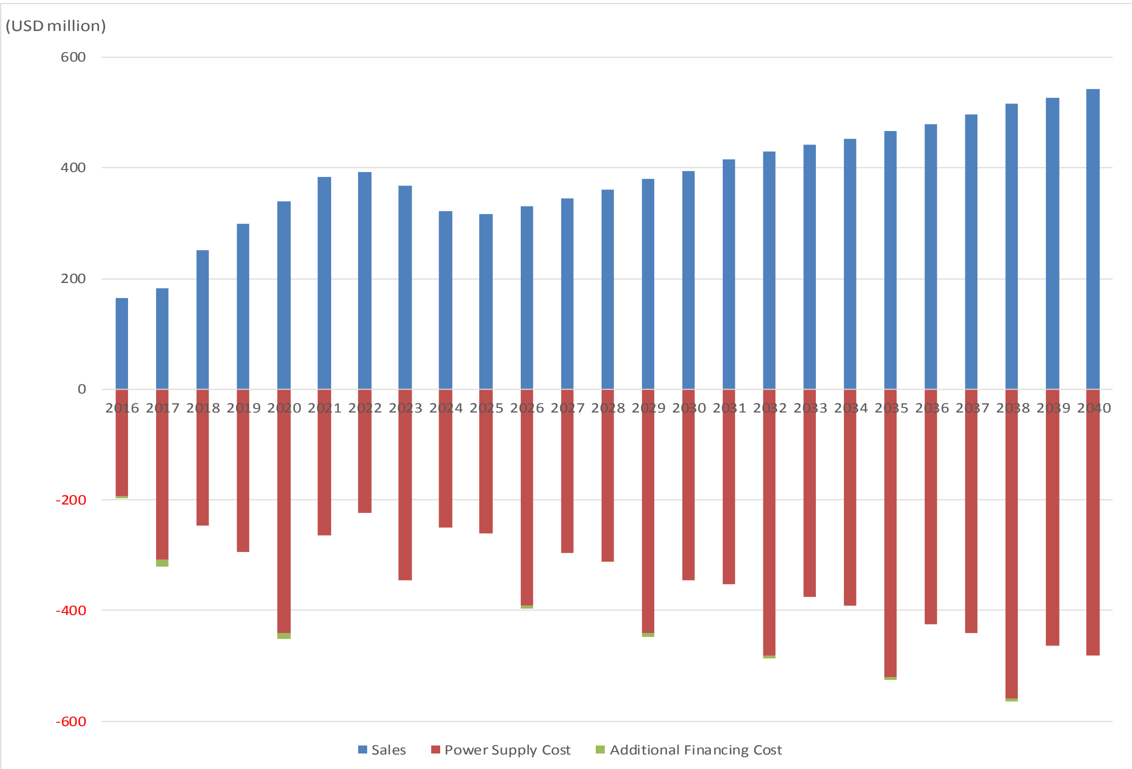
Figure 12-3 Simulated Power Supply Costs (excluding financing cost and profit margin) by Scenario

However, drought can dramatically increase power supply cost since limited available water volume for power generation reduces hydropower generation with lower generation cost and increases oil-fired power generation with very expensive power generation cost of around 30 USC/kWh. The Survey Team simulated impacts of drought on financial situation of CEB based on the Case of the Scenario C. The Figure 12-4 shows changes in power supply cost and tariff in case where drought occurs every three years. It is projected that the impact of drought will be significant by 2020 before the installation of lower cost power sources. The average power supply cost can increase to around 26 USC/kWh.



(Source: JICA Survey Team)

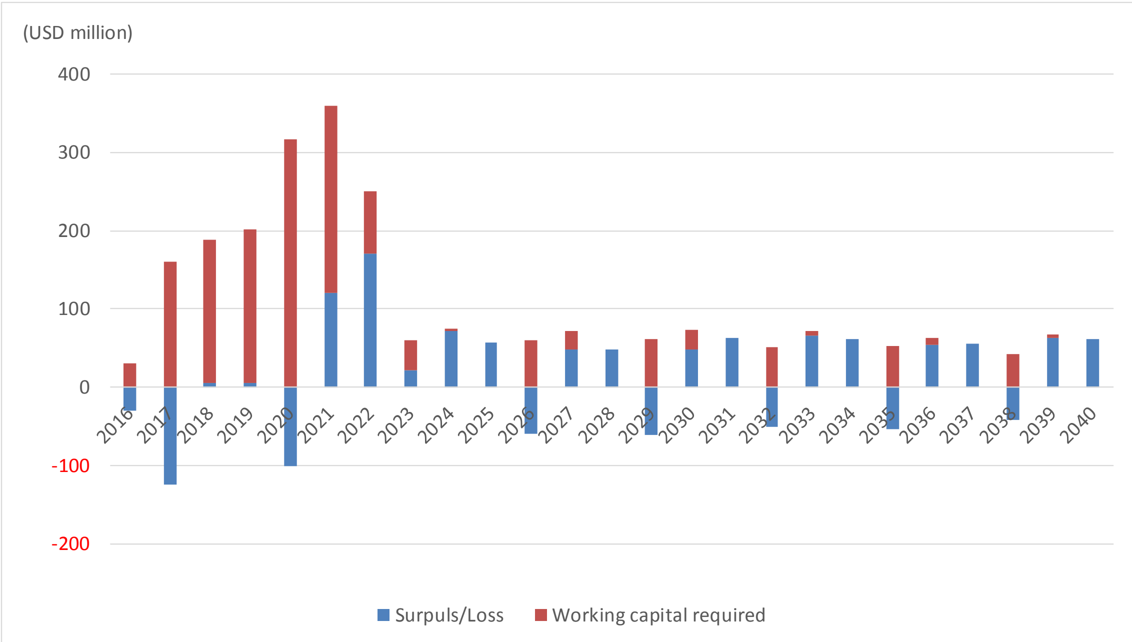
Figure 12-4 Projected Impact of Drought on Power Supply Cost and Tariff in the Scenario C



(Source: JICA Survey Team)

Figure 12-5 Simulated Cashflows in the Case of Drought (Scenario C)

On the other hand, in accordance with the tariff formula regulated by PUCSL, unexpected increases in power supply cost caused by drought cannot timely reflect in the tariff which is revised every six months based on the past power supply cost and the projected investment cost. Namely, a time lag to reflect the increases in the power supply cost caused by drought in the revised tariff can generate losses of power supply operation by CEB (Figure 12-5)



(Source: JICA Survey Team)

Figure 12-6 Projected Profit/Loss and Working Capital to be required in the Case of Drought (Scenario C)

In order to cover cash shortage caused by the loss, CEB needs to finance working capital by commercial loans which can be quite costly. In particular for the period until 2021, the amount of working capital to be financed by short-term loans can increase in order to cover losses by operation and financing cost (interest payment). In case where the drought occurs in 2017 and 2020, the short-term loans for working capital can increase to approximately 300 million USD in 2020.

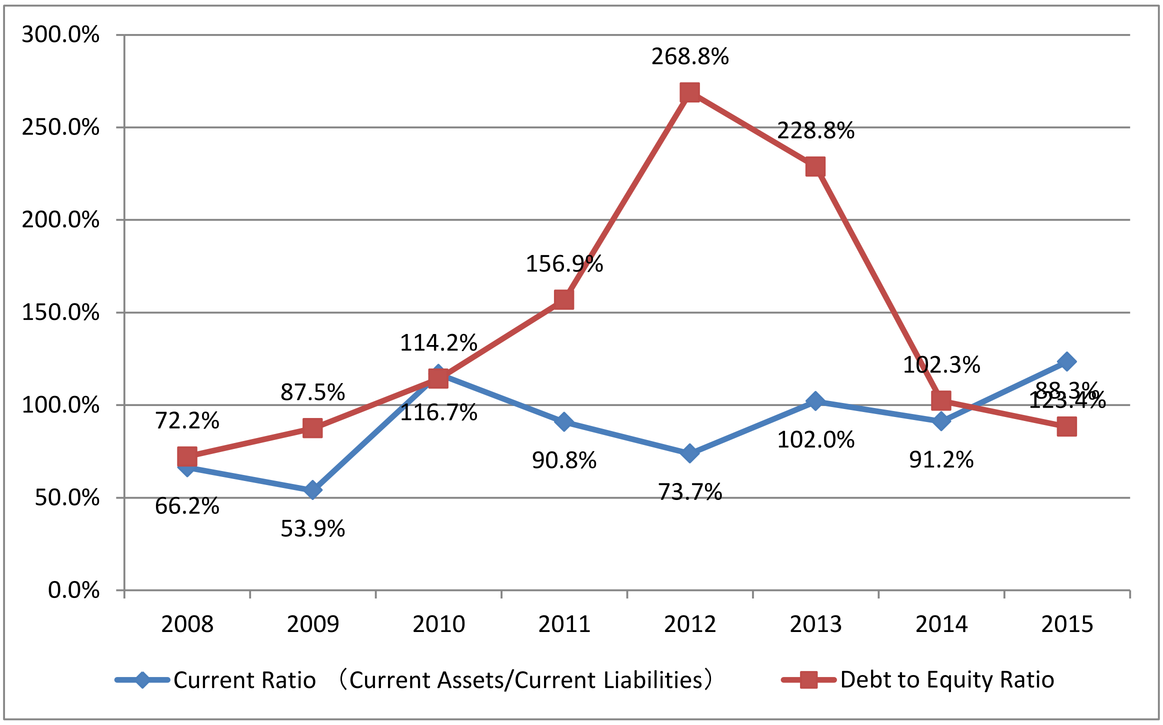
12.2.2 Tariff Collection

As of May 2016, the tariff collection rate reached 96.3%, which can be sufficiently high. Although further improvement is required in order to attain 100%, the issue of tariff collection cannot be considered a serious factor affecting the financial position of CEB.

12.2.3 Financial Soundness of CEB

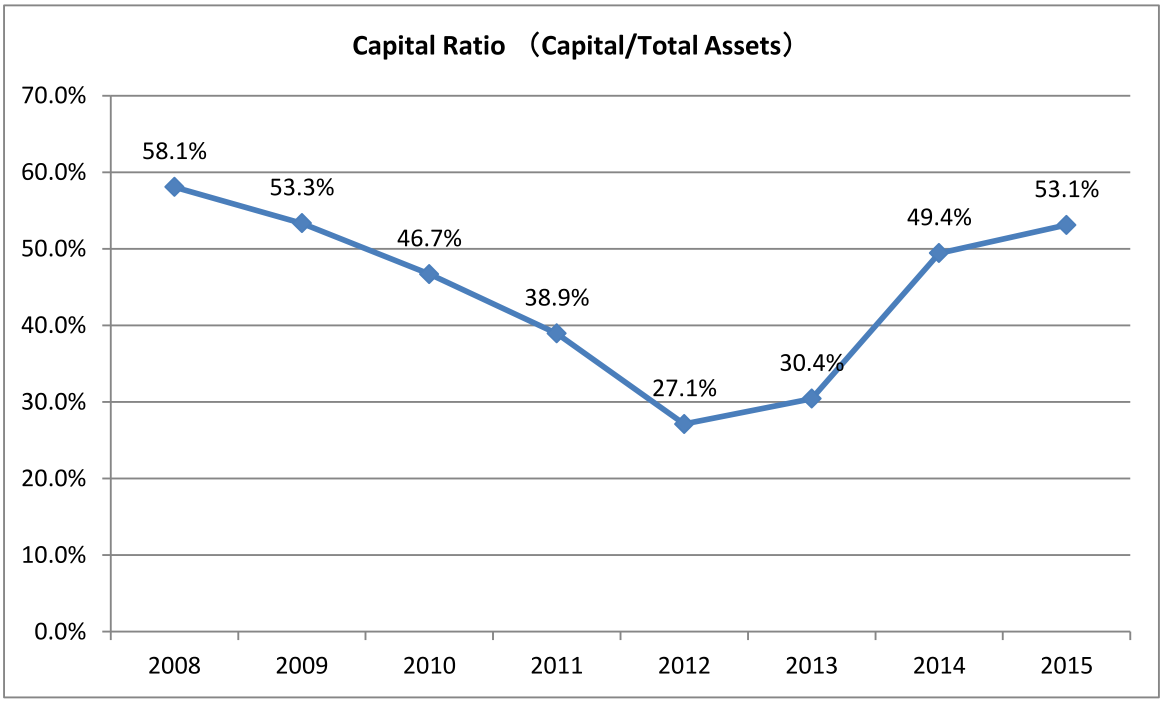
The current ratio is one of the financial indicators for assessing solvency, in particular for short-term debt (current assets including cash and asset high liquidity to current liabilities). In general, the desirable level of the current ratio is 2.00 times to current liabilities. Namely, twice the amount of current assets to current liabilities is required. In the case of CEB, the current ratio has been improved though it has been around 100% at most, which cannot be sufficiently sound.

The capital ratio and debt to equity ratio are indicators for assessing financial leverage and risk to total debt including non-current liabilities. In particular, the capital ratio indicates solvency to total debt by capital. Both indicators deteriorated by 2012. This was because of the significant increase in long-term debt since 2010. The debt to equity ratio reached 268.8% in 2012 and improved to 88.3% in 2015 due to the debt equity swap and the reduction of long term debt in 2014 as mentioned above. The capital ratio decreased to 27.1% in 2012 and improved to 53.1% in 2015 because of the increased equity due to the debt equity swap in 2014.



(Source: CEB, "Annual Report" (2008, 2009, 2010, 2011, 2012, 2013), Data provided by CEB)

Figure 12-7 Current Ratio and Debt to Equity Ratio



(Source: CEB, "Annual Report" (2008, 2009, 2010, 2011, 2012, 2013), Data provided by CEB)

Figure 12-8 Capital Ratio

The ADB approved "Supporting Electricity Supply Reliability Improvement" in July 2016 and the borrower of the approved loan is CEB. As conditionality, the loan agreement includes a financial covenant to set the financial monitoring indicators for CEB. (refer to Table 11-1)

12.3 Financial Sustainability Analysis of CEB

12.3.1 Calculation of Long-Run Marginal Cost (LRMC)

The Survey Team calculated LRMC based on the construction costs for additional facilities for power generation, transmission and distribution in order to meet power demand at peak hours and unit costs for additional costs for fuel, O&M and transmission and distribution loss to be included in the energy cost for power negation. The estimated LRMC is 48.12 USC/kWh, which does not differ by scenario since LRMC is a cost to cope with the increase in peak demand.

In Sri Lanka, power supply for the increase in the peak demand is by oil or gas fired power plant which are currently operated by IPP. The power purchase cost from IPPs accounts for the largest portion in additional costs for power generation under the current situation. It is expected that the peak demand will be basically supplied by IPPs. Therefore, LRMC is derived from the power purchase cost from IPPs and transmission and distribution cost required additionally.

Table 12-4 Long Run Marginal Cost

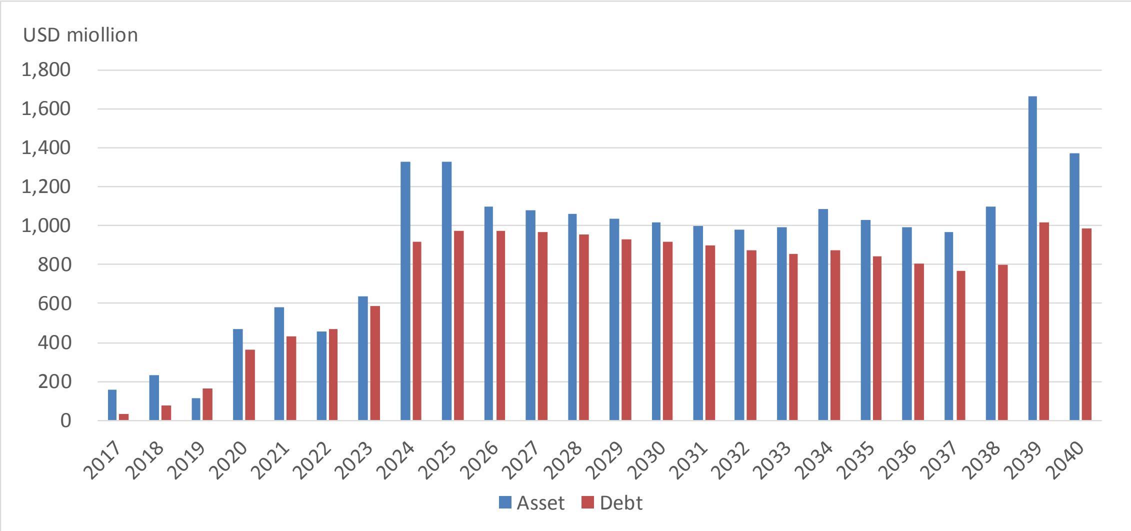
				Assumption
Generation	Power Purchase	44.41	USC/kWh	Fuel cost: 30.86USC/kWh Capacity Charge: 13.50 USC/kWh
Transmission	Capital Investment	0.24	USC/kWh	Investment cost (1kWh) in transmission system based on the planned capital investment of 595 million USD.
	O&M cost	0.28	USC/kWh	Estimated cost based on actual cost by 2016
Distribution	Capital Investment	0.89	USC/kWh	Estimated based on the actual investment cost in 2013
	O&M cost	1.48	USC/kWh	Estimated cost based on actual cost by 2016
System loss		0.87	USC/kWh	Estimated cost based on actual cost by 2016
LRMC		48.12	USC/kWh	

(Source: JICA Survey Team)

12.3.2 Impacts of Scenarios on Balance Sheet

This study simulated the impacts of capital investment on CEB's financial statements as a Single Operator of Transmission Network in Sri Lanka. The simulations show changes in assets (property, plants and equipment) through capital investment in power facilities and non-current liabilities through capital investment, changes in additional cost to transmission cost, and cashflows of transmission network operation in the case of the Scenario C.

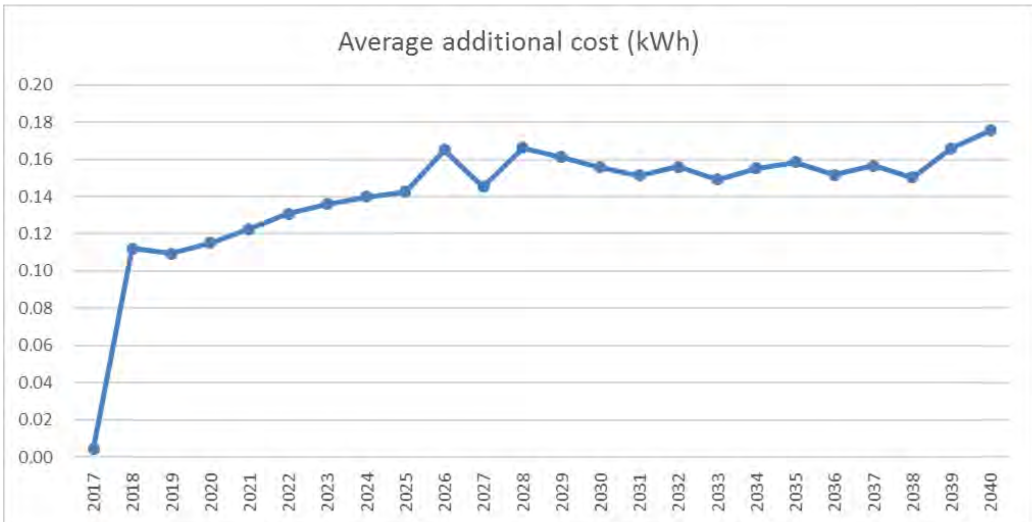
In order to meet the growing power demand, more capital investment on expansion of the transmission networks will be required besides incremental investment. Since property and equipment of transmission networks are depreciated for the long term of 35-40 years, the assets increase more than the non current liabilities to finance capital investment by debts.



(Source: JICA Survey Team)

Figure 12-9 Impact of Capital Investment for Transmission Network on Assets and Liabilities of CEB in the Scenario C

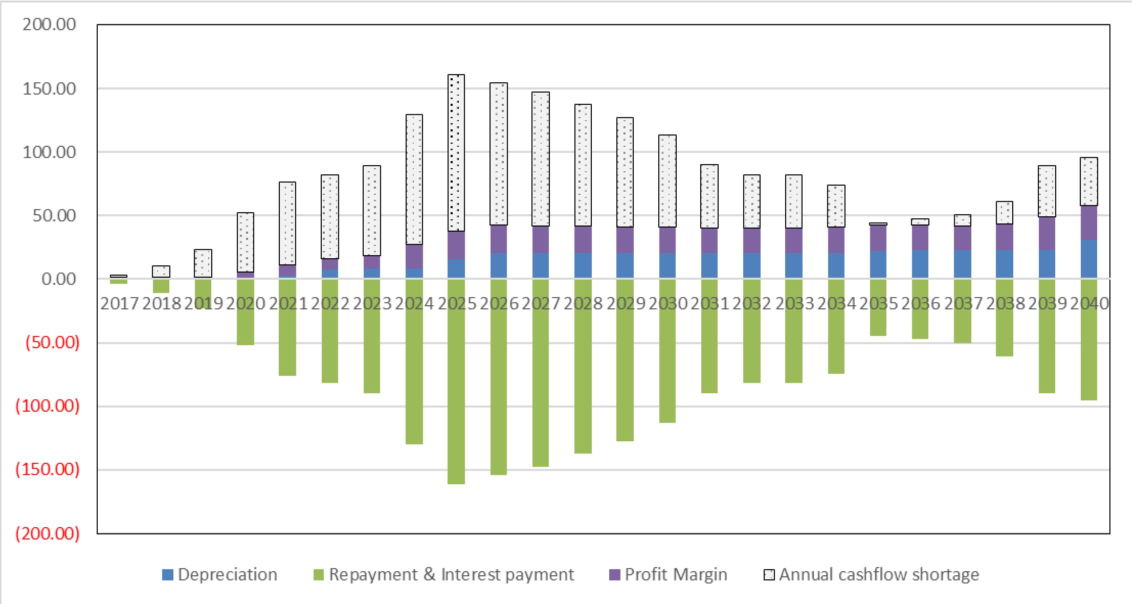
However, debt financing for capital investment requires additional cost for transmission due to the interest payment on loans. In particular, in case of use of commercial loans, the financing cost can be high at 10-16% which can be differed by each commercial bank. It is projected that the additional cost for financing is 0.11-0.12 USC/kWh for the period from 2018 to 2021 and increase to 0.14-0.17 for the period from 2026 to 2040.



(Source: JICA Survey Team)

Figure 12-10 Impact of Capital Investment for Transmission Network on Average Additional Cost to be required

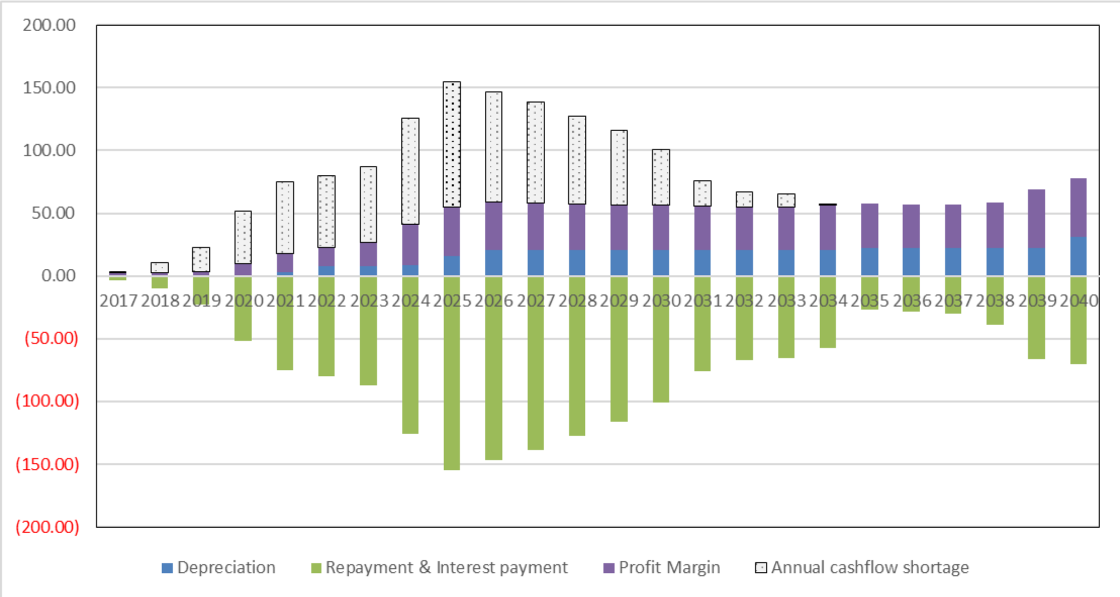
The debt financing also will bring about negative cashflow since the amount of repayment and interest payment will be accumulated year by year but the inflows of depreciation and profit margin are limited though after the inflows of long-term loans for the period from 2017 to 2024. As mentioned above, the annual depreciation cost for investment in transmission facilities can be relatively small due to the longer depreciation period. On the other hand, the repayment periods of long-term loans can be shorter: the repayment period for ODA loans of 25 years and the ones for commercial loans of 10 years. The negative cashflow can bring about more cost for financing working capital to cover the repayment and interest payment of loans. The current level of profit margin of around 16.5 million USD per annum on average, which is 2% of the operational assets for transmission, may partly cover the incremental cost of around 47 million USD per annum on average but may bring about an annual cashflow shortage.



(Source: JICA Survey Team)

Figure 12-11 Impact of Capital Investment for Transmission Network on Cashflow (Case of Profit Margin at 2% of Operational Assets)

The figure 12-12 show a simulation of profit margin required to cover capital investment by retained earnings of CEB. For the simulation, it is assumed that the profit margin derived from 3.5% of the total operational assets. In this case, for the first 9 years from 2017 to 2025, CEB needs to bear an increasingly heavy burden of repayments and interest payments on long-term debts for the capital investment for the transmission networks to meet the growing power demand, even though the profit margin increases from the current level of 2% of the operational assets to 3.5%. However, afterwards, the cash inflows from depreciation and profit margin may generate a surplus of cashflows and the surplus may enable CEB to cover the capital investments better, perhaps at least incremental ones. This can reduce the debt financing and the financing cost. It is anticipated that the repayments and interest payments will decrease from 2026. After the year 2035, an annual cashflow shortage may not be generated. Namely, CEB can improve its financial position through a reduction of debt financing.



(Source: JICA Survey Team)

Figure 12-12 Required Profit Margin to Cover Capital Investment by Retained Earnings (Return on Operational Assets of 3.5%)

12.3.3 Proposal of Investment Plan

Based on the above analysis, the JICA Survey Team proposes options for CEB in order to improve financial position and financial sustainability. It is essential to discuss the following recommendations with PUCSL who determines the Return on Assets level and the electricity tariff level since they require an increase in the electricity tariff.

(1) Increase in own capital for the transmission division via increased return on assets

While CEB's Generation Division enables avoidance of additional funding for capital investment through greater participation by IPP for the construction of new power generation facilities for the future, its Transmission Division, as a single buyer, needs to make capital investments for the future and ensure funding. The current Return on Assets level of 2% has not been a serious issue so far because concessional loans with low interest rates from JICA and ADB have been utilized for capital investments on the transmission network. However, it is expected that CEB will not use such ODA loans with low interest rates in the near future. On the other hand, CEB needs to implement construction of transmission lines and substations in a timely manner, in accordance with the construction schedules for power generation facilities. Therefore, it is inevitable that CEB's Transmission Division will implement capital investment using its own capital or take on commercial loans at some point in time.
CEB is required to expand its capital investment in transmission facilities to meet the growing power demand. However, the increase in debt finance for capital investment in transmission facilities, including substations and transmission lines, can increase the financial burden for CEB. Therefore, CEB should prepare a financial source other than loans, which can be costly. Because the current Return on Assets level of 2% on the operational assets has not been sufficient to cover the incremental investment, it is necessary for CEB to increase its own funds.

In order to cover the incremental investment by the own fund, CEB requires to accumulate retained earnings from the appropriate profit margin on the transmission tariff. Based on the simulation above, the profit margin of 3.5% on the operational assets can mostly cover the projected incremental cost and reduce debt finance for the capital investment. If the profit margin of 5% on the operational assets enables CEB to make capital investment by retained earnings after 2026. If the profit margin is set to

3.5% on the operational assets, it is necessary to increase the electricity tariff by about 0.06LKR/kWh over the present level, and when the profit margin on the operational assets is 5%, it is necessary to increase the electricity tariff by about 0.12LKR/kWh. In the case where its own capital increases via the increased Return on Assets, it is expected that the electricity tariff will be reduced in the long-run because of the reduced interest payments on the capital investment in future, though the electricity tariff will increase in the short term.

(2) Necessity of ensuring profit margin to deal with dramatic increase in power supply costs due to drought

As mentioned above, CEB's profitability can be fragile to fluctuation of power supply cost, in particular, by expensive fuel cost for oil-fired power generation in case of water shortage for hydropower generation. Since there is a lag between timing of sharp increase in power generation cost and for revision of electricity tariff and it is not possible to perfectly reflect the increased power generation cost into the tariff, CEB always needs to face financial difficulties to fill the gap between the electricity tariff and the actual power supply cost. CEB requires short-term loans to cover loss by the operation under the situation where the actual power supply cost is higher than the electricity tariff.

In order to avoid or mitigate impacts of fluctuation of power supply cost, in particular by water shortage for power generation, it is proposed to introduce setting a profit margin for preparation of cost escalation by water shortage. The profit margin enables CEB to compensate possible loss by a lag between the electricity tariff and the actual cost when drought occurs. The profit margin can be 7.5% for the period from 2018 to 2021 and 3% afterwards to minimize negative financial impact by drought.
However, in the case where the Return on Assets is increased, the profit margin can be used for purposes other than the increased power supply costs because there are no limits on the use of proceeds. In order to properly manage the use of proceeds, a mechanism to provide for droughts, which is reserved as a cost and used for this limited purpose when a drought occurs, can be considered as an alternative.

Chapter 13. Action Plan and Road Map

This MP is greatly different from the previous MP. The JICA Survey Team proposes a development plan combining various power sources, taking into account the advantage of each. It aims to minimize supply costs, considering environmental and social aspects including the reduction of CO_2 emissions, and the aspect of providing a stable supply of electric power. As a result, issues to be newly addressed which have not been taken into consideration so far, such as responding to a massive introduction of renewable energy, and measures to introduce LNG-fired TPP, are becoming apparent. For promoting this MP in the future, the JICA Survey Team proposes an action plan and road map to address the assumed tasks.

13.1 Action Plan

13.1.1 Direction Selection of Long-term Generation Expansion Plan

In this MP, the JICA Survey Team proposes the idea of balancing various power sources as the optimum plan, considering that the degree of importance for the three pillars - reduction of supply cost (economic efficiency), reduction of environmental burden (environment) and ensuring energy security (supply stability) - is the same. However, with regard to these three pillars, by changing the importance of each, different conclusions are drawn. In general, the importance of each pillar is decided in consideration of the national policy. The current administration places importance on environmental friendliness and is trying to proactively develop renewable energy.
The price of renewable energy has declined sharply, and the cost of supply per kWh for solar and wind power is becoming cheaper than coal-fired power. However, since renewable energy lacks stability of output, it is necessary to secure additional supply power for times when renewable energy cannot be relied upon. Considering the cost burden for additional supply power when 3 GW of wind power and 4 GW of solar power are installed in the system in 2040, the total supply cost becomes about 0.8 USC/kWh higher than a plan that combines various power sources in a balanced way. Since this increase in cost will be borne by people who are users of electricity, any policy to proactively develop renewable energy should be chosen after getting the consensus of the people with regard to this increase in cost. Although it is possible to develop more renewable energy, it is necessary to install many power storage facilities such as PSPP and batteries, which will further increase the cost burden on the people.

13.1.2 Condition Ordering for Introduction of a Large Amount of Renewable Energy

Among renewable energies, solar power generation and wind power generation are difficult to manage from the viewpoint of system operators, because the generation output is influenced by weather conditions and fluctuates suddenly. In a situation where the amount introduced into the system is small, it can be absorbed by the frequency control capacity in the system, so it is not a big problem. However, in order to promote the use of domestic energy, introduction of large amounts of renewable energy is proposed in this MP. With massive introduction of renewable energy, many issues become obvious, so it is necessary to prepare measures for solving these issues.

(1) Strengthen ability to respond to fluctuations

Solar power plants and wind power plants suddenly fluctuate in output depending on natural conditions. In each power plant, the output frequently fluctuates by 50% or more within one minute depending on the weather conditions of the area. In response to such fluctuations, it is necessary to change the output of hydro power plants and thermal power plants, and always keep the frequency constant by balancing demand and supply power. As a facility for frequency adjustment, power generation equipment with a wide output change range and fast change speed is required.

Solar power plants generate power only during the day, and hydropower plants and thermal power plants that can adjust frequency are operating, so in general this is not a big problem. However, a wind power plant operates all day. Since many reservoir-type hydropower plants are stopped during off-peak times, frequency adjustment ability becomes insufficient and there is a concern that the supply quality of electric power will deteriorate remarkably. As a measure to avoid such risks, one may operate reservoir-type hydropower even during off-peak hours, but this is very uneconomical and there is a possibility that surplus supply capacity will increase. Another measure is to introduce power storage facilities, such as PSPP or batteries, and to adjust the frequency while absorbing surplus supply power.

In terms of electric power storage facilities, because batteries have such problems as high cost and difficulties with large capacity at the level of current technologies, PSPP is the most feasible. Therefore, if the configuration rate of windpower generation equipment increases and there is a possibility of concern about a shortage of frequency adjustment ability during off-peak hours, it is desirable to introduce PSPP (especially adjustable speed type machines that can control frequency even during pumping operation) into the system.

The cost of batteries is very high at present, but can be expected to greatly reduce in the future. Although the capacity of batteries is small, a distributed arrangement is possible, and a load fluctuation suppression effect at the distribution line level can be expected. Because batteries can be installed in a short period of time, it is important to confirm the response ability for load fluctuation by installing a small capacity battery in the Hambantota area, where solar power has already been installed, in preparation for the future mass introduction of renewable energy.

(2) Suppress output when surplus power occurs

In order to realize a massive introduction of renewable energy, it is necessary for the system operator to be able to request that power generation entities suppress output (or shut down) when surplus power occurs. Suppressing output reduces the amount of power generation and the income of the power generation entities is reduced. It is necessary to decide how to compensate for this loss at the contract stage. Since it is a measure for stable operation of the system, the power producer has an obligation to obey the instructions of the system operator, but in order to ensure the certainty of the output suppression, it is necessary to set proper penalties or to compensate to some extent with money. In addition, if the system operator requests output suppression of an unlimited amount, it becomes impossible to set prospects for profitability as a power generation company. Therefore, it is necessary to decide the upper limit value (frequency or number of times) for output suppression in the contract in advance. In a situation where the forecasted output suppression amount exceeds 10% of the generated amount, the frequency and the amount of requests for suppressing the output increase, making it difficult to secure profitability as a power generating company, and it is desirable to restrict new development.

(3) Review of Feed-in-Tariff system

For renewable energy of 10MW or less, purchase prices higher than actual prices are offered for the purpose of promoting the development of renewable energy, and electricity is purchased at prices higher than other power sources. Additional cost is supposed to be directly reflected in the electricity tariff, and this places a burden on the citizen. The costs of solar power and wind power have drastically declined in actual price, and are reaching a level that can compete with thermal power, so it is necessary to review the Feed-in-Tariff system as soon as possible. Specifically, it is desirable to limit the scope of the Feed-in Tariff system to a small scale of about 1MW or less, and to revise the purchase price to a price based on the actual price.

(4) Institutional design enabling free entry

For large-scale renewable energy exceeding 10MW, development companies are selected by a bidding system. Currently, the bidding system that CEB is considering is one where CEB decides the development area and constructs the power transmission facilities at its own expense, then publicly invites an amount of renewable energy commensurate with the transmittable amount, and selects the winning bidder in order of the cheapest price provided. Power producers are planning to utilize their own assets, such as land, to carry out power generation projects. Therefore, there is a possibility that the project sites are not selected as development areas by CEB and the power producers are unable to develop their project sites no matter how long they wait.

In consideration of these points, it is desirable to introduce a system that allows power producers to freely propose to CEB separately from the bidding system. Since there is no bidding procedure, it is necessary for CEB to present the planned purchase price in advance based on price trends. Upon receiving an application from the power producer, CEB considers the connection fee and presents the results to the power producer. Power producers will proceed with their projects if they are profitable, even if they bear their connection expenses by themselves and sell at the price suggested by CEB.

(5) Establishment of an organization to consider connection availability, and training personnel

As shown in the previous paragraph, if the power producer freely proposes the application for renewable energy development projects, it is expected that the workload associated with considering connection costs will increase dramatically. Even if a fee for examination is charged in order to avoid disorderly requests for investigation, since the size of one site is not so large, it is assumed that the number of requests will be quite large. In addition, since the connection mainly corresponds to the 33 kV distribution line, the distribution office that manages the 33kV facilities will receive the application and consider the connection fee. At that time, if each distribution office responds based on its own examination items and judgment, a different judgment will be made depending on the region, which will cause distrust among the power producers, so it is desirable to unify the items to be examined and the judgment method by manualization. Since examination of connection costs is completely new work for power distribution companies, it is necessary to construct a new organization for each distribution company and to develop training personnel.

(6) Establishment of an organization to handle disputes

Power producers are trying to sell power at as high a price as possible, while CEB, a single buyer, attempts to buy electricity at as low a price as possible. In addition, from the viewpoint of securing stable supply, CEB, as a system operator, needs to ask power producers to suppress output in situations of excessive power generation. However, power producers want to generate as much power as possible in order to obtain a lot of revenue, and they may ignore the demand to suppress output. As described above, since the interests of power producers and CEB are completely contradictory, it is assumed that many cases will occur in which third-party arbitrations are necessary because the disputes cannot be solved by discussions between the two parties.

In the current organizational structure, PUCSL is responsible for dispute handling in relation to electric power. However, because advanced knowledge of electric engineering is required in handling such a dispute, it is desirable to build an expert organization in PUCSL.

(7) Environmental assessment

Generally, in the development of renewable energy of 50MW or less, an environmental assessment is unnecessary. For this reason, environmental and social considerations are left to the voluntary judgment of the developer. However, there are issues such as bird strikes and noise concerning windpower, and the alteration of vast land concerning solar power. In addition, many power producers who develop renewable energy are small-scale entities, so there is a possibility that they may leave a site as it is without properly handling waste after the project is over.

Considering these points, it is desirable to establish a system that checks items concerning environmental and social considerations, and obligates power producers to do a very simple environmental assessment when approving a renewable energy development project. It is also desirable to establish a system to ensure the proper treatment of waste after the project is over.

(8) Power generation forecasting based on accurate weather forecasting

The generation output of solar and wind power changes depending on the weather. For this reason, they are power generating facilities which are extremely unwieldy for the system operator. However, since the amount of electricity generated largely correlates with the weather, with accurate weather forecasting it is possible to estimate the amount of power generation with considerable accuracy.

For example, if the weather in a relatively narrow area can be forecasted several hours ahead, it is possible to predict the amount of renewable energy power generation with high precision, and prepare for the operation or stoppage of other generators in advance. In this way, accurate weather forecasting in a narrow area is a trump card for system operators for realizing a high-quality power supply even when a large amount of renewable energy is installed in the system, and it is desirable to improve weather forecasting techniques.

Specifically, by obtaining meteorological satellite images in the vicinity of Sri Lanka and predicting the behavior of clouds after several hours by obtaining the correlation between the changes in the clouds in the satellite image and the change in the actual weather, highly accurate, pinpoint weather prediction becomes possible. However, weather forecasting does not immediately become possible even if meteorological satellite images can be obtained. Highly accurate weather prediction becomes possible by accumulating a lot of data and analyzing the accumulated data.

(9) Ascertaining accurate electric power demand results by gaining power generation amount information for mini hydropower

Currently, mini hydropower is directly connected to the distribution line that supplies the customers, and every-hour data acquired at substations is not pure power demand data because the hydroelectric power generation amount is deducted. Since each mini hydropower station does not report the power generation results every hour, it is impossible to ascertain pure electric power demand every hour. Accurately ascertaining the demand trend is very important for future demand forecasting and it is desirable to change to a system that records and reports the amount of power generation every hour for all mini hydropower.

13.1.3 Candidate Site for Additional PSPP with Excellent Economic and Environmental Conditions

In this MP, development of 600MW PSPP is recommended by 2030 as a control facility for load fluctuation mainly during off-peak, in an optimum plan that combines various power supplies including coal-fired TPP in a balanced way. In addition, even if the development of coal-fired TPP is canceled in the future, if the government will be implementing policies that further promote the development of renewable energy, it is essential to develop PSPP or batteries to absorb the surplus electricity generated by renewable energy. At present, the electricity storage cost of batteries is about 500 to 1,000 USD/kWh, 3 to 5 times' higher than PSPP, and the service life is also less than 20 years (less than half of a PSPP). Battery cost reductions can be expected due to mass production effects and technological innovations in the future, but for prospects around 2030, the levelized cost of electricity (LCOE) for batteries is expected to be considerably higher than PSPP.

Considering the durations of the site survey, detailed design, and construction work, it is necessary to plan for about 10 years from decision-making to operation of PSPP. Therefore, if attempting to start operation around the year 2030, it is necessary to begin activities for a FS (Feasibility Study) at the candidate site soon.

It was found that there are several issues, such as high construction cost (1,063 USD/kW), and resettlement of more than 100 residents, etc., according to a review of the Maha 3 site, which is the promising candidate site in the JICA report "Development Planning on Optimal Power Generation for Peak Demand in Sri Lanka (February 2015)". It is considered that it will not be easy to develop this site. Therefore, it is necessary to find a new candidate site for the PSPP which has excellent economic and environmental conditions as one measure to solve this issue.

In the existing report, since the maximum unit capacity was set to 200MW from the viewpoint of system operation, the high effective head sites were excluded from the target at the stage of extraction of the optimum site due to restrictions on equipment manufacturing. It is concluded that the maximum unit capacity can be increased up to 400MW in 2040 in this MP survey, so there is a possibility that promising sites, excellent both economically and environmentally, remain in the list of sites excluded from the target at the initial stage due to restrictions on equipment manufacturing (refer to Appendix-1).

13.1.4 Promotion of Introduction of LNG-fired TPP

According to the "New Policies Scenario" in WEO 2016 by the IEA, the price of oil in 2040 will rise 2.4 times compared to 2015, and the LNG price in 2040 will be 1.2 times' the 2015 level. In other words, the fuel cost for 300MW oil-fired combined cycle is currently as high as 16 USC/kWh, but is assumed to rise to about 38 USC/kWh in 2040. The fuel cost for 300MW LNG-fired combined cycle is currently about 10 USC/kWh, but will be about 12 USC/kWh in 2040. Therefore, the current difference is about 6 USC/kWh, but when comparing the fuel costs in 2040 it is a very large difference of about 26 USC/kWh.

In this MP report, the JICA Survey Team proposes to introduce LNG-fired TPP as a power source instead of oil-fired TPP from the viewpoint of economic efficiency, and to convert some existing oil-fired TPP to LNG-fired. Even at present, the price of oil is high, so it is necessary to promote the introduction of LNG as soon as possible in order to reduce supply costs.

(1) Construction of fuel supply facilities

Since natural gas is a gas at normal temperature, it is necessary to liquefy it into LNG for transport and storage in large quantities. LNG needs to be transported and stored at an extremely low temperature of -162°C or less, and has the following issues.

Fuel supply facilities (transportation vessels, storage tanks, etc.) are very expensive compared to petroleum.

Because long-term storage is difficult, it is necessary to receive fuel regularly.

It takes time to construct the fuel receiving facilities.

As a long-term measure, it is considered most desirable to construct a dedicated port and LNG station around Colombo. However, because it takes time to construct a dedicated port, installing an FSRU (Floating Storage Registration Unit) within Colombo Port can be considered as a short-term strategy in order to promote the introduction of LNG as soon as possible.

It is important to decide which method to adopt as early as possible and to start construction of fuel supply facilities. However, it is necessary to comprehensively judge final decisions considering the required amount of LNG, the necessary timing, the procurement period, the reserve amount of domestically produced natural gas and the time when it can be introduced.

(2) Development prospects for domestic natural gas

The recoverable reserves of domestic natural gas currently confirmed amount to 0.3 TCF (Trillion cubic feet) at Dorado gas field. The total reserves of the two gas fields, including the Barracuda gas field adjacent to Dorado, are estimated to be about 2 TCF. These reserves are comparable to the amount of a 300MW CCGT operating at 50% plant factor for 240 years.

According to the PRDS's estimation, the supply cost from the domestic gas field is estimated at 16.5 USD/MMBTU. The imported LNG price is assumed to be 13.7 USD/MMBTU (Colombo CIF in 2015, not including the cost of LNG supply facilities), so LNG is still slightly cheaper than domestic gas even including the cost of LNG supply facilities. However, domestic gas has superiority in terms of energy security, such as price stability and supply stability, and considering this, has a more competitive price than LNG.

In this way, since domestic gas is estimated to have the necessary and sufficient reserves, and has a more competitive price than LNG, from the viewpoint of effective utilization of domestic resources it is desirable to accelerate activities targeting the early start of domestic gas supply commercial operations. Moreover, in order to reduce the usage of petroleum fuel at an early stage, it is advisable to introduce LNG by using FSRU, which can be constructed earlier, and to shift from LNG to domestic gas at the stage when the domestic gas supply becomes available.

(3) Fuel procurement

Since LNG-fired TPP is responsible for regulating supply and demand, the consumption of LNG fuel is greatly influenced by the supply and demand situation of electric power. In a contract for procurement of LNG fuel, stable fuel procurement becomes possible if buyers are limited and a long term contract of 10 years or more is concluded. However, because LNG fuel is very limited for applications other than electricity generation, there is no takeover destination even if a surplus of fuel occurs. Therefore, if the annual fuel import volume is fixed, there is a possibility of operating LNG-fired TPP in preference to coal-fired TPP in order to consume the contracted LNG fuel. In order to avoid such a situation, it is necessary to have elasticity in procuring LNG fuel. Specifically, it is advisable to procure about half of the consumption by spot contracts in addition to long-term contracts of 10 years or longer.

In Sri Lanka, organizations that operate LNG fuel supply facilities are likely to demand more than a certain amount of consumption from power generation entities in order to recover costs related to construction. If all the LNG-fired TPP is subjected to operational limitation from the fuel side, it becomes very difficult to bear the supply and demand adjustment function. Therefore, it is desirable that CPC or CEB manages and operates the LNG fuel supply facilities without entrusting this to a private company.

(4) Environmental and social considerations

In general, LNG-fired TPP doesn't emit air pollutants or thermal discharge to the extent that coal-fired TPP does. For this reason, it is likely for LNG-fired TPP to be established in areas relatively close to cities. From this point of view, it is considered that the effect on the natural environment is small, but there is a concern that social activities can be affected during the construction period. For example, there may be traffic jams around the construction area. Moreover, it is predicted that air pollution concentration in the city will already be high due to air pollutants from surrounding factories and vehicles. Therefore, it is necessary to check the environment around the site and limit the overall amount, including existing emission sources, and also carry out periodic monitoring surveys after commissioning.

13.1.5 Introduction of Coal-fired TPP with sufficient Consideration for the Environment

With regard to CO_2 emissions, it is difficult to mitigate these at the current technology level, so emissions per kWh from coal-fired TPP are about twice as large as those from LNG-fired TPP. In the actual data from 2015, the CO_2 emissions per kWh are 0.45 kg/kWh on average for all power generation facilities, which is almost the same low level as developed countries. In Scenario C, recommended by this MP, development of not only LNG thermal power but also coal-fired power is carried out, but development of renewable energy is also carried out at the same time, so the CO_2 emissions per kWh in future will be almost the same as the present situation.

In order to promote coal-fired TPP development, as for the ash storage area of the existing Norocholai power plant that is actually creating a negative impact on the environment, measures to prevent scattering, such as installing a fence, must be taken as soon as possible. CEB will take the necessary measures for the problem that is currently occurring and should explain to the stakeholders that it is possible to reduce the negative environmental impact on the surrounding area by emissions other than CO_2 to a level comparable to LNG-fired TPP by introducing appropriate environmental measures. It is necessary to dispel the negative image of coal-fired TPP and place it as one of the important power sources in LTGEP 2020-2039, which is the next rolling plan (to be submitted by April 30, 2019).

13.1.6 Steady Implementation of the Power Transmission Plan for Kerawalapitiya TPP

In this MP, the JICA Survey Team examined the power transmission method in the case of installing a large number of generators in the Kerawalapitiya area. As a result, when installing four 300MW machines in the Kerawalapitiya area, it is necessary to develop a 220kV transmission line between Kerawalapitiya - Kirindiwela. Based on this condition, in Scenario C (proposed as the optimum plan in this MP), the relevant transmission line will be required by 2023.
However, the population is already dense in Colombo city, and it is assumed that any transmission route should follow a detour, but even then it would be very difficult to secure an overhead transmission line route. Therefore, it is necessary to consider the following measures, decide countermeasures as soon as possible and carry out a feasibility study.

- A 220kV overhead transmission line route is secured by utilizing the existing transmission line route.
- Transmission line route is secured in cooperation with new development projects such as highway development.

13.1.7 Study for Inter-connected Transmission Line between Sri Lanka and India

In this MP, a rough economic evaluation of the Sri Lanka - India interconnection transmission line is carried out. As a result, it is economical when interconnection line capacity is 500MW. However, because the information on the partner country is estimated from published information such as websites, it is a very rough study. Since interconnection with other countries is also an effective measure from the aspect of stable system operation at the time of introducing a large amount of renewable energy, it is desirable to carry out a detailed economic evaluation and to start moving toward concrete plan formulation.

13.1.8 Nationwide deployment of distribution SCADA system

With regard to the distribution SCADA system, as a result of it having been independently developed by distribution companies, multiple vendors' systems exist in the network, and the functions and scalability are not unified. This causes restrictions in data exchange between these multiple vendors' devices. Therefore, it is very important to investigate a suitable type of SCADA system and appropriate communication methodology.

13.1.9 Improving Reliability of Distribution System

CEB's distribution companies have been collecting statistics for SAIDI, which is an indicator for evaluating operational performance related to supply reliability, since January 2016. This indicator shows the power outage duration per customer, and efforts to reduce it are required. Conceivable measures for this include suppression of the frequency of outages, early detection and early recovery of faulty points, implementation of construction using uninterruptible power supplies, and other methods. Among these, early detection of faulty points is the most effective method of reducing power outage duration with a small amount of investment. CEB has already introduced a system to detect faulty sections early and separate them. However, since the sections to be separated are wide and the faulty points are mainly found via visual observation, it takes a lot of time. Considering this situation, it is desirable to introduce a system to classify faulty sections in a more subdivided way, and to deploy equipment for early discovery of faulty points in distribution offices.

In Chapter 9, the system and equipment adopted in Japan is described. Based on experience in Japan, the effect of introducing these is considered to be very significant, but the likely effect on Sri Lanka's distribution system is unclear. Therefore, it is preferable to perform a pilot project in limited areas first, and undertake a nationwide roll-out once the effect has been confirmed.

13.2 Road Map

For the action plan shown in the previous section, the road map showing the execution timing and persons in charge of the implementation is shown below.

Table 13-1 Road Map

				2018						2019						2020						2021						Remarks
				1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	
		[Long-term Generation Expansion Plan]																										
1	LTGEP	Direction Selection for Long-term Generation Expansion Plan	MPRE, CEB, PUCSL	■	■	■																						Especially, setting development goals for renewable energy
		[Renewable Energy]																										
1	RE	Introduction of rules enabling requests to suppress the output of RE when supply surplus occurs	PUCSL										■	■	■													Application timing will be after 2030, but it is important to adopt early rules to correct inequality
2	RE	Review of NCRE Three-tier Tariff	PUCSL	■	■	■																						Applicable only to small-scale (1MW or less) facilities
3	RE	System design that allows free entry	PUCSL, SEA, CEB							■	■	■																After establishment of an organization to calculate connection line costs
4	RE	Establishment of an organization to calculate connection line costs	CEB				■	■	■																			Capacity building for CEB staff is required
5	RE	Establishment of an organization to handle disputes	PUCSL	■	■	■																						A mediator for disputes between the developer and CEB
6	RE	Environmental Impact Assessment for RE	SEA	■	■	■																						To prevent environmentally-damaging development, Post-treatment collateral after project completion
7	RE	Confirmation of the response ability for load fluctuation by installing a small capacity battery	CEB, SEA										■	■	■	■	■	■	■	■	■	■	■	■				Establish pilot project in Hambantota About one year is required for manufacturing
		[Pumped Storage Power Plants]																										
1	PSPP	Confirmation of necessity of PSPP	CEB Consultant	■	■	■																						Depends on the configuration, but it is necessary in the case of developing a large amount of renewable energy
2	PSPP	Feasibility Study (including site selection, EIA)	CEB Consultant				■	■	■	■	■	■																Re-identification of good sites (excellent both economically and environmentally) for PSPP
3	PSPP	Detailed design (DD)	CEB Consultant													■	■	■	■	■	■	■	■	■	■	■	■	Needs 5 to 6 years for the construction period after completion of DD
		[LNG Fuel Supply Facilities]																										
1	LNG	Selection of fuel supply method	MPRE, MPRD CEB, CPC	■	■	■																						Considering sufficient domestic gas reserves, FSRU is desirable
2	LNG	Selection of management organization (LNG MO)	MPRE, MPRD CEB, CPC	■	■	■																						Considering load adjustment function, it is desirable that CPC or CEB manages and operates
3	LNG	Feasibility Study (including EIA)	LNG MO Consultant				■	■	■	■	■	■																
4	LNG	Detailed design Procurement contractor	LNG MO Consultant										■	■	■	■	■	■										
5	LNG	Construction (if FSRU type)	LNG MO Contractor																■	■	■	■	■	■	■	■	■	4 to 5 years required for land-based type
6	LNG	Acceleration of activities aimed at early start of commercial operations for domestic gas supply	PRDS	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	To shift from LNG to domestic gas at the stage when domestic gas supply becomes available
		[Coal-fired Thermal Power Plants]																										
1	Coal	Environmental mitigation measures for existing coal-fired TPP	CEB	■	■	■																						Measures to prevent scattering of ash etc. at existing Norocholai power station
2	Coal	Consensus formation for coal-fired TPP development	MPRE, CEB	■	■	■																						It will be reflected in the next LTGEP (April 2019).
3	Coal	Determination of development framework	MPRE, CEB				■	■	■	■	■	■																Comparative evaluation of IPP, JV etc.
		[Transmission Line Plan for Kerawalapitiya TPP]																										
1	T/L	Route selection for 220kV Kerawalapitiya - Kirindiwela Transmission line	CEB				■	■	■																			If it is difficult to secure the route, underground cable will be considered
2	T/L	Feasibility Study (including EIA)	CEB				■	■	■	■	■	■																
		[Inter-connected Transmission Line between Sri Lanka and India]																										
1	T/L	Forming of consensus between two countries	MPRE, CEB	■	■	■																						
2	T/L	Pre-Feasibility Study	CEB				■	■	■	■	■	■																Including survey in Tamil Nadu
		[Distribution Facilities]																										
1	D/L	Nationwide deployment of distribution SCADA system	CEB				■	■	■																			
2	D/L	Introduction and verification of faulty point detection system (pilot project)	CEB, LECO				■	■	■	■	■	■	■	■	■													Selection of supply area for distribution substation near Colombo as pilot project area
3	D/L	Nationwide introduction of faulty point detection system	CEB, LECO													■	■	■	■	■	■	■	■	■				Depending on verification results in pilot project

(Source: JICA Survey Team)

Chapter 14. Proposals for JICA Power Sector Cooperation Program

14.1 Human Resource Development considering Massive Introduction of Renewable Energy and Support for Institutional Design

In this MP, the JICA Survey Team proposes the massive introduction of renewable energy. At the moment, the amount of renewable energy development, excluding small hydropower, is very small, but solar power and windpower are decreasing in price, and their installation is expected to increase rapidly in the near future. As described in the previous chapter, there are many issues regarding the mass introduction of renewable energy. However, in Sri Lanka, the amount of renewable energy is small at present, so attention has not been paid to these problems. In particular, there are very few people able to investigate the impact on the system at the time of massive introduction of renewable energy and the system enhancement measures needed when new connection is required. Such a study is a task that CEB's engineers must implement by themselves in the future. Because a large amount of renewable energy is already used in Japan, it is necessary to transfer Japanese technology and know-how and to develop human resources among CEB engineers.

In the action plan, the JICA Survey Team also proposes changes in the system in order to handle the massive introduction of renewable energy. These system changes are thought to be implemented based on Sri Lanka's own policy, but if necessary, the system construction rationale in Japan will be explained and support for system design provided.

14.2 Validation and Feasibility Study (FS) for PSPP

In this MP, the JICA Survey Team proposes the development of PSPP as a power supply for frequency adjustment at the time of mass introduction of wind power generation equipment. In the survey conducted by JICA in February 2015, the Maha 3 site (200MW × 3 units) was selected as the most promising PSPP site. However, it is necessary to validate the PSPP development, because target of power development policy in Sri Lanka was changed from coal-fired TPP to renewable energy. Furthermore, as described in the previous chapter, there is a possibility that promising sites, excellent both economically and environmentally, remain in the list of sites excluded from the target at the initial stage due to restrictions on equipment manufacturing. In consideration of this point, based on the new power development policy, PSPP development plan is validated, and after validation, it is desirable to extract the promising sites again and to implement a feasibility study as soon as possible for the selected promising site.

14.3 Human Resource Development considering Introduction of LNG-Fired TPP

In this MP, the JICA Survey Team proposes the introduction of LNG-fired TPP. At the moment, because there is no LNG-fired TPP in Sri Lanka, knowledge on LNG fuel is very poor. Even though the construction of LNG fuel supply facilities is left to engineers in other countries, it is desirable that CPC or CEB be involved in the handling of LNG fuel. Like petroleum fuels, LNG fuel carries the danger of fire and explosion, so it is very important to promote careful handling in order to avoid serious accidents. In addition, since it has completely different properties from petroleum, it is not possible to apply the know-how obtained by handling petroleum, and sufficient education is required for engineers handling it. Because a large amount of LNG-fired TPP is already used in Japan, it is necessary to transfer Japanese technology and know-how and to develop human resources among Sri Lankan engineers.

14.4 Feasibility Study for the Power Transmission Plan for Kerawalapitiya TPP

In this MP, the JICA Survey Team examined the power transmission method in the case of installing a large number of generators in the Kerawalapitiya area and proposed to develop the 220kV transmission line between Kerawalapitiya - Kirindiwela by 2023. Based on this plan, it is necessary to carry out a feasibility study for the relevant transmission line as soon as possible.

14.5 Implementation of a Pilot Project aimed at improving Supply Reliability of the Distribution System

In section 9.4.2, the JICA Survey Team proposes various measures to improve the supply reliability of distribution systems. Distribution facilities have a large number of installations, so it is difficult to introduce the proposed measures to improve supply reliability in all systems simultaneously. Therefore, it is desirable to select some areas as pilot project areas, introduce target devices to confirm the effect, then gradually expand the introduction once the effect has been confirmed.

In this MP, the JICA Survey Team proposes the introduction of a sequential fault location method in addition to the current Recloser system as a method to easily find the faulty section upon the occurrence of an accident in a distribution line. In this method, distribution lines can be divided into many sections, so it is more effective when applied to long distance distribution lines. It is also applicable to distribution lines with branches on the way.
As a concrete pilot project area, one distribution substation that is supplying both urban and rural areas near Colombo will be selected. Sequential fault location systems will be installed on 6 to 10 distribution lines supplied from the substation and the effect at the time of fault occurrence confirmed.

Chapter 15. Appendix

15.1 Appendix-1: Additional Pumped Storage Power Project

As mentioned in section 7.2 (1), Maha 3 PSPP, which was selected as the most likely project in a past study report, has a lot of issues to be solved. Accordingly, the following PSPP candidate site is selected additionally in this study as a likely alternative in order to solve the issues.

15.1.1 Profile of Additional Pumped Storage Power Project

(1) Outline of the project

The project involves the existing Victoria reservoir being used for the lower pond and the existing irrigation pond located on the eastern side of Victoria Lake being used for the upper pond by expanding the pond. The net head and maximum discharge are planned as 686m and 240m^3/s respectively, and the installed capacity could be 1,400MW. The unit capacity is set as 350MW, taking into consideration the manufacturing limit of pump-turbines.

It is 177km long, along the blue line route in the below figure, from Colombo city to the outlet site of the project and it takes 4.5 hours by car. In addition, there is a roadway 2m wide to the upper pond site; thus, it is accessible by car.

(Source: JICA Survey Team)

Figure 15-1 Location of Additional PSPP

The project profile is shown in Table 15-1; here, the peak duration hours are set at 6, which is common in developing countries.

Since it is possible to develop installed capacity of at most 1,400MW from the viewpoint of the topographical and geological features, a 2 stage development scheme is applied taking into consideration scale economy and the installation timing needed for the whole power system.

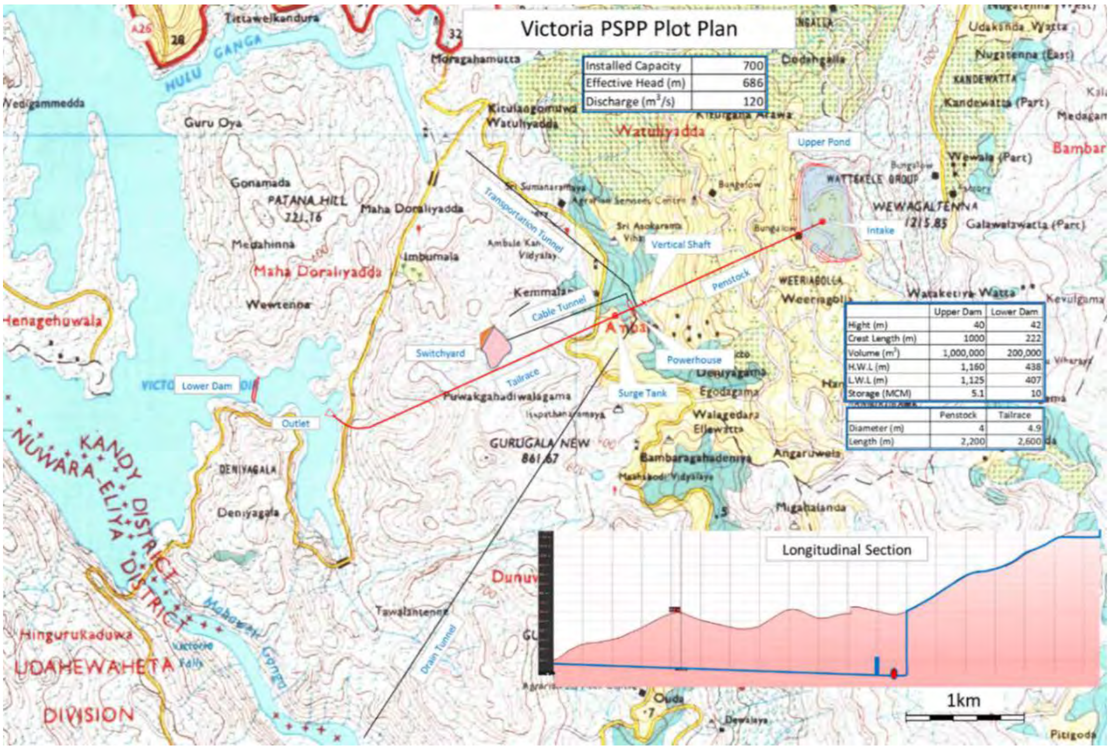
Table 15-1 Project Profile for Additional PSPP

		Upper Reservoir Upper dam	Lower Reservoir Lower dam
Coordinates		7° 15' 49.02" N 80° 50' 19.39" E	7° 15' 12.37" N 80° 47' 42.14" E
Name of River		Wewathenna	Mahaweli Ganga River System
Catchment area		0.3 km^2	6.7 km^2
HWL		EL. 1160 m	EL. 438 m
LWL		EL. 1125 m	EL. 407 m
Available drawdown		35 m	31 m
Gross storage capacity		5.5*10^6 m^3	10.0*10^6 m^3
Effective storage capacity		5.1*10^6 m^3	5.1*10^6 m^3
Reservoir area		0.17 km^2	0.3 km^2
		Generation	Pumping up
Output (Input)		1400MW	1571MW
Discharge		240 m^3/s	188 m^3/s
Gross head		727 m	—
Effective head		686 m	—
Max. pumping head		—	754 m
Min. pumping head		—	687 m
Peak duration time		6.0 hr	

(Source: JICA Survey Team)

(2) Plot plan for the main facilities

A plot plan for the main facilities (on 1/50,000 topographical map and Google Earth) and the longitudinal section along the waterway route are illustrated in Figure 15-2, Figure 15-3 and Figure 15-4, respectively.

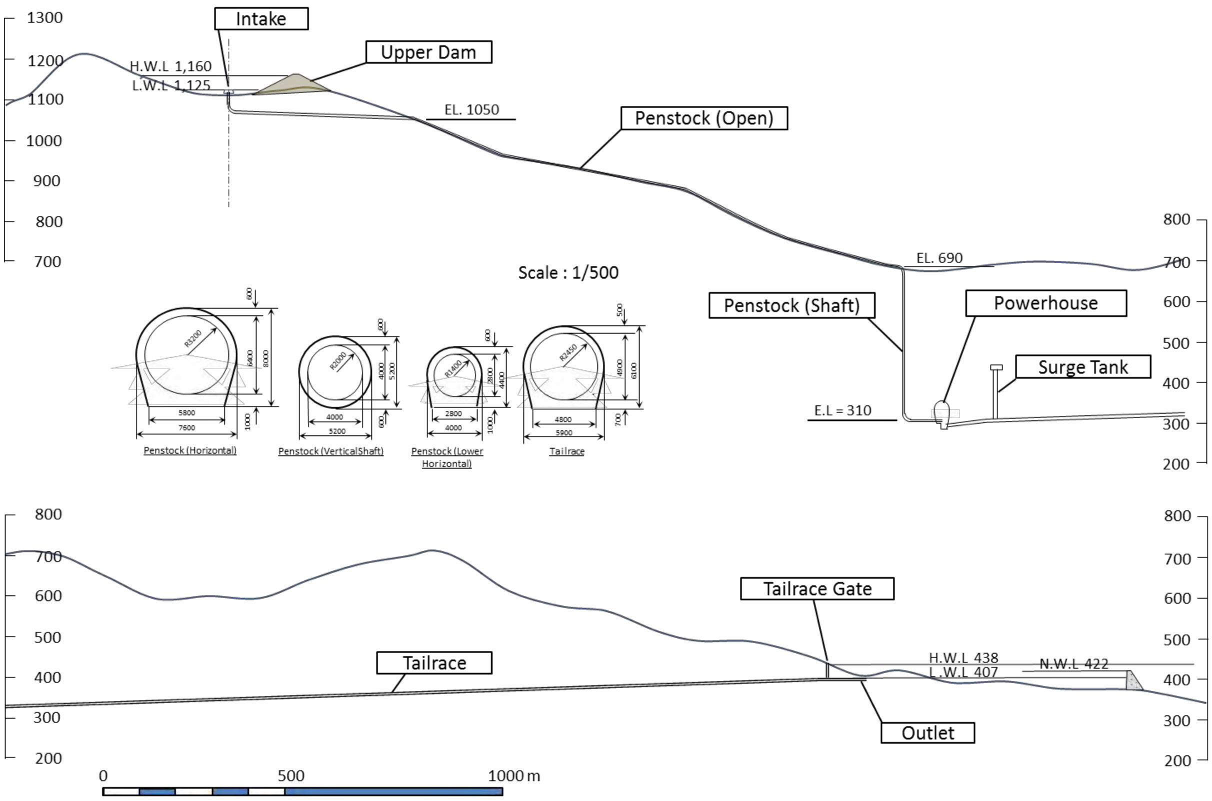


(Source: JICA Survey Team)

Figure 15-2 Plot Plan for Victoria PSPP (1/50,000 Topographical Map)

(Source: JICA Survey Team)

Figure 15-3 Plot Plan for Victoria PSPP (Google Earth)



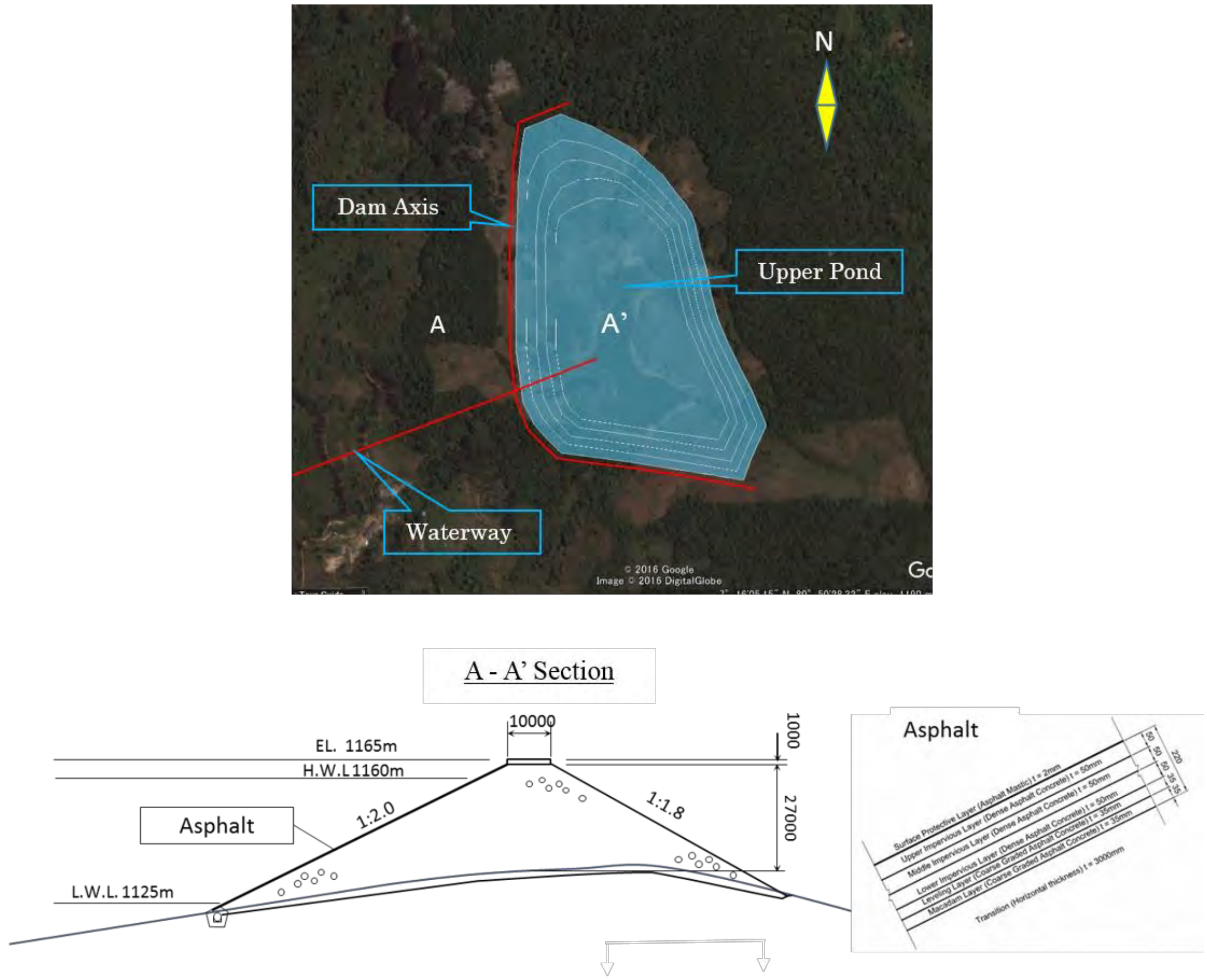
(Source: JICA Survey Team)

Figure 15-4 Longitudinal Section along Waterway

(3) Upper Dam

Although the left bank (east side) of the upper pond is formed by mountain ranges with EL. 1,200m, the elevation of the ridge of the right bank (west side) is as low as EL. 1,140m. Therefore, the upper dam is to be formed by augmenting the existing irrigation dam and prolonging it up to the tail end of the pond along the ridge.

Since the alignment of the dam axis is curved in a convex shape to the outside, an asphalt facing fill type dam, which can be flexible against tensile deformation, is adopted. The layout of the upper pond and a cross section of the upper dam are illustrated in Figure 15-5.

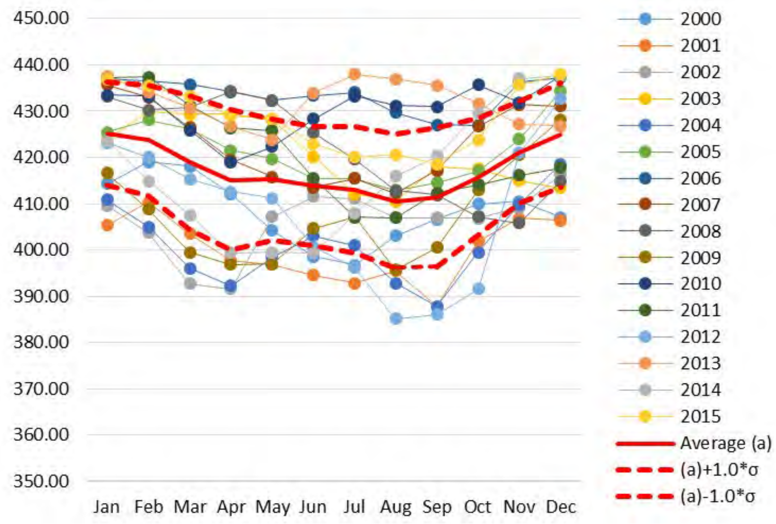


(Source: JICA Survey Team)

Figure 15-5 Layout of Upper Pond and Cross Section of Upper Dam

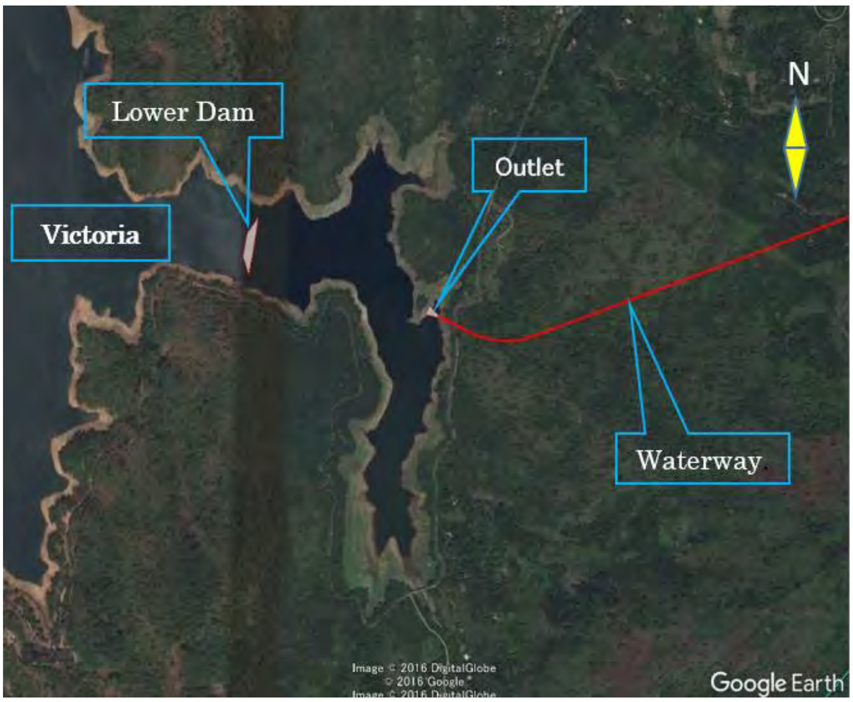
(4) Lower Dam

The existing Victoria reservoir (active storage capacity of 688MCM) is utilized as the lower dam. However, the Victoria reservoir is operated between LWL. 370m and HWL. 438m (available drawdown depth of 68m), and the water level has varied significantly on yearly and seasonal bases, for which actual records for the past 16 years are shown in Figure 15-6. The monthly mean water level from Apr. to Oct. is less than 416m. Accordingly, a submerged dam is installed as the lower dam in order to ensure the required storage capacity in drought years and during the dry season. The layout of the lower dam (submerged) and the outlet are illustrated in Figure 15-7.



(Source: JICA Survey Team based on CEB data)

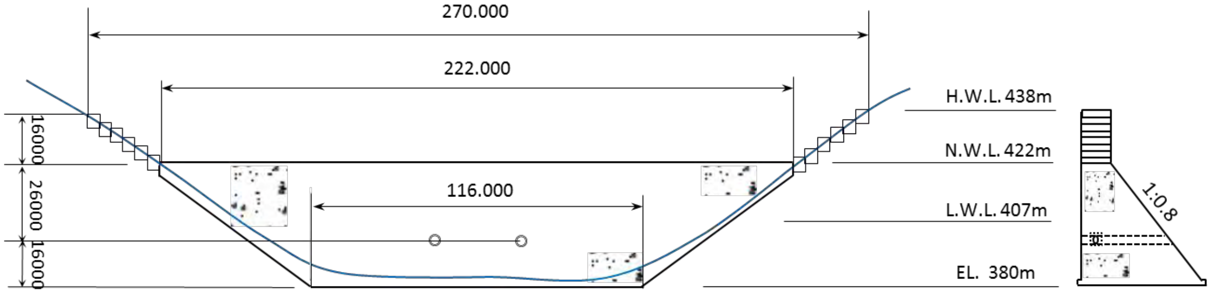
Figure 15-6 Operation Records of Victoria Reservoir (2000 – 2015)



(Source: JICA Survey Team)

Figure 15-7 Layout of Lower Dam (Submerged) and Outlet

Since the primary purpose for water operation of the Victoria reservoir is irrigation, the dam height is set as low as possible so that the dam can ensure the bare minimum storage capacity (gross capacity is less than 10MCM) for sole use. In addition, although the lowest water elevation since 2000 was 386m (Aug. 2012) and there is no experience of drawdown up to LWL. 370m, two sets of outlet facilities are installed in the dam so as to meet any discharge demand and to enable inflow water from the upper stream to discharge as it is. The front section and cross section of the lower dam are illustrated in Figure 15-8. Water levels are to be determined in detail based on a 1/5,000 topographical map.



(Source: JICA Survey Team)

Figure 15-8 Front Section and Cross Section of Lower Dam (Submerged)

(5) Project features for each main facility

Project features for each main facility based on the conceptual design are shown in Table 15-2.

Table 15-2 Project Features for Each Main Facility

Dam	Name	Upper dam	Lower dam
	Type	Asphalt Facing Rock Fill Dam	Concrete Gravity Dam
	Height	40.0 m	42.0 m
	Crest length	1000.0 m	222.0 m
	Crest width	10 m	10 m
	Slope	Upstream surface 1: 2.0 Downstream surface 1: 1.8	Upstream surface 1: 0.0 Downstream surface 1: 0.8
	Volume	1000*10^3 m^3	200*10^3 m^3
Intake	Type	Morning-glory type , RC structure	
	Entrance shape	H: 5.5m*W: 11.3m*8 mouths	
Headrace	Type	Pressure tunnel with Circular cross section	
	Internal diameter	6.4 m	
	Length	432 m	
Penstock	Type	Welded steel pipe (Open & Embedded type)	
	Internal diameter	6.4-2.0 m	
	Length	1 branch : 432 m 2 branches : #1,#2=1680 m , #3,#4=1680 m 4 branches : #1,#2=90.0m, #3,#4=90.0m,	
Tailbay	Type	Pressure tunnel with Circular cross section	
	Internal diameter	3.5-4.9m	
	Length	4 branches : #1=81.7m, #2=81.7m 2 branches : #1,#2=10.0 m , #3,#4=10.0 m	
Tailrace	Type	Pressure tunnel with Circular cross section	
	Internal diameter	4.9 m	
	Length	2590.0 m	
Tailrace Surge Tank	Type	Restricted orifice surge tank with Upper chamber	
	Upper chamber	W: 10.0m*H: 12.0m*L: 55.0m	
	Shaft	Internal diameter : 8.0 m , Height : 122.0 m	
	Orifice (Port)	Internal Diameter 3.3 m	
Outlet	Type	Lateral type, RC structure	
	Entrance shape	H: 4.9m*W: 24.1m	
Power house	Type	Underground type, RC structure	
	Height	57.5 m	
	Width	34.0 m	
	Length	218.0 m	
Pump-Turbine	Type	Single stage Francis type with vertical shaft, Reversible	
	Number of units	4 units	
	capacity	#1,#2 : 360MW/410MW #3,#4 : 360MW/410MW	
Generator-Motor	Type	Adjustable speed generator motor	
	Number of units	4 units	
	Capacity	#1,#2 : 415MVA #3,#4 : 415MVA	

(Source: JICA Survey Team)

15.1.2 Topography and Geology

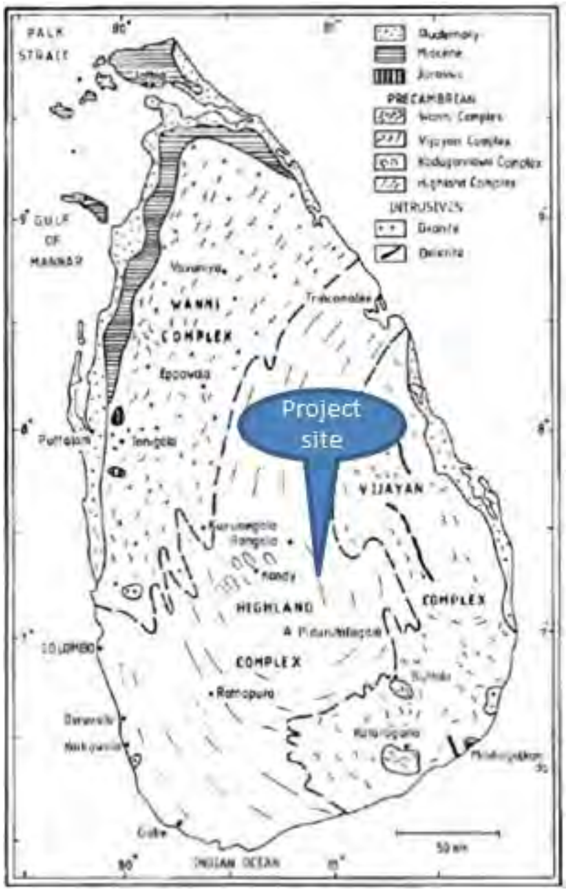
(1) General geology of Project site

Most of Sri Lanka's geology belongs to a part of the Earth's crust known as the "craton[37]", which is the Precambrian strata, and consists of metamorphic rocks originated in sedimentary rocks.

The Precambrian is subdivided into three main and one subordinate lithotectonic units running north-northeasterly, namely, Highland complex (2-3 Ga), Vijayan and Wanni Complex (1-2 Ga), and Kadugannawa Complex (0.9- 1 Ga) on the northern-most area. The main lithotectonic units and foliation trend lines are illustrated in Figure 15-9.

The Highland complex lies in the central part of Sri Lanka, where the Project site is located, and consists of granulite faces metaquartzites, metacarbonate and metapelitic gneisses.

These strata around the Project site are significantly deformed by folding (refer to Figure 15-10). However, they run in parallel with other metasedimentary lithological units. In general, fresh and hard rocks are cropped out surrounding the Victoria Lake, where the lower dam is planned, but the rocks surrounding the upper dam site are weathered strongly.



(Source: Encyclopedia of European and Asian regional geology; Chapman & Hall, 1997)

Figure 15-9 Simplified Geological Map

Figure 15-10 Folded Structures around Project Site

[37] A part of the Earth's crust that has attained stability, and has been little deformed for a prolonged period (Glossary of geology; American Geological Institute)

(2) Lineaments[38]

The distribution of lineaments around the PSPP site is shown in Figure 15-11. There is one lineament near the outlet, which runs NNE with a 6km length (A). Four E-W trend lineaments (B to E) are in the eastern area of lineament A, and one of them (C) crosses the tailrace tunnel.

There is no possibility of major fracture zones surrounding the Project site; however, the presence of lineaments suggests some hidden weak geological structure along and/or beneath them. Therefore, the geotechnical characteristics of lineament-C should be made clear based on suitable investigations such as geophysical exploration at the next FS study stage.

(Source: JICA Survey Team)

Figure 15-11 Lineaments around Victoria PSPP

(3) Specific topographic features

There are two blocks of specific topography which evoke landslides at the higher and lower slope of the upper pond on the Google Earth image (refer to Figure 5-12). In the case that there is a natural pond at the top of the mountain, there are many cases in which the pond was formed by a landslide.

For this project site, there is a high possibility that the concave terrain was naturally caused by differential erosion depending on the geological structure with an NS trend. However, the suggested block movement seems to be in an EW direction.

According to the site reconnaissance results, though there is no evidence of active landslides, it may be a trace of some past landslide and stable at present. However, since there is a possibility of instability during and after the impounding of water, the soundness of the blocks is to be identified in the next FS study stage.

[38] A linear topographic feature regional extent that is believed to reflect crustal structure (Hobbs et al., 1976)

(Source: JICA Survey Team)

Figure 15-12 Specific Topography Evoking Landslides Surrounding Upper Pond Site

(4) Comprehensive evaluation

According to the site reconnaissance survey results, the project is basically deemed to have fewer issues from the aspects of topography and geology except for the above mentioned two geological issues.
It is suggested that appropriate investigations on the above issues and other necessary items should be conducted at the next FS study stage and the feasibility of the Project be assessed properly.

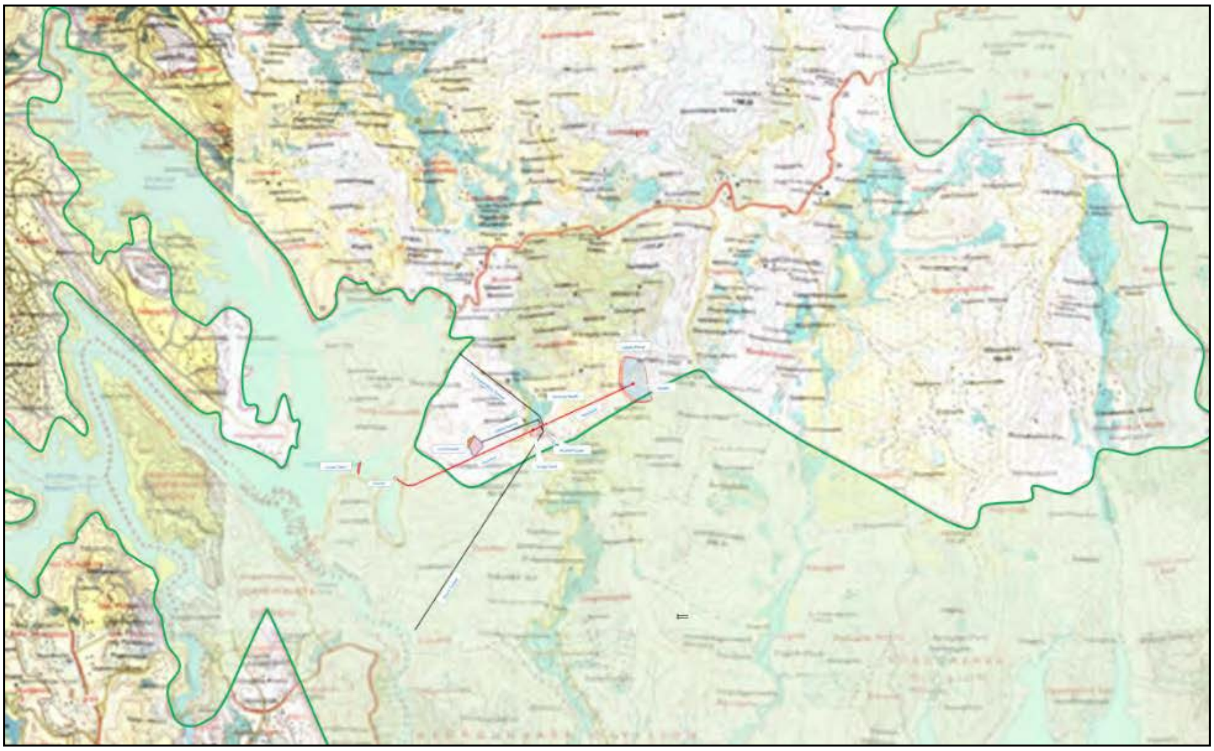
15.1.3 Environmental and Social Considerations

(1) Natural environment

The protection area of Victoria Randenigala Rantembe Sanctuary is designated around the Victoria Reservoir and its eastern area. However, each civil structure of the additional PSPP (except the lower dam and the outlet) is planned to be located outside the protection area (refer to Figure 15-13). Most land use in and around the planned site area consists of cultivated fields or artificial forest, which improved the previously felled natural forest. The main types of covered-vegetation in this area are as follows, and it has been deemed that no threatened species which should be absolutely protected by law or treaty are in the area according to interviews with the local people. However, it is anticipated that this area is likely being used as feeding fields by raptors, since soaring raptors were often seen over the project area during the site survey conducted in November 2016. Therefore, a detailed environmental survey needs to be carried out in the EIA.

(a) Upper reservoir:
There are some rows of pine trees (Caribbean pine, Mexican pine) more than 30 m high, some grass fields covered with wild-lawn-grass, and some shrubbery forests with middle sized trees of Djenitri, and Glabrous ternstroemia around the existing pond.
There are natural forests of Mahogany close to the artificial forests of araucaria-aceae, and eucalyptus pine in part of hinterland of the existing pond; however, these trees will not be affected by the project, since they are far from the planned upper pond.

(b) Lower reservoir:
There are trees of some species of pine and genus of Gliricidia (Locust tree) which are artificially or naturally grown around the lakeside of the Victoria reservoir.
These trees will not be affected by the project as the lower dam and the outlet will be constructed in the the Victoria reservoir.



(Source: JICA Survey Team-arranged based on CEB data)

Figure 15-13 Correlation between Victoria Randenigala Rantembe Sanctuary and PSPP Site

(c) Along waterway route:
Most of the ground surface along the planned waterway route is occupied by artificial forests, cultivated land, and paddy fields by reclaiming a gentle slope. Green vegetables of cabbage, trees of pepper and trees of coffee are planted in the above cultivated fields. However, since the waterway except the upper part of the penstock is planned to be placed under ground, the farmland will be not affected. Although the upper part of the penstock is planned to be placed only on the ground surface, which is occupied only by the artificial forests and is outside the sanctuary designated by the Ministry of Forest.

(2) Social environment
There is a village with 36 to 37 households (about 260 people living there), where people mainly use the surrounding forest management and are employed at tea plantations as their livelihood means, downstream of the planned upper pond or the existing irrigation weir. Adverse direct impacts on this village are not anticipated; however, water-management for the upper reservoir during construction and after commissioning should be considered so as not to affect the water usage of the existing irrigation pond, since the villagers use the water for irrigation from July to September.

(3) Comprehensive evaluation
Impact Indexes for the project regarding the Natural Environment and Social Environment are -0.50 and -0.50 respectively, and the comprehensive impact indicator is -0.50 according to the environmental impact evaluation as mentioned in section 6.5. The comprehensive impact indicator is diferent from that of the PSPP (-0.90) in section 6.6.
In addition, although part of project site (the lower dam and the outlet) is located in the Sanctuary, the Victoria PSPP could be developed. Because the Environment Conservation Act (revised in 1980 and 2000) in Sri Lanka stipulates that development activity in the Protected Area shall be approved by Minister of Environment in the item 24C and 24D in the chapter IV C “Approval for project” and if approved, the project can be developed. And also, there is the case that the EIA for the Broadland hydropower project, which is located in a protected area, was approved and the project is now under construction.
Based on the above mentioned analyses, the impacts on the whole environment caused by the project seems to be “insignificant impacts”.

15.1.4 Economic Efficiency

(1) Rough estimate of construction cost
The quantities of civil work are calculated according to the above planned features of the main facilities and the construction cost is estimated by multiplying the quantities with each civil work unit cost, which are applied in the study “Development Planning on Optimal Generation for Peak Demand in Sri Lanka”.

Table 15-3 Unit Costs for Civil Work

Item	Unit	Price	Remarks
Excavation			
Common	USD/m^3	15	for Open excavation
Rock	USD/m^3	25	for Open excavation
Tunnel	USD/m^3	80	for Horizontal Tunnel
Penstock	USD/m^3	220	for Inclined Tunnel, Surge Shaft
Underground	USD/m^3	115	for Powerhouse Cavern
Embankment			for fill type dams
Rock	USD/m^3	18	
Core	USD/m^3	23	
Concrete			
Mass	USD/m^3	150	for RCC Dam
Open	USD/m^3	220	for Structure (Intake, Outlet, etc.)
Lining	USD/m^3	220	for Tunnel
Lining	USD/m^3	275	for Vertical shaft (Surge tank)
Filling Concrete	USD/m^3	100	for Around Steel Liner (Inclined or vertical shaft)
Powerhouse	USD/m^3	220	for Sub-structure in Powerhouse
Reinforcing Bar	USD/ton	1,150	
Hydro-Mechanical			
Gate	USD/ton	3,825	
Penstock	USD/ton	5,500	
Trash rack	USD/ton	2,200	

(Source: "Development Planning on Optimal Generation for Peak Demand in Sri Lanka")

A rough estimate of the construction cost for Victoria PSPP is shown in Table 15-4.

Table 15-4 Rough Estimate of Construction Costs for Victoria PSPP

Item / Project	Stage I 350MW×2 ×10^3 USD	Stage II 350MW×2 ×10^3 USD	Total 350MW×4 ×10^3 USD	Maha 3 200MW×3 ×10^3 USD	Remarks
1. Preparation and Land Acquisition	5,050	1,087	6,138	4,888	
(1) Access Roads					
(2) Compensation & Resettlement					
(3) Camp & Facilities	5,050	1,087	6,138	4,888	3. Civil Works × 2%
2. Environmental Mitigation Cost	2,525	544	3,069	7,332	3. Civil Works × 1%
3. Civil Works	252,518	54,368	306,886	244,385	
4. Hydromechanical Works	72,243	59,508	131,751	56,516	
5. Electro-Mechanical Equipment	138,450	138,450	276,900	193,400	
6. Transmission Line	1,000	1,000	2,000	3,900	
Direct Cost	471,786	254,957	726,743	510,421	
7. Administration and Engineering Services	70,768	38,244	109,011	76,563	Direct Cost × 15%
8. Contingency	47,179	25,496	72,674	51,042	Direct Cost × 10%
9. Interest During Construction	0	0	0	0	Σ (1,2,3,…,8)*0.4*i*T
Total Cost	589,732	318,696	908,428	638,026	
Installed Capacity	700	700	1400	600	
USD per kW	842	455	649	1,063	

(Source: JICA Survey Team)

15.2 Appendix-2: Power Development Planning Simulation Results

		Capacity (MW)					Energy (GWh)					kWh (%)			Generation cost					CO2 emission				Regional impact			Fuel procurement				Fuel Price Increase				Generation fluctuation: Frequency control				Gene- Fluctuation													
																															0.001				288	270	200																
		--- Environmental evaluation ---									20	USC/kWh	30	hours													10	5			20	10			0.4	0.1	1.0		0.002	0.001		100									0.8		
6222		(0.57)	(1.13)	(0.56)	(0.52)	(0.90)					50,120	0.1301	50%		0.730304	39805	GWh			CO2	3.666667		80%		20%		20%	30%		20%	10%	20%		20%	1009	946	175.2		3000	3000		1%		60%							1009		
Scenario No.	LOLE	LNG	Coal	Wind	Solar	PSPP	LNG	Coal	PSPP	Surplus	LNG (kton)	LNG	Coal	Surplus	Fixed cost	Fuel cost	Total	Cost USC/kWh	Score	kton-C	kton-CO2	kg/kWh	Score	Total	Score	Environment	(LNG)	(Coal)	Total	Score	(LNG)	(Coal)	Total	Score	(LNG)	(Coal)	(PSPP)	Total	(Wind)	(Solar)	Sub Total	Surplus	Total	Score	Energy security	Cost	Environment	Energy security	Total		Eco: 60% Env: 20% Sec: 20%	Eco: 20% Env: 60% Sec: 20%	Eco: 20% Env: 20% Sec: 60%
A-4F-011	22.37	1134	4065	504	500	0	1670	27573	0	1	284	4.2%	69.3%	0.0%	146213	198122	344335	8.65	9.5	7016.1	25726	0.646	0.0	(5.8)	7.8	1.6	0.0	(1.8)	(1.8)	7.2	(0.7)	(4.9)	(5.6)	1.4	0.7	1.2	0.0	1.5	(1.0)	(0.5)	(1.5)	0.0	0.0	10.0	7.7	9.5	0.3	8.4	18.1	A-4F-011	22.2	11.2	20.9
A-6D-011	21.74	1710	3525	504	500	0	4297	24920	0	0	626	10.8%	62.6%	0.0%	141439	208164	349603	8.78	8.3	6638.4	24341	0.612	0.8	(5.5)	8.9	2.4	(0.7)	(1.3)	(2.1)	6.2	(0.5)	(4.3)	(4.8)	3.3	1.7	1.0	0.0	1.5	(1.0)	(0.5)	(1.5)	0.0	0.0	10.0	7.9	8.3	1.4	8.7	18.4	A-6D-011	21.0	12.8	21.5
A-4E-022	15.52	1134	3795	1004	1000	0	1523	25379	0	40	266	3.8%	63.8%	0.1%	141272	203345	344617	8.66	9.4	6468.6	23718	0.596	1.1	(6.0)	6.9	2.3	0.0	(1.5)	(1.5)	7.9	(0.7)	(4.4)	(5.1)	2.6	0.6	1.1	0.0	1.7	(2.0)	(1.0)	(3.0)	0.0	(1.3)	8.8	7.4	9.4	1.3	7.8	18.4	A-4E-022	22.3	12.6	20.4
A-6C-022	16.18	1710	3255	1004	1000	0	3884	22957	0	0	563	9.8%	57.7%	0.0%	136498	211507	348005	8.74	8.7	6111.2	22408	0.563	1.9	(5.7)	8.0	3.1	(0.7)	(1.1)	(1.9)	6.9	(0.4)	(3.8)	(4.2)	4.6	1.5	0.9	0.0	2.4	(2.0)	(1.0)	(3.0)	0.0	(0.6)	9.5	8.0	8.7	2.4	8.9	19.9	A-6C-022	22.3	14.8	22.6
A-4D-023	23.84	1134	3525	1004	1500	0	1947	24229	0	5	317	4.9%	60.9%	0.0%	136332	205469	341801	8.59	10.0	6221.4	22812	0.573	1.7	(6.0)	7.1	2.7	0.0	(1.3)	(1.3)	8.6	(0.7)	(4.1)	(4.8)	3.3	0.8	1.0	0.0	1.8	(2.0)	(1.5)	(3.5)	0.0	(1.7)	8.5	7.5	10.0	1.9	7.9	19.8	A-4D-023	23.9	14.1	21.3
A-4D-024	12.01	1134	3525	1004	2000	0	1594	23895	0	6	275	4.0%	60.0%	0.0%	137962	205536	343498	8.63	9.6	6107.5	22394	0.563	1.9	(6.2)	6.0	2.7	0.0	(1.3)	(1.3)	8.6	(0.7)	(4.0)	(4.7)	3.4	0.6	1.0	0.0	1.6	(2.0)	(2.0)	(4.0)	0.0	(2.4)	7.9	7.1	9.6	1.9	7.3	18.8	A-4D-024	22.8	13.5	20.0
A-4D-033	15.02	1134	3525	1504	1500	0	1515	23108	0	142	266	3.8%	58.1%	0.4%	136332	209469	345801	8.69	9.1	5923.9	21721	0.546	2.3	(6.3)	6.0	3.0	0.0	(1.3)	(1.3)	8.6	(0.7)	(3.8)	(4.5)	3.8	0.6	1.0	0.0	1.6	(3.0)	(1.5)	(4.5)	0.0	(2.9)	7.4	6.9	9.1	2.3	6.9	18.3	A-4D-033	22.0	13.7	19.3
A-4C-034	22.31	1134	3255	1504	2000	0	1957	21904	0	71	321	4.9%	55.0%	0.2%	131392	211607	342999	8.62	9.7	5665.7	20774	0.522	2.8	(6.2)	6.1	3.5	0.0	(1.1)	(1.1)	9.3	(0.7)	(3.5)	(4.2)	4.6	0.8	0.9	0.0	1.7	(3.0)	(2.0)	(5.0)	0.0	(3.3)	7.0	7.0	9.7	2.9	7.1	19.7	A-4C-034	23.5	15.3	20.3
A-4C-044	14.66	1134	3255	2004	2000	0	1557	20838	0	295	271	3.9%	52.4%	0.7%	131392	216019	347411	8.73	8.8	5384.7	19744	0.496	3.4	(6.5)	5.1	3.7	0.0	(1.1)	(1.1)	9.3	(0.7)	(3.2)	(4.0)	5.1	0.6	0.9	0.0	1.5	(4.0)	(2.0)	(6.0)	0.0	(4.5)	6.0	6.5	8.8	3.3	6.1	18.1	A-4C-044	21.4	14.8	18.2
A-4E-111	19.00	1134	3795	504	500	600	2079	27503	805	0	338	5.2%	69.1%	0.0%	146397	200865	347262	8.72	8.8	7016.2	25726	0.646	0.0	(6.0)	6.9	1.4	0.0	(1.5)	(1.5)	7.9	(0.7)	(4.9)	(5.6)	1.6	0.8	1.1	3.0	1.5	(1.0)	(0.5)	(1.5)	0.0	0.0	10.0	7.9	8.8	0.0	8.7	17.5	A-4E-111	21.1	10.5	21.0
A-6C-111	20.71	1710	3255	504	500	600	5669	23684	264	0	823	14.2%	59.5%	0.0%	141623	215357	356980	8.97	6.7	6496.3	23820	0.598	1.1	(5.7)	8.0	2.5	(0.7)	(1.1)	(1.9)	6.9	(1.0)	(4.0)	(5.0)	2.9	2.0	0.9	1.5	1.5	(1.0)	(0.5)	(1.5)	0.0	0.0	10.0	8.0	6.7	1.5	8.8	17.0	A-6C-111	18.3	12.0	20.8
A-4D-122	17.86	1134	3525	1004	1000	600	2004	25057	471	0	324	5.0%	62.9%	0.0%	141456	209807	351263	8.82	8.0	6419	23536	0.591	1.3	(6.3)	6.0	2.2	0.0	(1.3)	(1.3)	8.6	(0.7)	(4.3)	(5.0)	2.9	0.8	1.0	2.7	3.0	(2.0)	(1.0)	(3.0)	0.0	0.0	10.0	8.3	8.0	1.1	9.4	18.5	A-4D-122	20.7	12.5	22.4
A-6B-122	15.06	1710	2985	1004	1000	600	5307	21657	248	0	769	13.3%	54.4%	0.0%	136682	218989	355671	8.94	7.0	5961	21857	0.549	2.2	(6.0)	7.1	3.2	(0.7)	(0.9)	(1.6)	7.6	(0.9)	(3.4)	(4.3)	4.3	2.0	0.8	1.4	3.0	(2.0)	(1.0)	(3.0)	0.0	0.0	10.0	8.4	7.0	2.5	9.6	19.1	A-6B-122	19.9	14.4	22.9
A-4D-123	8.09	1134	3525	1004	1500	600	1649	24655	311	0	282	4.1%	61.9%	0.0%	143086	205051	348137	8.75	8.6	6290.2	23064	0.579	1.5	(6.5)	5.0	2.2	0.0	(1.3)	(1.3)	8.6	(0.7)	(4.2)	(4.9)	3.0	0.7	1.0	1.8	3.4	(2.0)	(1.5)	(3.5)	0.0	(0.1)	9.9	8.3	8.6	1.1	9.4	19.2	A-4D-123	21.9	12.9	22.8
A-4C-124	16.24	1134	3255	1004	2000	600	2310	23288	272	0	366	5.8%	58.5%	0.0%	138146	208445	346591	8.71	9.0	6022.1	22081	0.555	2.1	(6.5)	5.1	2.7	0.0	(1.1)	(1.1)	9.3	(0.6)	(3.9)	(4.5)	4.0	0.9	0.9	1.6	3.4	(2.0)	(2.0)	(4.0)	0.0	(0.6)	9.4	8.3	9.0	1.8	9.5	20.2	A-4C-124	22.9	14.3	23.5
A-4C-133	17.97	1134	3255	1504	1500	600	2097	22491	256	0	337	5.3%	56.5%	0.0%	136516	210952	347468	8.73	8.8	5815.7	21324	0.536	2.5	(6.5)	5.1	3.0	0.0	(1.1)	(1.1)	9.3	(0.7)	(3.7)	(4.3)	4.3	0.8	0.9	1.5	3.2	(3.0)	(1.5)	(4.5)	0.0	(1.3)	8.8	8.0	8.8	2.3	8.9	20.0	A-4C-133	22.5	14.7	22.7
A-4C-134	8.83	1134	3255	1504	2000	600	1735	22158	238	0	293	4.4%	55.7%	0.0%	138146	210889	349035	8.77	8.4	5702.2	20908	0.525	2.8	(6.7)	4.0	3.0	0.0	(1.1)	(1.1)	9.3	(0.7)	(3.6)	(4.3)	4.4	0.7	0.9	1.4	2.9	(3.0)	(2.0)	(5.0)	0.0	(2.1)	8.2	7.6	8.4	2.3	8.2	18.9	A-4C-134	21.5	14.1	21.2
A-4B-144	23.65	1134	2985	2004	2000	600	2222	19979	241	0	354	5.6%	50.2%	0.0%	131576	217222	348798	8.76	8.5	5230	19177	0.482	3.7	(6.7)	4.1	3.8	0.0	(0.9)	(0.9)	10.0	(0.6)	(3.0)	(3.7)	5.7	0.9	0.8	1.4	3.1	(4.0)	(2.0)	(6.0)	0.0	(3.0)	7.4	7.6	8.5	3.4	8.1	20.0	A-4B-144	22.2	16.0	21.7
B-D3-044	14.80	3726	825	2004	2000	0	16510	5578	0	0	2301	41.5%	14.0%	0.0%	105259	279541	384800.5	9.67	0.7	3346.6	12271	0.308	7.7	(5.2)	10.0	8.2	(4.0)	0.0	(4.0)	0.0	(6.3)	0.0	(6.3)	0.0	4.8	0.0	0.0	4.8	(4.0)	(2.0)	(6.0)	0.0	(1.2)	8.9	5.4	0.7	9.3	4.0	14.1	B-D3-044	9.4	19.7	13.3
B-C3-046	16.20	3438	825	2004	3000	0	15134	5578	0	0	2126	38.0%	14.0%	0.0%	105001	276561	381561.8	9.59	1.4	3201	11737	0.295	8.0	(5.6)	8.6	8.1	(3.5)	0.0	(3.5)	1.5	(5.6)	0.0	(5.6)	1.5	4.4	0.0	0.0	4.4	(4.0)	(3.0)	(7.0)	0.0	(2.6)	7.7	5.2	1.4	9.3	3.8	14.5	B-C3-046	10.4	19.9	13.2
B-B3-048	22.68	3150	825	2004	4000	0	13750	5576	0	0	1000	34.5%	14.0%	0.0%	104742	273526	378268.1	9.50	2.1	3053.8	11197	0.281	8.3	(5.9)	7.2	8.1	(3.1)	0.0	(3.1)	3.0	(4.9)	0.0	(4.9)	3.0	4.0	0.0	0.0	4.0	(4.0)	(3.5)	(7.5)	0.0	(3.5)	6.9	5.3	2.1	9.3	4.0	15.4	B-B3-048	11.8	20.3	14.0
B-C3-064	23.32	3438	825	3004	2000	0	13230	5535	0	58	1852	33.2%	13.9%	0.1%	101740	274006	375746.5	9.44	2.7	2962	10861	0.273	8.5	(5.6)	8.5	8.5	(3.5)	0.0	(3.5)	1.5	(4.6)	0.0	(4.6)	3.6	4.4	0.0	0.0	4.4	(6.0)	(2.0)	(8.0)	0.0	(3.6)	6.8	5.1	2.7	9.8	3.6	16.0	B-C3-064	12.9	21.4	13.9
B-C3-066	8.18	3438	825	3004	3000	0	11830	5538	0	47	1670	29.7%	13.9%	0.1%	105001	270603	375603.8	9.44	2.7	2811.9	10310	0.259	8.8	(6.1)	6.4	8.3	(3.5)	0.0	(3.5)	1.5	(3.9)	0.0	(3.9)	5.1	4.4	0.0	0.0	4.4	(6.0)	(3.0)	(9.0)	0.0	(4.6)	5.9	4.9	2.7	9.6	3.1	15.4	B-C3-066	12.5	20.8	13.0
B-B3-068	12.38	3150	825	3004	4000	0	10485	5521	0	77	1496	26.3%	13.9%	0.2%	104742	267632	372374.1	9.35	3.4	2662.4	9762	0.245	9.1	(6.5)	5.0	8.3	(3.1)	0.0	(3.1)	3.0	(3.3)	0.0	(3.3)	6.6	4.0	0.0	0.0	4.0	(6.0)	(3.5)	(9.5)	0.0	(5.5)	5.1	5.0	3.4	9.6	3.3	16.3	B-B3-068	13.9	21.3	13.8
B-C3-084	13.68	3438	825	4004	2000	0	10456	5420	0	548	1473	26.3%	13.6%	1.4%	101740	272808	374548.5	9.41	2.9	2618.1	9600	0.241	9.2	(6.2)	6.3	8.6	(3.5)	0.0	(3.5)	1.5	(3.3)	0.0	(3.3)	6.6	4.1	0.0	0.0	4.1	(7.0)	(2.0)	(9.0)	(0.4)	(5.2)	5.3	4.8	2.9	10.0	3.1	16.0	B-C3-084	13.1	21.6	13.3
B-B3-086	14.45	3150	825	4004	3000	0	9352	5379	0	794	1327	23.5%	13.5%	2.0%	101482	271645	373126.8	9.37	3.3	2486.3	9116	0.229	9.5	(6.5)	4.9	8.6	(3.1)	0.0	(3.1)	3.0	(2.7)	0.0	(2.7)	7.8	3.7	0.0	0.0	3.7	(7.0)	(3.0)	(10.0)	(1.0)	(7.3)	3.5	4.3	3.3	9.9	2.0	15.2	B-B3-086	13.0	21.0	11.6
B-A3-088	19.47	2862	825	4004	4000	0	8440	5308	0	1172	1206	21.2%	13.3%	2.9%	101222	271942	373164.1	9.37	3.2	2368.6	8685	0.218	9.7	(6.9)	3.5	8.5	(2.6)	0.0	(2.6)	4.5	(2.2)	0.0	(2.2)	8.8	3.3	0.0	0.0	3.3	(7.0)	(3.5)	(10.5)	(1.9)	(9.1)	1.9	3.8	3.2	9.8	1.2	14.2	B-A3-088	12.4	20.3	9.9
B-93-08A	24.09	2574	825	4004	5000	0	7583	5263	0	1677	1093	19.1%	13.2%	4.2%	100963	273009	373972.4	9.40	3.1	2263	8298	0.208	10.0	(7.2)	2.1	8.4	(2.1)	0.0	(2.1)	6.0	(1.8)	0.0	(1.8)	9.8	3.0	0.0	0.0	3.0	(7.0)	(4.0)	(11.0)	(3.2)	(11.2)	0.0	3.2	3.1	9.7	0.0	12.7	B-93-08A	11.3	19.3	7.6
B-C3-144	22.18	3438	825	2004	2000	600	16523	5577	17	0	2304	41.5%	14.0%	0.0%	108494	279717	388211.5	9.75	0.0	3349.1	12280	0.309	7.7	(5.6)	8.5	7.9	(3.5)	0.0	(3.5)	1.5	(6.3)	0.0	(6.3)	0.0	4.4	0.0	0.1	4.5	(4.0)	(2.0)	(6.0)	0.0	(1.5)	8.7	5.5	0.0	8.9	4.3	13.2	B-C3-144	7.9	18.7	13.1
B-B3-146	22.34	3150	825	2004	3000	600	15142	5577	7	0	2129	38.0%	14.0%	0.0%	108236	276778	385013.8	9.67	0.7	3203.5	11746	0.295	8.0	(5.9)	7.1	7.8	(3.1)	0.0	(3.1)	3.0	(5.6)	0.0	(5.6)	1.5	4.0	0.0	0.0	4.0	(4.0)	(3.0)	(7.0)	0.0	(3.0)	7.4	5.3	0.7	8.9	4.0	13.5	B-B3-146	8.9	18.8	12.9
B-B3-148	12.40	3150	825	2004	4000	600	13770	5578	13	0	1952	34.6%	14.0%	0.0%	111496	273639	385135.1	9.68	0.7	3056.2	11206	0.282	8.3	(6.5)	5.1	7.7	(3.1)	0.0	(3.1)	3.0	(4.9)	0.0	(4.9)	3.0	4.0	0.0	0.1	4.1	(4.0)	(3.5)	(7.5)	0.0	(3.4)	6.9	5.4	0.7	8.7	4.1	13.4	B-B3-148	8.8	18.4	12.9
B-C3-164	10.59	3438	825	3004	2000	600	13160	5576	70	0	1840	33.1%	14.0%	0.0%	108494	273463	381957.5	9.60	1.3	2962.9	10864	0.273	8.5	(6.2)	6.3	8.1	(3.5)	0.0	(3.5)	1.5	(4.6)	0.0	(4.6)	3.7	4.4	0.0	0.4	4.8	(6.0)	(2.0)	(8.0)	0.0	(3.2)	7.1	5.3	1.3	9.2	4.0	14.5	B-C3-164	10.3	19.8	13.5
B-B3-166	10.64	3150	825	3004	3000	600	11780	5576	49	0	1666	29.6%	14.0%	0.0%	108236	270464	378699.8	9.51	2.0	2818.1	10333	0.260	8.8	(6.5)	5.0	8.0	(3.1)	0.0	(3.1)	3.0	(3.9)	0.0	(3.9)	5.2	4.0	0.0	0.3	4.3	(6.0)	(3.0)	(9.0)	0.0	(4.7)	5.8	5.1	2.0	9.2	3.6	14.8	B-B3-166	11.3	19.9	13.2
B-A3-168	19.47	2862	825	3004	4000	600	10418	5572	74	0	1488	26.2%	14.0%	0.0%	107977	267314	375291.1	9.43	2.8	2668.6	9785	0.246	9.1	(6.9)	3.6	8.0	(2.6)	0.0	(2.6)	4.5	(3.2)	0.0	(3.2)	6.7	3.6	0.0	0.4	4.0	(6.0)	(3.5)	(9.5)	0.0	(5.5)	5.1	5.3	2.8	9.1	3.9	15.9	B-A3-168	12.9	20.5	14.2
B-B3-184	17.20	3150	825	4004	2000	600	10222	5432	160	256	1442	25.7%	13.6%	0.6%	104975	270836	375811.5	9.44	2.7	2595.7	9518	0.239	9.3	(6.5)	4.8	8.4	(3.1)	0.0	(3.1)	3.0	(3.1)	0.0	(3.1)	6.9	4.0	0.0	0.9	4.9	(7.0)	(2.0)	(9.0)	0.0	(4.1)	6.4	5.8	2.7	9.6	4.8	17.2	B-B3-184	13.5	21.9	16.1
B-A3-186	20.29	2862	825	4004	3000	600	9148	5364	93	519	1304	23.0%	13.5%	1.3%	104717	269977	374693.8	9.41	2.9	2463.8	9034	0.227	9.5	(6.9)	3.4	8.3	(2.6)	0.0	(2.6)	4.5	(2.6)	0.0	(2.6)	8.1	3.6	0.0	0.5	4.1	(7.0)	(3.0)	(10.0)	(0.3)	(6.2)	4.5	5.2	2.9	9.6	3.8	16.2	B-A3-186	13.2	21.2	14.3
B-A3-188	11.45	2862	825	4004	4000	600	8260	5309	51	974	1183	20.8%	13.3%	2.4%	107977	270494	378471.1	9.51	2.1	2349.5	8615	0.216	9.8	(7.4)	1.4	8.1	(2.6)	0.0	(2.6)	4.5	(2.2)	0.0	(2.2)	9.0	3.3	0.0	0.3	3.6	(7.0)	(3.5)	(10.5)	(1.4)	(8.4)	2.5	4.2	2.1	9.3	2.0	13.3	B-A3-188	10.5	19.1	10.3
B-93-18A	16.15	2574	825	4004	5000	600	7387	5263	103	1410	1069	18.6%	13.2%	3.5%	107718	271391	379109.4	9.52	2.0	2243.1	8225	0.207	10.0	(7.8)	0.0	8.0	(2.1)	0.0	(2.1)	6.0	(1.7)	0.0	(1.7)	10.0	2.9	0.0	0.6	3.5	(7.0)	(4.0)	(11.0)	(2.5)	(10.0)	1.1	3.8	2.0	9.1	1.2	12.3	B-93-18A	9.8	18.4	8.9
C-98-033	11.30	2574	2175	1504	1500	0	8895	15562	0	0	1253	22.3%	39.1%	0.0%	122404	239536	361940.3	9.09	5.7	4889.4	17928	0.450	4.5	(5.5)	8.7	5.3	(2.1)	(0.2)	(2.4)	5.2	(2.5)	(1.9)	(4.4)	4.2	3.2	0.5	0.0	3.7	(3.0)	(1.5)	(4.5)	0.0	(0.8)	9.3	7.4	5.7	5.4	7.9	19.0	C-98-033	18.2	17.9	20.8
C-7A-033	13.20	1998	2715	1504	1500	0	5186	19260	0	2	748	13.0%	48.4%	0.0%	128507	223213	351720.3	8.84	7.9	5368.2	19683	0.494	3.5	(5.8)	7.6	4.3	(1.2)	(0.7)	(1.9)	6.8	(0.9)	(2.8)	(3.7)	5.7	2.1	0.7	0.0	2.8	(3.0)	(1.5)	(4.5)	0.0	(1.8)	8.4	7.6	7.9	4.0	8.1	19.9	C-7A-033	21.4	16.8	21.7
C-5C-033	12.80	1422	3255	1504	1500	0	2315	22223	0	71	360	5.8%	55.8%	0.2%	134609	211312	345921.3	8.69	9.1	5771.6	21163	0.532	2.6	(6.1)	6.5	3.4	(0.3)	(1.1)	(1.4)	8.4	(0.6)	(3.6)	(4.2)	4.5	0.9	0.9	0.0	1.8	(3.0)	(1.5)	(4.5)	0.0	(2.7)	7.6	7.1	9.1	2.8	7.3	19.2	C-5C-033	22.5	14.9	20.3
C-97-044	16.56	2574	1905	2004	2000	0	8574	13506	0	1	1212	21.5%	33.9%	0.0%	117464	243874	361338.5	9.08	5.8	4358.8	15982	0.402	5.6	(5.8)	7.8	6.0	(2.1)	(0.0)	(2.2)	5.9	(2.3)	(1.4)	(3.7)	5.7	3.2	0.4	0.0	3.6	(4.0)	(2.0)	(6.0)	0.0	(2.4)	7.9	7.0	5.8	6.4	7.1	19.3	C-97-044	18.5	19.2	20.1
C-79-044	15.77	1998	2445	2004	2000	0	4922	17201	0	51	717	12.4%	43.2%	0.1%	123566	228199	351765.5	8.84	7.9	4845.2	17766	0.446	4.5	(6.1)	6.7	5.0	(1.2)	(0.5)	(1.7)	7.5	(0.8)	(2.3)	(3.1)	7.0	2.0	0.6	0.0	2.6	(4.0)	(2.0)	(6.0)	0.0	(3.5)	6.9	7.1	7.9	5.0	7.2	20.0	C-79-044	21.4	17.9	20.6
C-5B-044	16.18	1422	2985	2004	2000	0	2379	19898	0	188	372	6.0%	50.0%	0.5%	129669	218056	347725.5	8.74	8.7	5223.9	19154	0.481	3.8	(6.3)	5.6	4.1	(0.3)	(0.9)	(1.2)	9.1	(0.6)	(3.0)	(3.6)	5.8	0.9	0.8	0.0	1.7	(4.0)	(2.0)	(6.0)	0.0	(4.3)	6.2	6.7	8.7	3.8	6.5	19.0	C-5B-044	21.9	16.0	19.2
C-96-055	19.76	2574	1635	2504	2500	0	8283	11458	0	42	1177	20.8%	28.8%	0.1%	112524	248658	361181.6	9.07	5.8	3834.6	14060	0.353	6.7	(6.0)	6.9	6.7	(2.1)	0.0	(2.1)	6.0	(2.2)	(0.9)	(3.0)	7.1	3.2	0.3	0.0	3.5	(5.0)	(2.5)	(7.5)	0.0	(4.0)	6.4	6.5	5.8	7.4	6.1	19.3	C-96-055	18.6	20.4	18.9
C-78-055	21.56	1998	2175	2504	2500	0	4857	14990	0	156	714	12.2%	37.7%	0.4%	118627	234377	353003.6	8.87	7.6	4307.5	15794	0.397	5.7	(6.3)	5.8	5.7	(1.2)	(0.2)	(1.5)	8.2	(0.7)	(1.8)	(2.5)	8.3	1.9	0.5	0.0	2.4	(5.0)	(2.5)	(7.5)	0.0	(5.1)	5.5	6.6	7.6	6.0	6.3	19.8	C-78-055	21.0	19.0	19.4
C-5A-055	20.67	1422	2715	2504	2500	0	2485	17577	0	351	389	6.2%	44.2%	0.9%	124730	225225	349954.6	8.79	8.2	4685.1	17179	0.432	4.9	(6.6)	4.7	4.8	(0.3)	(0.7)	(1.0)	9.8	(0.6)	(2.4)	(3.0)	7.1	1.0	0.7	0.0	1.7	(5.0)	(2.5)	(7.5)	0.0	(5.8)	4.8	6.3	8.2	4.8	5.7	18.7	C-5A-055	21.1	17.0	18.1
C-88-133	16.46	2286	2175	1504	1500	600	8868	15635	63	0	1252	22.3%	39.3%	0.0%	125639	239786	365425.3	9.18	4.9	4906.2	17989	0.452	4.4	(5.9)	7.3	5.0	(1.7)	(0.2)	(1.9)	6.7	(2.5)	(1.9)	(4.4)	4.2	2.8	0.5	0.4	3.7	(3.0)	(1.5)	(4.5)	0.0	(0.8)	9.2	7.7	4.9	5.0	8.4	18.3	C-88-133	16.9	16.9	21.0
C-6A-133	17.51	1710	2715	1504	1500	600	4963	19626	262	0	722	12.5%	49.3%	0.0%	131742	223069	354811.3	8.91	7.2	5430.2	19911	0.500	3.3	(6.2)	6.2	3.9	(0.7)	(0.7)	(1.4)	8.3	(0.8)	(2.9)	(3.7)	5.7	2.0	0.7	1.5	4.2	(3.0)	(1.5)	(4.5)	0.0	(0.3)	9.7	8.6	7.2	3.5	10.0	20.7	C-6A-133	21.0	16.6	24.4
C-4C-133	17.97	1134	3255	1504	1500	600	2097	22491	256	0	337	5.3%	56.5%	0.0%	136516	210952	347468.3	8.73	8.8	5815.7	21324	0.536	2.5	(6.5)	5.1	3.0	0.0	(1.1)	(1.1)	9.3	(0.7)	(3.7)	(4.3)	4.3	0.8	0.9	1.5	3.2	(3.0)	(1.5)	(4.5)	0.0	(1.3)	8.8	8.0	8.8	2.3	8.9	20.0	C-4C-133	22.5	14.7	22.7
C-87-144	20.96	2286	1905	2004	2000	600	8507	13623	87	0	1203	21.4%	34.2%	0.0%	120699	243806	364505.5	9.16	5.1	4378.5	16055	0.403	5.5	(6.2)	6.3	5.7	(1.7)	(0.0)	(1.7)	7.4	(2.3)	(1.4)	(3.7)	5.7	2.8	0.4	0.5	3.7	(4.0)	(2.0)	(6.0)	0.0	(2.3)	7.9	7.4	5.1	5.9	7.7	18.8	C-87-144	17.4	18.4	20.6
C-69-144	22.47	1710	2445	2004	2000	600	4705	17501	256	0	691	11.8%	44.0%	0.0%	126802	227760	354562.5	8.91	7.3	4890.9	17933	0.451	4.5	(6.4)	5.2	4.6	(0.7)	(0.5)	(1.2)	9.0	(0.7)	(2.4)	(3.1)	7.0	1.9	0.6	1.5	3.9	(4.0)	(2.0)	(6.0)	0.0	(2.1)	8.1	8.1	7.3	4.5	9.1	20.8	C-69-144	21.2	17.8	23.3
C-4B-144	23.65	1134	2985	2004	2000	600	2222	19979	241	0	354	5.6%	50.2%	0.0%	131576	217222	348798.5	8.76	8.5	5230	19177	0.482	3.7	(6.7)	4.1	3.8	0.0	(0.9)	(0.9)	10.0	(0.6)	(3.0)	(3.7)	5.7	0.9	0.8	1.4	3.1	(4.0)	(2.0)	(6.0)	0.0	(3.0)	7.4	7.6	8.5	3.4	8.1	20.0	C-4B-144	22.2	16.0	21.7
C-96-155	8.80	2574	1635	2504	2500	600	8169	11607	146	0	1165	20.5%	29.2%	0.0%	119279	248530	367808.6	9.24	4.4	3859.3	14151	0.356	6.6	(6.6)	4.8	6.2	(2.1)	0.0	(2.1)	6.0	(2.1)	(0.9)	(3.0)	7.1	3.2	0.3	0.8	4.3	(5.0)	(2.5)	(7.5)	0.0	(3.2)	7.2	6.9	4.4	6.7	6.9	18.0	C-96-155	16.1	18.9	19.1
C-78-155	8.28	1998	2175	2504	2500	600	4821	14957	148	0	708	12.1%	37.6%	0.0%	125381	233789	359169.6	9.02	6.3	4294.3	15746	0.396	5.7	(6.8)	3.7	5.3	(1.2)	(0.2)	(1.5)	8.2	(0.7)	(1.8)	(2.5)	8.3	1.9	0.5	0.8	3.3	(5.0)	(2.5)	(7.5)	0.0	(4.3)	6.2	7.0	6.3	5.4	7.1	18.8	C-78-155	18.8	17.8	19.8
C-5A-155	8.78	1422	2715	2504	2500	600	2403	17442	286	4	380	6.0%	43.8%	0.0%	131484	224038	355521.6	8.93	7.0	4651.1	17054	0.428	5.0	(7.1)	2.6	4.5	(0.3)	(0.7)	(1.0)	9.8	(0.6)	(2.4)	(3.0)	7.2	1.0	0.7	1.6	3.3	(5.0)	(2.5)	(7.5)	0.0	(4.2)	6.2	7.1	7.0	4.3	7.3	18.6	C-5A-155	19.6	16.3	19.9
O-5B-133	15.61	1422	2985	1504	1500	600	3252	21358	313	0	489	8.2%	53.7%	0.0%	134793	215675	350468.3	8.80	8.1	5657.9	20746	0.521	2.8	(6.3)	5.6	3.4	(0.3)	(0.9)	(1.2)	9.1	(0.5)	(3.4)	(3.9)	5.3	1.3	0.8	1.8	3.9	(3.0)	(1.5)	(4.5)	0.0	(0.6)	9.4	8.5	8.1	2.8	9.9	20.8	O-5B-133	22.2	15.8	24.3
O-78-144	20.62	1998	2175	2004	2000	600	6558	15618	192	0	943	16.5%	39.2%	0.0%	123750	235762	359512.5	9.03	6.2	4645	17032	0.428	5.0	(6.3)	5.8	5.1	(1.2)	(0.2)	(1.5)	8.2	(1.4)	(1.9)	(3.3)	6.6	2.4	0.5	1.1	4.0	(4.0)	(2.0)	(6.0)	0.0	(2.0)	8.2	7.9	6.2	5.2	8.7	20.0	O-78-144	19.4	18.2	22.4
O-69-144	22.47	1710	2445	2004	2000	600	4705	17501	256	0	691	11.8%	44.0%	0.0%	126802	227760	354562.5	8.91	7.3	4890.9	17933	0.451	4.5	(6.4)	5.2	4.6	(0.7)	(0.5)	(1.2)	9.0	(0.7)	(2.4)	(3.1)	7.0	1.9	0.6	1.5	3.9	(4.0)	(2.0)	(6.0)	0.0	(2.1)	8.1	8.1	7.3	4.5	9.1	20.8	O-69-144	21.2	17.8	23.3
O-5A-144	23.06	1422	2715	2004	2000	600	3370	18776	121	0	507	8.5%	47.2%	0.0%	129853	221595	351448.5	8.83	7.9	5054	18531	0.466	4.1	(6.6)	4.7	4.2	(0.3)	(0.7)	(1.0)	9.8	(0.5)	(2.7)	(3.2)	6.7	1.3	0.7	0.7	2.7	(4.0)	(2.0)	(6.0)	0.0	(3.3)	7.1	7.5	7.9	3.9	8.1	19.9	O-5A-144	21.5	16.7	21.6
O-79-143	11.43	1998	2445	2004	1500	600	5356	17555	296	0	776	13.5%	44.1%	0.0%	128691	229320	358011.3	8.99	6.5	4974.6	18240	0.458	4.3	(6.3)	5.6	4.5	(1.2)	(0.5)	(1.7)	7.5	(0.9)	(2.4)	(3.3)	6.5	2.1	0.6	1.7	4.4	(4.0)	(1.5)	(5.5)	0.0	(1.1)	9.0	8.2	6.5	4.4	9.3	20.1	O-79-143	19.9	17.3	23.2
O-6A-143	10.15	1710	2715	2004	1500	600	3786	19077	188	0	562	9.5%	47.9%	0.0%	131742	222285	354027.3	8.89	7.4	5171.2	18961	0.476	3.9	(6.5)	5.1	4.1	(0.7)	(0.7)	(1.4)	8.3	(0.4)	(2.8)	(3.2)	6.7	1.5	0.7	1.1	3.3	(4.0)	(1.5)	(5.5)	0.0	(2.2)	8.0	7.8	7.4	3.8	8.5	19.6	O-6A-143	20.6	16.3	22.0
O-5B-143	9.44	1422	2985	2004	1500	600	2629	20261	243	0	407	6.6%	50.9%	0.0%	134793	217657	352450.3	8.85	7.7	5338	19573	0.492	3.5	(6.6)	4.5	3.7	(0.3)	(0.9)	(1.2)	9.1	(0.6)	(3.1)	(3.7)	5.7	1.0	0.8	1.4	3.2	(4.0)	(1.5)	(5.5)	0.0	(2.3)	8.0	7.7	7.7	3.2	8.4	19.3	O-5B-143	20.8	15.5	21.7
O-79-134	9.16	1998	2445	1504	2000	600	6210	17643	153	0	897	15.6%	44.3%	0.0%	130321	229857	360178.5	9.05	6.0	5096.4	18687	0.469	4.0	(6.3)	5.7	4.4	(1.2)	(0.5)	(1.7)	7.5	(1.2)	(2.4)	(3.7)	5.8	2.4	0.6	0.9	3.9	(3.0)	(2.0)	(5.0)	0.0	(1.1)	9.0	8.0	6.0	4.1	9.0	19.1	O-79-134	18.7	16.4	22.2
O-6A-134	8.98	1710	2715	1504	2000	600	4320	19565	232	0	634	10.9%	49.2%	0.0%	133372	221260	354632.5	8.91	7.2	5342	19587	0.492	3.5	(6.5)	5.1	3.8	(0.7)	(0.7)	(1.4)	8.3	(0.5)	(2.9)	(3.5)	6.2	1.7	0.7	1.3	3.7	(3.0)	(2.0)	(5.0)	0.0	(1.3)	8.9	8.2	7.2	3.4	9.3	19.9	O-6A-134	20.6	16.0	23.1
O-5B-134	9.68	1422	2985	1504	2000	600	2810	21044	155	0	432	7.1%	52.9%	0.0%	136423	214813	351236.5	8.82	8.0	5537.7	20305	0.510	3.1	(6.6)	4.6	3.4	(0.3)	(0.9)	(1.2)	9.1	(0.6)	(3.3)	(3.9)	5.3	1.1	0.8	0.9	2.8	(3.0)	(2.0)	(5.0)	0.0	(2.2)	8.0	7.7	8.0	2.8	8.3	19.1	O-5B-134	21.0	14.8	21.5
O-87-154	12.27	2286	1905	2504	2000	600	6946	13560	248	0	990	17.5%	34.1%	0.0%	120699	241631	362330.5	9.10	5.6	4186.3	15350	0.386	5.9	(6.4)	5.2	5.8	(1.7)	(0.0)	(1.7)	7.4	(1.5)	(1.4)	(2.9)	7.4	2.8	0.4	1.4	4.6	(5.0)	(2.0)	(7.0)	0.0	(2.4)	7.8	7.7	5.6	6.1	8.3	19.9	O-87-154	18.6	19.3	21.9
O-78-154	14.84	1998	2175	2504	2000	600	5264	15213	172	0	766	13.2%	38.2%	0.0%	123750	234450	358200.5	9.00	6.5	4403.8	16147	0.406	5.5	(6.6)	4.7	5.3	(1.2)	(0.2)	(1.5)	8.2	(0.9)	(1.8)	(2.7)	7.8	2.1	0.5	1.0	3.6	(5.0)	(2.0)	(7.0)	0.0	(3.4)	6.9	7.4	6.5	5.4	7.7	19.6	O-78-154	19.5	18.3	21.0
O-69-154	13.90	1710	2445	2504	2000	600	3976	16499	172	0	590	10.0%	41.4%	0.0%	126802	228884	355686.5	8.94	7.0	4576.3	16780	0.422	5.1	(6.7)	4.1	4.9	(0.7)	(0.5)	(1.2)	9.0	(0.4)	(2.1)	(2.6)	8.2	1.6	0.6	1.0	3.2	(5.0)	(2.0)	(7.0)	0.0	(3.9)	6.6	7.4	7.0	4.9	7.7	19.6	O-69-154	20.2	17.6	21.1
O-87-145	13.28	2286	1905	2004	2500	600	7825	13623	93	0	1119	19.7%	34.2%	0.0%	122330	242567	364896.6	9.17	5.0	4309.3	15801	0.397	5.7	(6.4)	5.3	5.6	(1.7)	(0.0)	(1.7)	7.4	(1.9)	(1.4)	(3.4)	6.4	2.8	0.4	0.5	3.7	(4.0)	(2.5)	(6.5)	0.0	(2.8)	7.5	7.3	5.0	5.8	7.6	18.4	O-87-145	17.1	18.0	20.1
O-78-145	13.39	1998	2175	2004	2500	600	5879	15602	169	0	852	14.8%	39.2%	0.0%	125381	233999	359379.6	9.03	6.2	4565.2	16739	0.421	5.1	(6.6)	4.8	5.1	(1.2)	(0.2)	(1.5)	8.2	(1.1)	(1.9)	(3.0)	7.1	2.3	0.5	1.0	3.8	(4.0)	(2.5)	(6.5)	0.0	(2.7)	7.6	7.6	6.2	5.1	8.2	19.5	O-78-145	19.1	17.8	21.5
O-69-145	13.91	1710	2445	2004	2500	600	4205	17255	130	0	624	10.6%	43.3%	0.0%	128433	226594	355026.6	8.92	7.2	4778.7	17522	0.440	4.7	(6.7)	4.2	4.6	(0.7)	(0.5)	(1.2)	9.0	(0.5)	(2.3)	(2.8)	7.6	1.7	0.6	0.7	3.0	(4.0)	(2.5)	(6.5)	0.0	(3.5)	6.9	7.4	7.2	4.4	7.9	19.5	O-69-145	20.3	17.0	21.1
																		9.75				0.6		(5.2)					(0.9)				(1.7)										0.0			10.0	8.6	8.6					
																		8.59				0.2		(7.8)					(4.0)				(6.3)										(11.2)			0.0	1.4	3.2					

Scenario A: Summary

				Capacity (MW)						Energy (GWh)					kWh (%)			Generation cost				CO2 emission	
Demand (MW)	Demand (GWh)	Year	LOLE	LNG	Coal	Wind	Solar	Back-up GT	PSPP	LNG	Coal	PSPP	Surplus	LNG (kton)	LNG	Coal	Surplus	Fixed cost	Fuel cost	Total	Cost USC/kWh	kton-CO2	kg/kWh
2369	13912	2016	16.87	0	825	124	0		0	0	5540	0	0	0	0.0%	39.8%	0.0%	52095	85696	137791	9.9	6755	0.486
2491	14782	2017	12.45	0	825	134	40		0	0	5577	0	0	0	0.0%	37.7%	0.0%	54263	103207	157470	10.7	7172	0.485
2639	15811	2018	24.71	0	825	184	60		0	0	5576	0	0	0	0.0%	35.3%	0.0%	57322	114328	171650	10.9	7293	0.461
2798	16911	2019	16.42	0	825	234	80		0	0	5578	0	0	0	0.0%	33.0%	0.0%	61615	143279	204894	12.1	7701	0.455
2955	18010	2020	9.03	0	825	264	100		0	0	5578	0	0	0	0.0%	31.0%	0.0%	66398	171071	237469	13.2	8105	0.450
3112	19108	2021	26.41	576	825	294	140		0	3961	5578	0	0	550	20.7%	29.2%	0.0%	66398	130862	197260	10.3	8136	0.426
3267	20205	2022	23.38	1007	1095	324	180		0	4421	7571	0	0	642	21.9%	37.5%	0.0%	72834	97143	169977	8.4	8976	0.444
3422	21302	2023	21.52	1170	1365	354	220		0	3466	9402	0	0	515	16.3%	44.1%	0.0%	78081	100561	178642	8.4	10209	0.479
3577	22397	2024	11.80	1170	1635	384	260		0	2666	11073	0	0	401	11.9%	49.4%	0.0%	84651	103901	188552	8.4	11355	0.507
3730	23492	2025	9.45	1170	1905	414	300		0	1947	12571	0	16	315	8.3%	53.5%	0.1%	90742	109179	199921	8.5	12447	0.530
3883	24586	2026	26.42	1170	1905	444	350		0	2519	12835	0	1	383	10.2%	52.2%	0.0%	90742	116966	207708	8.4	12877	0.524
4035	25679	2027	13.25	1170	2175	474	400		0	1909	14322	0	15	311	7.4%	55.8%	0.1%	97313	121966	219279	8.5	14003	0.545
4187	26771	2028	15.43	1170	2175	504	450		0	2421	14646	0	1	372	9.0%	54.7%	0.0%	97313	129755	227068	8.5	14459	0.540
4333	27862	2029	6.15	1170	2445	534	500		0	1784	16147	0	6	296	6.4%	58.0%	0.0%	103883	134621	238504	8.6	15583	0.559
4505	28952	2030	11.36	1170	2445	564	550		0	2217	16447	0	1	348	7.7%	56.8%	0.0%	104307	143002	247309	8.5	15991	0.552
4677	30041	2031	25.26	1170	2445	594	600		0	2557	16970	0	0	388	8.5%	56.5%	0.0%	104307	149646	253953	8.5	16555	0.551
4849	31130	2032	8.93	1170	2715	624	700	100	0	1868	18503	0	2	307	6.0%	59.4%	0.0%	111529	153829	265358	8.5	17687	0.568
5021	32217	2033	5.79	1134	2985	654	800	100	0	1426	19772	0	14	255	4.4%	61.4%	0.0%	120068	158647	278715	8.7	18680	0.580
5193	33304	2034	11.07	1134	2985	704	900	200	0	1691	20229	0	4	286	5.1%	60.7%	0.0%	120720	165636	286356	8.6	19166	0.575
5365	34390	2035	18.08	1134	2985	754	1000	200	0	2007	20526	0	2	324	5.8%	59.7%	0.0%	121143	173378	294521	8.6	19536	0.568
5536	35475	2036	8.40	1134	3255	804	1100	300	0	1511	21814	0	12	265	4.3%	61.5%	0.0%	128365	178200	306565	8.6	20523	0.579
5708	36559	2037	15.18	1134	3255	854	1200	300	0	1814	22231	0	5	301	5.0%	60.8%	0.0%	128365	185344	313709	8.6	20990	0.574
5879	37642	2038	7.33	1134	3525	904	1300	400	0	1409	23385	0	27	253	3.7%	62.1%	0.1%	135588	190645	326233	8.7	21901	0.582
6051	38724	2039	12.73	1134	3525	954	1400	400	0	1663	23888	0	11	283	4.3%	61.7%	0.0%	135256	197518	332774	8.6	22419	0.579
6222	39805	2040	23.47	1134	3525	1004	1500	500	0	1945	24215	0	6	316	4.9%	60.8%	0.0%	136332	205221	341553	8.6	22799	0.573

Scenario A: Capacity (kW) balance

(MW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640
Conventional	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640
PSPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thermal	1906	2076	2030	2283	2541	2541	2641	2761	3031	3206	3206	3476	3476	3746	3746	3746	4116	4350	4450	4450	4820	4820	5190	5164	5264
Oil	1081	1251	1205	1458	1716	1140	539	226	226	131	131	131	131	131	131	131	231	231	331	331	431	431	531	505	605
small GT	65	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	140	140	140	70	70	70	70	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	115	115	115	115	115	115	115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	51	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	161	161	161	161	161	161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	270	270	270	270	270	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	30	30	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	0	0
CEB Barge power	60	60	60	60	60	60	60	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	170	170	170	170	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	70	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
New CC	0	0	0	288	576	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	200	200	300	300	400	400	500
LNG	0	0	0	0	0	576	1007	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170	1134	1134	1134	1134	1134	1134	1134	1134
KPS CC (LNG)	0	0	0	0	0	0	161	161	161	161	161	161	161	161	161	161	161	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	163	163	163	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
New LNG	0	0	0	0	0	576	576	576	576	576	576	576	576	576	576	576	576	864	864	864	864	864	864	864	864
Coal	825	825	825	825	825	825	1095	1365	1635	1905	1905	2175	2175	2445	2445	2445	2715	2985	2985	2985	3255	3255	3525	3525	3525
Puttalam	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825
New Coal	0	0	0	0	0	0	270	540	810	1080	1080	1350	1350	1620	1620	1620	1890	2160	2160	2160	2430	2430	2700	2700	2700
NCRE	471	541	631	721	791	881	971	1061	1151	1261	1361	1461	1561	1661	1781	1871	2011	2151	2311	2491	2651	2811	2971	3131	3311
M-hydro	323	343	363	383	403	423	443	463	483	503	523	543	563	583	603	613	623	633	643	653	663	673	683	693	703
Wind	124	134	184	234	264	294	324	354	384	414	444	474	504	534	564	594	624	654	704	754	804	854	904	954	1004
Solar	0	40	60	80	100	140	180	220	260	300	350	400	450	500	550	600	700	800	900	1000	1100	1200	1300	1400	1500
Biomass	24	24	24	24	24	24	24	24	24	44	44	44	44	44	64	64	64	64	64	84	84	84	84	84	104
Total	3751	3991	4190	4533	4876	4966	5252	5462	5822	6107	6207	6577	6677	7047	7167	7257	7767	8141	8401	8581	9111	9271	9801	9935	10215

(GW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	0.8	0.8	0.8	0.8	0.8	0.8	1.1	1.4	1.6	1.9	1.9	2.2	2.2	2.4	2.4	2.4	2.7	3.0	3.0	3.0	3.3	3.3	3.5	3.5	3.5
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Oil	1.1	1.3	1.2	1.5	1.7	1.1	0.5	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	1.7	1.7	1.9	1.9	1.9	2.0	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Wind	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0
Solar	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	3.8	4.0	4.2	4.5	4.9	5.0	5.3	5.5	5.8	6.1	6.2	6.6	6.7	7.0	7.2	7.3	7.8	8.1	8.4	8.6	9.1	9.3	9.8	9.9	10.2

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	22.0%	20.7%	19.7%	18.2%	16.9%	16.6%	20.8%	25.0%	28.1%	31.2%	30.7%	33.1%	32.6%	34.7%	34.1%	33.7%	35.0%	36.7%	35.5%	34.8%	35.7%	35.1%	36.0%	35.5%	34.5%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	11.6%	19.2%	21.4%	20.1%	19.2%	18.8%	17.8%	17.5%	16.6%	16.3%	16.1%	15.1%	13.9%	13.5%	13.2%	12.4%	12.2%	11.6%	11.4%	11.1%
Oil	28.8%	31.3%	28.8%	32.2%	35.2%	23.0%	10.3%	4.1%	3.9%	2.1%	2.1%	2.0%	2.0%	1.9%	1.8%	1.8%	3.0%	2.8%	3.9%	3.9%	4.7%	4.6%	5.4%	5.1%	5.9%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydro	45.2%	43.0%	45.2%	42.2%	39.9%	39.6%	39.7%	38.5%	36.5%	35.1%	34.8%	33.2%	33.0%	31.5%	31.3%	31.0%	29.1%	27.9%	27.2%	26.7%	25.3%	24.9%	23.7%	23.5%	22.9%
Wind	3.3%	3.4%	4.4%	5.2%	5.4%	5.9%	6.2%	6.5%	6.6%	6.8%	7.2%	7.2%	7.5%	7.6%	7.9%	8.2%	8.0%	8.0%	8.4%	8.8%	8.8%	9.2%	9.2%	9.6%	9.8%
Solar	0.0%	1.0%	1.4%	1.8%	2.1%	2.8%	3.4%	4.0%	4.5%	4.9%	5.6%	6.1%	6.7%	7.1%	7.7%	8.3%	9.0%	9.8%	10.7%	11.7%	12.1%	12.9%	13.3%	14.1%	14.7%
Biomass	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.7%	0.7%	0.7%	0.7%	0.6%	0.9%	0.9%	0.8%	0.8%	0.8%	1.0%	0.9%	0.9%	0.9%	0.8%	1.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario A: Energy (kWh) balance

(million kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307
Conventional	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307
PSPP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thermal	8008	8715	8895	9714	10565	11451	11994	12868	13739	14518	15354	16231	17067	17931	18664	19527	20374	21201	21926	22539	23334	24054	24806	25563	26175
Oil	2468	3138	3319	4136	4987	1912	2	0	0	0	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	428	477	518	393	272	319	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	878	1079	1098	958	960	748	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	1152	1429	1451	956	159	824	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	8	51	68	6	35	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	102	182	15	39	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	1808	3522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15
LNG	0	0	0	0	0	3961	4421	3466	2666	1947	2519	1909	2421	1784	2217	2557	1868	1426	1691	2007	1511	1814	1409	1663	1945
KPS CC (LNG)	0	0	0	0	0	0	246	191	33	9	27	18	26	9	30	22	23	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	706	357	18	0	18	0	18	0	8	28	0	0	0	0	0	0	0	0	0
New LNG	0	0	0	0	0	3961	3469	2918	2615	1938	2474	1891	2377	1775	2179	2507	1845	1426	1691	2007	1511	1814	1409	1663	1945
Coal	5540	5577	5576	5578	5578	5578	7571	9402	11073	12571	12835	14322	14646	16147	16447	16970	18503	19772	20229	20526	21814	22231	23385	23888	24215
Puttalam	5540	5577	5576	5578	5578	5578	5560	5411	5284	5146	5230	5114	5189	5079	5140	5270	5142	4879	5053	5175	4919	5071	4831	4968	5086
New Coal	0	0	0	0	0	0	2011	3991	5789	7425	7605	9208	9457	11068	11307	11700	13361	14893	15176	15351	16895	17160	18554	18920	19129
NCRE	1575	1737	2016	2295	2491	2703	2905	3127	3350	3682	3924	4156	4398	4630	4982	5185	5455	5725	6082	6549	6856	7213	7569	7876	8343
M-hydro	1074	1141	1207	1273	1340	1406	1473	1539	1606	1672	1738	1805	1871	1938	2004	2038	2071	2104	2138	2171	2204	2238	2271	2304	2337
Wind	341	378	563	748	849	951	1052	1154	1255	1356	1458	1559	1661	1762	1864	1965	2067	2168	2353	2538	2676	2861	3046	3183	3368
Solar	0	55	83	110	138	193	248	303	358	413	487	551	624	689	762	827	965	1103	1240	1378	1516	1654	1792	1929	2067
Biomass	160	163	163	164	164	153	132	131	131	241	241	241	242	241	352	355	352	350	351	462	460	460	460	460	571
Total	13913	14782	15813	16911	18010	19108	20206	21302	22396	23507	24585	25694	26772	27868	28953	30019	31136	32233	33315	34395	35497	36574	37682	38746	39825
Surplus	0	0	0	0	0	0	0	0	0	16	1	15	1	6	1	0	2	14	4	2	12	5	27	11	6
Shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	(22)	(1)	0	0	(3)	0	0	0	0	(1)
Pumping-up	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(TWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	5.5	5.6	5.6	5.6	5.6	5.6	7.6	9.4	11.1	12.6	12.8	14.3	14.6	16.1	16.4	17.0	18.5	19.8	20.2	20.5	21.8	22.2	23.4	23.9	24.2
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	4.0	4.4	3.5	2.7	1.9	2.5	1.9	2.4	1.8	2.2	2.6	1.9	1.4	1.7	2.0	1.5	1.8	1.4	1.7	1.9
Oil	2.5	3.1	3.3	4.1	5.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	5.4	5.5	6.1	6.2	6.3	6.4	6.8	6.8	6.9	7.0	7.0	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6
Wind	0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.7	2.9	3.0	3.2	3.4
Solar	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	1.9	2.1
Biomass	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6
Total	13.9	14.8	15.8	16.9	18.0	19.1	20.2	21.3	22.4	23.5	24.6	25.7	26.8	27.9	29.0	30.0	31.1	32.2	33.3	34.4	35.5	36.6	37.7	38.7	39.8

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	39.8%	37.7%	35.3%	33.0%	31.0%	29.2%	37.5%	44.1%	49.4%	53.5%	52.2%	55.7%	54.7%	57.9%	56.8%	56.5%	59.4%	61.3%	60.7%	59.7%	61.5%	60.8%	62.1%	61.7%	60.8%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	20.7%	21.9%	16.3%	11.9%	8.3%	10.2%	7.4%	9.0%	6.4%	7.7%	8.5%	6.0%	4.4%	5.1%	5.8%	4.3%	5.0%	3.7%	4.3%	4.9%
Oil	17.7%	21.2%	21.0%	24.5%	27.7%	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Hydro	38.8%	37.0%	38.6%	36.5%	34.9%	33.3%	33.6%	32.1%	30.9%	29.7%	28.7%	27.7%	26.8%	26.0%	25.3%	24.5%	23.7%	23.0%	22.3%	21.7%	21.2%	20.6%	20.1%	19.6%	19.2%
Wind	2.5%	2.6%	3.6%	4.4%	4.7%	5.0%	5.2%	5.4%	5.6%	5.8%	5.9%	6.1%	6.2%	6.3%	6.4%	6.5%	6.6%	6.7%	7.1%	7.4%	7.5%	7.8%	8.1%	8.2%	8.5%
Solar	0.0%	0.4%	0.5%	0.7%	0.8%	1.0%	1.2%	1.4%	1.6%	1.8%	2.0%	2.1%	2.3%	2.5%	2.6%	2.8%	3.1%	3.4%	3.7%	4.0%	4.3%	4.5%	4.8%	5.0%	5.2%
Biomass	1.2%	1.1%	1.0%	1.0%	0.9%	0.8%	0.7%	0.6%	0.6%	1.0%	1.0%	0.9%	0.9%	0.9%	1.2%	1.2%	1.1%	1.1%	1.1%	1.3%	1.3%	1.3%	1.2%	1.2%	1.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario A: Fuel balance

(million USC)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	67952	84344	93448	120373	146767	105081	69978	71833	73609	76269	82382	85762	91874	95124	100766	106007	108395	111402	115953	120193	122942	127644	130511	135296	139501
Oil	44300	60208	68971	95544	121593	49815	45	0	0	0	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	6461	7910	9402	7582	5636	6932	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	13648	18358	20309	19055	20543	16895	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	24034	31163	34296	26032	4800	25488	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	26	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	131	913	1314	135	794	114	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	1864	3619	313	896	386	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	42427	88924	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300
LNG	0	0	0	0	0	29867	35642	29230	23190	18615	23096	19112	23273	18900	22597	25300	20084	16745	18886	21464	17629	20129	16941	19073	21389
KPS CC (LNG)	0	0	0	0	0	0	2060	1674	296	87	251	172	247	88	301	220	231	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	6252	3290	169	0	176	0	176	0	84	283	0	0	0	0	0	0	0	0	0
New LNG	0	0	0	0	0	29867	27330	24266	22725	18528	22669	18940	22850	18812	22212	24797	19853	16745	18886	21464	17629	20129	16941	19073	21389
Coal	23652	24136	24477	24829	25174	25399	34291	42603	50419	57654	59286	66650	68601	76224	78169	80707	88251	94597	96947	98609	105133	107335	113330	115983	117812
Puttalam	23652	24136	24477	24829	25174	25399	25557	25111	24756	24338	24947	24619	25179	24868	25375	26075	25544	24350	25274	25938	24778	25591	24499	25245	25894
New Coal	0	0	0	0	0	0	8734	17492	25663	33316	34339	42031	43422	51356	52794	54632	62707	70247	71673	72671	80355	81744	88831	90738	91918
NCRE	18508	19639	21656	23689	25087	26496	27764	29315	30879	33997	35670	37292	38979	40585	43826	45249	47026	48819	51271	55276	57334	59773	62211	64297	68303
M-hydro	11467	11950	12433	12916	13399	13882	14365	14848	15331	15814	16297	16780	17263	17746	18229	18471	18713	18956	19198	19440	19682	19925	20167	20409	20652
Wind	4782	5056	6425	7795	8545	9296	10047	10798	11548	12299	13050	13801	14552	15302	16053	16804	17555	18306	19675	21044	22061	23430	24799	25816	27185
Solar	0	331	496	662	827	1158	1488	1819	2150	2481	2920	3308	3747	4134	4574	4961	5788	6615	7442	8269	9096	9923	10750	11577	12403
Biomass	2259	2302	2302	2316	2316	2160	1864	1850	1850	3403	3403	3403	3417	3403	4970	5013	4970	4942	4956	6523	6495	6495	6495	6495	8063
Total	86460	103983	115104	144062	171854	131577	97742	101148	104488	110266	118052	123054	130853	135709	144592	151256	155421	160221	167224	175469	180276	187417	192722	199593	207804

(USC/kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	8.5	9.7	10.5	12.4	13.9	9.2	5.8	5.6	5.4	5.3	5.4	5.3	5.4	5.3	5.4	5.4	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Oil	17.9	19.2	20.8	23.1	24.4	26.1	22.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
small GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sapugaskanda	15.1	16.6	18.2	19.3	20.7	21.7	22.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GT No.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asia Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS CC	15.5	17.0	18.5	19.9	21.4	22.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AES CC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC	20.9	21.8	23.6	27.2	30.2	30.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern power	13.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uthurujanani	16.4	17.9	19.3	22.5	22.7	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEB Barge power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Furnace oil	0.0	18.3	19.9	20.9	23.0	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New CC	0.0	0.0	0.0	23.5	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LNG	0.0	0.0	0.0	0.0	0.0	7.5	8.1	8.4	8.7	9.6	9.2	10.0	9.6	10.6	10.2	9.9	10.8	11.7	11.2	10.7	11.7	11.1	12.0	11.5	11.0
KPS CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	8.4	8.8	9.0	9.7	9.3	9.6	9.5	9.8	10.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS-2 CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	8.9	9.2	9.4	0.0	9.8	0.0	9.8	0.0	10.5	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New LNG	0.0	0.0	0.0	0.0	0.0	7.5	7.9	8.3	8.7	9.6	9.2	10.0	9.6	10.6	10.2	9.9	10.8	11.7	11.2	10.7	11.7	11.1	12.0	11.5	11.0
Coal	4.3	4.3	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.9	4.9
Puttalam	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.8	4.8	4.9	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1
New Coal	0.0	0.0	0.0	0.0	0.0	0.0	4.3	4.4	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8
NCRE	11.8	11.3	10.7	10.3	10.1	9.8	9.6	9.4	9.2	9.2	9.1	9.0	8.9	8.8	8.8	8.7	8.6	8.5	8.4	8.4	8.4	8.3	8.2	8.2	8.2
M-hydro	10.7	10.5	10.3	10.1	10.0	9.9	9.8	9.6	9.5	9.5	9.4	9.3	9.2	9.2	9.1	9.1	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.8
Wind	14.0	13.4	11.4	10.4	10.1	9.8	9.6	9.4	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.6	8.5	8.4	8.4	8.3	8.2	8.2	8.1	8.1	8.1
Solar	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Biomass	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
Total	6.2	7.0	7.3	8.5	9.5	6.9	4.8	4.7	4.7	4.7	4.8	4.8	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.2	5.2

Scenario B: Summary

				Capacity (MW)						Energy (GWh)					kWh (%)			Generation cost				CO2 emission	
Demand (MW)	Demand (GWh)	Year	LOLE	LNG	Coal	Wind	Solar	Back-up GT	PSPP	LNG	Coal	PSPP	Surplus	LNG (kton)	LNG	Coal	Surplus	Fixed cost	Fuel cost	Total	Cost USC/kWh	kton-CO2	kg/kWh
2369	13912	2016	16.87	0	825	124	0		0	0	5540	0	0	0	0.0%	39.8%	0.0%	52095	85696	137791	9.9	6755	0.486
2491	14782	2017	12.45	0	825	134	40		0	0	5577	0	0	0	0.0%	37.7%	0.0%	54263	103207	157470	10.7	7172	0.485
2639	15811	2018	24.27	0	825	184	90		0	0	5578	0	0	0	0.0%	35.3%	0.0%	57322	113571	170893	10.8	7264	0.459
2798	16911	2019	15.36	0	825	234	140		0	0	5578	0	0	0	0.0%	33.0%	0.0%	61615	142133	203748	12.0	7654	0.453
2955	18010	2020	8.04	0	825	304	190		0	0	5578	0	0	0	0.0%	31.0%	0.0%	66398	166163	232561	12.9	7930	0.440
3112	19108	2021	19.18	576	825	404	240		0	3864	5578	0	0	538	20.2%	29.2%	0.0%	66398	121964	188362	9.9	7842	0.410
3267	20205	2022	17.19	1295	825	504	290		0	5648	5577	0	0	806	28.0%	27.6%	0.0%	71111	103001	174112	8.6	7709	0.382
3422	21302	2023	15.25	1746	825	604	340		0	6277	5577	0	0	887	29.5%	26.2%	0.0%	74636	112184	186820	8.8	7956	0.373
3577	22397	2024	36.96	1746	825	704	400		0	6881	5577	0	0	971	30.7%	24.9%	0.0%	74636	121798	196434	8.8	8212	0.367
3730	23492	2025	24.49	2034	825	804	500		0	7323	5577	0	0	1036	31.2%	23.7%	0.0%	77676	131857	209533	8.9	8411	0.358
3883	24586	2026	11.10	2322	825	1004	600		0	7536	5577	0	0	1065	30.7%	22.7%	0.0%	81195	141434	222629	9.1	8499	0.346
4035	25679	2027	13.82	2322	825	1204	700		200	7748	5577	1	0	1099	30.2%	21.7%	0.0%	83446	151305	234751	9.1	8603	0.335
4187	26771	2028	6.81	2322	825	1404	800	100	400	7961	5577	5	0	1128	29.7%	20.8%	0.0%	86024	161014	247038	9.2	8691	0.325
4333	27862	2029	7.88	2322	825	1604	900	100	600	8175	5577	9	0	1153	29.3%	20.0%	0.0%	88275	170518	258793	9.3	8768	0.315
4505	28952	2030	12.62	2322	825	1804	1000	200	600	8283	5575	25	0	1168	28.6%	19.3%	0.0%	89025	180474	269499	9.3	8811	0.304
4677	30041	2031	16.15	2322	825	2004	1100	200	600	8531	5576	47	0	1202	28.4%	18.6%	0.0%	89025	189172	278197	9.3	8917	0.297
4849	31130	2032	23.86	2322	825	2204	1200	300	600	8782	5574	71	0	1239	28.2%	17.9%	0.0%	89351	198163	287514	9.2	9028	0.290
5021	32217	2033	41.74	2286	825	2404	1300	300	600	9035	5572	90	0	1277	28.0%	17.3%	0.0%	89990	207130	297120	9.2	9141	0.284
5193	33304	2034	19.15	2574	825	2604	1400	400	600	9276	5574	108	0	1308	27.9%	16.7%	0.0%	93835	215750	309585	9.3	9238	0.277
5365	34390	2035	25.34	2574	825	2804	1500	400	600	9418	5572	138	0	1330	27.4%	16.2%	0.0%	94259	224746	319005	9.3	9303	0.271
5536	35475	2036	9.92	2862	825	3004	1600	500	600	9679	5567	176	0	1363	27.3%	15.7%	0.0%	98104	233439	331543	9.3	9398	0.265
5708	36559	2037	17.15	2862	825	3204	1700	500	600	9936	5555	201	1	1400	27.2%	15.2%	0.0%	98104	242430	340534	9.3	9501	0.260
5879	37642	2038	26.78	2862	825	3404	1800	600	600	10195	5551	217	11	1438	27.1%	14.7%	0.0%	98430	251497	349927	9.3	9613	0.255
6051	38724	2039	13.58	3150	825	3704	1900	600	600	10228	5472	221	66	1443	26.4%	14.1%	0.2%	101617	260496	362113	9.4	9558	0.247
6222	39805	2040	17.28	3150	825	4004	2000	700	600	10220	5432	159	261	1442	25.7%	13.6%	0.7%	102367	270393	372760	9.4	9518	0.239

Scenario B: Capacity (kW) balance

(MW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1840	2040	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240
Conventional	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640
PSPP	0	0	0	0	0	0	0	0	0	0	0	200	400	600	600	600	600	600	600	600	600	600	600	600	600
Thermal	1906	2076	2030	2283	2541	2541	2659	2797	2797	2990	3278	3278	3378	3378	3478	3478	3578	3542	3930	3930	4318	4318	4418	4680	4780
Oil	1081	1251	1205	1458	1716	1140	539	226	226	131	131	131	231	231	331	331	431	431	531	531	631	631	731	705	805
small GT	65	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	140	140	140	70	70	70	70	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	115	115	115	115	115	115	115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	51	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	161	161	161	161	161	161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	270	270	270	270	270	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	30	30	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	0	0
CEB Barge power	60	60	60	60	60	60	60	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	170	170	170	170	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	70	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
New CC	0	0	0	288	576	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	100	100	200	200	300	300	400	400	500	500	600	600	700
LNG	0	0	0	0	0	576	1295	1746	1746	2034	2322	2322	2322	2322	2322	2322	2322	2286	2574	2574	2862	2862	2862	3150	3150
KPS CC (LNG)	0	0	0	0	0	0	161	161	161	161	161	161	161	161	161	161	161	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	163	163	163	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
New LNG	0	0	0	0	0	576	864	1152	1152	1440	1728	1728	1728	1728	1728	1728	1728	2016	2304	2304	2592	2592	2592	2880	2880
Coal	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825
Puttalam	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825
New Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCRE	471	541	661	781	921	1091	1261	1431	1611	1851	2171	2491	2811	3131	3471	3781	4091	4401	4711	5041	5351	5661	5971	6381	6811
M-hydro	323	343	363	383	403	423	443	463	483	503	523	543	563	583	603	613	623	633	643	653	663	673	683	693	703
Wind	124	134	184	234	304	404	504	604	704	804	1004	1204	1404	1604	1804	2004	2204	2404	2604	2804	3004	3204	3404	3704	4004
Solar	0	40	90	140	190	240	290	340	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Biomass	24	24	24	24	24	24	24	24	24	44	44	44	44	44	64	64	64	64	64	84	84	84	84	84	104
Total	3751	3991	4220	4593	5006	5176	5560	5868	6048	6481	7089	7609	8229	8749	9189	9499	9909	10183	10881	11211	11909	12219	12629	13301	13831

(GW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	0.6	1.3	1.7	1.7	2.0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.6	2.6	2.9	2.9	2.9	3.2	3.2
Oil	1.1	1.3	1.2	1.5	1.7	1.1	0.5	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Hydro	1.7	1.7	1.9	1.9	1.9	2.0	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Wind	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.7	4.0
Solar	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	3.8	4.0	4.2	4.6	5.0	5.2	5.6	5.9	6.0	6.5	7.1	7.6	8.2	8.7	9.2	9.5	9.9	10.2	10.9	11.2	11.9	12.2	12.6	13.3	13.8

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	22.0%	20.7%	19.5%	18.0%	16.5%	15.9%	14.8%	14.1%	13.6%	12.7%	11.6%	10.8%	10.0%	9.4%	9.0%	8.7%	8.3%	8.1%	7.6%	7.4%	6.9%	6.8%	6.5%	6.2%	6.0%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	11.1%	23.3%	29.8%	28.9%	31.4%	32.8%	30.5%	28.2%	26.5%	25.3%	24.4%	23.4%	22.4%	23.7%	23.0%	24.0%	23.4%	22.7%	23.7%	22.8%
Oil	28.8%	31.3%	28.6%	31.7%	34.3%	22.0%	9.7%	3.9%	3.7%	2.0%	1.8%	1.7%	2.8%	2.6%	3.6%	3.5%	4.3%	4.2%	4.9%	4.7%	5.3%	5.2%	5.8%	5.3%	5.8%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%	4.9%	6.9%	6.5%	6.3%	6.1%	5.9%	5.5%	5.4%	5.0%	4.9%	4.8%	4.5%	4.3%
Hydro	45.2%	43.0%	44.8%	41.6%	38.9%	38.0%	37.5%	35.8%	35.1%	33.1%	30.5%	28.7%	26.8%	25.4%	24.4%	23.7%	22.8%	22.3%	21.0%	20.5%	19.3%	18.9%	18.4%	17.5%	16.9%
Wind	3.3%	3.4%	4.4%	5.1%	6.1%	7.8%	9.1%	10.3%	11.6%	12.4%	14.2%	15.8%	17.1%	18.3%	19.6%	21.1%	22.2%	23.6%	23.9%	25.0%	25.2%	26.2%	27.0%	27.8%	28.9%
Solar	0.0%	1.0%	2.1%	3.0%	3.8%	4.6%	5.2%	5.8%	6.6%	7.7%	8.5%	9.2%	9.7%	10.3%	10.9%	11.6%	12.1%	12.8%	12.9%	13.4%	13.4%	13.9%	14.3%	14.3%	14.5%
Biomass	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.7%	0.6%	0.6%	0.5%	0.5%	0.7%	0.7%	0.6%	0.6%	0.6%	0.7%	0.7%	0.7%	0.7%	0.6%	0.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario B: Energy (kWh) balance

(million kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5308	5312	5316	5332	5354	5378	5397	5415	5445	5483	5508	5524	5528	5466
Conventional	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307
PSPP	0	0	0	0	0	0	0	0	0	0	0	1	5	9	25	47	71	90	108	138	176	201	217	221	159
Thermal	8008	8715	8848	9631	10297	10938	11225	11854	12458	12900	13113	13325	13541	13755	13864	14113	14365	14616	14862	15002	15261	15506	15764	15718	15673
Oil	2468	3138	3270	4053	4719	1496	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15	15	18	18	21
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	428	477	516	400	168	314	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	878	1079	1091	891	944	613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	1152	1429	1425	950	69	496	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	8	51	70	5	14	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	102	166	13	26	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	1794	3498	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15	15	18	18	21
LNG	0	0	0	0	0	3864	5648	6277	6881	7323	7536	7748	7961	8175	8283	8531	8782	9035	9276	9418	9679	9936	10195	10228	10220
KPS CC (LNG)	0	0	0	0	0	0	156	28	150	16	0	10	14	14	60	66	89	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	410	73	138	9	0	0	0	23	21	31	103	20	8	17	0	0	8	0	0
New LNG	0	0	0	0	0	3864	5082	6176	6593	7298	7536	7738	7947	8138	8202	8434	8590	9015	9268	9401	9679	9936	10187	10228	10220
Coal	5540	5577	5578	5578	5578	5578	5577	5577	5577	5577	5577	5577	5577	5577	5575	5576	5574	5572	5574	5572	5567	5555	5551	5472	5432
Puttalam	5540	5577	5578	5578	5578	5578	5577	5577	5577	5577	5577	5577	5577	5577	5575	5576	5574	5572	5574	5572	5567	5555	5551	5472	5432
New Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCRE	1575	1737	2062	2378	2758	3216	3673	4142	4634	5284	6166	7047	7928	8808	9798	10647	11497	12342	13193	14153	14996	15848	16692	17876	19175
M-hydro	1074	1141	1207	1273	1340	1406	1473	1539	1606	1672	1738	1805	1871	1938	2004	2038	2071	2104	2138	2171	2204	2238	2271	2304	2337
Wind	341	378	563	748	988	1326	1664	2003	2341	2679	3356	4032	4709	5385	6062	6738	7415	8092	8768	9445	10121	10798	11474	12489	13504
Solar	0	55	128	193	266	331	404	469	555	692	830	968	1106	1244	1382	1519	1657	1795	1933	2071	2208	2346	2484	2622	2760
Biomass	160	163	164	164	164	153	132	131	132	241	242	242	242	241	350	352	354	351	354	466	463	466	463	461	574
Total	13913	14782	15812	16911	18009	19108	20205	21303	22399	23491	24586	25680	26781	27879	28994	30114	31240	32355	33470	34600	35740	36862	37980	39122	40314
Surplus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	11	66	261
Shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumping-up	0	0	0	0	0	0	0	0	0	0	0	(1)	(6)	(13)	(36)	(67)	(100)	(128)	(154)	(197)	(251)	(286)	(308)	(315)	(227)

(TWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	5.5	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.5	5.4
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	3.9	5.6	6.3	6.9	7.3	7.5	7.7	8.0	8.2	8.3	8.5	8.8	9.0	9.3	9.4	9.7	9.9	10.2	10.2	10.2
Oil	2.5	3.1	3.3	4.1	4.7	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Hydro	5.4	5.5	6.1	6.2	6.3	6.4	6.8	6.8	6.9	7.0	7.0	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6
Wind	0.3	0.4	0.6	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.4	4.0	4.7	5.4	6.1	6.7	7.4	8.1	8.8	9.4	10.1	10.8	11.5	12.5	13.5
Solar	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.3	2.5	2.6	2.8
Biomass	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6
Total	13.9	14.8	15.8	16.9	18.0	19.1	20.2	21.3	22.4	23.5	24.6	25.7	26.8	27.9	29.0	30.1	31.2	32.4	33.5	34.6	35.7	36.9	38.0	39.1	40.3

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	39.8%	37.7%	35.3%	33.0%	31.0%	29.2%	27.6%	26.2%	24.9%	23.7%	22.7%	21.7%	20.8%	20.0%	19.2%	18.5%	17.8%	17.2%	16.7%	16.1%	15.6%	15.1%	14.6%	14.0%	13.5%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	20.2%	28.0%	29.5%	30.7%	31.2%	30.7%	30.2%	29.7%	29.3%	28.6%	28.3%	28.1%	27.9%	27.7%	27.2%	27.1%	27.0%	26.8%	26.1%	25.4%
Oil	17.7%	21.2%	20.7%	24.0%	26.2%	7.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.2%	0.3%	0.3%	0.4%	0.5%	0.5%	0.6%	0.6%	0.4%
Hydro	38.8%	37.0%	38.6%	36.5%	34.9%	33.3%	33.6%	32.1%	30.9%	29.7%	28.7%	27.7%	26.8%	26.0%	25.2%	24.4%	23.6%	22.9%	22.2%	21.6%	21.0%	20.5%	20.0%	19.5%	19.0%
Wind	2.5%	2.6%	3.6%	4.4%	5.5%	6.9%	8.2%	9.4%	10.5%	11.4%	13.7%	15.7%	17.6%	19.3%	20.9%	22.4%	23.7%	25.0%	26.2%	27.3%	28.3%	29.3%	30.2%	31.9%	33.5%
Solar	0.0%	0.4%	0.8%	1.1%	1.5%	1.7%	2.0%	2.2%	2.5%	2.9%	3.4%	3.8%	4.1%	4.5%	4.8%	5.0%	5.3%	5.5%	5.8%	6.0%	6.2%	6.4%	6.5%	6.7%	6.8%
Biomass	1.2%	1.1%	1.0%	1.0%	0.9%	0.8%	0.7%	0.6%	0.6%	1.0%	1.0%	0.9%	0.9%	0.9%	1.2%	1.2%	1.1%	1.1%	1.1%	1.3%	1.3%	1.3%	1.2%	1.2%	1.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario B: Fuel balance

(million USC)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	67952	84344	92410	118732	140063	92579	70371	76183	82291	87486	90739	94289	97686	100881	103471	106081	108977	111892	114414	116266	118907	121795	124813	125245	125485
Oil	44300	60208	67927	93903	114889	37928	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300	300	360	360	420
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	6461	7910	9361	7725	3493	6835	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	13648	18358	20178	17731	20198	13888	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	24034	31163	33717	25917	2061	15460	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	26	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	131	913	1345	97	318	566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	1864	3295	272	614	1179	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	42161	88205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300	300	360	360	420
LNG	0	0	0	0	0	29252	44736	50323	56207	61176	64190	67515	70627	73599	75898	78423	81178	84022	86379	88162	90677	93541	96430	97167	97467
KPS CC (LNG)	0	0	0	0	0	0	1333	245	1322	144	0	91	132	138	607	675	903	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	3671	668	1279	83	0	0	0	223	209	319	1086	205	89	183	0	0	92	0	0
New LNG	0	0	0	0	0	29252	39732	49410	53606	60949	64190	67424	70495	73238	75082	77429	79189	83817	86290	87979	90677	93541	96338	97167	97467
Coal	23652	24136	24483	24829	25174	25399	25635	25860	26084	26310	26549	26774	26999	27222	27453	27538	27619	27690	27795	27864	27930	27954	28023	27718	27598
Puttalam	23652	24136	24483	24829	25174	25399	25635	25860	26084	26310	26549	26774	26999	27222	27453	27538	27619	27690	27795	27864	27930	27954	28023	27718	27598
New Coal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NCRE	18508	19639	21944	24185	26883	30101	33230	36589	40107	45459	51789	58106	64422	70725	78579	84683	90786	96821	102938	110596	116629	122748	128782	137331	147506
M-hydro	11467	11950	12433	12916	13399	13882	14365	14848	15331	15814	16297	16780	17263	17746	18229	18471	18713	18956	19198	19440	19682	19925	20167	20409	20652
Wind	4782	5056	6425	7795	9571	12074	14577	17080	19584	22087	27093	32100	37106	42113	47119	52126	57132	62139	67145	72152	77158	82165	87172	94681	102191
Solar	0	331	770	1158	1597	1985	2424	2811	3328	4155	4982	5809	6636	7463	8289	9116	9943	10770	11597	12424	13251	14078	14905	15732	16558
Biomass	2259	2302	2316	2316	2316	2160	1864	1850	1864	3403	3417	3417	3417	3403	4942	4970	4998	4956	4998	6580	6538	6580	6538	6509	8105
Total	86460	103983	114354	142917	166946	122680	103601	112772	122398	132945	142528	152395	162108	171606	182050	190764	199763	208713	217352	226862	235536	244543	253595	262576	272991
(USC/kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	8.5	9.7	10.4	12.3	13.6	8.5	6.3	6.4	6.6	6.8	6.9	7.1	7.2	7.3	7.5	7.5	7.6	7.7	7.7	7.8	7.8	7.9	7.9	8.0	8.0
Oil	17.9	19.2	20.8	23.2	24.3	25.4	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
small GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sapugaskanda	15.1	16.6	18.1	19.3	20.8	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GT No.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asia Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS CC	15.5	17.0	18.5	19.9	21.4	22.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AES CC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC	20.9	21.8	23.7	27.3	29.9	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern power	13.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uthurujanani	16.4	17.9	19.2	19.4	22.7	23.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEB Barge power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Furnace oil	0.0	18.3	19.9	20.9	23.6	24.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New CC	0.0	0.0	0.0	23.5	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LNG	0.0	0.0	0.0	0.0	0.0	7.6	7.9	8.0	8.2	8.4	8.5	8.7	8.9	9.0	9.2	9.2	9.2	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.5
KPS CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	8.5	8.8	8.8	9.0	0.0	9.1	9.4	9.9	10.1	10.2	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS-2 CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	9.0	9.2	9.3	9.2	0.0	0.0	0.0	9.7	10.0	10.3	10.5	10.3	11.1	10.8	0.0	0.0	11.5	0.0	0.0
New LNG	0.0	0.0	0.0	0.0	0.0	7.6	7.8	8.0	8.1	8.4	8.5	8.7	8.9	9.0	9.2	9.2	9.2	9.3	9.3	9.4	9.4	9.4	9.5	9.5	9.5
Coal	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1
Puttalam	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1
New Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NCRE	11.8	11.3	10.6	10.2	9.7	9.4	9.0	8.8	8.7	8.6	8.4	8.2	8.1	8.0	8.0	8.0	7.9	7.8	7.8	7.8	7.8	7.7	7.7	7.7	7.7
M-hydro	10.7	10.5	10.3	10.1	10.0	9.9	9.8	9.6	9.5	9.5	9.4	9.3	9.2	9.2	9.1	9.1	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.8
Wind	14.0	13.4	11.4	10.4	9.7	9.1	8.8	8.5	8.4	8.2	8.1	8.0	7.9	7.8	7.8	7.7	7.7	7.7	7.7	7.6	7.6	7.6	7.6	7.6	7.6
Solar	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Biomass	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
Total	6.2	7.0	7.2	8.5	9.3	6.4	5.1	5.3	5.5	5.7	5.8	5.9	6.1	6.2	6.3	6.3	6.4	6.5	6.5	6.6	6.6	6.6	6.7	6.7	6.8

Scenario C: Summary

				Capacity (MW)						Energy (GWh)					kWh (%)			Generation cost				CO2 emission	
Demand (MW)	Demand (GWh)	Year	LOLE	LNG	Coal	Wind	Solar	Back-up GT	PSPP	LNG	Coal	PSPP	Surplus	LNG (kton)	LNG	Coal	Surplus	Fixed cost	Fuel cost	Total	Cost USC/kWh	kton-CO2	kg/kWh
2369	13912	2016	16.87	0	825	124	0		0	0	5540	0	0	0	0.0%	39.8%	0.0%	52095	85696	137791	9.9	6755	0.486
2491	14782	2017	12.45	0	825	134	40		0	0	5577	0	0	0	0.0%	37.7%	0.0%	54263	103207	157470	10.7	7172	0.485
2639	15811	2018	24.27	0	825	184	90		0	0	5578	0	0	0	0.0%	35.3%	0.0%	57322	113571	170893	10.8	7264	0.459
2798	16911	2019	15.36	0	825	234	140		0	0	5578	0	0	0	0.0%	33.0%	0.0%	61615	142133	203748	12.0	7654	0.453
2955	18010	2020	8.04	0	825	304	190		0	0	5578	0	0	0	0.0%	31.0%	0.0%	66398	166163	232561	12.9	7930	0.440
3112	19108	2021	20.28	576	825	354	240		0	3910	5578	0	0	0	20.5%	29.2%	0.0%	66398	124721	191119	10.0	7963	0.417
3267	20205	2022	17.38	1007	1095	404	290		0	4052	7528	0	0	0	20.1%	37.3%	0.0%	72834	97066	169900	8.4	8790	0.435
3422	21302	2023	17.09	1170	1365	454	340		0	3073	9288	0	0	0	14.4%	43.6%	0.0%	78081	100288	178369	8.4	9935	0.466
3577	22397	2024	9.46	1458	1365	504	400		0	3747	9419	0	0	0	16.7%	42.1%	0.0%	82929	109115	192044	8.6	10331	0.461
3730	23492	2025	6.80	1458	1635	554	500		0	2718	11048	0	6	0	11.6%	47.0%	0.0%	89020	112799	201819	8.6	11356	0.483
3883	24586	2026	17.60	1458	1635	604	600		0	3312	11203	0	0	0	13.5%	45.6%	0.0%	89020	121835	210855	8.6	11745	0.478
4035	25679	2027	27.50	1458	1635	704	700		200	3680	11427	100	0	0	14.3%	44.5%	0.0%	91271	130629	221900	8.6	12086	0.471
4187	26771	2028	11.51	1458	1635	804	800	100	400	4145	11509	94	0	0	15.5%	43.0%	0.0%	93849	139899	233748	8.7	12348	0.461
4333	27862	2029	14.64	1458	1635	904	900	100	600	4632	11559	78	0	0	16.6%	41.5%	0.0%	96100	149487	245587	8.8	12601	0.452
4505	28952	2030	23.48	1458	1635	1004	1000	200	600	5056	11560	62	0	0	17.5%	39.9%	0.0%	96850	159399	256249	8.9	12775	0.441
4677	30041	2031	9.11	1458	1905	1104	1100	200	600	3717	13521	143	0	0	12.4%	45.0%	0.0%	103420	160509	263929	8.8	13960	0.465
4849	31130	2032	15.66	1458	1905	1204	1200	300	600	4252	13568	151	0	0	13.7%	43.6%	0.0%	103746	169273	273019	8.8	14213	0.457
5021	32217	2033	9.74	1422	2175	1304	1300	300	600	3053	15350	158	0	0	9.5%	47.6%	0.0%	112285	171525	283810	8.8	15333	0.476
5193	33304	2034	17.03	1422	2175	1404	1400	400	600	3550	15441	185	0	0	10.7%	46.4%	0.0%	112611	180050	292661	8.8	15599	0.468
5365	34390	2035	23.60	1422	2175	1504	1500	400	600	3959	15510	212	0	0	11.5%	45.1%	0.0%	113034	189108	302142	8.8	15835	0.460
5536	35475	2036	10.15	1710	2175	1604	1600	500	600	4483	15566	224	0	0	12.6%	43.9%	0.0%	116879	198047	314926	8.9	16096	0.454
5708	36559	2037	15.55	1710	2175	1704	1700	500	600	5016	15598	201	0	0	13.7%	42.7%	0.0%	116879	207212	324091	8.9	16358	0.447
5879	37642	2038	7.92	1710	2445	1804	1800	600	600	3876	17296	160	0	0	10.3%	45.9%	0.0%	123776	209281	333057	8.8	17413	0.463
6051	38724	2039	17.19	1710	2445	1904	1900	600	600	4346	17425	233	0	0	11.2%	45.0%	0.0%	123444	217946	341390	8.8	17707	0.457
6222	39805	2040	22.84	1710	2445	2004	2000	700	600	4735	17511	258	0	0	11.9%	44.0%	0.0%	124194	227283	351477	8.8	17956	0.451

Scenario C: Capacity (kW) balance

(MW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1840	2040	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240	2240
Conventional	1374	1374	1529	1529	1544	1544	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640	1640
PSPP	0	0	0	0	0	0	0	0	0	0	0	200	400	600	600	600	600	600	600	600	600	600	600	600	600
Thermal	1906	2076	2030	2283	2541	2541	2641	2761	3049	3224	3224	3224	3324	3324	3424	3694	3794	4028	4128	4128	4516	4516	4886	4860	4960
Oil	1081	1251	1205	1458	1716	1140	539	226	226	131	131	131	231	231	331	331	431	431	531	531	631	631	731	705	805
small GT	65	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	140	140	140	70	70	70	70	35	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	115	115	115	115	115	115	115	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	51	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	161	161	161	161	161	161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	270	270	270	270	270	270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	30	30	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	0	0
CEB Barge power	60	60	60	60	60	60	60	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	170	170	170	170	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	70	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105	105
New CC	0	0	0	288	576	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	100	100	200	200	300	300	400	400	500	500	600	600	700
LNG	0	0	0	0	0	576	1007	1170	1458	1458	1458	1458	1458	1458	1458	1458	1458	1422	1422	1422	1710	1710	1710	1710	1710
KPS CC (LNG)	0	0	0	0	0	0	161	161	161	161	161	161	161	161	161	161	161	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	163	163	163	163	163	163	163	163	163	163	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
New LNG	0	0	0	0	0	576	576	576	864	864	864	864	864	864	864	864	864	1152	1152	1152	1440	1440	1440	1440	1440
Coal	825	825	825	825	825	825	1095	1365	1365	1635	1635	1635	1635	1635	1635	1905	1905	2175	2175	2175	2175	2175	2445	2445	2445
Puttalam	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825	825
New Coal	0	0	0	0	0	0	270	540	540	810	810	810	810	810	810	1080	1080	1350	1350	1350	1350	1350	1620	1620	1620
NCRE	471	541	661	781	921	1041	1161	1281	1411	1601	1771	1991	2211	2431	2671	2881	3091	3301	3511	3741	3951	4161	4371	4581	4811
M-hydro	323	343	363	383	403	423	443	463	483	503	523	543	563	583	603	613	623	633	643	653	663	673	683	693	703
Wind	124	134	184	234	304	354	404	454	504	554	604	704	804	904	1004	1104	1204	1304	1404	1504	1604	1704	1804	1904	2004
Solar	0	40	90	140	190	240	290	340	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
Biomass	24	24	24	24	24	24	24	24	24	44	44	44	44	44	64	64	64	64	64	84	84	84	84	84	104
Total	3751	3991	4220	4593	5006	5126	5442	5682	6100	6465	6635	7055	7575	7995	8335	8815	9125	9569	9879	10109	10707	10917	11497	11681	12011

(GW)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	0.8	0.8	0.8	0.8	0.8	0.8	1.1	1.4	1.4	1.6	1.6	1.6	1.6	1.6	1.6	1.9	1.9	2.2	2.2	2.2	2.2	2.2	2.4	2.4	2.4
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	0.6	1.0	1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.7	1.7	1.7	1.7	1.7
Oil	1.1	1.3	1.2	1.5	1.7	1.1	0.5	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Hydro	1.7	1.7	1.9	1.9	1.9	2.0	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Wind	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Solar	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	3.8	4.0	4.2	4.6	5.0	5.1	5.4	5.7	6.1	6.5	6.6	7.1	7.6	8.0	8.3	8.8	9.1	9.6	9.9	10.1	10.7	10.9	11.5	11.7	12.0

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	22.0%	20.7%	19.5%	18.0%	16.5%	16.1%	20.1%	24.0%	22.4%	25.3%	24.6%	23.2%	21.6%	20.5%	19.6%	21.6%	20.9%	22.7%	22.0%	21.5%	20.3%	19.9%	21.3%	20.9%	20.4%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	11.2%	18.5%	20.6%	23.9%	22.6%	22.0%	20.7%	19.2%	18.2%	17.5%	16.5%	16.0%	14.9%	14.4%	14.1%	16.0%	15.7%	14.9%	14.6%	14.2%
Oil	28.8%	31.3%	28.6%	31.7%	34.3%	22.2%	9.9%	4.0%	3.7%	2.0%	2.0%	1.9%	3.0%	2.9%	4.0%	3.8%	4.7%	4.5%	5.4%	5.3%	5.9%	5.8%	6.4%	6.0%	6.7%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%	5.3%	7.5%	7.2%	6.8%	6.6%	6.3%	6.1%	5.9%	5.6%	5.5%	5.2%	5.1%	5.0%
Hydro	45.2%	43.0%	44.8%	41.6%	38.9%	38.4%	38.3%	37.0%	34.8%	33.1%	32.6%	30.9%	29.1%	27.8%	26.9%	25.6%	24.8%	23.8%	23.1%	22.7%	21.5%	21.2%	20.2%	20.0%	19.5%
Wind	3.3%	3.4%	4.4%	5.1%	6.1%	6.9%	7.4%	8.0%	8.3%	8.6%	9.1%	10.0%	10.6%	11.3%	12.0%	12.5%	13.2%	13.6%	14.2%	14.9%	15.0%	15.6%	15.7%	16.3%	16.7%
Solar	0.0%	1.0%	2.1%	3.0%	3.8%	4.7%	5.3%	6.0%	6.6%	7.7%	9.0%	9.9%	10.6%	11.3%	12.0%	12.5%	13.2%	13.6%	14.2%	14.8%	14.9%	15.6%	15.7%	16.3%	16.7%
Biomass	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.7%	0.7%	0.6%	0.6%	0.6%	0.8%	0.7%	0.7%	0.7%	0.6%	0.8%	0.8%	0.8%	0.7%	0.7%	0.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario C: Energy (kWh) balance

(million kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Hydro	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5407	5401	5385	5369	5450	5458	5465	5492	5519	5531	5508	5467	5540	5565
Conventional	4330	4330	4902	4902	4954	4954	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307	5307
PSPP	0	0	0	0	0	0	0	0	0	0	0	100	94	78	62	143	151	158	185	212	224	201	160	233	258
Thermal	8008	8715	8848	9631	10297	11138	11580	12361	13166	13766	14515	15107	15657	16194	16622	17244	17829	18412	19003	19481	20064	20629	21190	21789	22267
Oil	2468	3138	3270	4053	4719	1650	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15	15	18	18	21
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	428	477	516	400	168	314	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	878	1079	1091	891	944	720	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	1152	1429	1425	950	69	520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	8	51	70	5	14	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	102	166	13	26	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	1794	3498	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	3	3	6	6	9	9	12	12	15	15	18	18	21
LNG	0	0	0	0	0	3910	4052	3073	3747	2718	3312	3680	4145	4632	5056	3717	4252	3053	3550	3959	4483	5016	3876	4346	4735
KPS CC (LNG)	0	0	0	0	0	0	226	74	21	0	19	26	43	189	174	15	165	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	587	179	0	0	0	18	103	139	309	91	62	0	10	34	0	23	0	15	23
New LNG	0	0	0	0	0	3910	3239	2820	3726	2718	3293	3636	3999	4304	4562	3611	4025	3053	3540	3925	4483	4993	3876	4331	4712
Coal	5540	5577	5578	5578	5578	5578	7528	9288	9419	11048	11203	11427	11509	11559	11560	13521	13568	15350	15441	15510	15566	15598	17296	17425	17511
Puttalam	5540	5577	5578	5578	5578	5578	5517	5365	5429	5290	5340	5459	5504	5530	5530	5504	5531	5422	5447	5484	5516	5542	5428	5455	5488
New Coal	0	0	0	0	0	0	2011	3923	3990	5758	5863	5968	6005	6029	6030	8017	8037	9928	9994	10026	10050	10056	11868	11970	12023
NCRE	1575	1737	2062	2378	2758	3016	3318	3634	3924	4426	4764	5307	5850	6397	7052	7556	8067	8573	9084	9704	10213	10722	11231	11743	12361
M-hydro	1074	1141	1207	1273	1340	1406	1473	1539	1606	1672	1738	1805	1871	1938	2004	2038	2071	2104	2138	2171	2204	2238	2271	2304	2337
Wind	341	378	563	748	988	1125	1310	1495	1632	1818	1955	2293	2631	2970	3308	3646	3985	4323	4661	4999	5338	5676	6014	6352	6691
Solar	0	55	128	193	266	331	404	469	555	692	830	968	1106	1244	1382	1519	1657	1795	1933	2071	2208	2346	2484	2622	2760
Biomass	160	163	164	164	164	154	131	131	131	244	241	241	242	245	358	353	354	351	352	463	463	462	462	465	573
Total	13913	14782	15812	16911	18009	19108	20205	21302	22397	23499	24586	25821	26908	27976	29043	30250	31354	32450	33579	34704	35808	36859	37888	39072	40193
Surplus	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumping-up	0	0	0	0	0	0	0	0	0	0	0	(143)	(135)	(111)	(86)	(203)	(214)	(224)	(263)	(301)	(318)	(285)	(228)	(331)	(366)

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	5.5	5.6	5.6	5.6	5.6	5.6	7.5	9.3	9.4	11.0	11.2	11.4	11.5	11.6	11.6	13.5	13.6	15.4	15.4	15.5	15.6	15.6	17.3	17.4	17.5
LNG (Gas)	0.0	0.0	0.0	0.0	0.0	3.9	4.1	3.1	3.7	2.7	3.3	3.7	4.1	4.6	5.1	3.7	4.3	3.1	3.6	4.0	4.5	5.0	3.9	4.3	4.7
Oil	2.5	3.1	3.3	4.1	4.7	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PSPP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
Hydro	5.4	5.5	6.1	6.2	6.3	6.4	6.8	6.8	6.9	7.0	7.0	7.1	7.2	7.2	7.3	7.3	7.4	7.4	7.4	7.5	7.5	7.5	7.6	7.6	7.6
Wind	0.3	0.4	0.6	0.7	1.0	1.1	1.3	1.5	1.6	1.8	2.0	2.3	2.6	3.0	3.3	3.6	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.4	6.7
Solar	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.3	2.5	2.6	2.8
Biomass	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6
Total	13.9	14.8	15.8	16.9	18.0	19.1	20.2	21.3	22.4	23.5	24.6	25.8	26.9	28.0	29.0	30.3	31.4	32.5	33.6	34.7	35.8	36.9	37.9	39.1	40.2

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Coal	39.8%	37.7%	35.3%	33.0%	31.0%	29.2%	37.3%	43.6%	42.1%	47.0%	45.6%	44.3%	42.8%	41.3%	39.8%	44.7%	43.3%	47.3%	46.0%	44.7%	43.5%	42.3%	45.7%	44.6%	43.6%
LNG (Gas)	0.0%	0.0%	0.0%	0.0%	0.0%	20.5%	20.1%	14.4%	16.7%	11.6%	13.5%	14.3%	15.4%	16.6%	17.4%	12.3%	13.6%	9.4%	10.6%	11.4%	12.5%	13.6%	10.2%	11.1%	11.8%
Oil	17.7%	21.2%	20.7%	24.0%	26.2%	8.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
PSPP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.3%	0.3%	0.2%	0.5%	0.5%	0.5%	0.6%	0.6%	0.6%	0.5%	0.4%	0.6%	0.6%
Hydro	38.8%	37.0%	38.6%	36.5%	34.9%	33.3%	33.6%	32.1%	30.9%	29.7%	28.7%	27.5%	26.7%	25.9%	25.2%	24.3%	23.5%	22.8%	22.2%	21.5%	21.0%	20.5%	20.0%	19.5%	19.0%
Wind	2.5%	2.6%	3.6%	4.4%	5.5%	5.9%	6.5%	7.0%	7.3%	7.7%	8.0%	8.9%	9.8%	10.6%	11.4%	12.1%	12.7%	13.3%	13.9%	14.4%	14.9%	15.4%	15.9%	16.3%	16.6%
Solar	0.0%	0.4%	0.8%	1.1%	1.5%	1.7%	2.0%	2.2%	2.5%	2.9%	3.4%	3.7%	4.1%	4.4%	4.8%	5.0%	5.3%	5.5%	5.8%	6.0%	6.2%	6.4%	6.6%	6.7%	6.9%
Biomass	1.2%	1.1%	1.0%	1.0%	0.9%	0.8%	0.6%	0.6%	0.6%	1.0%	1.0%	0.9%	0.9%	0.9%	1.2%	1.2%	1.1%	1.1%	1.0%	1.3%	1.3%	1.3%	1.2%	1.2%	1.4%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Scenario C: Fuel balance

(million USC)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	67952	84344	92410	118732	140063	96821	67058	68039	74852	74782	81513	86492	91946	97691	102710	100289	105477	104177	109120	113547	118915	124512	123008	128079	132805
Oil	44300	60208	67927	93903	114889	41877	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300	300	360	360	420
small GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapugaskanda	6461	7910	9361	7725	3493	6823	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT No.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asia Power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
KPS CC	13648	18358	20178	17731	20198	16363	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AES CC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West coast CC	24034	31163	33717	25917	2061	16408	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Northern power	26	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uthurujanani	131	913	1345	97	318	411	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CEB Barge power	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace oil	0	1864	3295	272	614	1872	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New GT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New CC	0	0	0	42161	88205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Back-up GT	0	0	0	0	0	0	0	0	0	0	0	0	60	60	120	120	180	180	240	240	300	300	360	360	420
LNG	0	0	0	0	0	29545	32959	25916	31799	24027	29650	33208	37788	42850	47343	35619	40316	30451	34699	38571	43393	48622	38700	42925	46952
KPS CC (LNG)	0	0	0	0	0	0	1890	651	185	0	175	248	418	1874	1744	155	1685	0	0	0	0	0	0	0	0
KPS-2 CC (LNG)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	120	0	0	0	0	0	0	0	0	0	0
West coast CC (LNG)	0	0	0	0	0	0	5238	1650	0	0	0	176	1045	1406	3200	959	639	0	108	374	0	254	0	169	258
New LNG	0	0	0	0	0	29545	25831	23615	31614	24027	29475	32784	36325	39570	42279	34505	37992	30451	34591	38197	43393	48368	38700	42756	46694
Coal	23652	24136	24483	24829	25174	25399	34099	42123	43053	50755	51863	53284	54098	54781	55247	64550	64981	73546	74181	74736	75222	75590	83948	84794	85433
Puttalam	23652	24136	24483	24829	25174	25399	25365	24904	25413	24998	25453	26225	26654	27003	27239	27194	27415	26969	27182	27438	27683	27888	27422	27634	27875
New Coal	0	0	0	0	0	0	8734	17219	17640	25757	26410	27059	27444	27778	28008	37356	37566	46577	46999	47298	47539	47702	56526	57160	57558
NCRE	18508	19639	21944	24185	26883	28628	30595	32835	34851	39125	41410	45223	49050	52905	58314	61815	65401	68932	72519	77659	81231	84789	88362	91977	97074
M-hydro	11467	11950	12433	12916	13399	13882	14365	14848	15331	15814	16297	16780	17263	17746	18229	18471	18713	18956	19198	19440	19682	19925	20167	20409	20652
Wind	4782	5056	6425	7795	9571	10587	11956	13326	14342	15711	16728	19231	21734	24237	26741	29244	31747	34250	36754	39257	41760	44263	46767	49270	51773
Solar	0	331	770	1158	1597	1985	2424	2811	3328	4155	4982	5809	6636	7463	8289	9116	9943	10770	11597	12424	13251	14078	14905	15732	16558
Biomass	2259	2302	2316	2316	2316	2174	1850	1850	1850	3445	3403	3403	3417	3459	5055	4984	4998	4956	4970	6538	6538	6523	6523	6566	8091
Total	86460	103983	114354	142917	166946	125449	97653	100874	109703	113907	122923	131715	140996	150596	161024	162104	170878	173109	181639	191206	200146	209301	211370	220056	229879

(USC/kWh)	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Thermal	8.5	9.7	10.4	12.3	13.6	8.7	5.8	5.5	5.7	5.4	5.6	5.7	5.9	6.0	6.2	5.8	5.9	5.7	5.7	5.8	5.9	6.0	5.8	5.9	6.0
Oil	17.9	19.2	20.8	23.2	24.3	25.4	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
small GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sapugaskanda	15.1	16.6	18.1	19.3	20.8	21.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GT No.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asia Power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS CC	15.5	17.0	18.5	19.9	21.4	22.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AES CC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC	20.9	21.8	23.7	27.3	29.9	31.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Northern power	13.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uthurujanani	16.4	17.9	19.2	19.4	22.7	22.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CEB Barge power	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Furnace oil	0.0	18.3	19.9	20.9	23.6	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New GT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New CC	0.0	0.0	0.0	23.5	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LNG	0.0	0.0	0.0	0.0	0.0	7.6	8.1	8.4	8.5	8.8	9.0	9.0	9.1	9.3	9.4	9.6	9.5	10.0	9.8	9.7	9.7	9.7	10.0	9.9	9.9
KPS CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	8.4	8.8	8.8	0.0	9.2	9.5	9.7	9.9	10.0	10.3	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KPS-2 CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West coast CC (LNG)	0.0	0.0	0.0	0.0	0.0	0.0	8.9	9.2	0.0	0.0	0.0	9.8	10.1	10.1	10.4	10.5	10.3	0.0	10.8	11.0	0.0	11.0	0.0	11.3	11.2
New LNG	0.0	0.0	0.0	0.0	0.0	7.6	8.0	8.4	8.5	8.8	9.0	9.0	9.1	9.2	9.3	9.6	9.4	10.0	9.8	9.7	9.7	9.7	10.0	9.9	9.9
Coal	4.3	4.3	4.4	4.5	4.5	4.6	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.9	4.9	4.9
Puttalam	4.3	4.3	4.4	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.8	4.8	4.8	4.9	4.9	4.9	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1
New Coal	0.0	0.0	0.0	0.0	0.0	0.0	4.3	4.4	4.4	4.5	4.5	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.8	4.8	4.8
NCRE	11.8	11.3	10.6	10.2	9.7	9.5	9.2	9.0	8.9	8.8	8.7	8.5	8.4	8.3	8.3	8.2	8.1	8.0	8.0	8.0	8.0	7.9	7.9	7.8	7.9
M-hydro	10.7	10.5	10.3	10.1	10.0	9.9	9.8	9.6	9.5	9.5	9.4	9.3	9.2	9.2	9.1	9.1	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.8
Wind	14.0	13.4	11.4	10.4	9.7	9.4	9.1	8.9	8.8	8.6	8.6	8.4	8.3	8.2	8.1	8.0	8.0	7.9	7.9	7.9	7.8	7.8	7.8	7.8	7.7
Solar	0.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Biomass	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
Total	6.2	7.0	7.2	8.5	9.3	6.6	4.8	4.7	4.9	4.8	5.0	5.1	5.2	5.4	5.5	5.4	5.4	5.3	5.4	5.5	5.6	5.7	5.6	5.6	5.7