Chapter 10

Selection of the Most Promising Site

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10.1 General

In this chapter, the most promising site is selected from the promising candidate sites selected in the Chapter 9. As shown in the sub-chapter 9.6.8, Halgran 3, Maha 2, and Loggal are selected as the promising candidate sites from 11 candidate sites as a result of the ranking study.

At Maha 2 site, alternative candidate site for the upper reservoir has been found in the vicinity of the original Upper reservoir site. Accordingly, new pumped storage power plant using the alternative upper reservoir has been planned by 1/10,000 topological map as same way to the previous stage. As a result, it is identified that the pumped storage scheme by the alternative upper reservoir has a potential to be on the similar level with the original Maha 2 from technical point of view as well as from the economic point of view. Also, serious problems have not been detected from the primary survey of natural/social environmental aspect as well as from that of geological aspect. Therefore, study for selection of the promising site is carried out including the alternative upper reservoir candidate site found in the vicinity of the original Maha 2. Although, the lower reservoir of the alternative Maha 2 is common with the original Maha 2, the pumped storage scheme using the alternative upper reservoir is called as Maha 3 afterward.

The most promising site is to be selected from 4 candidate site in the 3 regions.

10.2 Outline of Evaluation for the Most Promising Site Selection

10.2.1 Outline of Environmental Study (2)

(1) Objective

The Environmental Study (2) aims to collect information on environmental and social conditions of the three (3) promising sites for pumped storage power plant as the second stage of the site selection, and to compare three (3) sites in view of expected impacts on the natural and social environments. The Study also aims to collect information on environmental and social conditions of proposed transmission line's routes from the three (3) promising sites.

(2) Methodologies

- A comprehensive site survey at each site (upper and lower dams/reservoirs) is conducted. Based on the information collected during the Environmental Study (1), site surveys at each site are carefully planned and conducted. Collection of secondary information is also conducted at local government agencies if necessary.
- Regarding the fauna and flora of each site, detailed site surveys on them using standard ecological sampling is conducted.
- Regarding the social conditions of each site, a questionnaire survey is conducted to collect

information of the community and analyze the information.

- Regarding the condition of the land use of each site, a ground truth survey is conducted to verify the land use pattern and level. The results are shown in a tabular form and a map at each site.

(3) Survey area

At each site, "directly affected area: dam site and reservoir area" and "buffer zone: 500 meters from the high water of the reservoir and from dam site (or within watershed boundary)" are considered to be the survey area.

(4) Issues arose at one cluster and one site

1) Loggal cluster

The Environmental Study (2) started in December 2013 after the 2nd SHM.

Loggal was selected as the first survey site and a consultation meeting with the local people was held. At the 1st meeting, some of the participants strongly opposed the Project (development of a PSPP) and they conveyed their idea to a member of the parliament (MP) who is elected from the region. The MP requested the Ministry of Power and Energy (CEB's ministry) to suspend the Study, and CEB and the JICA Study Team decided to temporally suspend the Study at Loggal cluster (upper and lower sites).

After a discussion between the Ministry and the MP, the Study resumed under a condition: not provoking the local people. According to the condition, only surveys on the local governmental offices and secondary data were conducted. Therefore, the accuracy of the Study is less than other sites.

2) Maha 2 site

Based the experience at Loggal site, CEB explained Divisional Secretariat Office, Grama Niladhari, members, Pradeshiya Sabha and tea estates, and obtained agreements from them before the Study at Halgran and Maha clusters. After these agreements, the Survey Team (University of Peradeniya) conducted the surveys at these sites, with staff of the Divisional Secretariat if necessary.

The area of proposed dam/reservoir site of Maha 2 is managed by one tea estate. After the arrangement described in the previous lines, the Survey Team went to the site. However, one of the managers strongly opposed the Project, and part of the surveys could not be conducted. Only surveys on the local governmental offices and secondary data were therefore conducted, and the accuracy of the Study is less than other sites.

(5) Environmental and Social Considerations on routes of transmission lines and their evaluation

Environmental and social considerations and their evaluation are conducted for routes of transmission lines from Halgran, Maha and Loggal. The process is the following:

1) Study on the possible routes from the technical point of view (refer to the sections 10.3.4、10.4.4、10.6.4 for the details)

2) Study on the possible routes based on the results of 1) and the relationships with the locations / boundaries of the protected areas (refer to the sections 10.3.4、10.4.4、10.6.4 for the details)

The information on the locations / boundaries of the protected areas are based on the “Sensitive Area Map” obtained from CEA in April 2013. The routes are shown as belts with 3 – 4 km width (alternaitve ranges of the routes) because of their uncertainies at this stage.

3) Survey and evaluation of each route

The following points are surveyed for the each proposed route as part of the Environmental Study (2) utilizing the existing data and information. Based on the survey results, evaluation is conducted.

- Populated areas and their scales
- Barriers and their locations (protected areas (re-check), IBAs, bird migration routes, built-up areas, residential areas, archeological sites, temples and military bases)

10.2.2 Outline of Topographic Survey and Geological Survey (1)

The geological investigation survey and relevant topography survey were scheduled to conduct for the selected 3 candidate sites (including 4 options as Maha 3, Maha 2, Halgran 3, and Logal) that were aimed for and should become the basis for the upcoming pre-feasibility (Pre-FS) study. However, the surveys for the “Loggal site” was not commenced and eventually cancelled as these had not obtained the permission from local residents and governments. Thus the whole surveys have consisted of 2 sites for 3 options (ie. Maha 1, Maha 2 and Halgran 3). The quantity of geological investigation and topography survey are summarized in Table 10.2.2-1.

Table 10.2.2-1 Quantity of Topography and Geological Survey

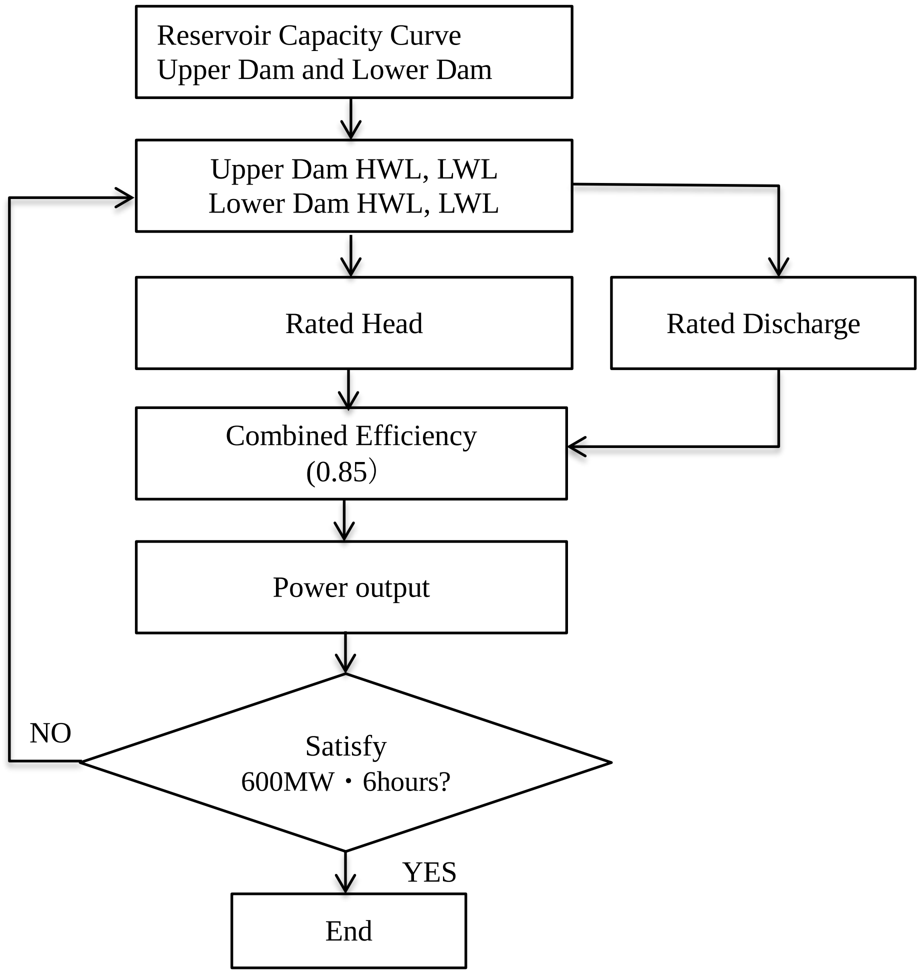
		Quantity
Topographic Survey (T-1)		
Site		2 candidate sites for 3 potions (Maha2, Maha3, Halgran 3. *Loggal cancelled)
Area		Maha 2 (1.18 km2), Maha 3 (1.14 km2), Halgran 3 (2.57 km2)
Scale		1:5,000
Methodology		Topography survey at Lower reservoir, Upper reservoir, and Water route
	1)	Ground control survey for topographic survey and mapping
	2)	Installation of new bench marks
	3)	Ground mapping at a scale of 1:5,000 for Upper reservoir, Lower reservoir, Dams, Intake and Outlet area respectively. (water route excluded)
Geological Survey (G-1)		
Site		2 Candidate sites for 3 options (Maha 2, Maha3, Halgran 3. *Loggal site cancelled)
Area		Maha 2 and Maha 3 (10km2), Halgran 3 (15km2)
Scale		1:10,000
Methodology		Geological survey at whole area covering Lower reservoir, Upper reservoir, Water route, material sites
	1)	Collection of available data and maps
	2)	Aerophotograph, satelite image study
	3)	Geological survey of the candidate sites
		a) Geological mapping
		b) Geotechnical study

(Source: JICA Study Team)

10.2.3 Review of Pumped Storage Planning

Based on 1/5,000 maps created by the topographic survey by the local consultant; although 1/10,000 maps are used for the selection of the promising site, the capacity curves of upper reservoirs and lower reservoirs are revised; accordingly the necessary capacity of stored water and High Water Level (HWL) , Low Water Level (LWL), and dams' height are also revised.

Particularly, since the accuracy of upper reservoirs capacity and lower reservoirs capacity goes up, planned dams' height; dams' volumes become more accurate, which is the one of the key factors of construction cost. As for the maximum discharge and the rated head of the planned pumped storage schemes, those are calculated repeatedly until conditions such as 6 hours of equivalent peaking hours and 600 MW of the maximum output are satisfied under 0.85 of fixed combined efficiency for generating mode. Figure 10.2.3-1 shows the flow chart of pumped storage planning review.



(Source: JICA Study Team)

Figure 10.2.3-1 Flow Chart of Pumped Storage Planning Review

10.2.4 Review of Manufacturing Limitation of Pump-turbine.

As described in the sub-chapter 9.4.3, a unit capacity of more than 200 MW is applicable to every promising candidate site selected. In this sub-chapter, based on the reviewed pumped storage scheme, it is reviewed that whether every site satisfies the criteria of manufacturing limitation of 200 MW of a unit capacity as well as that of 150 MW. The definite contents of the study can be referred the sub-chapter 9.4.3. Table 10.2.4-1 shows applicability of a unit capacity 200MW to every promising site as well as Table 10.2.4-2 shows that of 150 MW unit capacity.

In this regard, it was obvious that Halgran 3 cannot satisfy applicability criteria of 150 MW of a unit capacity in the stage of promising candidate sites selection, so that it is excluded from planning of pumped storage scheme having unit capacity 150 MW. Therefore, the study of manufacturing limitation in this chapter also excludes Halgran 3 applied 150 MW unit capacity.

As for Loggal, it is judged that both of unit capacities 200 MW and 150 MW can be applicable, however, it is judged that applicability of 150 MW unit capacity is on the borderline of the limitation considered that Inlet Height (B1) is calculated as 202mm (the minimum limitation from manufacturing requirement is 200mm).

Table 10.2.4-1 Result of Study on Manufacturing Limitation (200MW*3units)

Candidate site	unit	Halgran 3	Maha 2	Maha 3	Loggal
Maximum Gross Pumping Head	m	677.34	448.93	512	591.33
Effective Head	m	643.47	426.48	486.4	561.76
Discharge	m3/s	111.94	168.89	148.09	128.22
Installed Capacity (total)	MW	609	621	612	609
Turbine unit Out-put	kW	207,000	211,000	208,000	206,000
Rotation Speed	min-1	600	429	429	500
Manufactuaring Limiation (200 MW*3units)					
(1) Dimension of Runner					
Inlet Dia (D1)	mm	3,500	3,530	4,310	3,940
Inlet Height (B1)	mm	210	339	278	264
Evaluation		OK	OK	OK	OK
(2) Specific Speed					
Pump Specific Speed >25	m-m3/s	26.1	32.8	30.4	28.1
Kq <4300		3,665	3,219	3,014	3,269
Power Specific Speed	m-kW	84.2	101.7	85.7	83.0
Evaluation		OK	OK	OK	OK

(Source: JICA Study Team)

Table 10.2.4-2 Result of Study on Manufacturing Limitation (150MW*4units)

Candidate site	unit	Maha 2	Maha 3	Loggal
Maximum Gross Pumping Head	m	450.4	513.06	591.33
Effective Head	m	427.88	487.4	561.76
Discharge	m3/s	168.34	147.78	128.22
Installed Capacity (total)	MW	600	600	612
Turbine unit Out-put	kW	157,000	156,000	156,000
Rotation Speed	min-1	429	500	600
Manufactuaring Limiation (150MW*4units)				
(1) Dimension of Runner				
Inlet Dia (D1)	mm	4,020	3,660	3,260
Inlet Height (B1)	mm	264	231	202
Evaluation		OK	OK	OK
(2) Specific Speed				
Pump Specific Speed >25	m-m3/s	32.7	30.4	28.1
Kq <4300		2,783	3,039	3,923
Power Specific Speed	m-kW	87.3	86.2	86.7
Evaluation		OK	OK	OK

(Source: JICA Study Team)

10.2.5 Transmission Line

(1) Types of Connections

Connecting methods of transmission line (T/L) from proposed “Pumped Storage Power Plant (PSPP)” to existing transmission system are described as follows.

1) Connection to “Electrical Stations”

This connection type means connection to switchyard of “Electrical Stations” (such as, “Power Station”, “Substation”, and “Switching Station”, etc.). New T/L from proposed PSPP can be composed by one route (two circuits). For this connection, Connecting bay spaces for new T/L in the switchyard of electrical station are required.

2) Connection to “Existing T/L”

This connection type means direct connection to existing T/L.

This connection type can be categorized into two types of connections, i.e., “T-Connection” and “PI-Connection”.

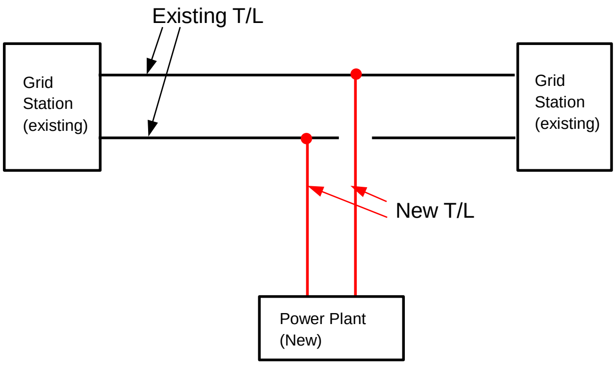
In case of “T-Connection”, new T/L can be composed of one route only. Switching devices and protection devices are also required for one route of T/L only. Thus, installation costs can be kept in low level. However, reliability of transmission system is low, since protection section of existing T/L and new T/L cannot be divided. And, for T/L maintenance work, it is difficult to be planned outage periods for solely new branch-side T/L. Adjustments of outage periods for existing T/L and new branch-side T/L are required. Here, T-connection to 220kV transmission system is not allowed by regulation of transmission system in CEB. Thus, this connection type is not feasible.

As for “PI-Connection”, connection type can be divided into two types, i.e., “one-circuit PI connection” and “two-circuit PI connection”.

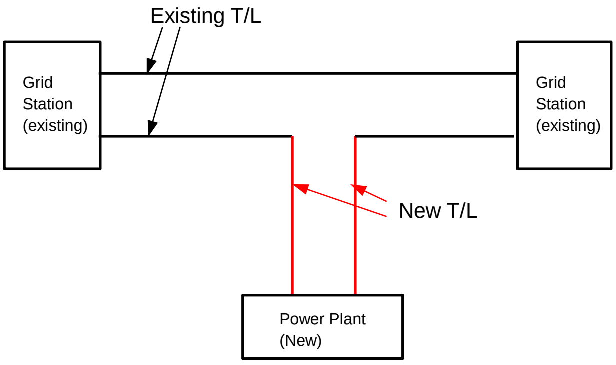
In case of “one-circuit PI connection”, new T/L can be composed of one route only. This connection type is composed of connecting two circuits of new T/L to one of two circuits of existing T/L. Feasibility of this connection type shall be decided in consideration with transmission capacities and power flow conditions of relevant transmission system.

In case of “two-circuit PI connection”, new T/L shall be composed by two routes. Switching devices and protection devices also shall be prepared for two routes of T/L. Thus, installation costs will be double of “T-connection” or “one-circuit PI connection”. However, reliability of transmission system will be improved, since protection area of relevant T/L can be divided.

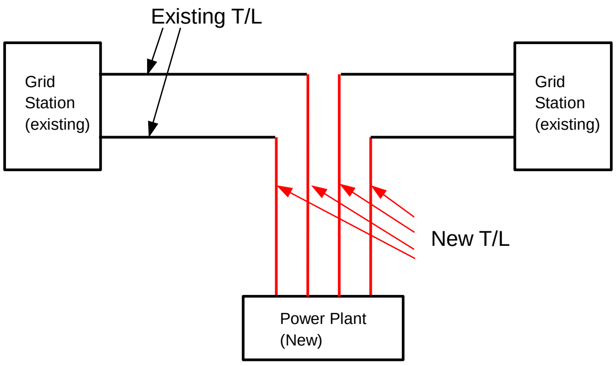
i) T-Connection



ii) PI-Connection (one circuit)



iii) PI-Connection (two circuits)



(Source: JICA Study Team)

Figure 10.2.5-1 Types of T/L Connections to Existing T/L

(2) Transmission Capacity

1) Maximum Imput/Output of proposed PSPP

Generating capacity of proposed PSPP is 600 MW. However, input/output over 600 MW appears at some conditions depended on site conditions and operating modes. Calculated maximum input/outputs (used for consideration of T/L) of proposed PSPP are shown in Table 10.2.5-1.

Table 10.2.5-1 Maximum Input/Output of PSPP

Site	Unit number	Maximum Input/Output	
		Generating Mode (Output)	Pumping Mode (Input)
Maha	3 Units	200 MW × 3 Units = 600 MW	194 MW × 3 Units = 582 MW
	4 Units	150 MW × 4 Units = 600 MW	151 MW × 4 Units = 604 MW
Halgran	3 Units	200 MW × 3 Units = 600 MW	228 MW × 3 Units = 684 MW
Loggal	3 Units	200 MW × 3 Units = 600 MW	212 MW × 3 Units = 636 MW
	4 Units	150 MW × 4 Units = 600 MW	169 MW × 4 Units = 676 MW

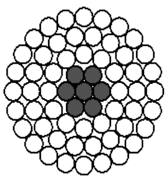
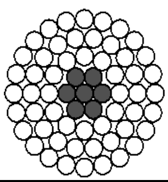
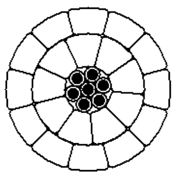
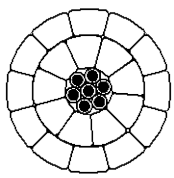
(Source: JICA Study Team)

Transmission capacity of T/L from proposed PSPP shall be secured to be capable of maximum output by only one of two circuit transmission capacity in contingency conditions.

2) Types of Conductors

Applicable types of conductors are shown in Table 10.2.5-2.

Table 10.2.5-2 Specifications of Applicable Conductor Types

Description	Unit	ACSR Zebra	TACSR/AS Zebra	Low Loss ASCR/AS 550mm^2	Low Loss TACSR/AS 550mm^2
Nominal Diameter	mm	28.62	28.62	28.62	28.62
Cross Sectional Area					
Aluminium	mm^2	428.9	428.9	550.4	550.4
Steel Core	mm^2	55.59	55.59	40.08	40.08
Total	mm^2	484.5	484.5	590.5	590.5
Nominal Weight	kg/km	1,621	1,555	1,814	1,814
Ultimate Tensile Strength	kN	131.9	130.4	140.9	140.9
DC Resistance at 20°C	Ω/km	0.0674	0.0657	0.0519	0.0526
Cross Section					

(Source: JICA Study Team)

“ACSR Zebra × 2 conductors per phase” is generally used for CEB’s 220kV T/L.

In addition, “Low Loss TACSR/AS 550mm2” is planned to use for future T/L (220kV Habarana – Veyangoda T/L) by CEB.

3) Transmission Capacity and Types of Conductors

Transmission Capacity of "ACSR Zebra × 2 conductors per phase" used in CEB is shown in Table 10.2.5-3.

Table 10.2.5-3 Transmission Capacity of ACSR Zebra

Item	Unit	ACSR Zebra	
		Normal (Continuous)	Contingency (Short time)
Transmission Capacity (x 2 conductors / phase)	MW	484	581

(Source: JICA Study Team)

As for three types of conductors other than "ACSR Zebra × 2 conductors per phase" shown in Table 10.2-2, transmission capacities were shown in Table 10.2-4. Those transmission capacities were calculated by method generally used in Japan. (Those types of conductors are no track records of use in CEB's T/L)

For reference, transmission capacity of ACSR Zebra was also calculated by calculation method generally used in Japan, and shown in Table 10.2.5-4.

Table 10.2.5-4 Transmission Capacity

Item		Unit	ACSR/AS Zebra		TACSR/AS Zebra		Low Loss ACSR/AS 550mm^2		Low Loss TACSR/AS 550mm^2	
			Normal (Continuous)	Contingency (Short time)	Normal (Continuous)	Contingency (Short time)	Normal (Continuous)	Contingency (Short time)	Normal (Continuous)	Contingency (Short time)
Allowable current										
T_{max}	: Maximum Temperature	°C	75	90	150	180	75	90	150	180
T	: Ambient Temperature	°C	32	32	32	32	32	32	32	32
θ	: Temperature Rise from Ambient Temperature	°C	43	58	118	148	43	58	118	148
V	: Wind Velocity	m/s	0.447	0.447	0.447	0.447	0.447	0.447	0.447	0.447
d	: Diameter of Conductor	cm	2.862	2.862	2.862	2.862	2.862	2.862	2.862	2.862
η	: Radiation Factor	-	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
W_s	: Solar Radiation	W/cm^2	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
R_{20}	: DC Resistance at 20°C	Ω/km	0.0674	0.0674	0.0657	0.0657	0.0519	0.0519	0.0519	0.0519
R_t	: AC Resistance at T_{max} of Conductor Temperature $R_t = R_{20} \times 1.05\ [\ 1 + 0.00403 \times (T_{max} - 20)\ ]$	Ω/km	0.0865	0.0907	0.1051	0.1135	0.0666	0.0699	0.083	0.0896
h_w	: Heat Loss Coefficient by Convection (by Rice) $hw = 5.72 \times 10^{-3} \frac{\sqrt{\frac{V}{d}}}{(273 + T + \frac{\theta}{2})^{0.123}}$	-	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011	0.0011
h_r	: Heat Loss Coefficient by Radiation (by Stefan Boltzman) $hr = 5.67 \times 10^{-4} \frac{(\frac{273 + T + \theta}{100})^4 - (\frac{273 + T}{100})^4}{\theta}$	-	0.0008	0.0009	0.0011	0.0013	0.0008	0.0009	0.0011	0.0013
I	: Allowable Current $I = \sqrt{\frac{\{hw + \eta\left(hr - \frac{Ws}{\pi\theta}\right)\}\, d\theta\pi}{Rt}}$	A	675	870	1347	1546	770	991	1516	1740
Transmission Capacity (× 2 conductor / phase)										
V	: Voltage	kV	220	220	220	220	220	220	220	220
I × 2	: Allowable Current (× 2 conductors / phase)	A	1350	1740	2694	3092	1540	1982	3032	3480
cos θ	: Power Factor	-	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
P	**: Transmission Capacity** $P = \sqrt{3} \times V \times I \times 2 \times \cos\theta$	**MW**	**463**	**597**	**924**	**1060**	**528**	**680**	**1040**	**1193**

(Source: JICA Study Team)

Referring Table 10.2.5-3, "ACSR Zebra × 2 conductors per phase" does not have enough capacity by 1 route for T/L from PSPP.

In case of using one of three types of conductors other than "ACSR Zebra × 2 conductors per phase" shown in Table 10.2-2, required transmission capacities for T/L from PSPP can be secured by 1 route. For standardization, "Low Loss TACSR/AS 550 mm 2 × 2 conductors per phase" was selected for 1 route T/L from PSPP. (Considering transmission capacity, "Low Loss ACSR/AS 550mm^2 × 2 conductors per phase" also can be used for T/L from proposed PSPP. For system analysis in this study, "Low Loss ACSR/AS 550mm^2 × 2 conductors per phase" is selected as conductor for calculated condition. Use of "Low Loss ACSR/AS 550mm^2 × 2 conductors per phase" corresponds to rather strict condition than "Low Loss TACSR/AS 550mm^2 × 2 conductors per phase".)

On the other hand, in case of 2 route T/L PI connection, it is possible to secure required transmission capacity by using "ACSR Zebra × 2 conductors per phase". Thus, "ACSR Zebra × 2 conductors per phase" was selected for 2 route T/L PI connection.

10.2.6 Power System Analysis

(1) Outline

Power system analysis is carried out in order to confirm that whether every promising candidate site can be connected to the existing power system of CEB without problems. Objective of each analysis is as shown below.

1) Power flow analysis

Under the normal and N-1 conditions, it is confirmed that there are no thermal violation and no voltage violation.

2) Short circuit current analysis

Three phase short circuit current at bus of substations related to promising candidate site is calculated. And it is confirmed that the current is less than the current of criteria.

3) Transient stability study

a) Three phase fault

It is confirmed that the generator can be operated with stable sate at the three phase line fault.

b) One unit tripping

It is confirmed that no frequency violation is observed at one unit tripping.

(2) Conditions for power system analysis

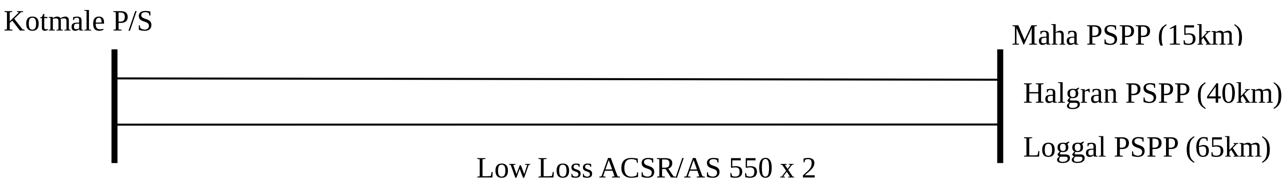
1) Generating and Loading Scenario

Power system analysis in the following case considered severe was carried out.

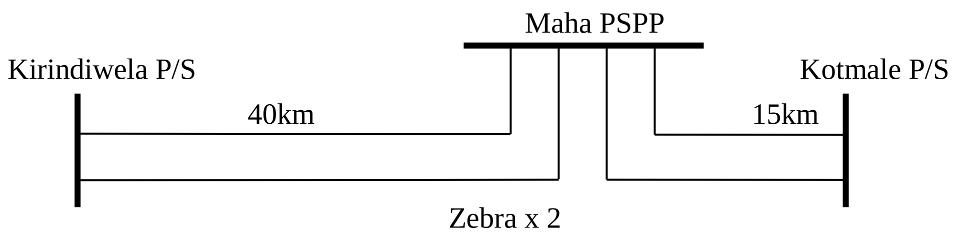
- Hydro Maximum Night Peak – Generating Operation
- Thermal Maximum Night Peak – Generating Operation
- Off Peak – Pumping Operation

2) Transmission Line for PSPP

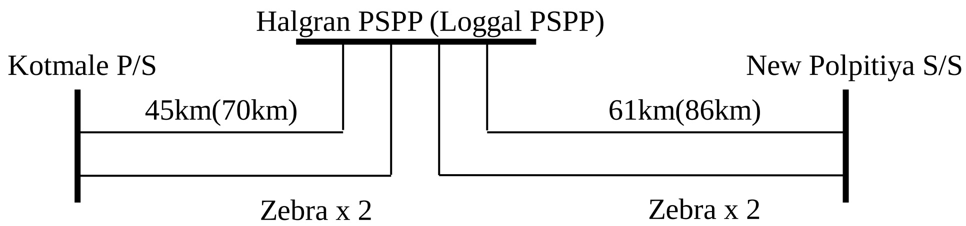
- Maha PSPP 200MW × 3units or 150MW × 4units
- Halgran PSPP 200MW × 3units
- Loggal PSPP 200MW × 3units or 150MW × 4units
- two circuits of transmission line from each site; Maha PSPP, Halgran, and Loggal, is connected to Kotmale P/S
- Maha PSPP is connected to the transmission line from Kotmale to Kirindiwela.
- Low Loss ACSR/AS 50 × 2 conductors of each transmission line would be adopted for the condition which does not exceed the short time allowable current of the transmission line from PSPP to Kotmale P/S in the outage of the line based on the results of the meeting with CEB.



a) Connection to Kotmale P/S



b) Connection to Kotmale – Kirindiwela



c) Connection to Kotmale - New Polpitiya

(Source: JICA Study Team)

Figure 10.2.6-1 Transmission Line for PSPP

3) Generator Constants of PSPP

From Table 10.2.6-1 to Table 10.2.6-5 show Generator constants of every PSPP. The rated capacity of Transformer is assumed as same as each generator's one, and the impedance is assumed as 0.12pu in each.

Table 10.2.6-1 Generator Constants of Maha (200MW)

Capacity	$T_{do'}$	$T_{d'}$	H	X_d	X_q	$X_{d'}$	$X_{d''}$	X1
241MVA	11.8s	3.64s	3.67s	0.781pu	0.542pu	0.241pu	0.167pu	0.0936pu

(Source: JICA Study Team)

Table 10.2.6-2 Generator Constants of Maha (150MW)

Capacity	$T_{do'}$	$T_{d'}$	H	X_d	X_q	$X_{d'}$	$X_{d''}$	X1
179MVA	10.5s	2.8s	3.41s	0.901pu	0.621pu	0.24pu	0.17	0.0954pu

(Source: JICA Study Team)

Table 10.2.6-3 Generator Constants of Halgran (200MW)

Capacity	$T_{do'}$	$T_{d'}$	H	X_d	X_q	$X_{d'}$	$X_{d''}$	X1
233MVA	12.6s	3.12s	3.79s	0.952pu	0.658pu	0.236pu	0.163pu	0.0914pu

(Source: JICA Study Team)

Table 10.2.6-4 Generator Constants of Halgran (200MW)

Capacity	$T_{do'}$	$T_{d'}$	H	X_d	X_q	$X_{d'}$	$X_{d''}$	X1
238MVA	12.6s	3.06s	3.67s	0.971pu	0.671pu	0.236pu	0.163pu	0.0914pu

(Source: JICA Study Team)

Table 10.2.6-5 Generator Constants of Loggal (150MW)

Capacity	$T_{do'}$	$T_{d'}$	H	X_d	X_q	$X_{d'}$	$X_{d''}$	X1
174MVA	11.3s	2.79s	3.49s	0.952pu	0.655pu	0.235pu	0.166	0.0933pu

(Source: JICA Study Team)

(3) Criteria

Criteria to evaluate the power system stability are as shown below;

1) Voltage

- From -10% to +10% with 132kV and above

2) Frequency

Frequency Standard is shown below. On the N-1 conditions, Upper limit threshold would be 51.5Hz based on alarm threshold of some thermal power plants in Sri-lanka, and lower limit threshold would be 48.75Hz which is the threshold of load shedding

- From 50.5Hz to 49.5Hz in normal operatin mode
- From 51.5Hz to 48.75Hz in N-1 fault operatin mode

3) Transient Stability Study

It is confirmed that the generator can be operated with stable state if the following fault occurs. (It is confirmed that rotor angle of the generator typically converges after the fault.)

- 0.0s Simulation Start
- 1.0s Three Phase Fault
- 1.12s Fault Line Trip
- 1.62s Line Re-Close with Fault
- 1.74s Fault Line Trip
- 30.0s Simulation End

4) Allowable Maximum 3 phase short circuit levels

- 40kA

10.2.7 Construction Cost

Construction cost is estimated by the same manners as shown in the sub-chapter 9.4.4. Revised points are mainly 1) each upper and lower dam's volume is revised based on the 1/5,000 topographic map created by the topographic survey carried out by the local consultant, 2) cost of each electro-mechanical equipment is revised based on the revised pumped storage scheme in the sub-chapter 10.2.3, 3) construction cost for transmission line in each site is newly added, and 4) the interest during construction period for each site is newly added.

Rate of interest during construction period in this chapter is set by weighed average of yen loan and other loans assuming, i) rate of yen loan portion and other portion, iii) covered ratio of yen loan and other loan;

Interest rate of yen loan	1.4%
Interest rate of other than yen loan	10.0%
Ratio of covered by yen loan	85%
Ratio of covered by other than yen loan	15%
Interest during construction period	2.69%

10.3 Halgran 3

10.3.1 Outline of Site

This scheme is the pumped storage power project having the rated output of 600MW utilizing the rated head of 643.47m obtained between the upper reservoir located on the west side tributary of Halgran river and the lower reservoir located in the downstream of the upper reservoir. The maximum discharge for generation is 111.94m^3/s and the equivalent peak generation time is 6 hours. Due to its rather high head, it is out of applicability of 150 MW unit capacity; accordingly the scheme with 3 units of 200 MW unit capacity is planned.

The raito of horizontal waterway length (m) and the gross head; L/H, is 6.6.

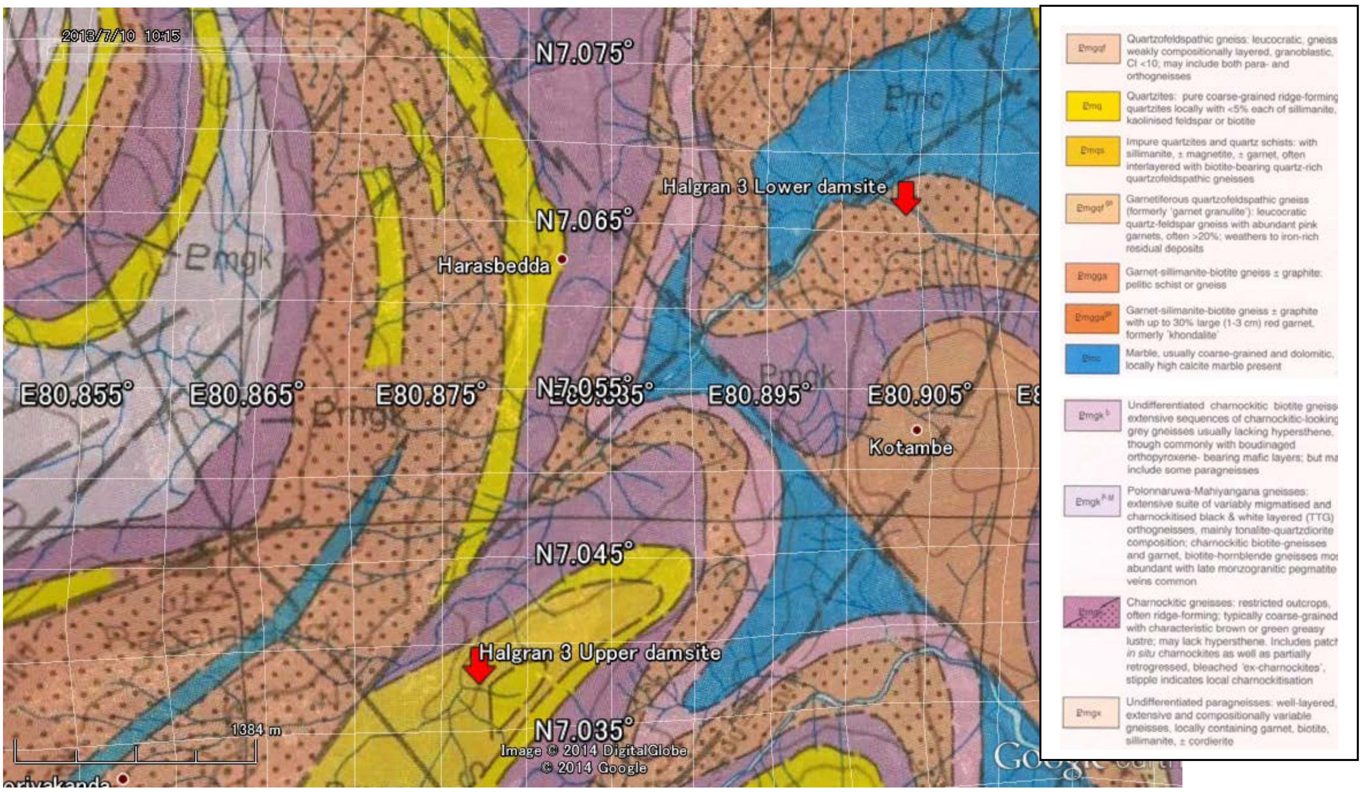
10.3.2 Geology

(1) Outline

According to the previous 1:100,000 map, Halgran 3 site is fallen on mainly gneisses and quartzite, and on limestone partially on lower reservoir site.

The upper reservoir consists of quartzite and quartzite schist, and locates itself on the north wing of the syncline fold axis thus dipping SW in general. The lower reservoir locates itself on the south wing of the syncline folding axis thus dipping NE in general. It comprises Charnokite and limestone. The limestone is distributed on the left bank from the reservoir in upstream through down to the downstream of the dam site. Several faulting zones were extracted. Among all, the water route crosses the NW-SE fault fracture zone in the middle, and this fault has a certain fault displacement (fault escarpment cliff) and gneiss contains limestone band near the fault. It is indicated the water route may encounter a crushed inferior limestone nearby the estimated fault. The NE-SW trending fault is estimated on at the upstream end of the lower reservoir.

The previous 100,000 map is attached in Figure 10.3.2-1.

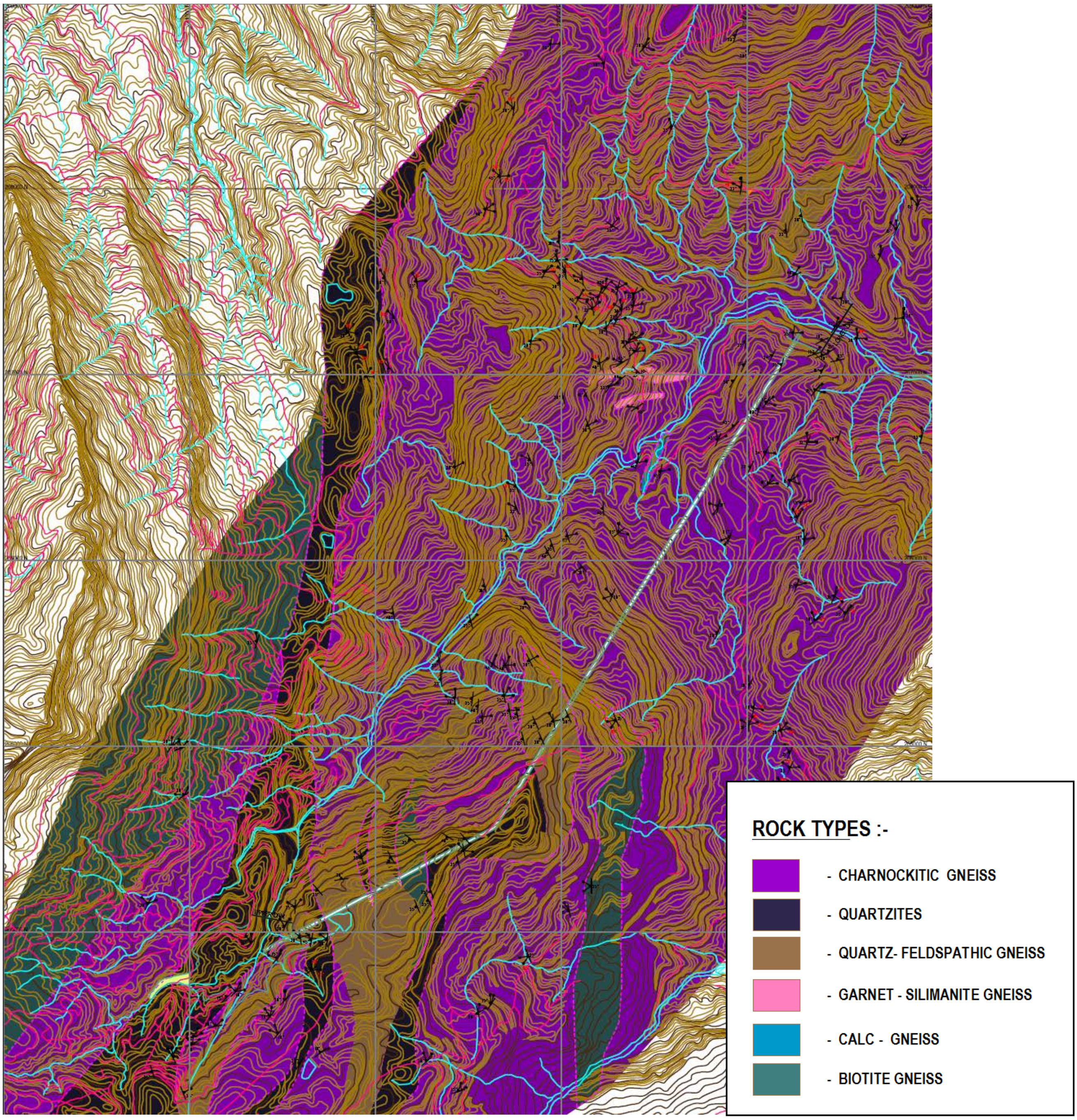


(Source: Geological Survey and Mines Bureau, Sri Lanka)

Figure 10.3.2-1 Geology of Halgran 3 Site (1:100,000)

(2) Geological mapping

The site geology map (1:10,000) made by the subcontractor in this Study is shown in Figure 10.3.2-2. The main feature of the survey this time is below.



(Source: JICA Study Team)

Figure 10.3.2-2 Geological Map compiled in Halgran 3 Site (1:10,000)

The upper dam site is situated at the very steep V shape valley of stream running to NE with 30-45 deg. banks on the both sides. The reservoir area is in the SW area of the dam axis towards where several streams run from various angles radially thus forms the basin structure. The lower dam site is in about 3km downstream to the NE of the same river. The river turns rightward at the tail of the lower reservoir, forming the wide open dissected low angle slope on the left bank, and moderately steeper slope on the right bank.

The field geology survey conducted confirmed the basic geology structure of the previous geology map (1:100,000) but some parts are quite different. The upper dam site and reservoir consists of quartzite with quartz feldspathic gneiss basically, and it matches with the previous map. The lower dam site however are distributed charnockite all over the area, and no limestone (of 1:100,000 geology) was found except one minor calc-gneiss rock outcrop. There is a minor biotite gneiss in the tunnel path.

The quartzite is hard but develops joints, whereas the charnockite is massive and hard.

Besides 2 faults found in the previous map (1:100,000), NE-SW lineament was interpreted across the upper dam axis, and another E-W lineament is interpreted crossing lower dam axis. However no evidence was found at the site for both lineaments.

(3) Geotechnical conditions of the site

1) Upper dam site

The moderately, slightly weathered to fresh quartzite basically forms the foundation. There are some fresh quartzite feldspathic gneiss on the right abutment but in the higher area than dam crest. The residual soil of rock origin covers the most of the area but has only 2m in thickness, but on the river bed it has 1-5m. The quartzite has sufficient strength but has a propensity having developed joints, so potentially there may be deeper weathering along joints in the quartzite.

The quartzite rock basically composes CH to partially CM on the foundation. The water sealing treatment must be well conducted after confirming the permeability underneath the foundation.

The average trend of the quartzite is N50E with 20-35 NW dips at the dam axis, which is dipping to left bank almost orthogonal but possibly towards downstream. This is not so favorable direction considering the dense development of joints. No features like fractures were observed along the site for NE-SW lineament. So it is considered not significant at this stage.

2) Upper reservoir

The basement of the reservoir is mostly quartzite but shifted to charnockite in the upstream tail. The surface is covered by residual soil of rock origin, but shallow for 1-2m in thickness. The quartzite has potentially developed joints but there are no issues for water tightness in general.

But on the left rim 300m upstream of the dam axis, there forms relatively thinner ridge in width.

The neighboring valley gets lower in elevation towards north, which runs along the NE-SW fracture fault estimated in 100,000 map. This NE-SW valley seems bordering the quartzite in the reservoir and neighboring charnockite in the west. Considering the geologic unit boundary, this narrow ridge may be deeply weathered thus proper water sealing treatment may be required. It needs further investigation.

3) Waterway

The whole length is about 4.7km, the longest among the three candidate sites.

The geology comprises quartzite and quartzite feldspathic gneiss in the upstream 2km half, and charnockite in the downstream half of the route. There is a minor biotite gneiss along in the upstream half, About nearly the boundary of these rocks it is estimated the NW-SE trending fault is crossing the tunnel.

The highly weathered quartzite is exposed mainly. Although it maintains rock strength and hard in rock pieces, and thus the shape of the mountainous ridge maintains uneroded, it suggests the weathering extends relatively deep. The general trend of quartzite is NE-SW but not consistent.

The headrace expects less weathering as a whole along the alignment depth and expects CM class at worst or better CH quartzite or quartzite feldspathic gneiss. But It is probable to have a deep weathering along many joints thus permeable around the area near surge tank.

The rest half of the tunnel lies in charnockite. It can expects CH – B class rock condition in general, but the average dominant direction of layers has very solid NE-SW with NW dips, and it is almost parallel to the tunnel alignment (such as N30-40 with 15-20 NW dips), so it is unfavorable for tunnel excavation.

The estimated NW-SE fault forms the sharp cliff escarpment on the surface with amount of talus deposit. It is highly likely to represent geological structural weakness like the past fault activity. The fracture may be consolidated at present but may have some issues in tunnel excavation.

4) Powerhouse

The power house lies in the charnockite body. It is CH – B class rock of massive feature, and therefore has no geological issues, as far as it is not located close to the estimated NW-SE fault.

5) Lower dam site

The charnockite is the foundation of dam axis, with the slightly weathered to fresh massive bed rock on the right abutment, and moderately weathered rock on the left abutment. The right bank is covered by talus deposit on the lower part for 2m thickness of sandy clay material, and residual soil (sandy to clay) of rock origin on the left bank for 1-2m thickness. There are fresh bed rocks along the riverbed and alluviums are shallow as 1-2m thickness. Part of the left abutment gets thinner in ridge width andt shows moderately weathered charnockite. There may be deeper weathering around there, requiring denser water sealing treatment. Basically the charnockite comprises CH (on the right) to CM (on the left where weathered) class on the bed rock surface.

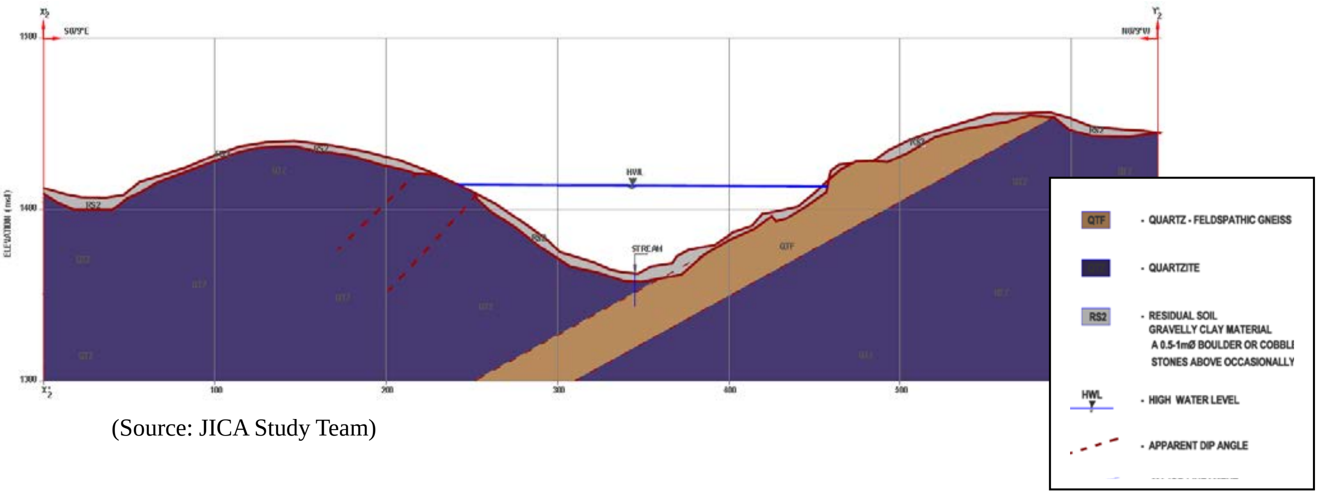
The trend of the charnockite layers show N30E with 20 NW dips or so consistent, and it is dipping upstream at the dam axis. This is favorable direction.

There is E-W trending lineament along the river, but there are no such features as fractures around the rocks exposed along the river. This is considered not be significant.

6) Lower reservoir

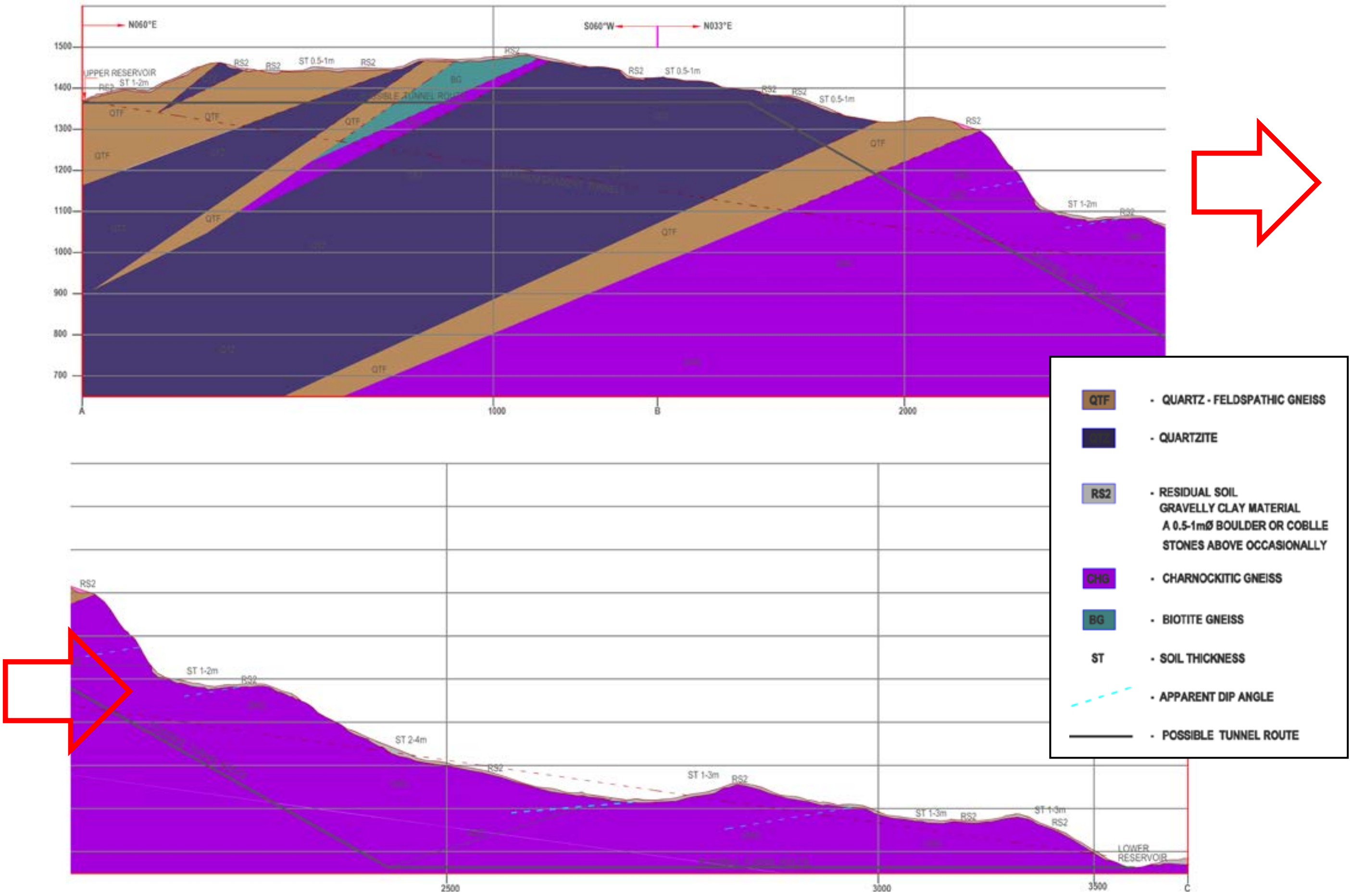
The reservoir is situated on the right turning corner of the river, whose left bank forms wide open low gentle slope covered by residual soil of rock origin, and some colluviums and talus. The right bank is moderate to steeper slope covered by residual soil and talus. Numbers of small streams from the left bank run downward to the main river from north and west, thus the reservoir site forms a basin structure collecting water.

The foundation of the area is all charnockite, but the most of the surface is covered by residual soil. The left bank has residual soil in 5m thick in maximum with locally moderately steep slopes, where the residual soil on the right bank has much shallower in 1-2m in thickness. Several rock exposures of charnockite along the reservoir show moderately to strongly weathered face in general. Although there may be weathered on surface, the reservoir has sufficient capability of water storage without water leakage, but there may be some local instability issues along the left bank. For example, it is above the HWL but there is a thick talus on the back water area as thick as 7m. It is possible there be some local thick deposit along left bank.



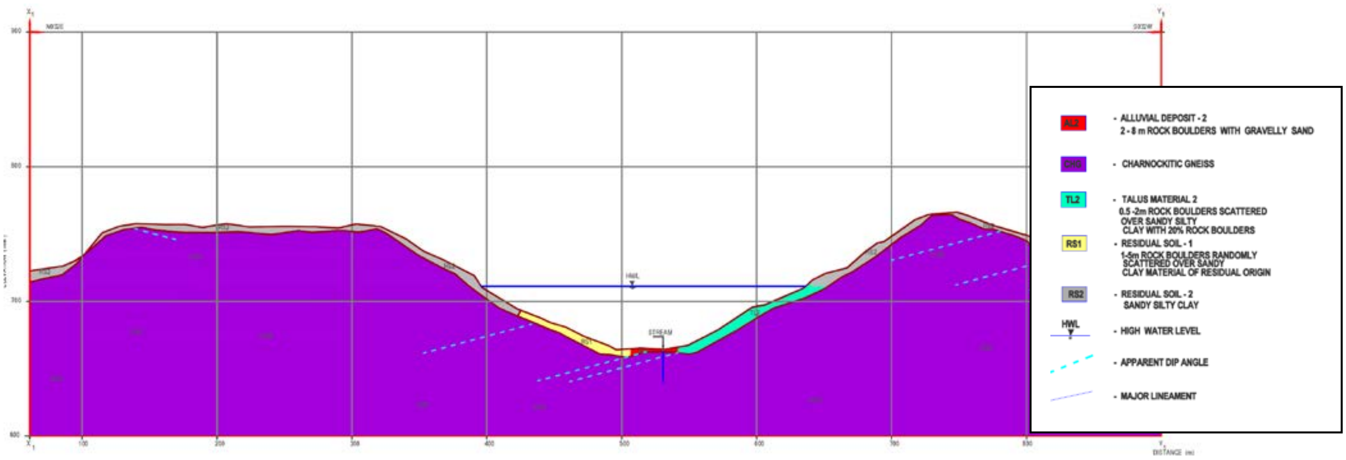
(Source: JICA Study Team)

Figure 10.3.2-3 Geological Cross Section along Upper Dam Axis of Halgran 3 Site (1:10,000)



(Source: JICA Study Team)

Figure 10.3.2-4 Geological Cross Section along Water Route of Halgran 3 Site (1:10,000)



(Source: JICA Study Team)

Figure 10.3.2-5 Geological Cross Section along Lower Dam Axis of Halgran 3 Site (1:10,000)

10.3.3 Construction Works

As described in the sub-chapter 9.5.7 (4), the access to Halgran 3 whole site is good; however, it is judged that access to river bed for dam construction works is not so good due to its steep topography. The study team tried to go to the river bed through a path shown on 1/10,000 map; however, they could not but give up getting the river bed finally, due to loss of a path and its steep valley. On the other hand, it is judged that access for construction works in upper dam area is not so difficult because of its gentle topography.

As for acquisition of temporary yard for construction works, it is judged not to be so difficult because there are some extent of the land having gentle topography in the left bank side of reservoir area. In the lower reservoir area, gentle topography is dominant in whole area, so that it is judged that there seems to be no serious problem for temporary yard acquisition. However, there exist many houses on the waterway route, so that the layout of various works tunnels may be limited.

The length of the access tunnel to powerhouse is approximately 1,500m, which is the second longest in the promising three sites.

The available depth of the upper dam is 28m and that of the lower dam is 20m. Those are not in unsafe level from slope stability aspect. Generally, if it is more than 30m, it may cause instability of the slope surrounding the reservoir.

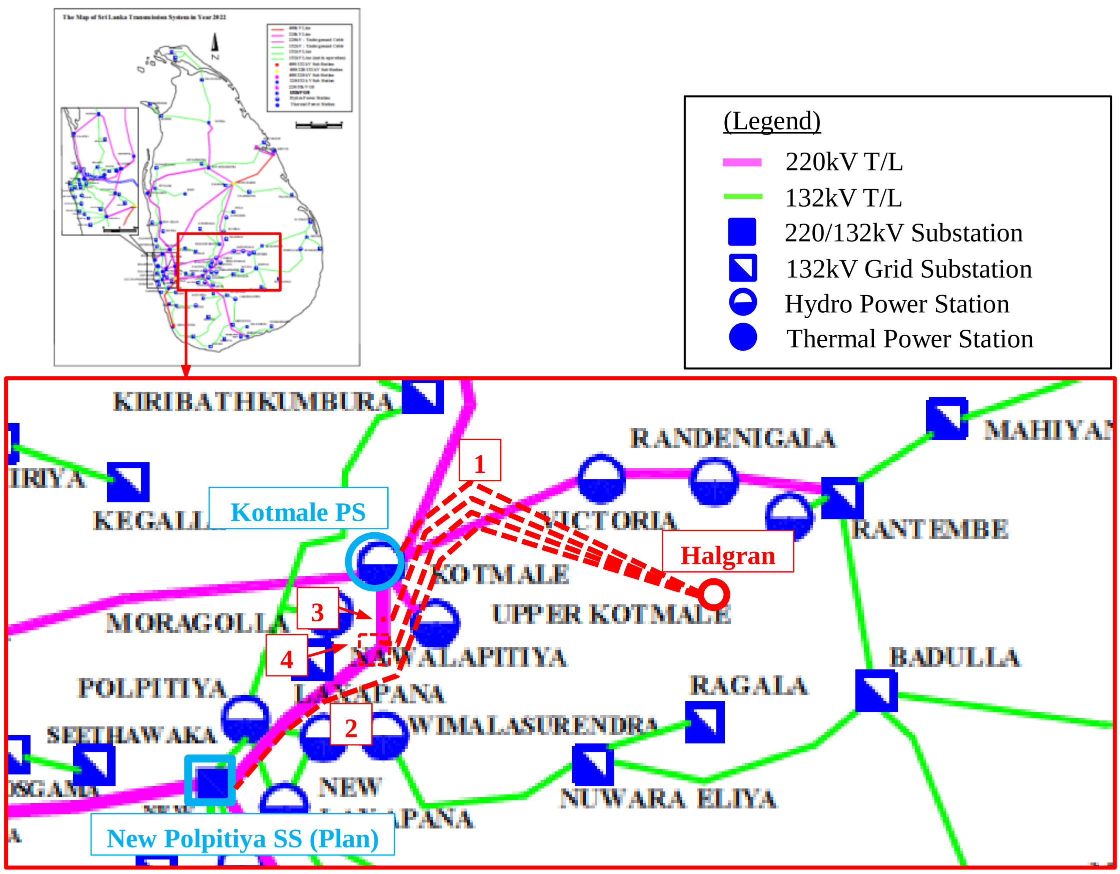
10.3.4 Transmission Line and Connecting Points

(1) Connecting Points

Referring transmission system in Sri Lanka and transmission development plan, connecting points of T/L from proposed PSPP are considered. As a result of the consideration, the T/L is required to connect Kotmale PS or further western points of 220kV transmission systems, due to conditions of system capacities and power flows. 132 kV transmission systems do not have enough capacity for connection of T/L from proposed PSPP.

Considering above, following options is selected for connecting points of T/L from PSPP (Halgran). Locations of each connecting point are show in Figure 10.3.4-1.

i) Connection to Kotmale PS
ii) Connection to New Polpitiya SS
iii) PI Connection to Kotmale - New Polpitiya T/L
iv) Connection to new “switching station” near Kotmale PS



Connection Points from "Halgran"

1	To "Kotmale PS
2	To "New Polpitiya SS"
3	To "Kotmale – New Polpitiya T/L" (2cct PI Connection)
4	To new "Switching Station " near Kotmale PS

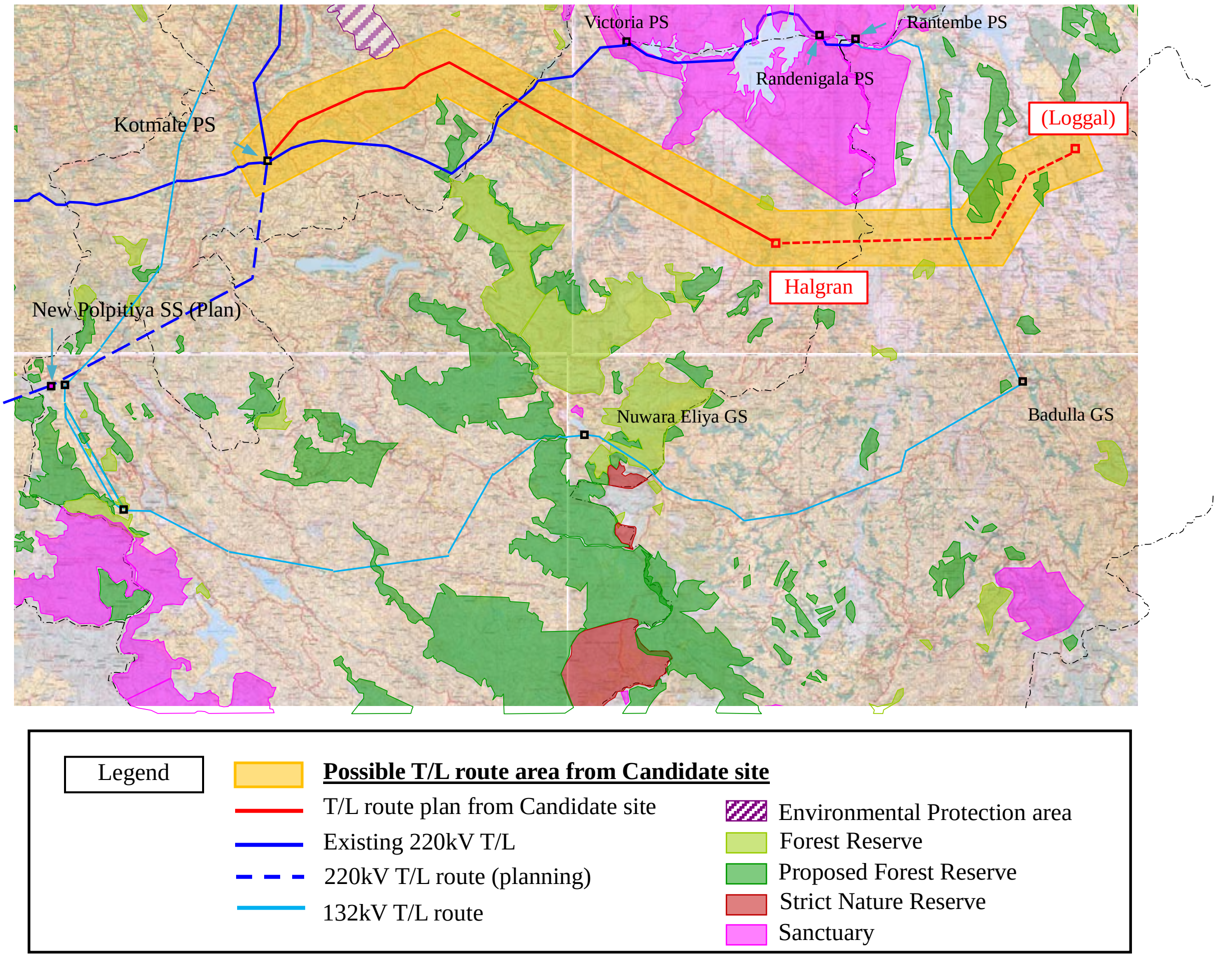
(Source: JICA Study Team)

Figure 10.3.4-1 Connection Points from "Halgran"

(2) Transmission Line Route

In consideration with "Environmental Sensitive Area", rough T/L routes from Halgran site to each connecting point is selected.

Selected rough T/L routes and "Environmental Sensitive Area" in surrounding area are shown in Figure 10.3.4-2.



(Source: JICA Study Team)

Figure 10.3.4-2 Transmission Line Route Plan from "Halgran"

The nearest 220 kV transmission system from Halgran site corresponds to T/L from "Rantembe PS" to "Kotmale PS" via "Randenigala PS" and "Victoria PS". However, that T/L does not have enough capacity to connect T/L from proposed PSPP.

In addition, surrounding area between Rantembe PS and Victoria PS are designated as "Sanctuary". And, "Forest reserve" exists area between Victoria PS and Kotmale PS. In consideration with those situations, augment work for existing T/L between Rantembe PS and Kotmale PS and/or connecting work of new T/L to Rantembe PS, Randenigala PS, and Victoria PS are difficult to conduct.

Thus, the nearest connecting point which can be connected T/L from proposed PSPP is Kotmale PS.

(3) Concerns for Connection to Kotmale PS

As for connection to Kotmale PS, following conditions are required to consider for selection of connecting points of T/L from proposed PSPP.

Present “Layout” of the switchyard is shown in Figure 10.3.4-3, and “Single Line Diagram” of the switchyard is shown in and Figure 10.3.4-4. There are no bay spaces in the switchyard for additional connection of new T/L.

Switchyard of Kotmale PS is located in hilly area, and is surrounded by sloped terrain. If expansions of switchyard area are required to secure yard spaces for new T/L connections, it is supposed that huge volume of cut and fill works is required to develop flat area for yard spaces.

And, when T/L from Upper Kotmale PS were connected to Kotmale PS switchyard, following i) to iii) were conducted. i) Additional yard space (second yard space) was developed in western side of original switchyard. ii) 1 circuit of Kotmale – Biyagama T/L was changed connecting bay from bay in the original yard to new bay in the second yard. iii) Electrical connections between original and second yards were conducted by using transmission line towers and conductor wires. As a result of those additional construction works, layout of Kotmale PS switchyard has been complicated and it is difficult to secure spaces for new T/L connections. In addition, Kotmale - Biyagama T/L near Kotmale PS switchyard area were arranged in unusual manner. Due to those conditions, overhead area around Kotmale PS switchyard have been congested by connected transmission lines.

On the other hand, in CEB’s transmission development plan, new T/L (Kotmale - New Polpitiya T/L) is planned to construct and connect to Kotmale PS. i.e, New T/L connection to switchyard of Kotmale PS are required other than T/L from proposed PSPP. “Kotmale – New Polpitiya T/L” is in the planning stage and specific connecting method to Kotmale PS Switchyard has been not decided at present.

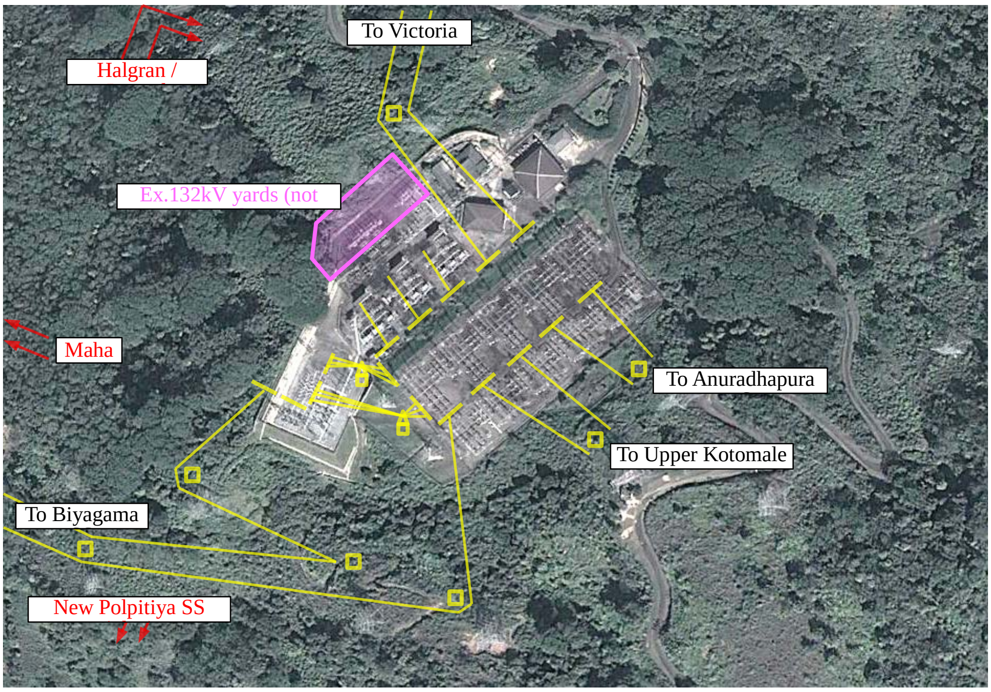
In case of that T/L from proposed PSPP is decided to connect to Kotmale PS switchyard, it is required to secure spaces for 4 bay and relevant equipment (2 circuits for T/L from PSPP, and 2 circuits from “Kotmale – New Polpitiya T/L”).

According to CEB, existing 132kV equipment is not used at present. If those unused area for 132kV equipment can be demolished and can be reused for connecting yards of new T/L, it may be possible to consider for new T/L connections.

However, if it is found that those unused 132kV yards are difficult to reuse or are not suitable for required new T/L connection, other options (such as, expansion of switchyard to around area, or new development of yard space in other area) shall be considered. For those options, increase of construction costs and/or long term outage works of existing T/L will be required.

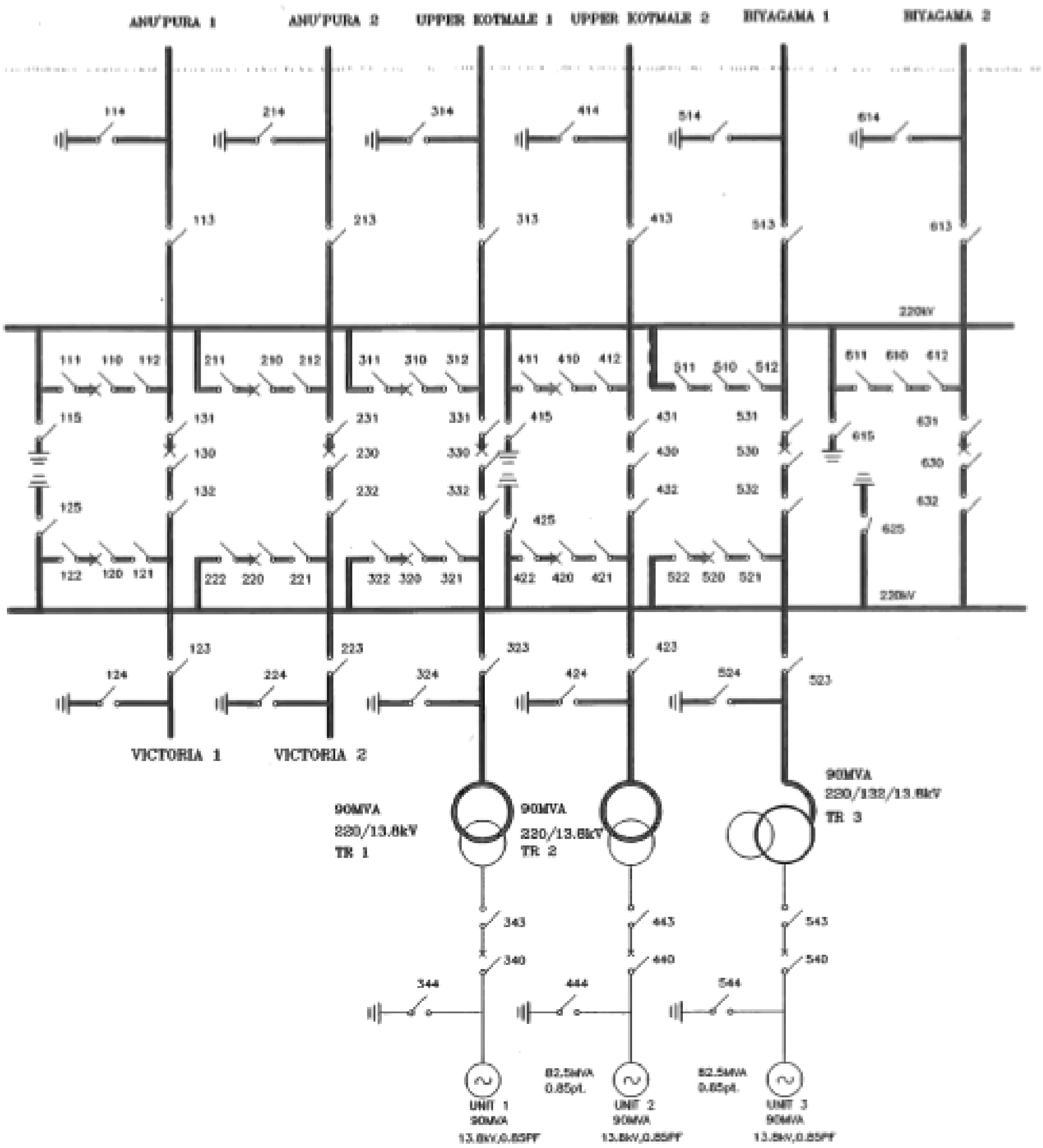
For each case, it is necessary to develop effective connecting plan inconsideration with connection of T/L from proposed PSPP and “Kotmale – New Polpitiya T/L” integrally.

However, detailed considerations of connecting method to switch yard of Kotmale PS are out of scope of this study. As for cost estimations for the connection, only construction cost of T/L between proposed PSPP to Kotmale PS switchyard is estimated in this study.



(Source: JICA Study Team)

Figure 10.3.4-3 Layout of Kotmale PS Switchyard



(Source: JICA Study Team)

Figure 10.3.4-4 Single Line Diagram of Kotmale PS Switchyard

(4) Assessments of T/L routes and connecting points from "Halgran"

Assessment of each "T/L routes and connecting points" from "Halgran" are as follows.

i) Connection to Kotmale PS

Connection to Kotmale PS is the nearest connecting point of four options; length 40 km and one route.

However, as for switchyard of Kotmale PS, there are no spaces for new connection of T/L at present layout. Subject to be solved those constraints, this option can be feasible.

In case that it is difficult to secure space in the switchyard for new T/L connection, in addition to construction cost of T/L, costs for rearrangement of the switchyard shall be considered. And those costs are supposed to be expensive.

ii) Connection to New Polpitiya PS

This option is Connection to New Polpitiya SS: length 60 km and 1 route.

T/L route from Halgran to New Polpitiya cannot set out by straight line, since “Environmental Sensitive Area” widely exists in this area around Nuwara Eliya. T/L route from Halgran to New Polpitiya is required to be devirted through Kotmale PS area. Thus, T/L route will be longer and construction costs also will be increased. T/L route between Halgran to Kotmale PS is almost same as the route of “i) Connection to Kotmale PS”. As for T/L route between Kotmale and New Polpitiya, another T/L (Kotmale – New Polpitiya T/L) is planned in CEB’s Transmission Development Plan. The T/L route from proposed PSPP will be set out in parallel route with the CEB’s planned T/L.

Kotmale to New Polpitiya T/L in CEB’s Transmission Development Plan is under planning stage at present. Detailed T/L route and location of New Polpitiya SS have not decided yet. Route of T/L from proposed PSPP is required to set out in consideration with route of CEB’s Planned T/L. Thus, T/L route of this portion (from Kotmale PS to New Polpitiya) for T/L from proposed PSPP cannot be decided individually.

On the other hand, referring layout of transmission system, in case of pumping operation mode in proposed PSPP, electric power for pumping operation will be mainly supplied from Kotmale PS. At that condition, power flow passes through “Kotmale PS” to “New Polpitiya SS” to PSPP. Due to long distance of this pathway for the power flow, it is supposed to appear some problems on stabilities of transmission system.

iii) PI Connection to Kotmale - New Polpitiya T/L

This option is PI connection to “Kotmale – New Polpitiya T/L”, which is planned by CEB.

This connection type is divided into two types, i.e., “1-circuit PI connection” and “2-circuit PI connection”.

T/L from proposed PSPP is preferable to connect to “Kotmale – New Polpitiya T/L” at the point near Kotmale PS, to shorten T/L route. Since “Kotmale – New Polpitiya T/L” is under planning stage, it is possible to design T/L towers in consideration with loading conditions at connecting points preliminarily.

iii)-1 1-circuit PI Connection

Conductors of planned T/L (Kotmale – New Polpitiya T/L) is composed by ACSR Zebra × 2 conductors per phase. Thus, by using one-circuit PI connection type, it is impossible to secure enough capacity for T/L from proposed PPSP.

To select “one-circuit PI connection”, upgrades of conductors for “Kotmale – New Polpitiya T/L” are required. As a result of consideration by using “Low Loss TACSR/AS 550mm2” as conductors, stabilities of transmission system cannot be secured.

Selection of larger conductor size, increase of capacity, or increase of numbers of conductor wires per phase are required to secure stability of transmission system. For this, construction cost of T/L will be increased. Same upgrades of conductor types shall be also conducted for “Kotmale – New Polpitiya T/L”. Length and number of route of proposed connecting transmission is 40 km and 1 route.

iii)-2 2-circuit PI Connection

In case of “two-circuit PI connection” 2 routes (4 circuits) of new T/L are required. Length of T/L route from Halgran to Kotmale PS corresponds to approx.40km. In case of 2 route installation, construction cost will be double of “1-circuit PI connection” or “Connection to Kotmale PS”.

iv) Connection to new “switching station” near Kotmale PS

This option is connection to new switching station, which is assumed to construct near Kotmale PS.

T/L from proposed PSPP; length 40 km, can be composed by 1 route (2 circuits). And, it may be possible to plan other T/L connections or reinforcement of transmission system by using that switching station, if the switching station can be installed in appropriate location.

However, installation costs of the switching station will be required, in addition to construction cost of T/L.

Detailed considerations for location and cost estimations are out of scope of this study.

Comparisons of each option described above shown in Table 10.3.4-1.

Table 10.3.4-1 Comparison of T/L Routes and Connection Point (from "Halgran")

	i) To "Kotomale P/S"	ii) To "New Polpitiya S/S"	iii)-1 To T/L between "Kotomale - New Polpitiya"	iii)-2 To T/L between "Kotomale - New Polpitiya"	iv) To New "Switching Station"
Connecting type	Connection to P/S	Connection to S/S	PI Connection (1cct)	PI Connection (2cct)	Connection to S/S
Route Length	40km × 1 route	60km × 1 route	40km × 1 route	40km × 2 route	40km × 1 route
Conductor	Low Loss TACSR/AS 550mm^2 (×2 cond./phase)	Low Loss TACSR/AS 550mm^2 (×2 cond./phase)	Low Loss TACSR/AS 550mm^2 (×2 cond./phase)	ACSR Zebra (×2 cond./phase)	Low Loss TACSR/AS 550mm^2 (×2 cond./phase)
Assessment					
Cost [MUSD]					
Transmission Line	22.9	34.4	22.9	39.2	22.9
Reinforcement of existing T/L	0	0	(0) (*4)	0	0
Augmentation of Connection Point	(0) (*3)	0	0	0	(0) (*5)
Total	22.9	34.4	22.9	39.2	22.9
Other (*1)					
Condition of Connection Point	B - Lay out of Kotmale PS switchyard is congested.	A	B - Conductors of "Kotomale to New Polpitiya T/L" shall be upgraded.	A	A
Environmental and Social	A	B - Affected area will be larger due to longer T/L route.	A	B - Affected area will be larger due to increase of nos. of T/L route.	A
T/L Construction and Maintenance	A	B - Affected area will be larger due to longer T/L route.	A	B - Affected area will be larger due to increase of nos. of T/L route.	A
System Analysis	A	C - Stability of system cannot be secured.	C - Stability of system cannot be secured.	A	A
Rating (*2)	1	-	-	2	-

Remarks
(*1) Assessment (Other): A: Good <----------> C: Bad
(*2) Rating : Order of Preferability ("-" means "Out of consideration".)
(*3) The cost for augmentation / rearrangement of the switchyard is excluded for this consideration.
(*4) The cost for upgrades of conductors of T/L between "Kotomale - New Polpotiya" is excluded for this consideration.
(*5) The cost for installation of new "Switching Station" is excluded for this consideration.

Referring descriptions in Table 10.3.4-1, as a result, the most preferable option is "i) Connection to Kotmale PS". The second option is "iii)-2 2-cct PI Connection to Kotmale – New Polpitiya SS".

Option ii), iii)-1, and, iv) were not selected, considering following conditions.

As for Option iii)-1, transmission capacity does not enough by using "ASCR Zebra × 2 conductors per phase", and stability of system cannot be secured by using "Low Loss TASCR/AS 550mm^2 × 2 conductors per phase". To select this connection type, upgrading (larger size, increase of capacity, or increase of numbers of wires, etc.) of conductor are required. For this, construction cost shall be increased.

As for Option ii), it is supposed that stabilities of transmission system cannot be secured due to long distance of pathway of power flow in pumping operation of PSPP.

As for Option iv), it will be effective option, in case that integrated plan in consideration with Halgran, other future PS, and other T/L reinforcements are developed. And, detailed considerations for new switching station have not conducted.

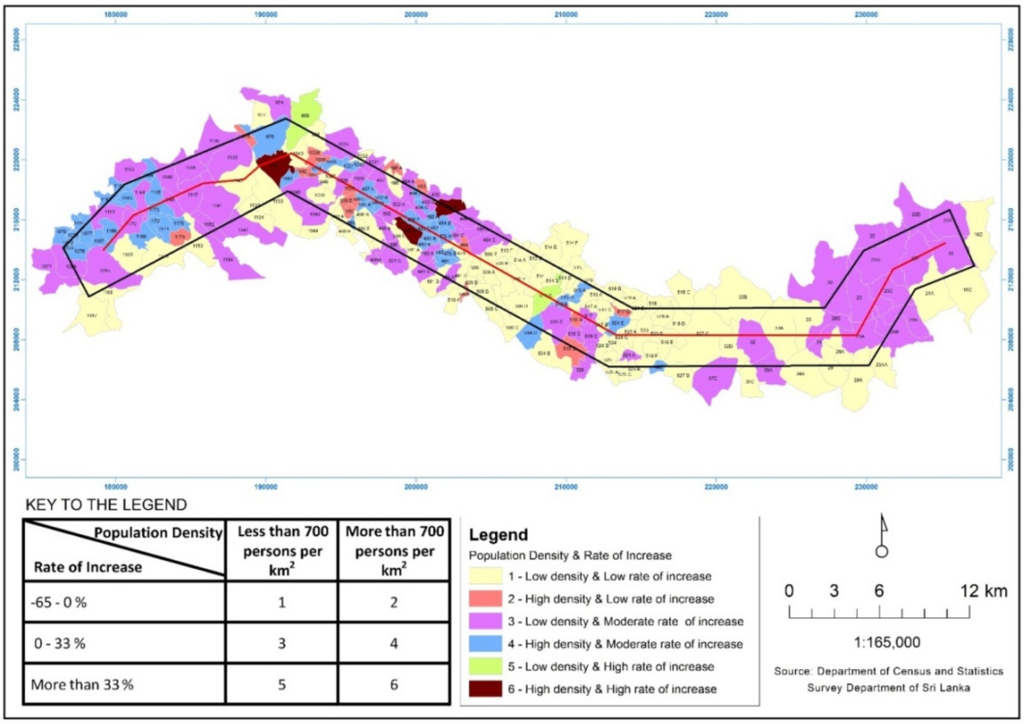
Detailed system analysis for T/L connection from Halgran site is considered for i) and iii)-2. Results of system analysis are shown in the following part.

As a result of system analysis, there are no problems for "i) Connection to Kotmale PS" and "iii)-2 2-cct PI Connection to Kotmale – New Polpitiya SS".

(5) Environmental study and evaluation

1) Populated areas and their scales

Described in the previous section (2), the route of the transmission line is proposed from the technical point of view and the natural environmental factor (avoiding the existing protected areas. Population density and population growth rate (10 years: 2001 - 2011) of each GN Division within the proposed route are calculated[1] as important social factors. It is to identify GN divisions which has high population density and high rate of population increase. They are categorized into six groups and expressed in different colors on the map (Figure 10.3.4-5). The proposed route is shown as a belt with 3 - 4 km width (alternative range of the route) because of its uncertainties at this stage.



(Source: JICA Study Team)

Figure 10.3.4-5 Population density and their growth rate along the route

[1] Data are from Department of Census and Statistics Survey of Sri Lanka.

On the route, there are a few GN Divisions with relatively high population density and high increase rate, however the impacts can be avoided and/or mitigated.

2) Barriers and their locations

Utilizing the existing data, possible barriers and their locations on the route are identified. Table 10.3.4-2 shows the result.

Table 10.3.4-2 Barriers and the route

Barrier	On the route and its buffer	Source
Natural Environment		
Protected areas	Galaha Reserved Forest is partially on the route.	CEA, Forest Department, Department of Wildlife Conservation
IBAs	None	BirdLife International (2004)
Bird migration routes	None	Sarath Kotagama and Athula Wijeyasinghe (1998). Siri Laka Kurullo. Wildlife Heritage Trust, Sri Lanka, cxviii+394.
Social Environment		
Built-up areas	Some but can be avoided.	50,000 topographic maps from Survey Department of Sri Lanka
Residential areas	Some but can be avoided.	
Archeological sites	There are small sites on the route, but can be avoided.	CEA
Temples	There are temples on the route, but can be avoided.	50,000 topographic maps from Survey Department of Sri Lanka
Hospitals	There are some hospitals on the route, but can be avoided.	
Military bases	None	
Other facilities	None in particular	

(Source: JICA Study Team)

No significant negative impacts are expected on both natural and social environments.

3) Evaluation

The evaluation result of the route from Halgran to Kotmale PS is in Table 10.3.4-3.

Table 10.3.4-3 Assessment on the Halgran - Kotmale PS route

Assessment aspect	Assessment
Population Density and its growth	A
Social Environment (barriers)	A
Overall Evaluation (Social Environment)	**A**
Natural Environment (barriers)	A
Overall Evaluation(Natural Environment)	**A**

(Source: JICA Study Team)

A: Project is not likely to have significant negative impacts on natural environment and society and/or limited to a small scale.
B: Project is likely to have negative impacts on natural environment and society.
C: Project is likely to have significant negative impacts on natural environment and society.
D: Project clearly gives significant negative impacts on natural environment and society.

10.3.5 Power System Stability

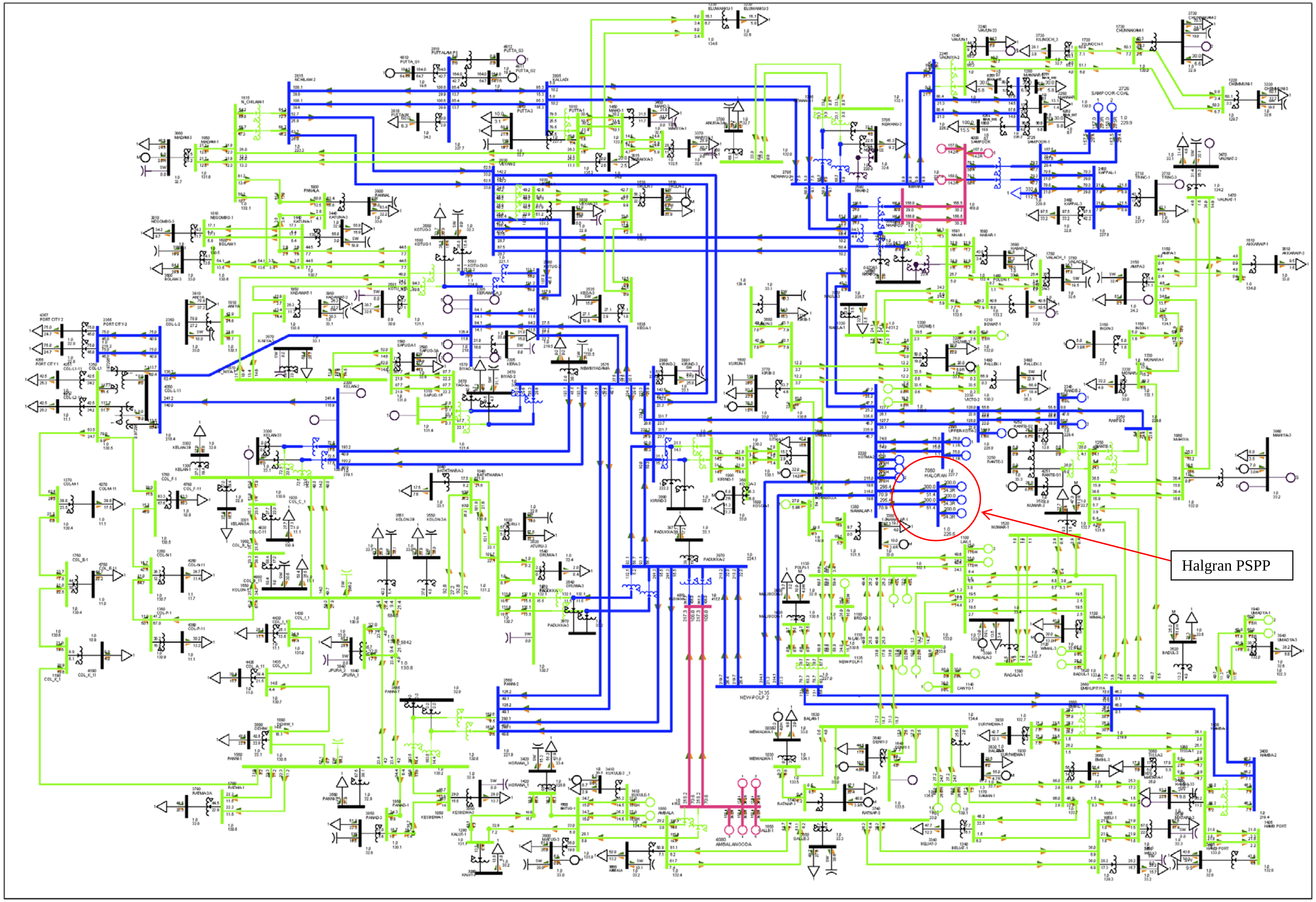
(1) Power Flow Analysis

Power flow analyses of 6 cases are carried out based on the plants installation scenario and loading (demand) scenario in 2025. Figure 10.3.5-1 to Figure 10.3.5-6 show the results of power flow analyses.

No thermal violations and no voltage violations are resulted in all of the normal operation cases.

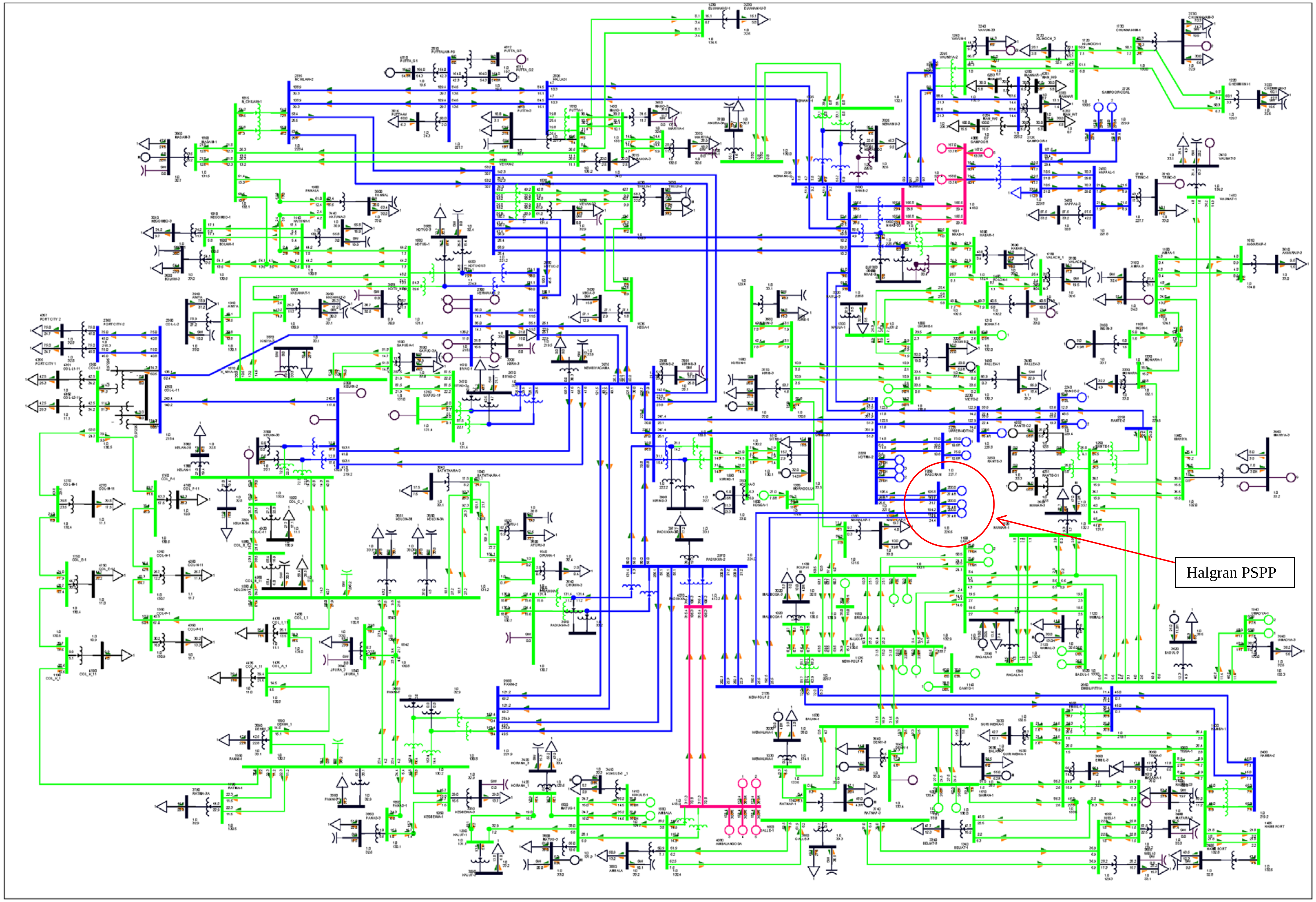
Also, in case T/L from Halgran 3 is connected to Kotmale P/S, no thermal violations are resulted in the remaining T/L on condition that one circuit outage (N-1) occurs on 220kV T/L from Kotmale P/S to Kirindiwela S/S, and one circuit outage (N-1) on 220kV T/L Kotmale P/S to New Polpitiya S/S.

As well, in case ofPI Connection to T/L between Kotmale P/S and New Polpitiya S/S, no thermal violations are resulted in the remaining T/L on condition that one circuit outage (N-1) occurs on 220kV T/L from Halgran PSPP to Kotmale P/S, and one circuit outage on 220kV T/L from Halgran PSPP to New Polpitiya S/S.



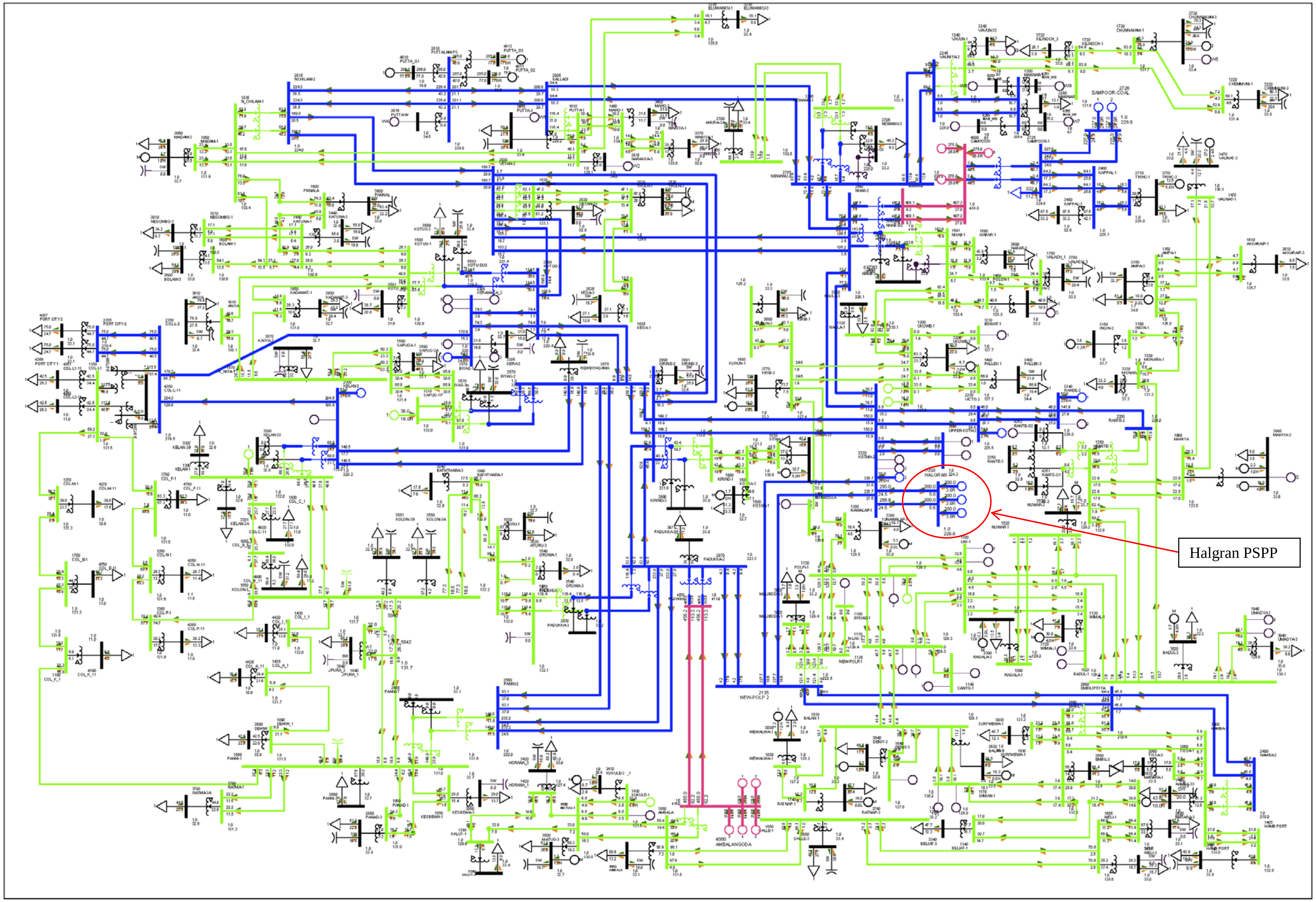
(Source: JICA Study Team)

Figure 10.3.5-1 Power Flow Diagram (Hydro Maximum Night Peak in 2025, Generating Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)



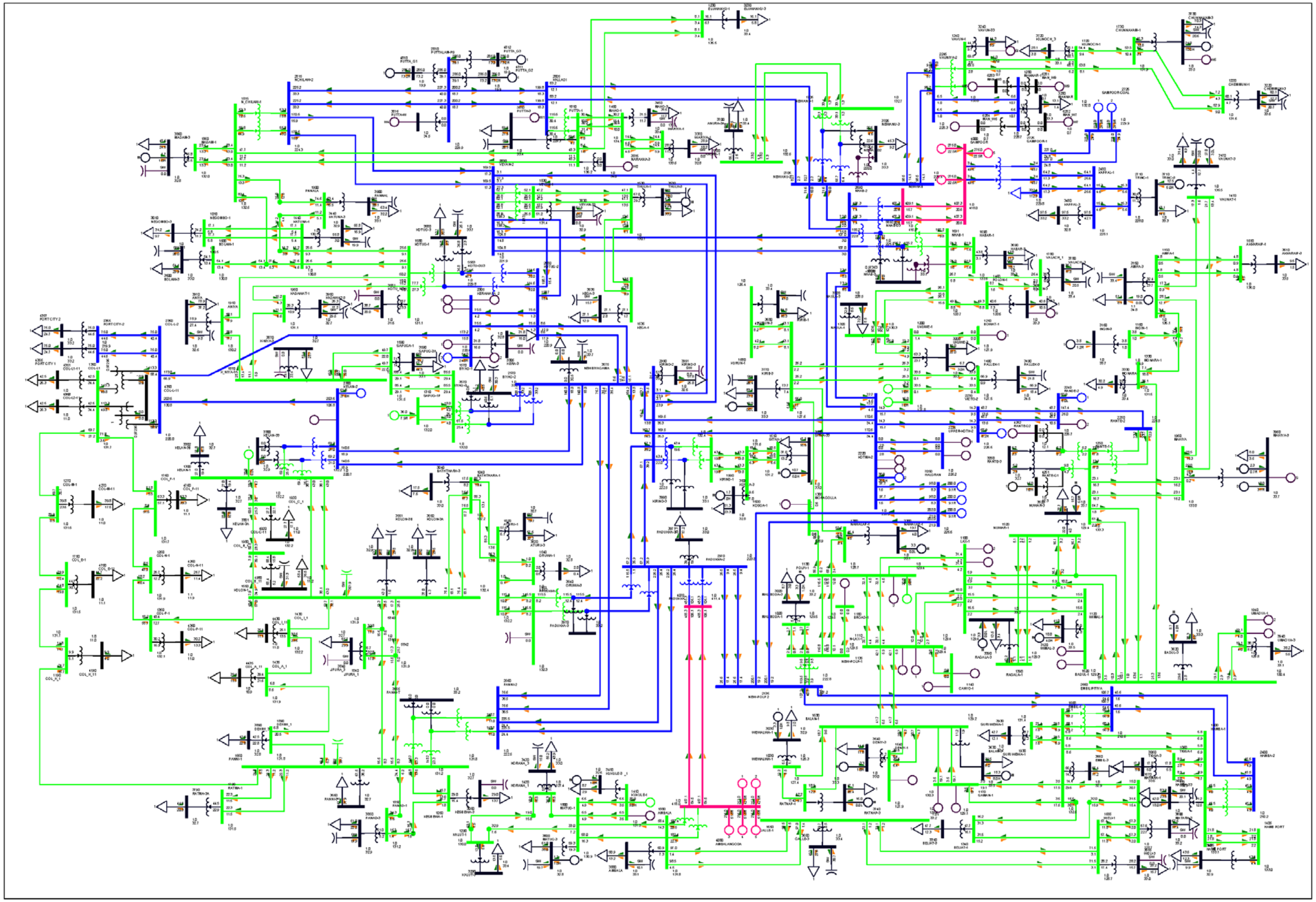
(Source: JICA Study Team)

Figure 10.3.5-2 Power Flow Diagram (Hydro Maximum Night Peak in 2025, Generating Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)



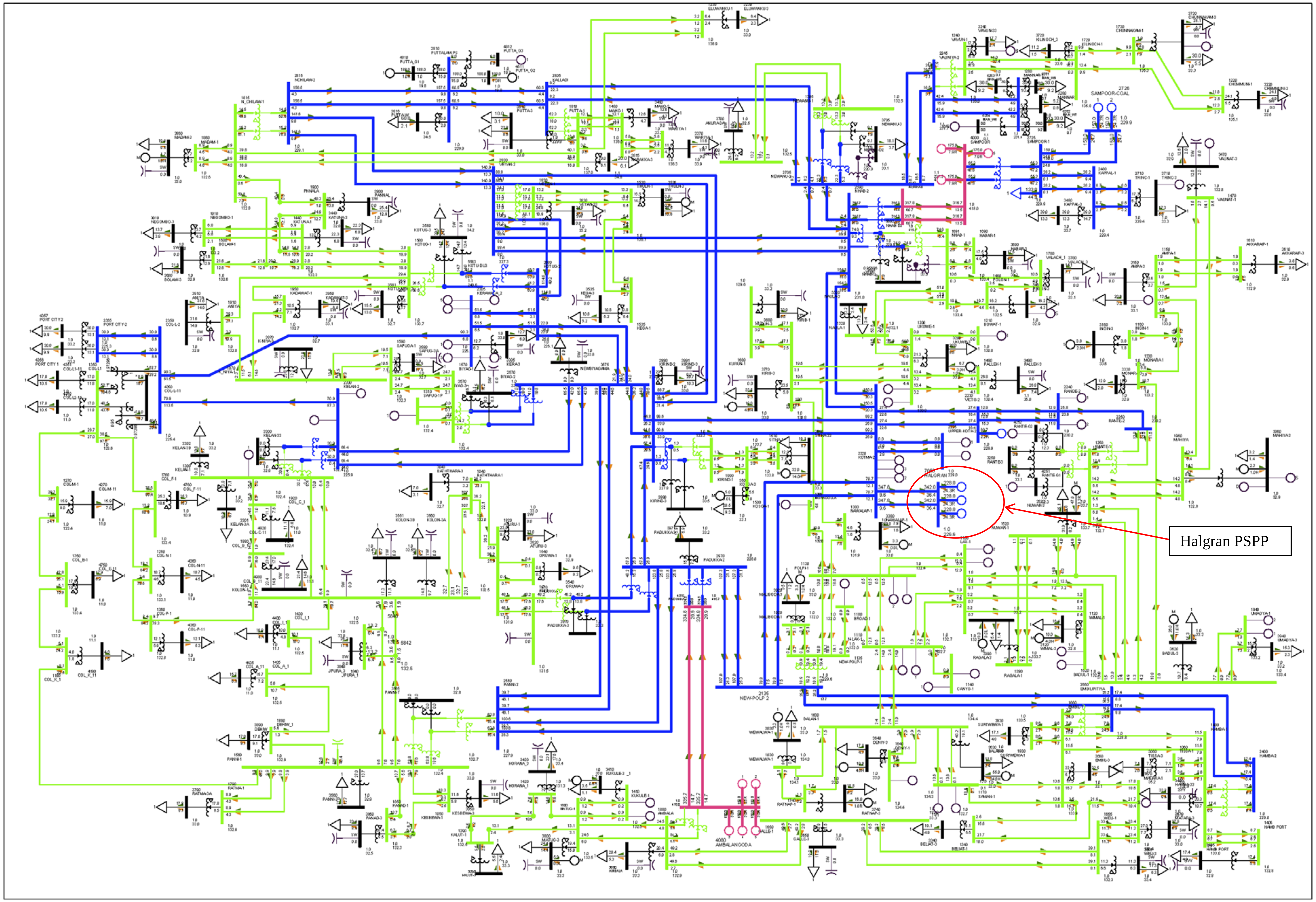
(Source: JICA Study Team)

Figure 10.3.5-3 Power Flow Diagram (Thermal Maximum Night Peak in 2025, Generating Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)



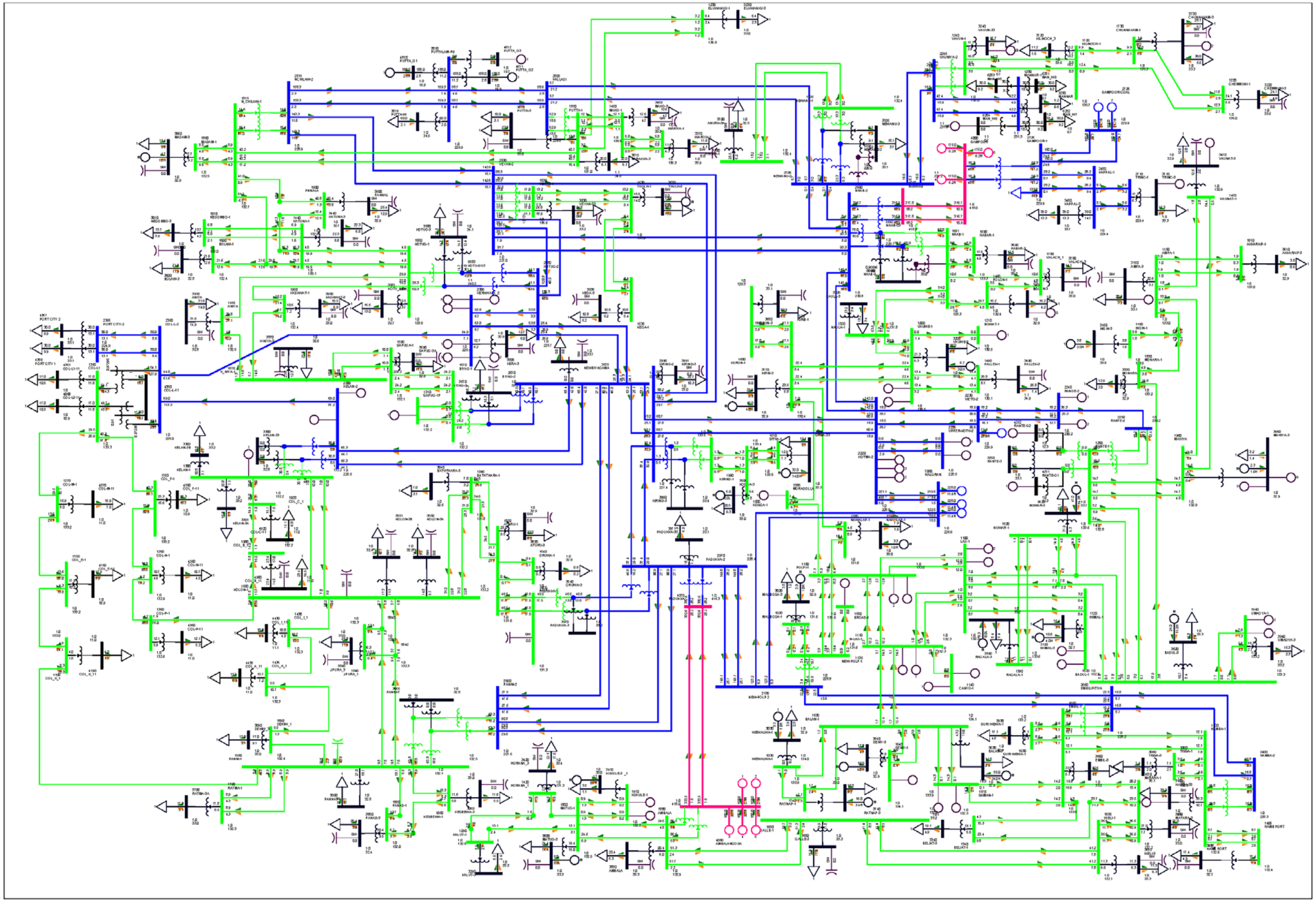
(Source: JICA Study Team)

Figure 10.3.5-4 Power Flow Diagram (Thermal Maximum Night Peak in 2025, Generating Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)



(Source: JICA Study Team)

Figure 10.3.5-5 Power Flow Diagram (Off Peak in 2025, Pumping Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)



(Source: JICA Study Team)

Figure 10.3.5-6 Power Flow Diagram (Off Peak in 2025, Pumping Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)

(2) Short Circuit Current Analysis

In the short circuit current analysis, three phase fault currents at bus conductors of Halgran PSPP, Kotmale P/S, and New Polpitiya S/S are calculated for Hydro Night Peak and Thermal Night Peak as the most severe demand cases. The three phase fault current at the Halgran PSPP and Kotmale P/S, New Polpitiya S/S are shown in Table 10.3.5-1. In all cases, calculated currents satisfies the criteria.

Table 10.3.5-1 The Three Phase Short Circuit Currents

Demand	T/L	Unit Capacity	P/S, S/S		Currents
Peak (Wet Season)	Kotmale P/S	200MW	Kotmale	220kV	25.4kA
			Halgran	220kV	11.8kA
	PI Connection	200MW	Kotmale	220kV	25.1kA
			Halgran	220kV	21.2kA
			New Polpitiya	220kV	21.1kA
Peak (Dry Season)	Kotmale P/S	200MW	Kotmale	220kV	21.4kA
			Halgran	220kV	11.1kA
	PI Connection	200MW	Kotmale	220kV	21.7kA
			Halgran	220kV	19.8kA
			New Polpitiya	220kV	19.1kA

(Source: JICA Study Team)

(3) Transient Stability Analysis

1) Three phase line fault at Halgran PSPP

In case that T/L from Halgran PSPP is connected to T/L between Kotmale P/S and New Polpitiya S/S with PI connection, it is set in the calculation that three phase line fault occurs on the tranmission line below since the power flow is heavier than others.

Peak: Halgran PSPP – Kotmale, Off-Peak: Halgran PSPP – New Polpitiya.

The results of transient stability analysis of three phase line fault are shown in Figure 10.3.5-7 to Figure 10.3.5-12.

The results of transient stability analyses show that the network is kept in stable. However, the weak damping phenomena are observed in around the initial 10 seconds. Therefore, it is suggested that relative large plants shoud be equipped with powe system stabilizers.

2) One Unit Tripping at Halgran PSPP

a) Frequency drop followed by loss of generator

The results of the dynamic simulation for one unit tripping Halgran PSPP are shown in Figure 10.3.5-13 to Figure 10.3.5-16.

The results of the study for all cases show that the system frequencies do not drop to 48.75Hz which is the criteria; the load shedding is taken place.

Also, the system frequency drop in Thermal maximum scenario (TMNP) is larger than that in Hydro maximum scenario (HMNP). This is because there is difference of the number of power plants with free governor operation. The plants operated with free governor mode in these simulations are shown below.

HMNP: Samanalawewa, Bowathenna, Kotmale, Upper Kotmale, Victoria, Puttalam, Ambalangoda, Sampoor

TMNP: Victoria, Kotmale, Kelanitissa

Therefore, it is suggested that free governor operation system should be considered for relatively large plants to be constructed in the future.

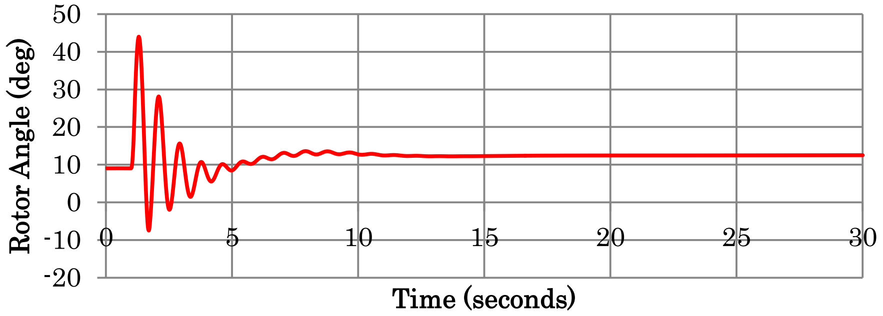
b) Frequency Rise by loss of pumping

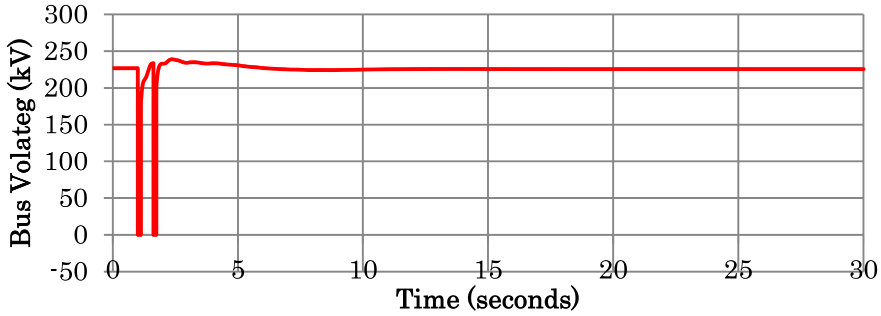
The results of the dynamic simulation for one unit tripping in pumping mode Halgran PSPP are shown in Figure 10.3.5-17 and Figure 10.3.5-18.

The results show for all cases that the system frequencies do not rise to 51.5Hz which is the criteria; the alarm of a thermal power plant is taken place.

In this regard, however, it is set in these simulation that the coal power plants (Puttalam, Ambalangoda, Sampoor) are operated with free governor mode.

Therefore, it is suggested that free governor operation system should be considered for relatively large plants to be constructed in the future.

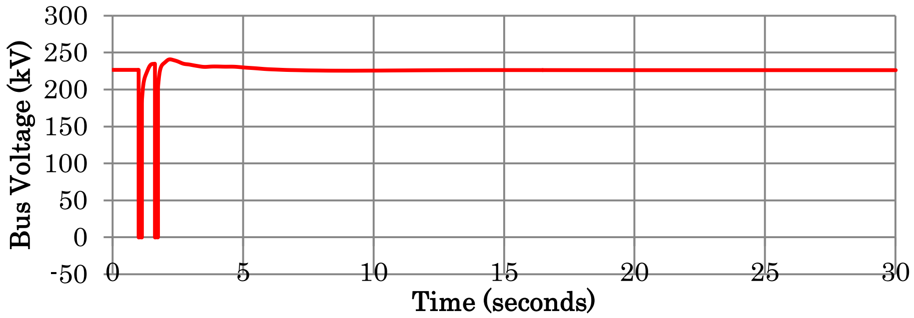


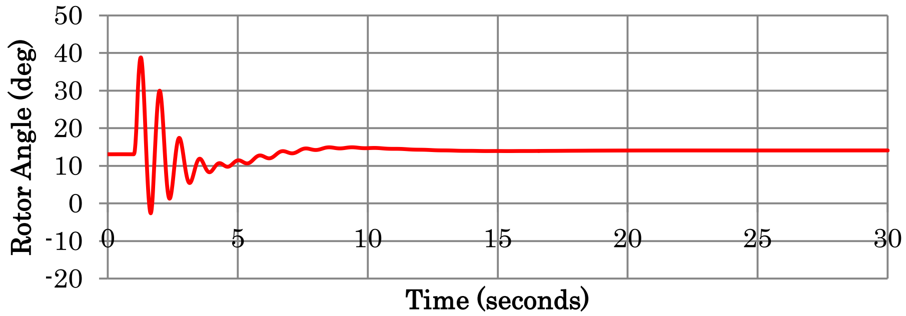


(Hydro Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)

(Source: JICA Study Team)

Figure 10.3.5-7 Three-phase Fault at Halgran end of Halgran-Kotmale 220kV Line-USR

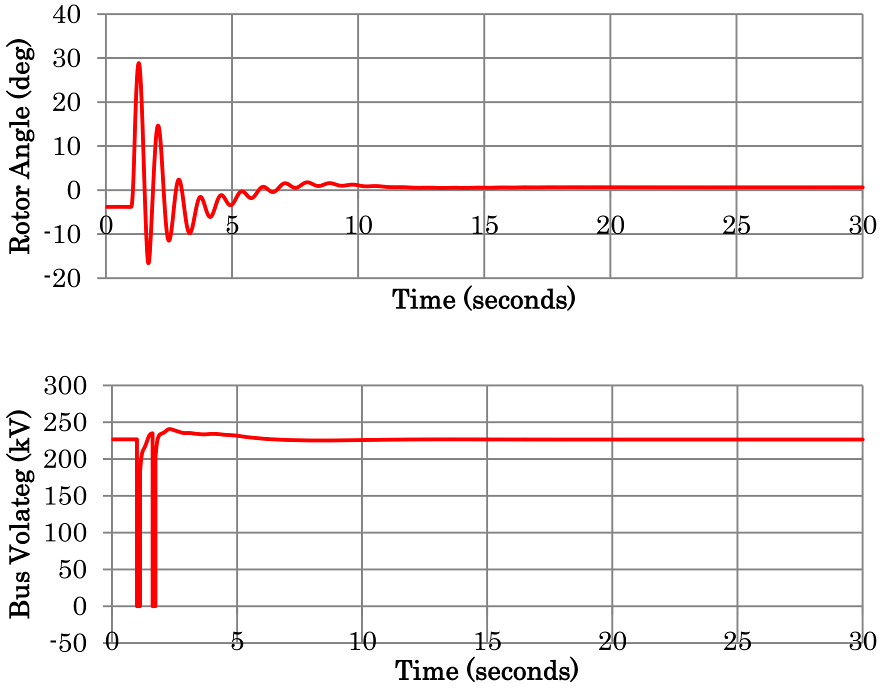




(Hydro Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)

(Source: JICA Study Team)

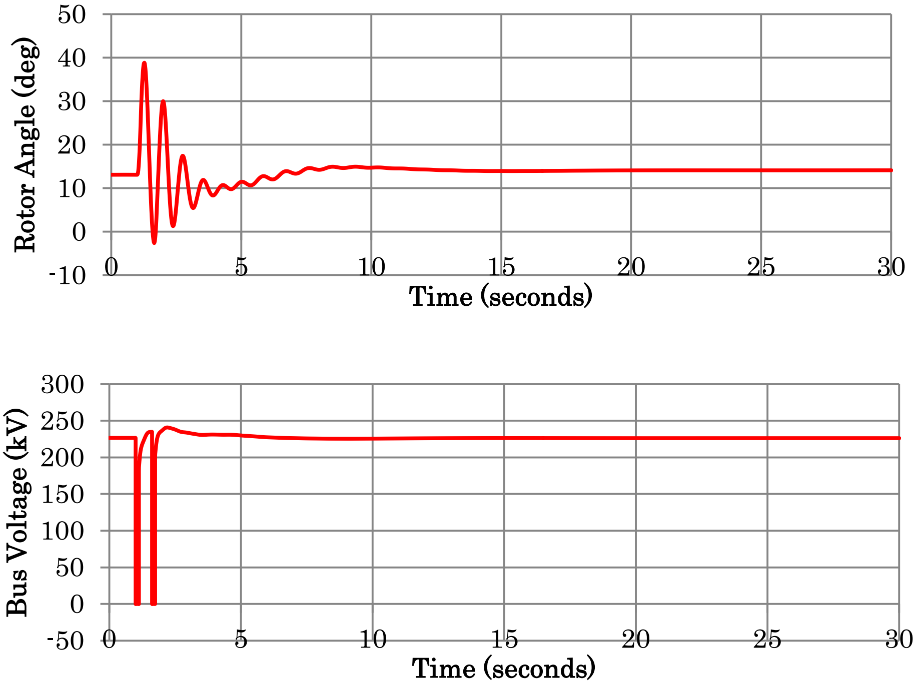
Figure 10.3.5-8 Three-phase Fault at Halgran end of Halgran-New Polpitiya 220kV Line-USR



(Thermal Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)

(Source: JICA Study Team)

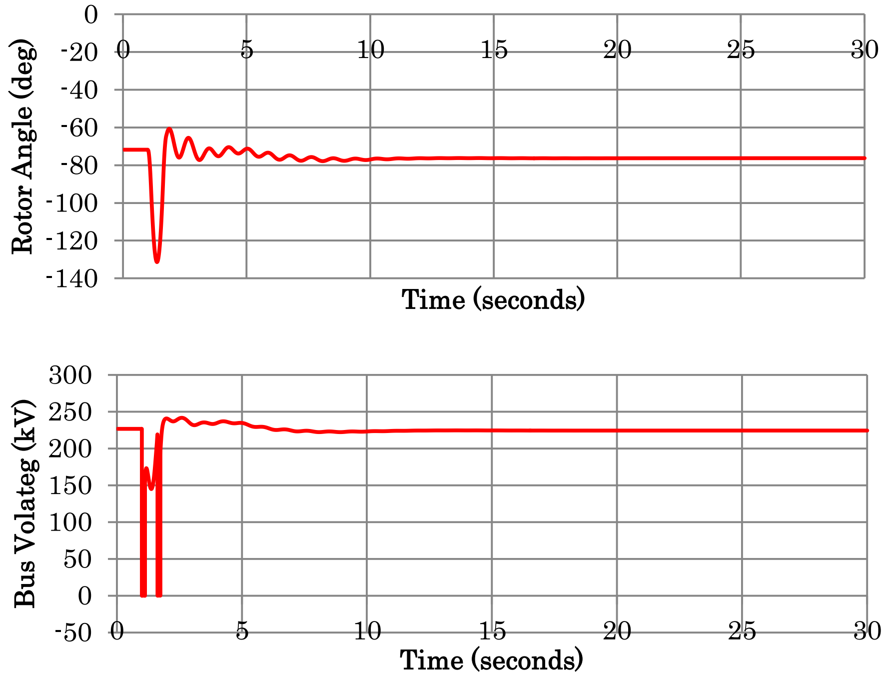
Figure 10.3.5-9 Three-phase Fault at Halgran end of Halgran-Kotmale 220kV Line-USR



(Thermal Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)

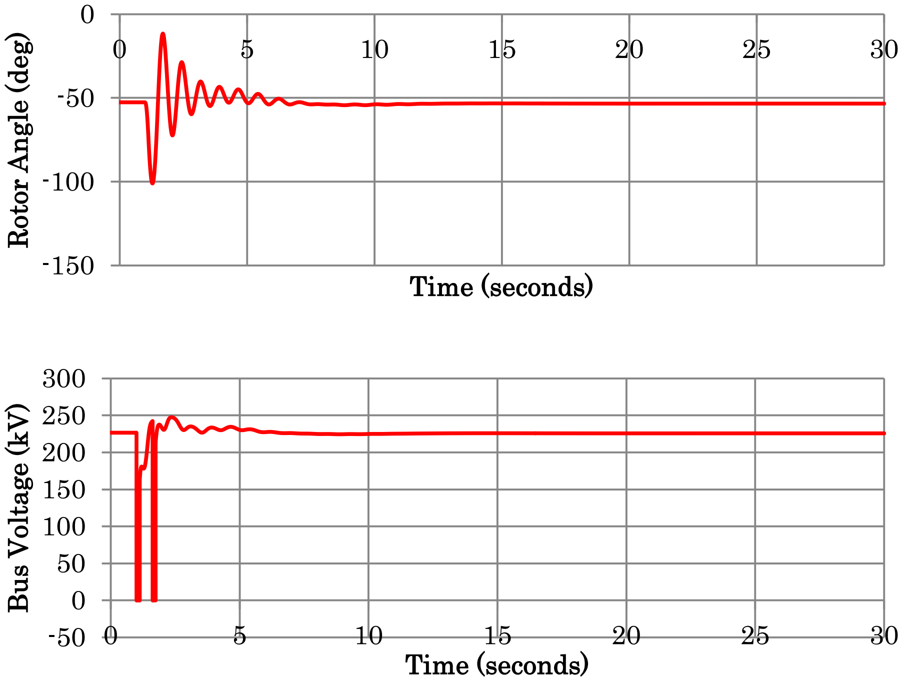
(Source: JICA Study Team)

Figure 10.3.5-10 Three-phase Fault at Halgran end of Halgran-New Polpitiya 220kV Line-USR



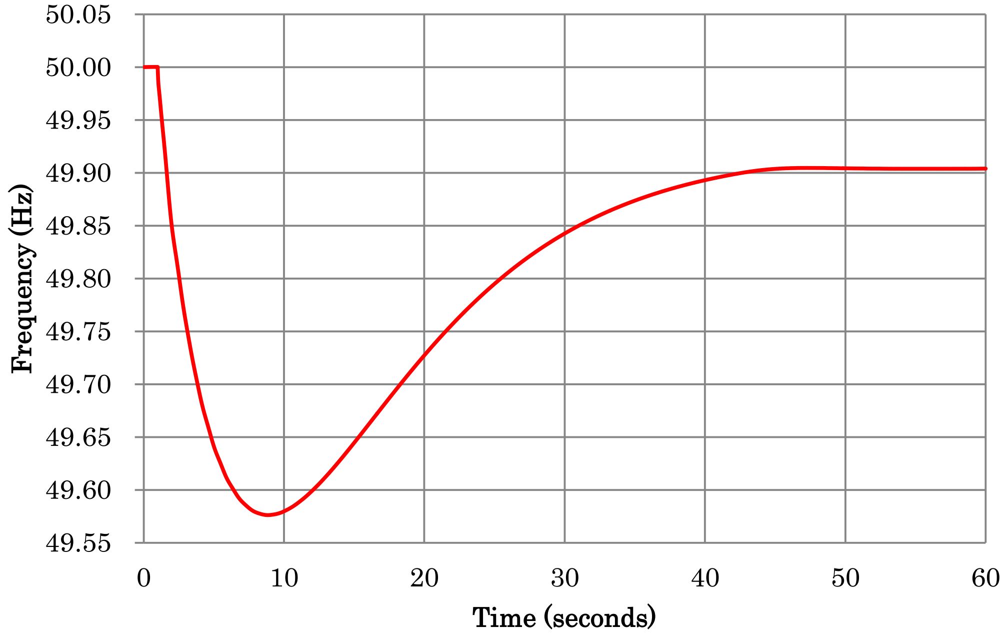
(Off Peak in 2025,Pumping Operation, Connected to Kotmale, Halgran Unit Capacity 200MW)
(Source: JICA Study Team)

Figure 10.3.5-11 Three-phase Fault at Halgran end of Halgran-Kotmale 220kV Line-USR



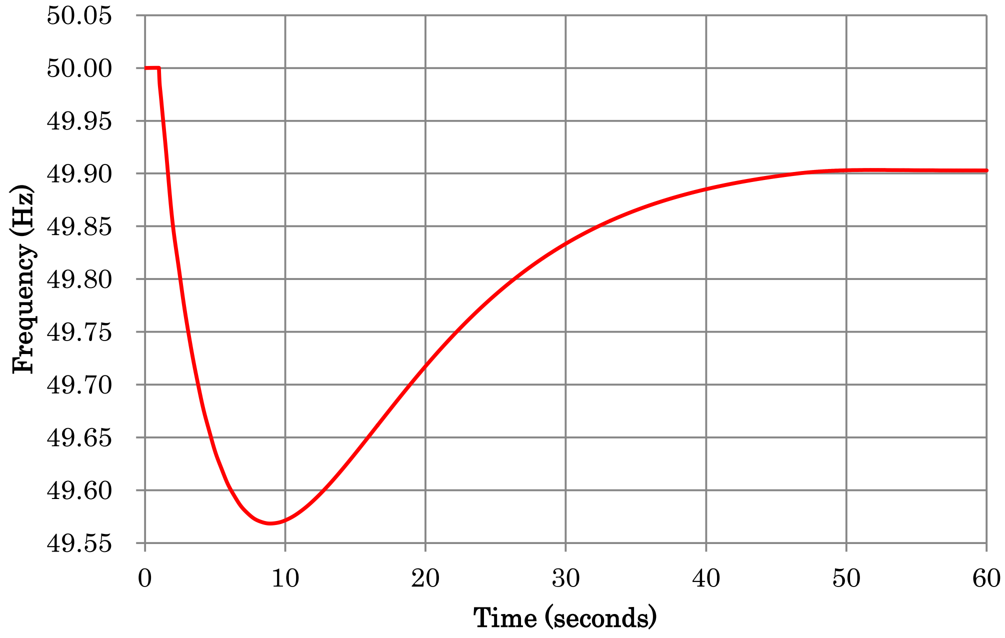
(Off Peak in 2025,Pumping Operation, Connected to Kotmale and New Polpitiya, Halgran Unit Capacity 200MW)
(Source: JICA Study Team)

Figure 10.3.5-12 Three-phase Fault at Halgran end of Halgran-Kotmale 220kV Line-USR



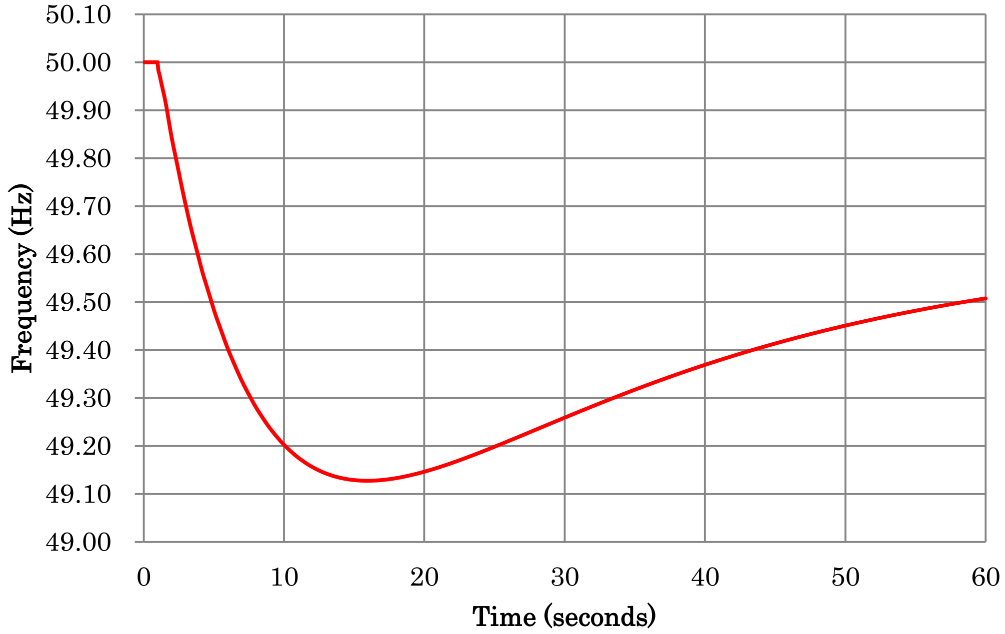
(Hydro Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale)
(Source: JICA Study Team)

Figure 10.3.5-13 200MW Unit Tripping at Halgran PSPP



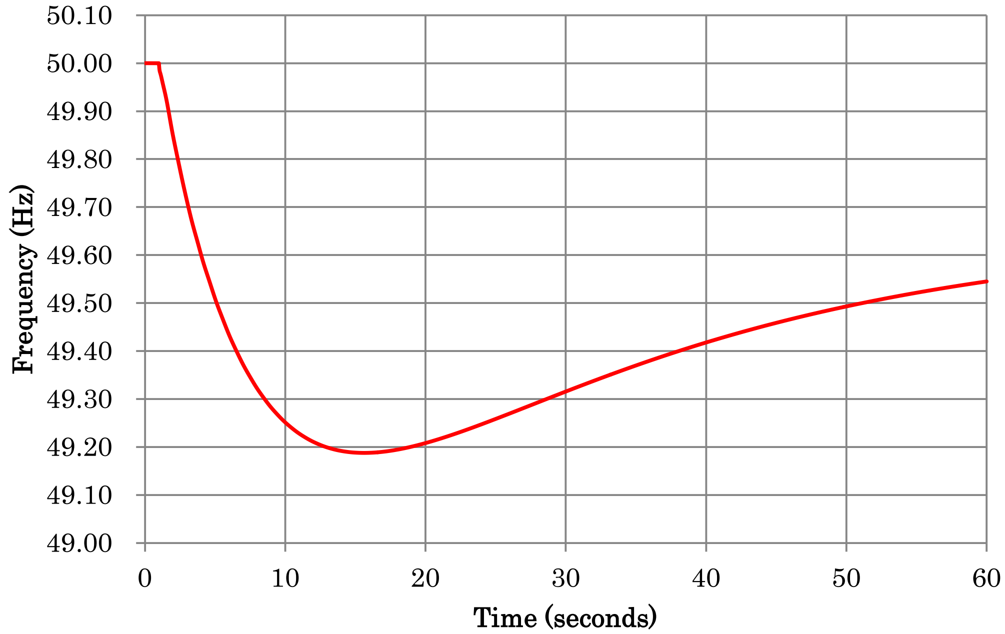
(Hydro Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale and New Polpitiya)
(Source: JICA Study Team)

Figure 10.3.5-14 200MW Unit Tripping at Halgran PSPP



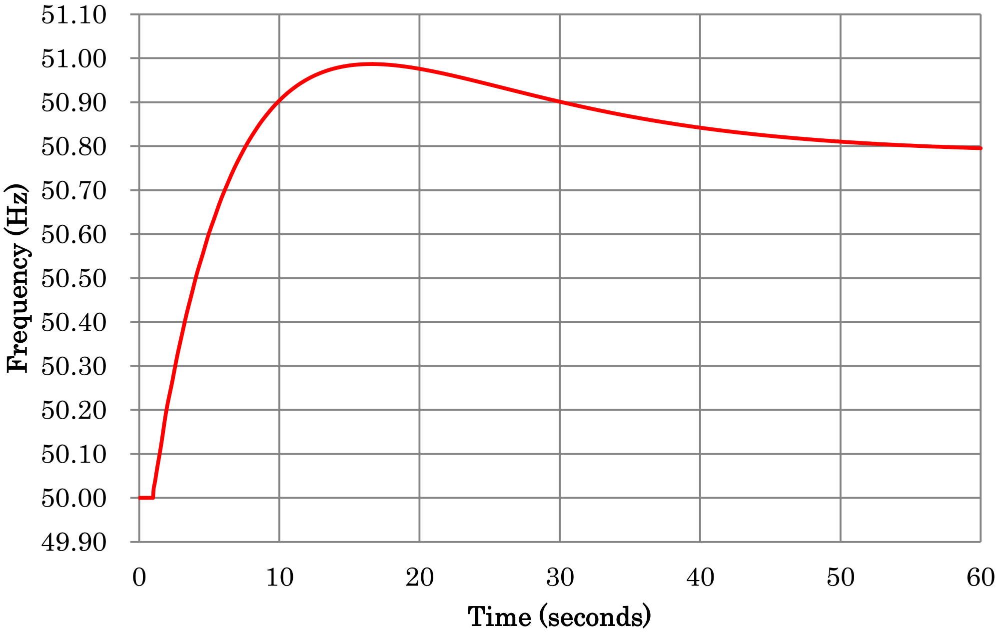
(Thermal Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale)
(Source: JICA Study Team)

Figure 10.3.5-15　200MW Unit Tripping at Halgran PSPP



(Thermal Maximum Night Peak in 2025,Generating Operation, Connected to Kotmale and New Polpitiya)
(Source: JICA Study Team)

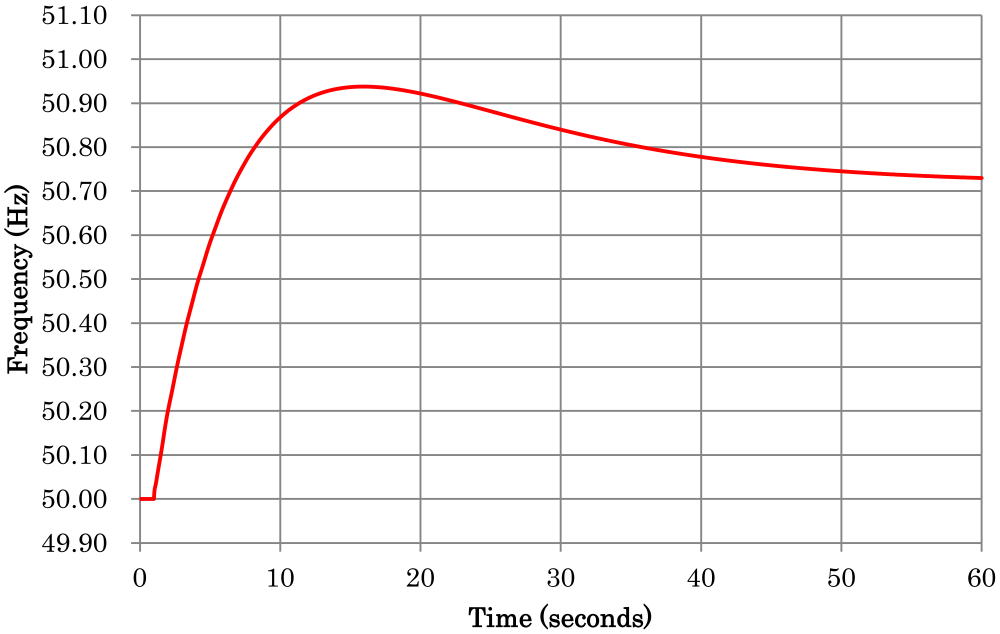
Figure 10.3.5-16　200MW Unit Tripping at Halgran PSPP



(Off Peak in 2025,Pumping Operation, Connected to Kotmale)

(Source: JICA Study Team)

Figure 10.3.5-17 200MW Unit Tripping at Halgran PSPP



(Off Peak in 2025,Pumping Operation, Connected to Kotmale and New Polpitiya)

(Source: JICA Study Team)

Figure 10.3.5-18 200MW Unit Tripping at Halgran PSPP