CHAPTER 8

PRELIMINARY DESIGN

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8.1 OVERHEAD TRANSMISSION FACILITIES

8.1.1 Outline of 230kV Overhead Transmission Line

OHL_Route3 is double circuit overhead transmission line which branches at the midpoint of NPP and WPP and goes to GS5. The location of the transmission line is flat area with an altitude of 10 to 20 m. The ground is good in general. The route of the transmission line is restricted around GS5, because of the residence. The outline of 230kV transmission line is shown in Table 8.1-1. The location map of 230kV overhead transmission line after selection is shown in Fig. 8.1-1. A rough route sectional view is shown in Fig. 8.1-2 and the steel tower which is due to branch is shown in Fig. 8.1-3.

Table 8.1-1 Outline of 230kV Overhead Transmission Line

Route	OHL_Route3
Nominal Voltage	230kV
Circuits	2cct
Location	From : Midpoint of NPP and WPP To : GS5
Total Length	10.2km
Supporting structure	Steel tower or Special steel tower : 31
Conductor	TACSR[*1] 610mm^2 × 2 or equivalent
Ground Wire	OPGW[*2] 90mm^2 or equivalent
Ground Wire	AC[*3] 100mm^2 or equivalent

*1 TACSR : Thermal-resistant Aluminum alloy Conductor Steel Reinforced
*2 OPGW : Optical Fiber Ground Wire
*3 AC : Aluminum Clad Steel

Source: JICA Study Team

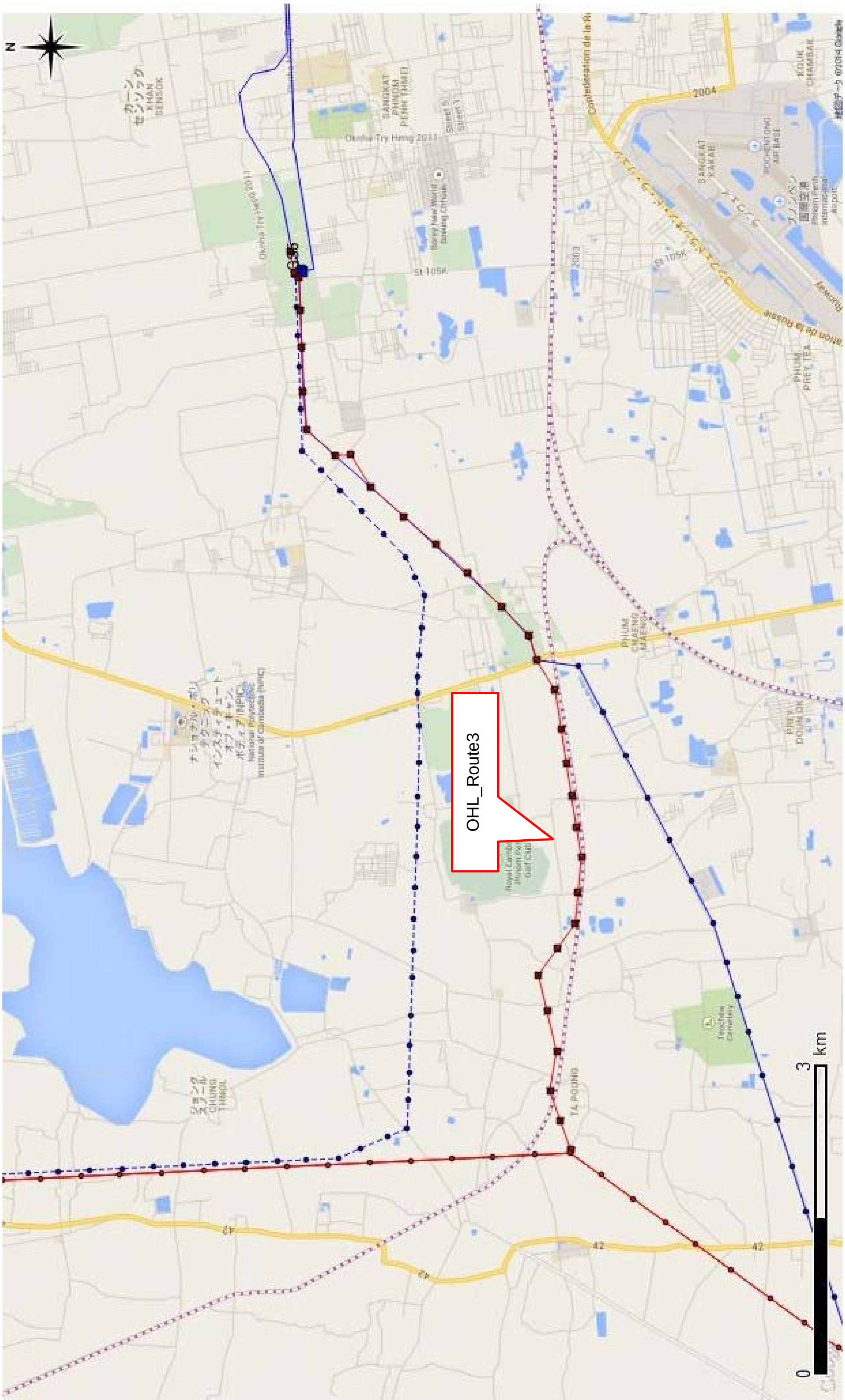
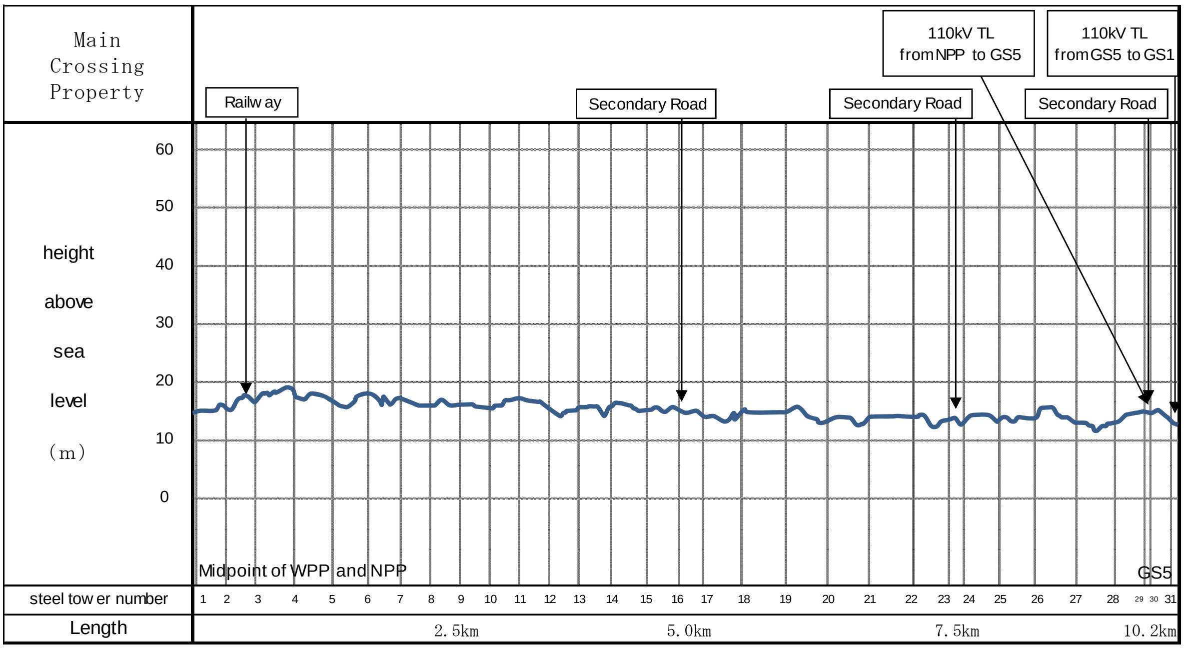


Fig. 8.1-1 Location Map of 230kV Overhead Transmission Line



Source: JICA Study Team

Fig. 8.1-2 Rough Route Sectional View of 230kV Overhead Transmission Line

Fig. 8.1-3 230kV Steel Tower in the Midpoint of NPP and WPP

8.1.2 Transmission Capacity of 230kV Overhead Transmission Line

OHL_Route3 branches from the 230kV transmission line between NPP and WPP. The transmission capacity of the 230kV overhead transmission line from the midpoint of NPP and WPP to GS5 shall be more than 861 MVA/cct which is equivalent of the 230kV transmission line between NPP and WPP. In consideration of the future substation's construction around the midpoint of NPP and WPP, TACSR 610mm^2 × 2 whose capacity is more than 1,300 MVA/cct shall be used. Conductor (transmission capacity) and Ground Wire which will be used by EDC's 230kV transmission lines are shown in Table 8.1-2.

Table 8.1-2 Conductor (Transmission Capacity) and Ground Wire used by EDC

Type		230kV (Capacity)
Conductor	TACSR	610mm^2 × 2 (1,359MVA/cct)
	ACSR*1	632mm^2 × 2 (861MVA/cct) 400mm^2 × 2 (604MVA/cct) 632mm^2 (430MVA/cct) 400mm^2 (302MVA/cct)
Ground Wire	AC	90 mm^2, 100 mm^2
	GSW*2	90 mm^2
	OPGW	90 mm^2, 100 mm^2

*1 ACSR : Aluminum Conductor Steel Reinforced
*2 GSW : Galvanized Stranded Steel Wire

Source: JICA Study Team

8.1.3 Preliminary Design of 230kV Overhead Transmission Line

Preliminary design of transmission line for this Study is carried out via the following steps 1 to 6. The preliminary design is carried out from the data which came to hand at the GREPTS (General Requirement of Electric Power Technical Standards), SREPTS (Specific Requirements of Electric Power Technical Standards), and a spot.

Step 1 Setup of climatic conditions
Step 2 Selection of conductor and ground wire
Step 3 Setup of Ground Clearance
Step 4 Setup of wiring conditions
Step 5 Setup of insulator set, supporting structure, and the foundation
Step 6 Separate setting of a special part

(1) Setup of climatic conditions

The main factors affecting the design of transmission line are climatic conditions. In consideration of SREPTS and the basic design of 230kV and 115kV overhead transmission line carried out by the Cambodia, basic climatic conditions are shown in Table 8.1-3. In consideration of not-paved roads and actual dust conditions, the pollution level shall be little considered.

Table 8.1-3 Basic Climatic Conditions

Items	Range	Value
Temperature	Maximum	40°C
	Minimum	15°C
	Average	28°C
Altitude above sea level		Not exceed 1,000m
Isokeraunic Level (IKL)		38-132 thunderstorm days/year
Climate		Tropical
Annual Rainfall	Average	1,290mm
Maximum Wind Velocity		32.0m/s
Maximum Humidity		100%
Pollution Level		Salt contamination is little considered. Tropical condition shall be considered.

Source: JICA Study Team

(2) Selection of conductors and ground wire

Conductor whose capacity is more than 1,300MVA/cct shall be used. Ground wires which are used at 230kV transmission line between NPP and WPP shall be used. Technical characteristics of conductor are shown in Table 8.1-4. And technical characteristics of ground wires are shown in Table 8.1-5. In consideration of IKL, two ground wires shall be attached.

Table 8.1-4 Technical Characteristics of Conductor

Type of Conductor	TACSR/AC 610 mm^2
Component of stranded wires	Al 54/3.80, AC 7/3.80
Total area of Conductor	691.8 mm^2
Total Diameter	34.20 mm
Weight	2,198 kg/km
Ultimate Tensile strength	180,000 N
Modulus of elasticity	71.8 kN/mm^2
Coefficient of linear expansion	20.6×10^{-6}/°C
Maximum working tension	Less than 72,000N
DC resistance at 20°C	0.0458 ohm/km

Source: JICA Study Team

Table 8.1-5 Technical Characteristics of Ground Wires (230kV)

Type	AC 100 mm^2	OPGW 90mm^2
Component of stranded wires	AC 7/4.3	AC 8/3.7, OP unit:1/6.0
Total area of wires	101.6 mm^2	106.4 mm^2
Total Diameter	12.9 mm	13.4 mm
Weight	643.7 kg/km	613.0 kg/km
Ultimate Tensile strength	112,400 N	98,300 N
Modulus of elasticity	149,100 N/mm^2	149,000 N/mm^2
Coefficient of linear expansion	12.9×10^{-6}/°C	12.9×10^{-6}/°C
Maximum working tension	Less than 40,460 N	Less than 35,380 N
DC resistance at 20°C	0.745 ohm/km	0.889 ohm/km
Number of optical fiber	—	24

Source: JICA Study Team

(3) Setup of ground clearance

The height of steel tower is determined by setup of clearance conditions. The minimum height from the ground is set by GREPTS and SRPETS. With this Study, in consideration of going through the flat ground near Phnom Penh and a large number of crossing roads, ground clearance is considered as the minimum height of conductor above ground of roads which secures 14.2m. Minimum height of conductor above ground (230kV) is shown in Table 8.1-6.

Table 8.1-6 Minimum Height of Conductor above Ground (230kV)

Definition area	clearances
Among bare conductors and supporting structures, arms, guy wires and so on	No less than 1.45m
Urban areas	7.7m
Areas where third persons hardly approach	6.7m
Roads and railways	14.2m
River and seas	Adding 4.2m
Other facilities	4.2m
Trees	3.2m

Source: JICA Study Team

(4) Setup of wire conditions

(a) Maximum working tension of conductor

The maximum working tension of the conductor is decided taking into account of the following two factors.

- The maximum tension (>Maximum working tension) of the conductor must not exceed 40 percent of the ultimate Strength Tensile of the conductor.

- EDS (Every Day Stress) (Tension at 28°C with no wind) is less than 25 percent of the ultimate strength tensile of the conductor.

(b) Maximum working tension of ground wire

The maximum working tension of the ground wire is generally set up like “the sag of the ground wire under EDS condition is below 80% of the conductor’s sag at the standard span length (350m)”. The result by which requirements were satisfied is shown in Table 8.1-7.

Table 8.1-7 Maximum Working Tension and EDS (Max Span Length = 500m)

Type	UTS	Maximum Working Tension	EDS
TACSR/AC 610mm^2	180,000N	49,030N (MWT / UTS =27%)	33,620N (EDS/UTS=19%)
AC 100mm^2	112,400N	19,620N (MWT / UTS =18%)	13,930N (EDS/UTS=13%)
OPGW 90mm^2	98,300N	19,620N (MWT / UTS =20%)	14,320N (EDS/UTS=15%)

* The part where span length is especially short and branch part inquire separately. Source: JICA Study Team

(c) Sag of conductor

Because the transmission line progress place of this study does not almost have a vertical interval and is subject to the influence of steel tower's height by span length, it sets the maximum span length to 500 m. The outline calculation result of sag by span length is shown in Table 8.1-8.

Table 8.1-8 Sag of Conductor (at 150°C with no wind)

Span length	Sag
200 m	6.77 m
250 m	8.80 m
300 m	11.3 m
350 m	14.2 m
400 m	17.5 m
450 m	21.1 m
500 m	25.1 m

Source: JICA Study Team

(5) Setup of insulator set, supporting structure, and the foundation

(a) Insulator set

The ball socket type or clevis type suspension insulator (standard disc type porcelain insulator) which shall comply with IEC (International Electrotechnical Commission) 60120 and 60305 or equivalent is used for an insulator set. The specifications of an insulator are shown in Table 8.1-9. An insulator is shown in Fig. 8.1-4. The insulator number may be 17 pieces equivalent to the 230kV transmission line which passes from WPP to NPP.

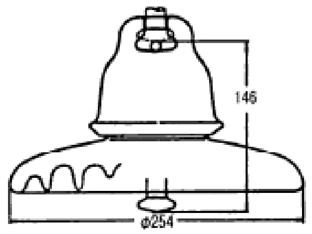


Fig. 8.1-4 SU165BN

Source: NGK Catalogue

Table 8.1-9 Insulator Size

Type	Height	Diameter	R.U.S.	Remarks
SU165BN × 2	146mm	254mm	330kN	Tension (NGK)
U160BP × 2	146mm	320mm	320kN	Tension (Chinese)
SU165BN	146mm	254mm	165kN	suspension (NGK)
U160BP	146mm	320mm	160kN	suspension (Chinese)
SU120CN	146mm	254mm	120kN	suspension (NGK)
U120BP	146mm	254mm	120kN	suspension (Chinese)

Source: JICA Study Team

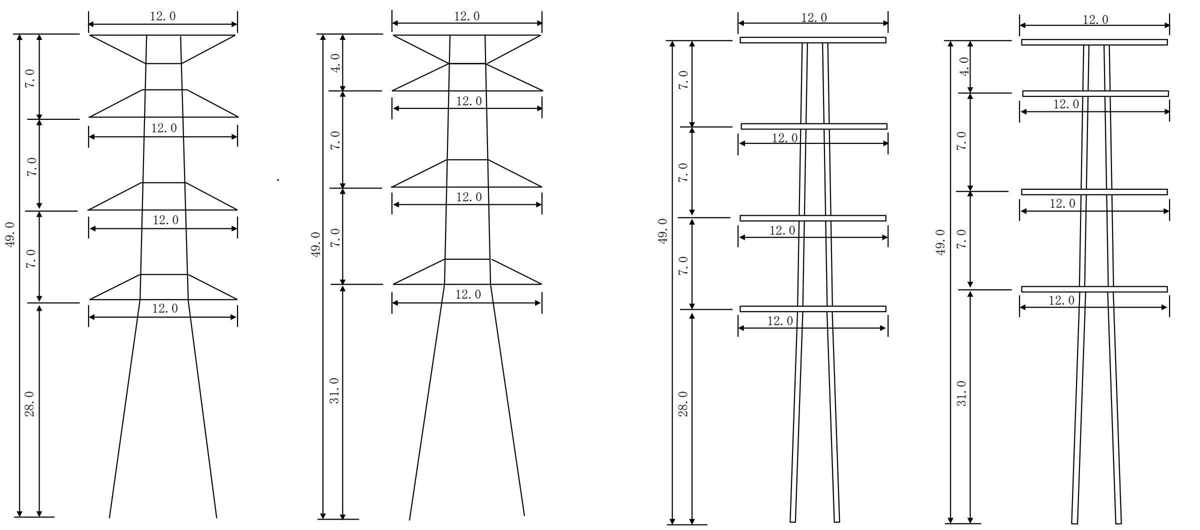
(b) Supporting structure

Supporting structure uses a steel tower or a special steel tower. Special steel tower shall be used along the railway. Fundamental steel tower types are four models (A ~ D) shown in Table 8.1-10. The part which crosses a 115kV transmission line designs individually. The example of the construction drawing of a steel tower is shown in Fig. 8.1-5

Table 8.1-10 Fundamental Steel Tower Type

Tower Type	Insulator String	Horizontal Angle of Line
A	Suspension	0° ~ 3°
B	Tension	0° ~ 30°
C	Tension with supporting	0° ~ 60°
D	Tension with supporting	Dead end tower

Source: JICA Study Team



Source: JICA Study Team

Fig. 8.1-5 Steel Tower's Example
(Left side : steel tower, Right side : Special steel tower)

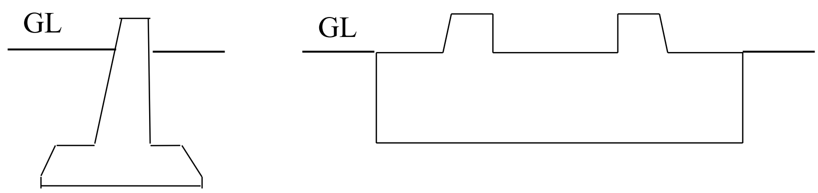
(c) Foundation

The result of having boring, it is assumed that supporters come out more shallowly. Therefore generally adopts Pad & Chimney foundation shown in Table 8.1-11. As the result of an additional geological survey, the possibility of the use of Mat foundation use is examined. The example of foundation type is shown in Fig. 8.1-6.

Table 8.1-11 Foundation Type and Application

Foundation Type	Application
Pad & Chimney	- N value : More than 10 - Flat area with good soil condition
Mat	- N value : Less than 10 - Flat area with soft soil condition, and in which differential displacement might occur at Pad & Chimney

Source: JICA Study Team



Source: JICA Study Team

Fig. 8.1-6 Foundation's Example
(Left :Pad & Chimney, Right :Mat)

(6) Separate setting of a special part

(a) The crossing part of 115kV transmission line

For the restrictions of this ground, it crosses 115kV transmission line 2 times. The height of steel tower is needed over 60m at least, because the height of the 115kV existing steel tower is 28 ~ 40m and it is a flat ground. Therefore, checking about the installation of the red and white steel tower and the aviation sign etc. is required.

(b) The part along the railway

The railway is not used now. But at the part along the railway, it considers so that there may be no cave-in of a railway in considering of the possibility of prospective use.

(c) Road crossing part

At the road crossing part, the height of the conductor at least needs 14.2m. But it makes higher, because of the existing distribution line and the existing structure.

8.1.4 230kV Rough Construction Process

The rough construction process shown in Table 8.1-13 was based on the track record neighboring countries and in the past. If land acquisition is completed, a process can be shortened by putting in many construction groups.

Table 8.1-12 Rough Construction Process of 230kV Transmission Line

Work Items	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Check survey and soil boring	■	■	■																					
Cleaning of right of way			■	■	■	■	■	■	■	■	■	■												
Construction of access road							■	■	■															
Preparation of documents / drawings and approval	■	■	■	■	■	■																		
Manufacturing							■	■	■	■	■	■	■	■	■	■	■	■	■					
Foundation work							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Tower erection work									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Stringing work																	■	■	■	■	■	■	■	
Test and commissioning																								■

Source: JICA Study Team

8.1.5 Outline of 115kV Overhead Transmission Lines

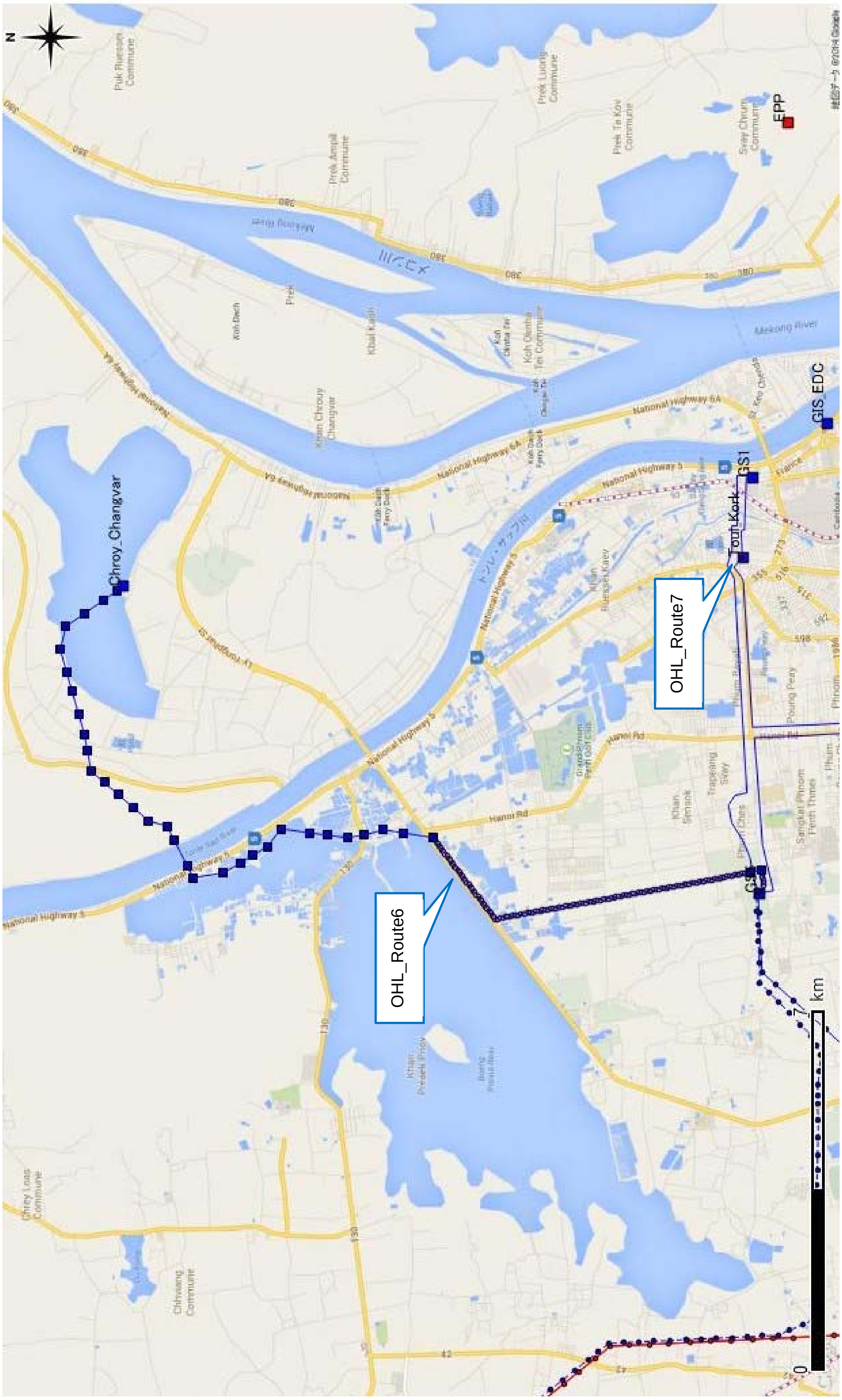
There are two 115kV overhead transmission lines in this Study. One is OHL_Route6 which connects from GS5 to Chroy Changvar S/S. Another is OHL_Route7 which branches at the midpoint of GS5 and GS1 and goes to Toul Kork S/S. The outline of 115kV overhead transmission lines is shown in Table 8.1-14. The location map of 115kV overhead transmission lines is shown in Fig. 8.1-7 and Fig. 8.1-8. A rough OHL_Route6 sectional view is shown in Fig. 8.1-9.

Table 8.1-13 Outline of 115kV Overhead Transmission Lines

Route	OHL_Route6	OHL_Route7
Nominal Voltage	115kV	115kV
Circuits	2cct	2cct
Location	From GS5 To Chroy Changvar	From Midpoint of GS5 and GS1 To Toul Kork
Total Length	20.2km	0.1km
Supporting structure	Concrete pole...........136 Steel pipe pole ....9 Steel tower.................33 (included 4cct steel tower: 4)	Steel pipe pole.............1
Conductor	ACSR 632mm^2 or ACSR 250mm^2 equivalent	AAC* 250mm^2 × 2
Ground-Wire	OPGW 70mm^2 or equivalent AC 90mm^2 or equivalent	OPGW 70mm^2 × 2

*AAC : All Aluminum Conductor

Source: JICA Study Team



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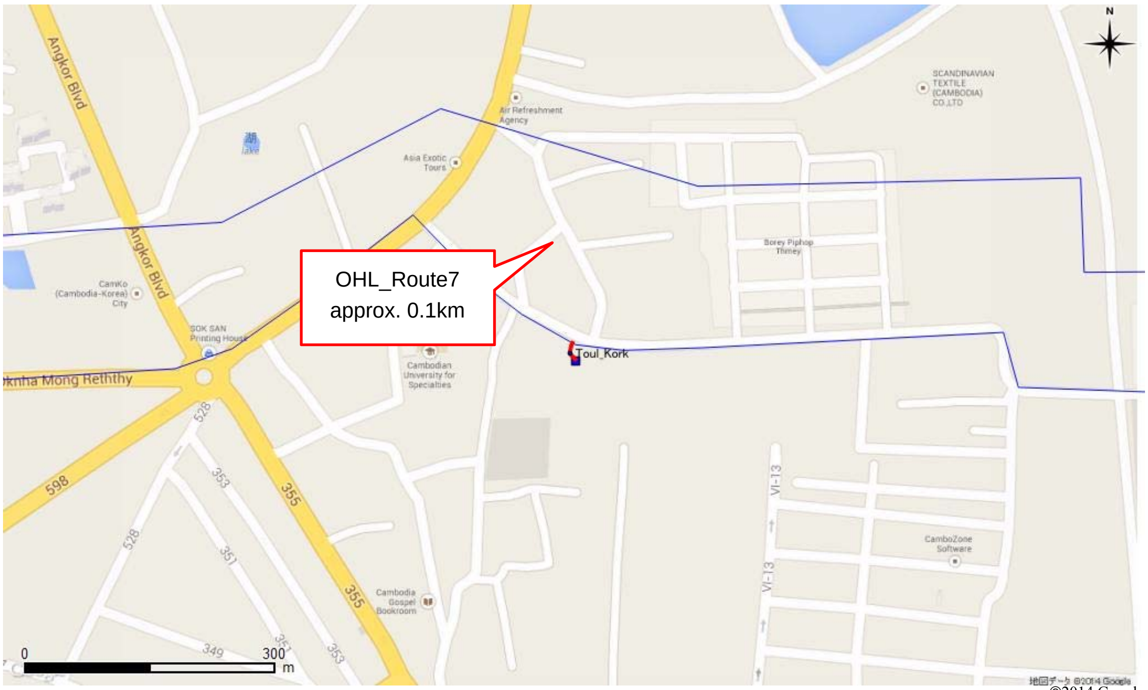
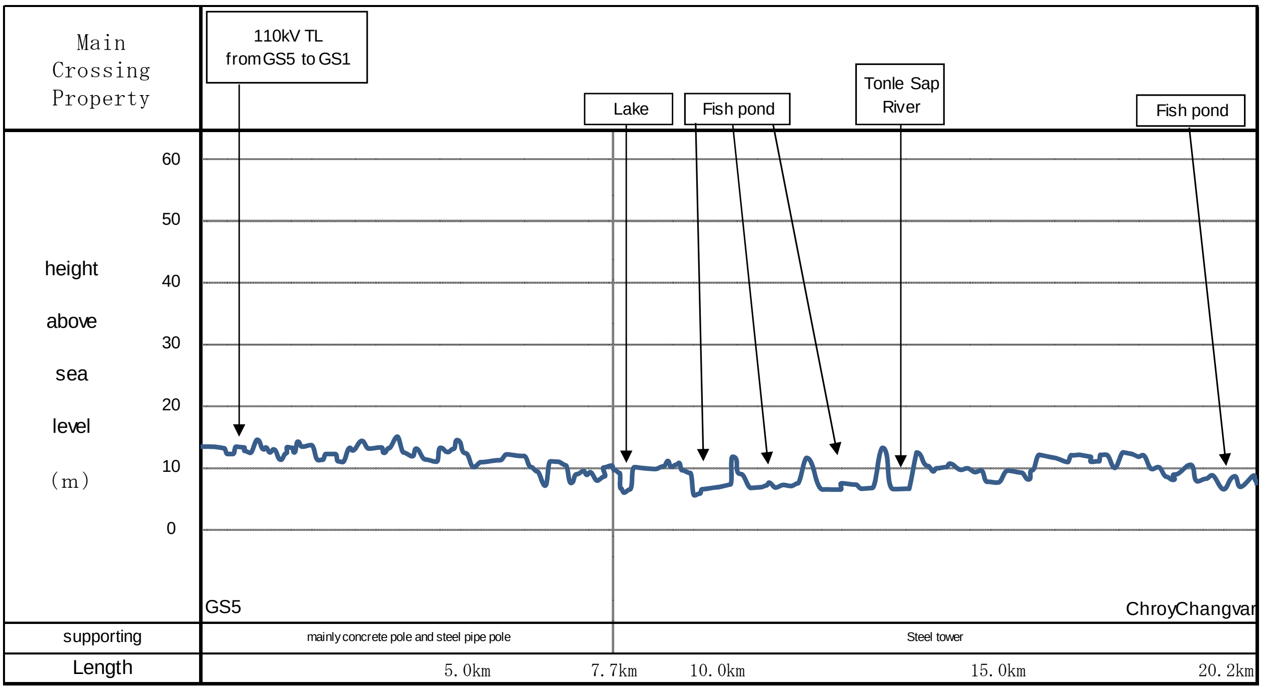
Source: JICA Study Team

Fig. 8.1-7 Location Map of 115kV Overhead Transmission Lines



Source: JICA Study Team

Fig. 8.1-8 Location Map of 115kV_OHL_Route7



Source: JICA Study Team

Fig. 8.1-9 Rough Route Sectional View of 115kV_OHL_Route6

8.1.6 Transmission Capacity of 115kV Overhead Transmission Line

The future demand of Chroy Changvar assumes 234 MW (246MVA) of maximum power demand in 2030 from Table 3.2-8 “Peak Demand of Each Grid Substation in Phnom Penh System”. Therefore, OHL-Route6 shall have the transmission capacity of 75% of two circuits larger than this maximum power demand, and it shall use ACSR 632mm^2 which has an adoption track record in Cambodia. OHL_Route7 branches at the midpoint of GS5 and GS1. Therefore AAC 250mm^2 × 2 which is used at 115kV transmission line between GS5 and GS1 shall be used. Conductor (Transmission Capacity) and Ground Wire which are used by EDC are shown in Table 8.1-15.

Table 8.1-14 Conductor (Transmission Capacity) and Ground Wire used by EDC

Type		115kV (Capacity)
Conductor	ACSR	632mm^2 (215MVA/cct) 150mm^2 (85MVA/cct)
	AAC	250mm^2 × 2 (238MVA/cct)
Ground Wire	AC	90mm^2
	GSW	50mm^2, 70mm^2
	OPGW	70mm^2

8.1.7 Preliminary Design of 115kV Transmission Line

Preliminary design of 115kV transmission lines for this Study is carried out a procedure equivalent to 220kV.

(1) Setup of climatic conditions

The climatic conditions are the same as that of 230kV transmission line.

(2) Selection of conductors and ground wire

The conductor which has a track record by the 115kV transmission line is selected. Technical characteristics of conductor are shown in Table 8.1-16. And Technical characteristics of ground wire are shown in Table 8.1-17. In consideration of IKL, two ground wires shall be attached in the steel tower section.

Table 8.1-15 Technical Characteristics of Conductors (115kV)

Type of Conductor	ACSR 632mm^2	AAC 250 mm^2
Component of stranded wires	Al 45/4.20, St 7/2.80	19/4.22
Total area of Aluminum wires	666.55 mm^2	265.7 mm^2
Approximate Overall Diameter	33.60 mm	21.10 mm
Weight	2,060 kg/km	731 kg/km
Ultimate Tensile strength	148,700 N	40,400 N
Modulus of elasticity	71.1 kN/mm^2	56.0 kN/mm^2
Coefficient of linear expansion	20.85×10^{-6}/°C	23×10^{-6}/°C
Maximum working tension	Less than 53,500 N	Less than 14,540 N
DC resistance at 20°C	0.04633 ohm/km	0.1083 ohm/km

Source: JICA Study Team

Table 8.1-16 Technical Characteristics of Ground-wires (115kV)

Type	OPGW 70 mm^2	AC 90 mm^2
Component of stranded wires	St 8/3.2, Al 1/5.0	AC 7/4.115
Total area of steel wires	64.34 mm^2	93.05 mm^2
Overall Diameter	11.4 mm	12.35 mm
Weight	454 kg/km	619 kg/km
Ultimate Tensile strength	78,000 N	101,000 N
Modulus of elasticity	149 kN/mm^2	149 kN/mm^2
Coefficient of linear expansion	12.9×10^{-6}/°C	12.9×10^{-6}/°C
Maximum working tension	Less than 28,080 N	Less than 36,360 N
DC resistance at 20°C	0.774 ohm/km	0.9197 ohm/km
Number of optical fiber	24	—

Source: JICA Study Team

(3) Setup of ground clearance

The minimum height from the ground is set by GREPTS and SREPTS. Minimum height of conductor above ground (115kV) is shown in Table 8.1-18.

Table 8.1-17 Minimum Height of Conductor above Ground (115kV)

Definition area	clearances
Among bare conductors and supporting structures, arms, guy wires and so on	No less than 0.70m
Urban areas	7.0m
Areas where third persons hardly approach	6.0m
Roads and railways	13.5m
River and seas	Adding 3.5m
Other facilities	3.5m
Trees	2.5m

Source: JICA Study Team

(4) Setup of wire conditions

(a) Maximum working tension of conductor

The maximum working tension of the conductor is decided taking into account of the following two factors.

- The maximum tension (>Maximum working tension) of the conductor must not exceed 40 percent of the ultimate Strength Tensile of the conductor.
- EDS (Tension at 28°C with no wind) is less than 25 percent of the ultimate strength tensile of the conductor.

(b) Maximum working tension of ground wire

The maximum working tension of the ground wire is generally set up like "the sag of the ground wire under EDS condition is below 80% of the conductor's sag at the standard span length (450m)". The result by which requirements were satisfied is shown in Table 8.1-19.

Table 8.1-18 Maximum Working Tension and EDS (Max Span Length = 600m)

Type	UTS	Maximum Working Tension	EDS
ACSR 632mm^2	148,700N	47,070N (MWT / UTS =32%)	31,780N (EDS/UTS=22%)
AC 90mm^2	101,000N	19,620N (MWT / UTS =20%)	14,120N (EDS/UTS=14%)
OPGW 70mm^2	78,000N	19,620N (MWT / UTS =26%)	15,000N (EDS/UTS=20%)

* The part where span length is especially short and branch part inquire separately. Source: JICA Study Team

(c) Sag of conductor

Because the transmission line progress place of this study does not almost have a vertical interval and is subject to the influence of steel tower quantity by span length, it sets the maximum span length to 600m. The outline calculation result of sag by span length is shown in Table 8.1-20.

Table 8.1-19 Sag of Conductor (at 90°C with no wind)

Span length	Sag
200 m	5.34 m
250 m	7.09 m
300 m	9.49 m
350 m	12.3 m
400 m	15.4 m
450 m	18.9 m
500 m	22.9 m
550 m	27.2 m
600 m	32.0 m

Source: JICA Study Team

(5) Setup of insulator set, supporting structure, and the foundation

(a) Insulator set

The ball socket type or clevis type suspension insulator (standard disc type porcelain insulator) which shall comply with IEC 60120 and 60305 or equivalent is used for an insulator set. The specifications of an insulator are shown in Table 8.1-21. The insulator number may be 9 pieces equivalent to general 115kV transmission line.

Table 8.1-20 Insulator Size

Type	Height	Diameter	R.U.S.	Remarks
SU165BN	146mm	254mm	165kN	Tension (NGK)
U160BP	146mm	320mm	160kN	Tension (Chinese)
SU120CN	146mm	254mm	120kN	suspension (NGK)
U120BP	146mm	254mm	120kN	suspension (Chinese)

Source: JICA Study Team

(b) Supporting structure

Supporting structure uses a steel tower, a concrete pole, and a steel pipe pole. A concrete pole is adopted only as a suspension type. A steel pipe pole is used for the tension type connected with a concrete pole and a steel tower. A river crossing point is separately considered as an individual design.

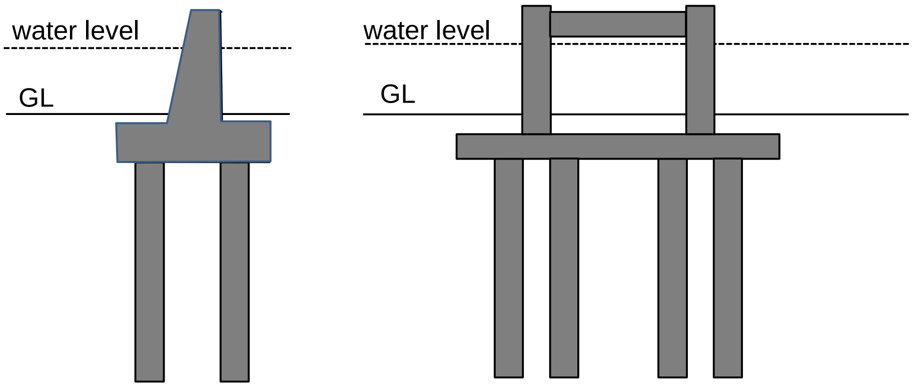
(c) Foundation

As the result of the boring, it is assumed that supporters are deep. Therefore, generally it adopts Pile foundation or Rahmen foundation shown in Table 8.1-22. As the result of an additional geological survey, the use of other foundation is also considered. The structure of Pile foundation and Rahmen foundation is shown in Fig. 8.1-10.

Table 8.1-21 Foundation Type and Application

Foundation Type	Application
Pad & Chimney	- N value : More than 10 - Flat area with good soil condition
Mat	- N value : Less than 10 - Flat area with soft soil condition, and in which differential displacement might occur at Pad & Chimney
Pile	- N value : Less than 10 - Flat area with soft soil condition, and in which it is difficult to withstand compression stress at Pad & Chimney and Mat
Rahmen	- N value : Less than 10 - Flat area with soft soil condition, and high water level

Source: JICA Study Team



(Source: JICA Study Team)

Fig. 8.1-10 Foundation's Example
(Left : Pile, Right : Rahmen)

(6) Separate setting of a special part

(a) Crossing point in Tonle Sap River

At the crossing point in Tonle Sap River, the steel tower is the type of 4cct design with 230kV transmission line. The upside transmission lines are 230kV, and the lower transmission lines are 115kV. If crossing of a ship is taken into consideration, the height of the steel tower at least needs 90m. At the same time, the examination about the installation of the red and shite steel tower and the aviation sign etc. is required.

(b) Crossing point of 115kV transmission line

The transmission line needs to cross the 115kV transmission line from GS5 to GS1 near GS5. The steel tower adopts on the both ends of the crossing point.

8.1.8 115kV Rough Construction Process

The rough construction process shown in Table 8.1-25 is required for 12 months as a construction period in the dry season. If land acquisition is completed, a process can be shortened by putting in many construction groups.

Table 8.1-22 Rough Construction Process of 115kV Transmission Line

Work Items	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Check survey and soil boring	■	■	■																					
Cleaning of right of way		■	■	■	■	■																		
Construction of access road							■	■	■	■	■								■	■				
Preparation of documents / drawings and approval	■	■	■	■	■	■																		
Manufacturing			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Foundation work			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Tower erection work									■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Stringing work																■	■	■	■	■	■	■	■	
Test and commissioning																								■

Source: JICA Study Team

8.2 UNDERGROUND TRANSMISSION FACILITIES

8.2.1 Outline of Underground Transmission Line Route

The 230kV/115kV underground transmission lines are shown in Table 8.2-1 and the route maps are shown in the following pages. And detailed cable route is shown in Appendix-4. UG_Route 5 was decided to be excluded from the scope of the Project following the discussion between JICA and EDC.

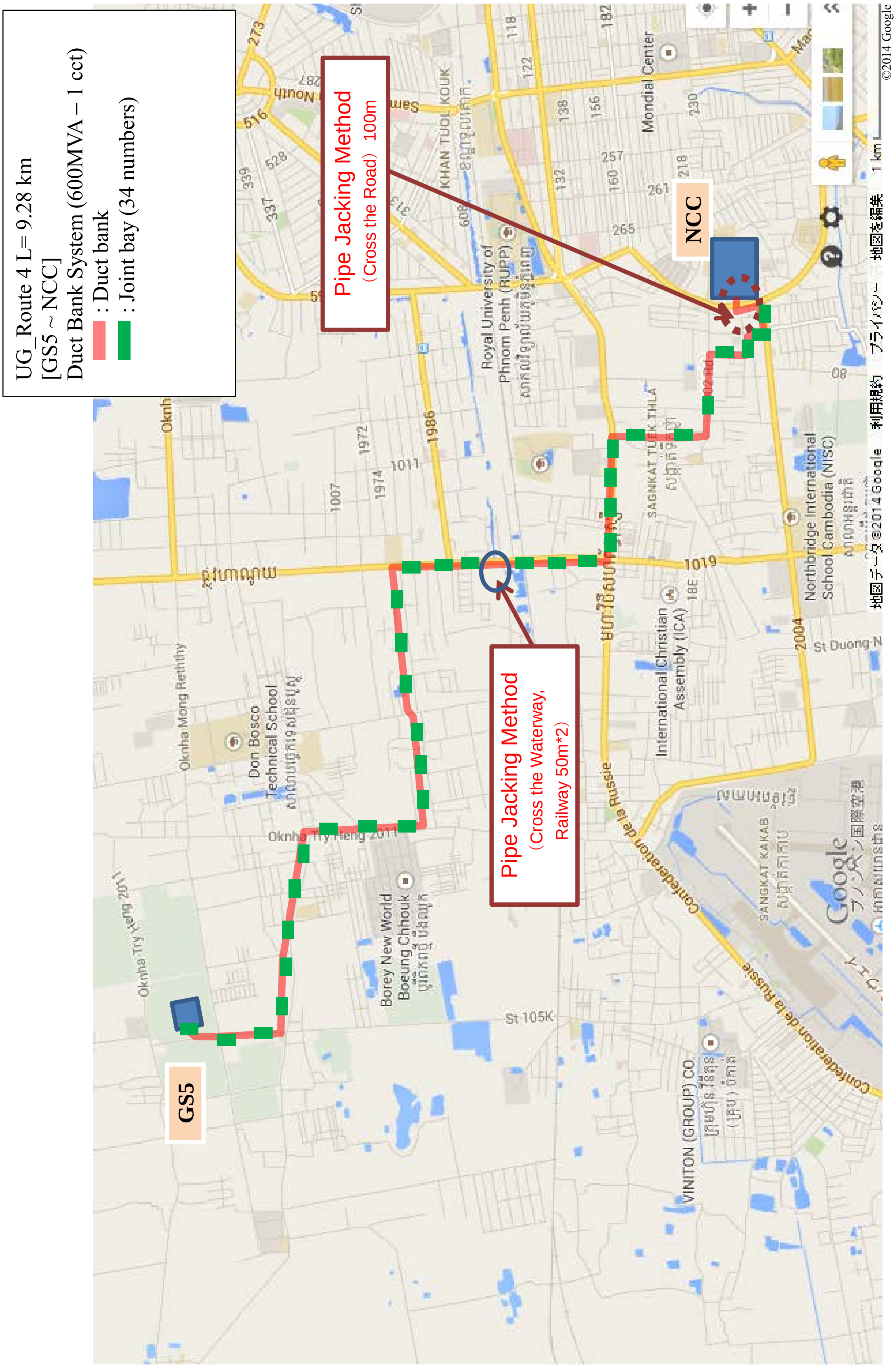
Table 8.2-1 Route Profile of 230kV/115kV Underground Transmission Lines

Route Name	Starting Point	Ending Point	Voltage Level	No. of Circuit	Route Length
UG_Route5	NCC*	GS3	115 kV	2	0.4 km
UG_Route4	GS5	NCC	230 kV	1	9.28 km

: UG_Route 5 was decided to be excluded from the scope of the Project following the discussion between JICA and EDC.

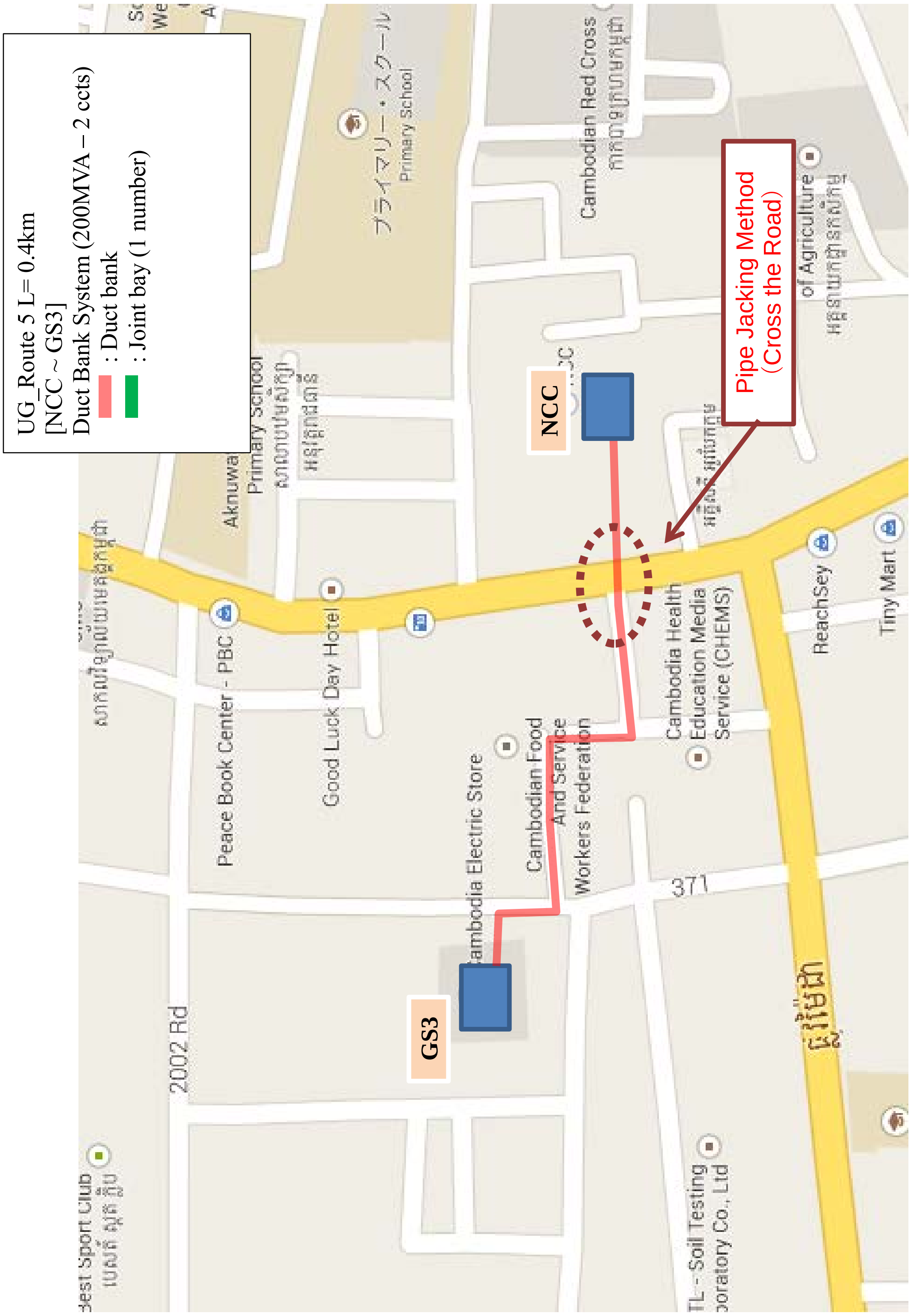
* NCC : National Control Center

Source: JICA Study Team



Source: JICA Study Team

Fig. 8.2-1 Location Map of Tentative Route (UG_Route 4)



Source: JICA Study Team

Fig. 8.2-2 Location Map of Tentative Route (UG_Route 5)

8.2.2 Transmission Capacity of Underground Transmission Line

The transmission capacity of the 230kV underground transmission line (1 circuit) from GS5 to NCC shall be 600MVA and the transmission capacity of the 115kV underground transmission line (2 circuits) from NCC to GS3 shall be 200MVA.

8.2.3 Type of 230kV/115kV Underground Cable and Installation Method

The duct bank system is to be applied as standard installation method of underground cable.

If the direct burial installation method is to be applied, open cut trenching will remain open for about one month, thus, there is a possibility of hindrances occurring to the life of the neighborhood and traffic disturbances, especially in the congested areas, narrow roads, heavy traffic roads, etc. To protect the above inconveniences, the duct bank system shall be applied to eliminate open cut places.

Moreover, in order to cope with the issue described in Section 4.2 (2) “Field survey of underground transmission line project of Phase 1”, the points shown below adopt the pipe jacking method.

- From the technical viewpoint, the duct bank system construction method is very difficult. (Such as waterway crossing and railway crossing)
- Crossing of a wide road

(1) Burial Depth, Soil Temperature and Soil Thermal Resistivity

For the calculation of the current carrying capacity of the underground transmission line (cable), it is recommended that the maximum conductor temperature shall be 90°C as a mandatory condition to keep the XLPE (Cross-Linked Polyethylene) insulation in sound condition from the thermal deterioration/impact during its design life of 30 years.

In particular, if the burial depth is deeper, then the cables may be safer from the outside mechanical damages, but current carrying capacity of cables will be reduced according to the burial depth. In Cambodia, the burial depth of underground equipment such as the distribution cables and communication cables have been specified at 1.2m. Based on the above facts, the JICA Study Team decided that the burial depth should be a minimum of 1.2m from the surface of the ground.

On the other hand, the soil temperature and soil thermal resistivity were specified as 30°C and 1.2 K.m/W according to the same specified value of surrounding countries such as Thailand and Vietnam.

The above-mentioned parameter is the same as that of the Phase 1 Project (Preparatory Survey for Phnom Penh City Transmission and Distribution System Expansion Project in Cambodia).

(2) Cable Type and Installation Configuration

The current carrying capacities with related conductor sizes of 230kV/115kV underground cables shall be shown in Fig. 8.2-3 and Fig. 8.2-4 calculated on the conditions of Table 8.2-2.

Table 8.2-2 Calculated Conditions of Underground Cable Capacity

Burial depth (Top of ducts)	1.2 m
Distance between each cables	250 mm
Soil thermal resistivity	1.2 K.m/W
Soil temperature	30°C

Source: JICA Study Team

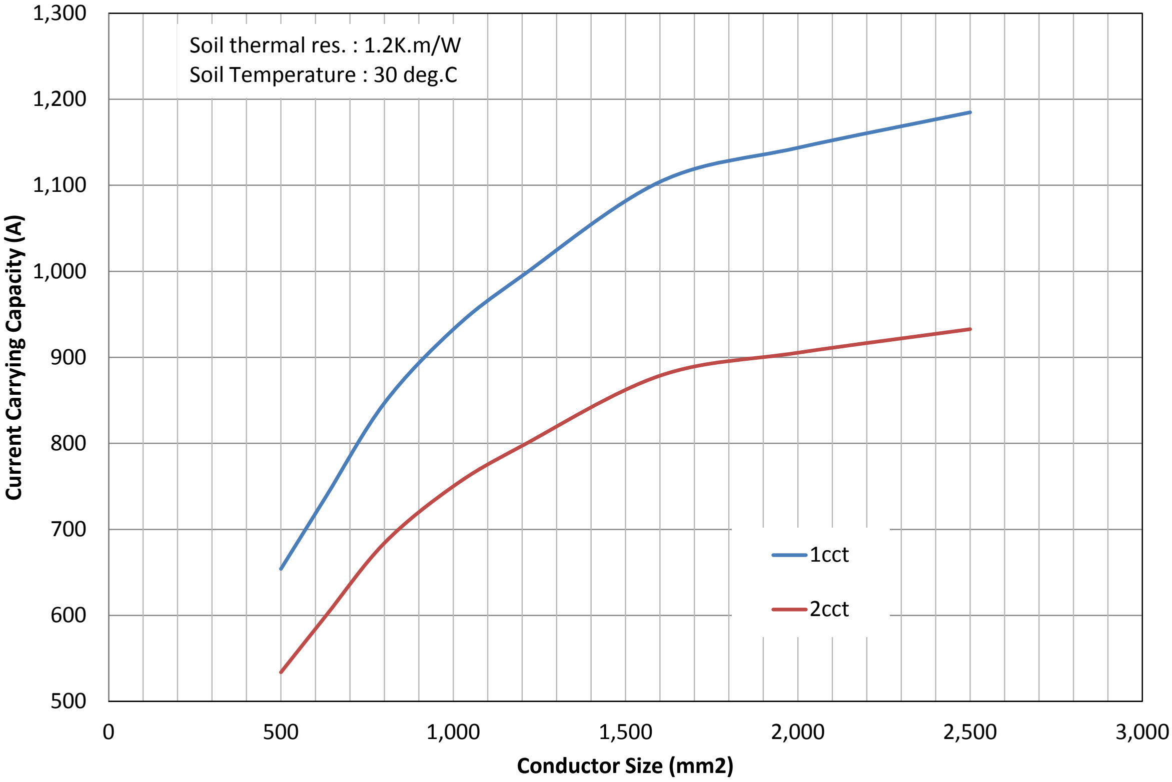


Fig. 8.2-3 Current Carrying Capacities of 230kV Underground Cables

Source: JICA Study Team

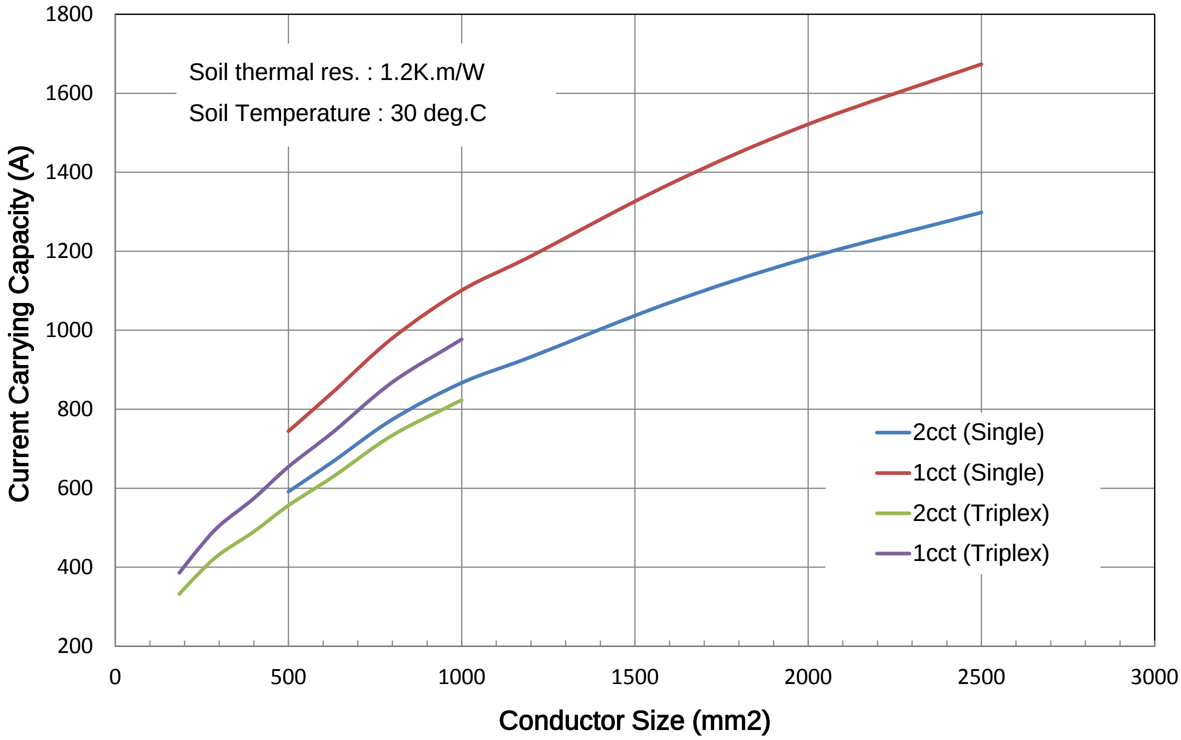


Fig. 8.2-4 Current Carrying Capacities of 115kV Underground Cables

Source: JICA Study Team

The required power current of the 600MVA transmission capacity at 230kV voltage is 1,506A. This power current is too large for the 230kV voltage level.

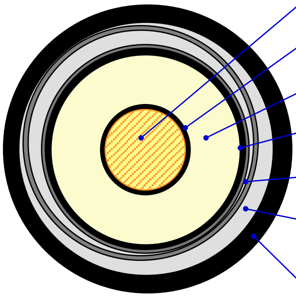
As shown in Fig. 8.2-3, the power current carrying capacity of the maximum conductor size of 2,500 mm^2 is 1,185A which is unable to pass the required capacity of 1,506A at a 600MVA transmission capacity.

Based on the above study, it is necessary to have two (2) cables per phase to carry the 600MVA transmission capacity. In other words, a total of six cables are necessary for the one circuit.

From the above calculation results shown in Fig. 8.2-3, dual cables with 1,200 mm^2 copper conductor are capable to pass the required capacity for a 600MVA transmission capacity at 230kV voltage.

The required power current of the 200MVA transmission capacity at 115kV voltage (2 cct) is 670A (133.3MVA/ cct). As shown in Fig. 8.2-4, both single and triplex cables with 1,000 mm^2 copper conductor are capable to pass the required capacity for a 200MVA (2cct) transmission capacity at 115kV voltage. From the result of study in the Phase 1 Project, the application of triplex cables is preferable due to cheaper civil construction costs.

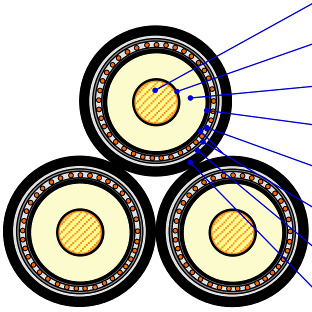
Typical cable construction of 230kV 1,200 mm^2 1-core type XLPE cable and 115kV 1,000 mm^2 triplex type XLPE cable are shown in Fig. 8.2-5 and Fig. 8.2-6.



	1,200 mm^2
Overall diameter	Approx. 127 mm
Weight	Approx. 23 kg/m
Drum length	Max. 600 m

Fig. 8.2-5 Typical Cable Construction of 230kV 1,200mm^2 1-core Type XLPE Cable

Source: JICA Study Team



	1,000 mm^2
Core diameter	Approx. 88 mm
Overall diameter	Approx. 191 mm
Weight	Approx. 45 kg/m
Drum length	Max. 400 m

Fig. 8.2-6 Typical Cable Construction of 115kV 1,000 mm^2 Triplex Type XLPE Cable

Source: JICA Study Team

8.2.4 Study of Construction Method of Underground Transmission Facilities

The study of the construction method of underground transmission lines shall be done considering the following factors.

- ✓ Conditions of the road, such as the width, nos. of lanes, intersection, interruption, congestion, etc.
- ✓ Underground equipment, such as the manhole of a drainage system, water air valve, etc.
- ✓ Surrounding conditions, such as land estates, buildings, etc.

(1) Construction Method

Considering existing man made trees and manholes onto the sideway, and underground distribution cables beneath the sideway, underground cables will be installed under the roadway especially inside the space alongside the sideway. But Pipe Jacking Method is applied in the following locations.

- From the technical viewpoint, the duct bank system construction method is very difficult. (Such as waterway crossing and railway crossing)

- Crossing of a wide road with heavy traffic volume.

Comparison Sheet by construction method between 1-core / pipe and 3-core / pipe at 230kV is shows in Table 8.2-3.

From the comparison sheet shown in Table 8.2-3, the application of 1-core cable installed into one pipe method is preferable due to cheaper construction costs and shorter construction time in the 230kV underground transmission line. If externally caused injury and an accident occur, replacement of all the three cables will be needed. The viewpoint of this maintenance is also taken into consideration, 1-core / pipe is adopted.

Standard Cross-sectional Drawing (Duct Bank Method) is shown in Fig. 8.2-7.

Pipe Jacking Method applied to the following four locations;

✓ 230kV underground transmission line.
Waterway crossing 1 location (Refer to Fig. 8.2-1)
Railway crossing 1 location (Refer to Fig. 8.2-1)
Crossing of a wide road with heavy traffic volume in front of NCC
1 location (Refer to Fig. 8.2-1)

✓ 115kV underground transmission line.
Crossing of a wide road with heavy traffic volume in front of NCC
1 location (Refer to Fig. 8.2-2)

At the location of a straight road with clear view, and no traffic signal at nearby crossing road, the pipe jacking method is not necessary to apply. In this case, Duct Bank Method is acceptable even the cable crossing the intersection.

In this case, location is conducted by each lane to reduce the traffic jam.

Stand facility for pipe jacking method are required. Required size for construction base of pipe jacking method are shown in Fig. 8.2-8 and Fig. 8.2-9. And Standard Cross-sectional Drawing of Pipe Jacking Method is shown in Fig. 8.2-10.

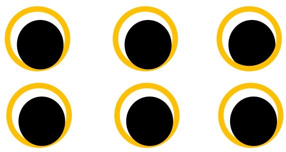
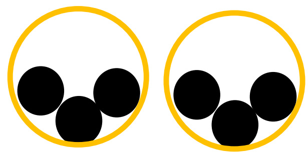
One of the points of concern for Pipe Jacking Method is the dielectric breakdown of cable.

Usually, air mortar is generally filled up in a Hume pipe with Pipe Jacking Method. However, by generation of heat from a cable, if air mortar dries, transfer of the heat to circumference soil will worsen. As a result, cable temperature is further raised, and in the worst case, the dielectric breakdown of cable may occur.

For this reason, the structure transmits the heat which a cable emits to surrounding soil, and emission cooling of the heat is promptly required.

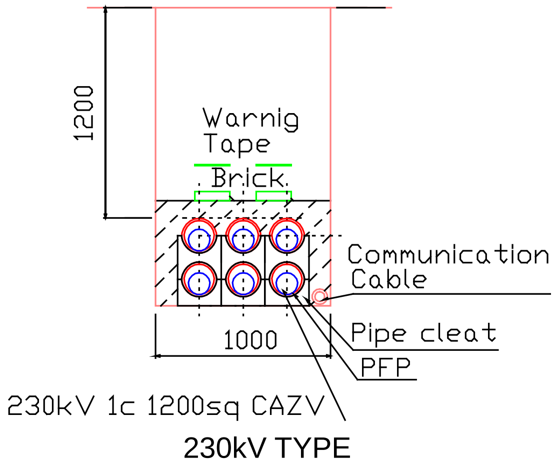
As this countermeasure, TC Grout (Thermal Conduction Grout) is applied as a filling material between Hume pipe and pipe of cable. TC Grout drawing is shown in Fig. 8.2-11 as reference. And G value of each material is shown in Table 8.2-4.

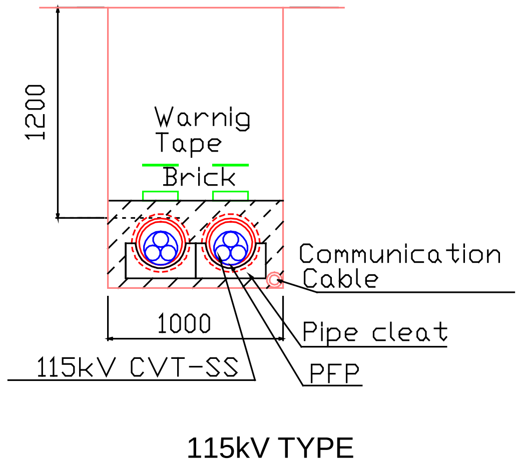
Table 8.2-3 Comparison Sheet by Construction Method between 1-core / Pipe and 3-core / Pipe (230kV)

Construction method	1-core /1 pipe	3-core / 1 pipe
Cross sectional view (conceptual)		
Inside diameter of pipe	ϕ 175 × 6 pipes	ϕ 300 × 2 pipes
Maximum span of installation cable	Approximately 300 m	Approximately 200 m
Material of pipe	Standard (116 USD/m × 9 km × 6 sets = 6.3 million USD)	Cheap (260 USD/m × 9 km × 2 sets = 4.7 million USD
Trench excavation, back filling and installation of pipes	Standard (361 USD/m × 9 km = 3.2 million USD)	Somewhat cheap (318 USD/m × 9 km = 2.9 million USD
Material of cable	Standard (353 USD/unit × 9km × 6 sets =19.1 million USD)	Same[1] (353 USD/unit × 9km × 6 sets =19.1 million USD)
Installation of cable	Standard (39 USD/unit × 9km × 6 sets =2.1 million USD)	Somewhat expensive (78 USD/unit × 9km × 2 sets =4.2 million USD)
Material of cable connection	Standard (14,124 USD/unit × 204 units =2.9 million USD)	Expensive (14,124 USD/unit × 270 units =3.8 million USD)
Construction cost of Joint Bay	Standard (64,200 USD/unit × 34 units =2.2 million USD)	Expensive (64,200 USD/unit × 45 units =2.9 million USD)
Total Cost	Standard (35.8 million USD)	Expensive (37.6 million USD)
Construction Period	Standard (14 months)	About 1.5 times (21 months)
Evaluation	Recommended	-

Length of underground transmission line: 9 km Source: JICA Study Team

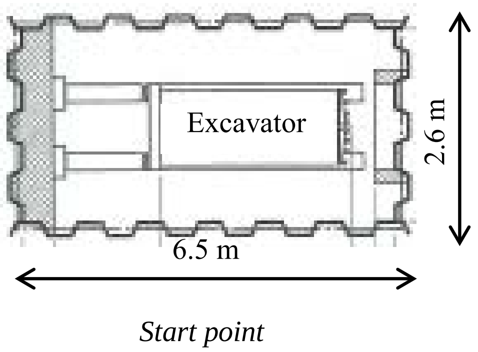
1 Although this comparison was performed in the same cable size, since there is no distance between cable (Phase) according to the conditions, in the case of 3-core / pipe, increase of required cable diameter may occur.

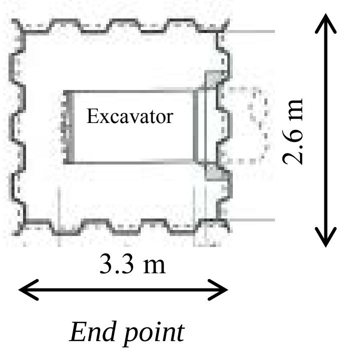




Source: JICA Study Team

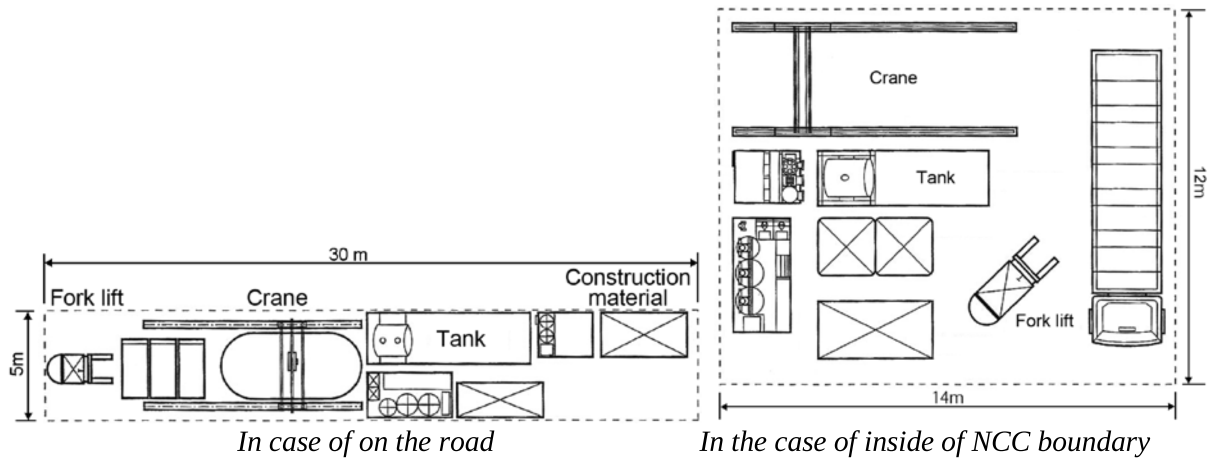
Fig. 8.2-7 Standard Cross-sectional Drawing (Duct Bank Method)





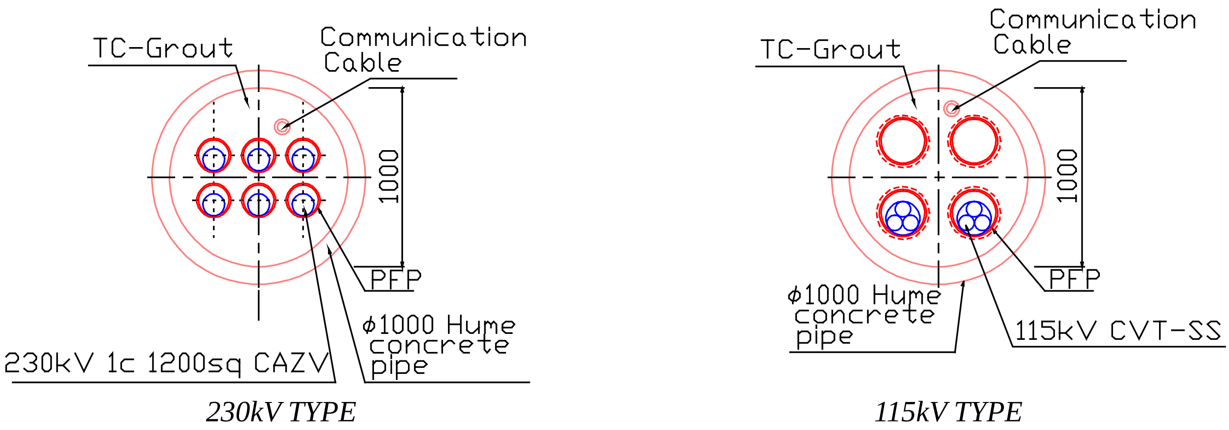
Source: JICA Study Team

Fig. 8.2-8 Required Scape for Stand of Pipe Jacking Method



Source: JICA Study Team

Fig. 8.2-9 Required Size for Construction Base of Pipe Jacking Method (Start point)



Source: JICA Study Team

Fig. 8.2-10 Standard Cross-sectional Drawing (Pipe Jacking Method)

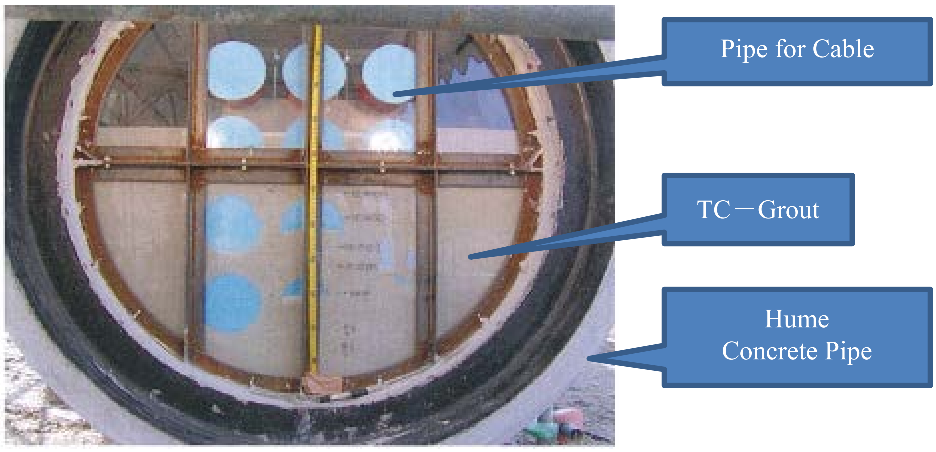


Fig. 8.2-11 Thermal Conduction Grout

Source: JICA Study Team

Table 8.2-4 G value of Each Material (k.cm/w)

Name of material	G value
Concrete	Approx. 100
Soil	Approx. 50 ~ 100
TC Grout	**Approx. 70 ~ 170**
Water	Approx. 170
Air mortar	Approx. 500 ~ 1,000
Air	Approx. 4,000

Source: JICA Study Team

(2) Study of Joint Bay

JICA Study Team studied the Joint Bay which was necessary for power cable connections. The structure figure of the Joint Bay are shown in Fig. 8.2-12.

✓ Structure of the Joint Bay
Temporary inside dimensions of Joint Bay for cable connection works are shown in Table 8.2-5. For economical and ruggedness structure, reinforced concrete structure shall be applied.

✓ Construction method of Joint Bay
It will take approximately several months from the laying of the power cable to the connection.
By adopting a temporary steel cover plate, common vehicles are able to pass through except during construction period of 230kV transmission line.

Table 8.2-5 Temporary Inside Dimension of Joint Bay

	Length	Width	Depth
230kV 1,200sq-1C × 6	10.5m	2m	1.6m
115kV 1,000sq-CVT × 2	8.1m	2m	1.6m

Source: JICA Study Team

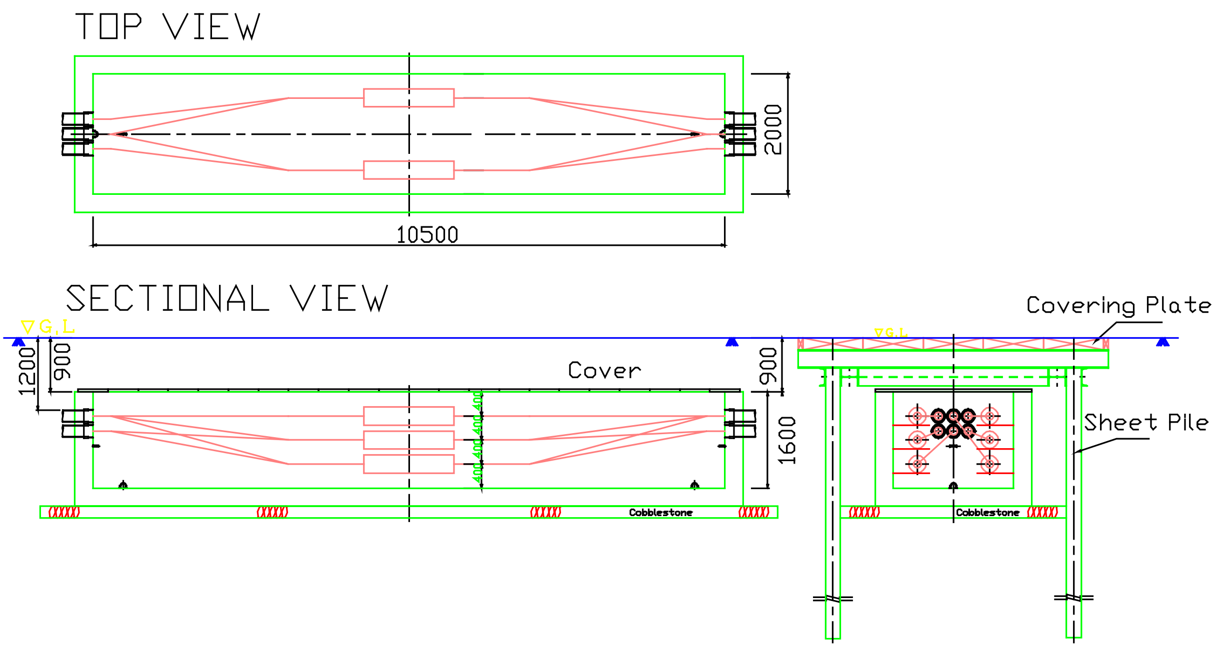


Fig. 8.2-12 Temporary Structure Figure of 230kV Joint Bay

Source: JICA Study Team

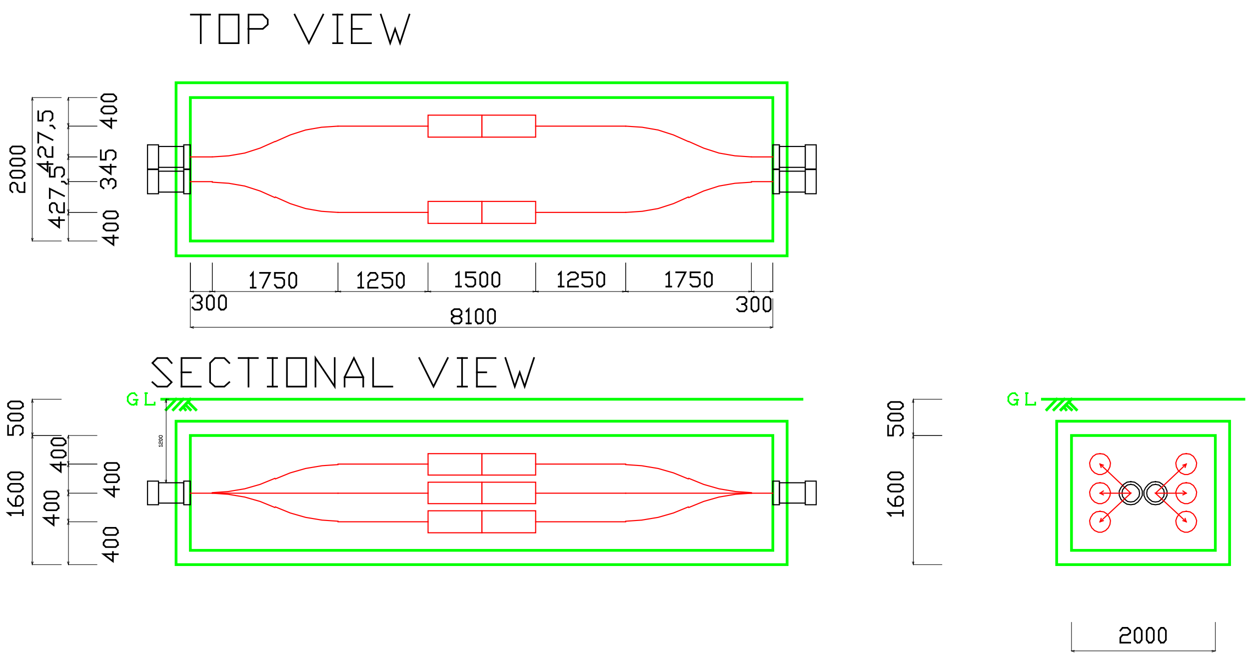


Fig. 8.2-13 Temporary Structure Figure of 115kV Joint Bay

Source: JICA Study Team

8.2.5 Construction Schedule

Construction schedule is shown in Table 8.2-7 and Table 8.2-8. Because two or more construction work teams are introduced, shorter implementation schedule will be expected.

Table 8.2-6 Construction Schedule for Underground Transmission Facilities 1

Items	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E
230kV Underground																								
Procurement/Manufacturing	■	■	■	■	■	■	■																	
Joint Bay Construction																								
No.01MH																■								
No.02MH														■	■									
No.03MH													■	■										
No.04MH												■												
No.05MH											■	■												
No.06MH										■														
No.07MH									■	■														
No.08MH								■	■															
No.09MH								■																
No.10MH							■	■																
No.11MH						■	■																	
No.12MH						■																		
No.13MH					■	■																		
No.14MH													■											
No.15MH										■	■													
No.16MH				■	■																			
No.17MH				■																				
No.18MH														■	■									
No.19MH														■										
No.20MH													■	■										
No.21MH												■	■											
No.22MH												■												
No.23MH											■	■												
No.24MH										■	■													
No.25MH										■														
No.26MH									■	■														
No.27MH								■	■															
No.28MH								■																
No.29MH							■	■																
No.30MH						■	■																	
No.31MH						■																		
No.32MH					■	■																		
No.33MH				■	■																			
No.34MH				■																				
Pipe Jacking Construction																								
NCC ~ Cross the road 200m													■	■	■									
Cross the railway 50m											■	■												
Cross the waterway 50m								■	■	■														
Excavation of Pipe setting Backfilling 20m/day																								
NCC -No.01MH 200m（200m）																								
No.01MH-No.02MH 210m																■								
No.02MH-No.03MH 210m															■	■								
No.03MH-No.04MH 250m															■									
No.04MH-No.05MH 300m													■											
No.05MH-No.06MH 250m												■												
No.06MH-No.07MH 300m											■													
No.07MH-No.08MH 280m										■														
No.08MH-No.09MH 300m									■															
No.09MH-No.10MH 300m									■															
No.10MH-No.11MH 300m								■																
No.11MH-No.12MH 250m							■	■																
No.12MH-No.13MH 300m							■																	
No.13MH-No.14MH 120m														■										
No.14MH-No.15MH 250m（150m）														■										
No.15MH-No.16MH 120m													■											
No.16MH-No.17MH 290m						■																		
No.17MH-No.18MH 300m											■	■												
No.18MH-No.19MH 300m															■	■								
No.19MH-No.20MH 300m															■									
No.20MH-No.21MH 210m														■										
No.21MH-No.22MH 200m													■	■										
No.22MH-No.23MH 300m													■											
No.23MH-No.24MH 290m												■												
No.24MH-No.25MH 300m											■	■												
No.25MH-No.26MH 300m											■													
No.26MH-No.27MH 290m										■														
No.27MH-No.28MH 300m									■															
No.28MH-No.29MH 300m									■															
No.29MH-No.30MH 300m								■																
No.30MH-No.31MH 300m							■	■																
No.31MH-No.32MH 250m							■																	
No.32MH-No.33MH 300m						■																		
No.33MH-No.34MH 220m					■	■																		
No.34MH- GS5 250m					■																			

B: Beginning of the month
M: Middle of the month
E: End of the month

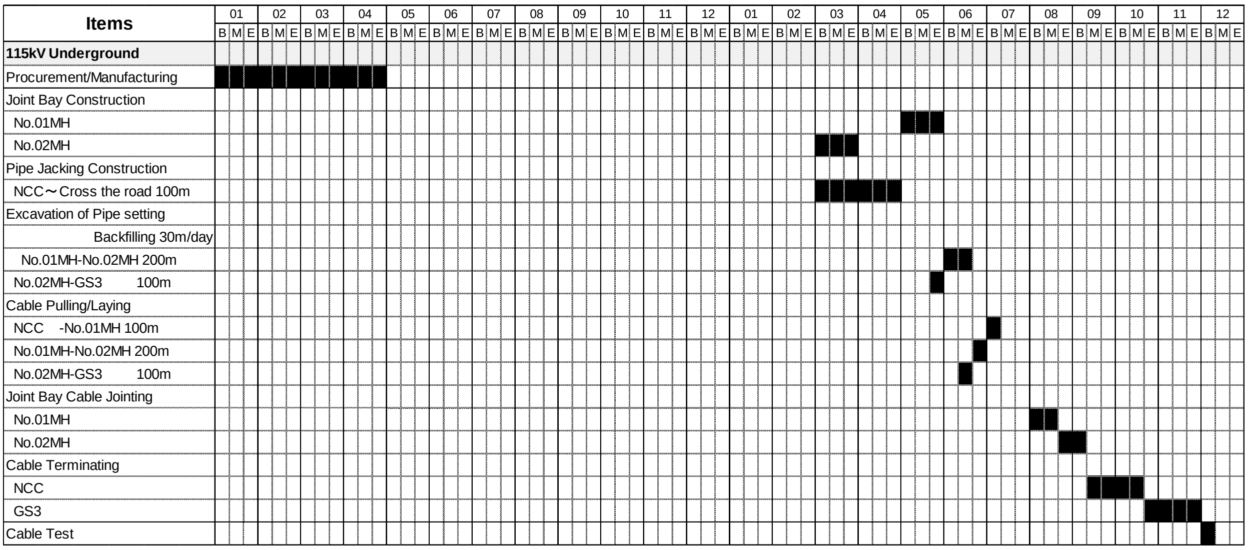
Source: JICA Study Team

Table 8.2-7 Construction Schedule for Underground Transmission Facilities 2

Items	01	02	03	04	05	06	07	08	09	10	11	12	01	02	03	04	05	06	07	08	09	10	11	12
	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E	B M E
Cable Pulling/Laying																								
NCC -No.01MH 200m																	E							
No.01MH-No.02MH 210m																	E							
No.02MH-No.03MH 210m																	M							
No.03MH-No.04MH 250m																	B							
No.04MH-No.05MH 300m																	B							
No.05MH-No.06MH 250m														E										
No.06MH-No.07MH 300m														E										
No.07MH-No.08MH 280m														M										
No.08MH-No.09MH 300m														M										
No.09MH-No.10MH 300m														B										
No.10MH-No.11MH 300m														B										
No.11MH-No.12MH 250m													E											
No.12MH-No.13MH 300m													E											
No.13MH-No.14MH 120m																B								
No.14MH-No.15MH 250m																B								
No.15MH-No.16MH 120m																M								
No.16MH-No.17MH 290m																M								
No.17MH-No.18MH 300m																E								
No.18MH-No.19MH 300m																E								
No.19MH-No.20MH 300m															E									
No.20MH-No.21MH 210m															E									
No.21MH-No.22MH 200m															M									
No.22MH-No.23MH 300m															M									
No.23MH-No.24MH 290m															B									
No.24MH-No.25MH 300m												M			B									
No.25MH-No.26MH 300m												B												
No.26MH-No.27MH 290m												B												
No.27MH-No.28MH 300m											E													
No.28MH-No.29MH 300m											E													
No.29MH-No.30MH 300m											M													
No.30MH-No.31MH 300m											M													
No.31MH-No.32MH 250m											B													
No.32MH-No.33MH 300m											B													
No.33MH-No.34MH 220m										E														
No.34MH- GS5 250m										E														
Joint Bay Cable Jointing																								
No.01MH																						B M		
No.02MH																						B M		
No.03MH																					M E			
No.04MH																					M E			
No.05MH																				E	B			
No.06MH																				E	B			
No.07MH																B M								
No.08MH																B M								
No.09MH															M E									
No.10MH															M E									
No.11MH														E	B									
No.12MH														E	B									
No.13MH																				B M				
No.14MH																				B M				
No.15MH																			M E					
No.16MH																			M E					
No.17MH																		E	B					
No.18MH																		E	B					
No.19MH																		B M						
No.20MH																		B M						
No.21MH																	M E							
No.22MH																	M E							
No.23MH																E	B							
No.24MH																E	B							
No.25MH														B M										
No.26MH														B M										
No.27MH													M E											
No.28MH													M E											
No.29MH												E	B											
No.30MH												E	B											
No.31MH												B M												
No.32MH												B M												
No.33MH											M E													
No.34MH											M E													
Cable Terminating																								
NCC																						E	B M E	
GS5																						E	B M E	
Cable Test																								B
Communication Cable																								

Source: JICA Study Team

Table 8.2-8 Construction Schedule for Underground Transmission Facilities 3



Source: JICA Study Team

8.3 SUBSTATION EQUIPMENT

8.3.1 New Substation (NCC, Toul Kork, Chroy Changvar)

(1) Design concept

(a) Substation type

One of the fundamental decisions to be made at the planning stage is the selection of the type of substation to be applied.

The general characteristics of a GIS (Gas Insulated Switchgear) substation make it particularly suitable for applications in urban areas, in environmentally sensitive areas, and in areas with high levels of atmospheric pollution. GIS substation is advantageous and new construction of the substation on site within a limited, even in the construction replacement substation of the application of the AIS (Air Insulated Switchgear).

Table 8.3-1 Comparison of AIS and GIS

	GIS	AIS
Installation area	small	large
Cost	high	low
Recovery time of equipment failure	long	short
Anti-fouling performance	high	low
Consideration of the surrounding environment	easy	difficult

Source: JICA Study Team

In this project, NCC and Toul Kork Substation construction sites that EDC has been secured are located in urban area of Phnom Penh City and the site size is too small to apply AIS. Therefore, JICA Study Team determined to apply the indoor type GIS substation to these two substations.

On the other hand, as for Chroy Changvar substation, assuming that the site area is sufficient, the application of AIS substation which has an advantage of cost was considered.

(b) Capacity of the substations

The final capacity of the new distribution substation shall be 150MVA, which is determined in consideration of the future demand and capacity of the other Phnom Penh City substation.

The final capacity of the new interconnection substation shall be 600MVA, which is determined in consideration of the future demand and effective utilization of transmission facilities capacity.

In addition, the initial capacity is 50% of the final plan capacity for both of distribution substation and interconnection substation.

(c) Capacity and number of transformers

Since the sites of NCC and Toul Kork are constrained, the capacity and number of transformer in NCC and Toul Kork should be as follows.

NCC: 230kV/115kV Transformer 300MVA ×1
(To secure a space for one future expansion)
115kV/22kV Transformer 75MVA ×1
(To secure a space for one future expansion)

Toul Kork: 115kV/22kV Transformer 75MVA ×1
(To secure a space for one future expansion)

Since the site has to keep a margin in order to take into account a scheduled extension to 230kV AIS substation, the capacity and number of transformer in Chroy Changvar is as follows.

Chroy Changvar: 115kV/22kV Transformer 75MVA × 1
(To secure a space for one or two future expansion)

(d) Protection rely system

The protection relay of the new substation should be to match that of the existing substation equipment from the viewpoint of maintenance and operations as much as possible. The main protection relays should be as shown in the following:

- 230kV & 115kV Bus protection relay: differential relay
- 230kV & 115kV Line protection relay: differential relay
- 230kV & 115kV Transformer protection relay: differential relay
- 22kV distribution line relay: over current relay, earth fault relay

(e) Reactive power supply capability

A phase modifying equipment to be installed in this project is shunt capacitor of 150MVar. Placement of phase modifying equipment in the new substation is as follows.

NCC: 115kV Shunt Capacitor 30MVar ×1
(The installed in substation building rooftop)

Chroy Changvar: 115kV Shunt Capacitor 30MVar ×1
(To ensure a space for three future expansion)

(2) Basic specifications of the main equipment

(a) Main transformer

Table 8.3-2 Basic Specification of Main Transformer (NCC)

		Basic specification
230kV/115kV Transformer	Type	YN Auto d1
	Rated voltage	230 kV／115 kV
	Rated capacity (Primary/secondary)	300MVA

Source: JICA Study Team

(b) Distribution transformer

Table 8.3-3 Basic Specification of Distribution Transformer

		Basic specification
115kV/22kV Transformer	Type	YNd11+zn
	Rated voltage	115 kV／22 kV
	Rated capacity (Primary/secondary)	75MVA

Source: JICA Study Team

(c) 230kV switchgear (NCC)

Table 8.3-4 Basic Specification of 230kV Switchgear

	Basic specification
Rated voltage	230 kV
Bus bar configuration	Single bus-bar type (Double bus in the future)
Insulation type	GIS
Rated current	2,000A
Rated short-time withstand current	40kA

Source: JICA Study Team

(d) 115kV switchgear

Table 8.3-5 Basic Specification of 115kV Switchgear

		Basic specification
NCC, Chroy Changvar	Rated voltage	115kV
	Bus bar configuration	Single bus bar type (double bus in the future *1)
	Insulation type	GIS (NCC) / AIS (Chroy Changvar)
	Rated current	1250A, 2,000A (Secondary MTr)
	Rated short-time withstand current	31.5kA
Toul Kork	Rated voltage	115 kV
	Bus bar configuration	Single bus bar type
	Insulation type	GIS
	Rated current	1,250A
	Rated short-time withstand current	31.5kA

Source: JICA Study Team

(e) 22kV switchgear

Table 8.3-6 Basic Specification of 22kV Switchgear

	Basic specification
Rated voltage	24 kV
Bus bar configuration	Single bus bar type
Housing	Metal-clad, indoor, switchgear
Rated current	2,500A or 3,150A (Bus-bar, Tr(75MVA)), 2,000A or 2,500A (Tr, Bus-tie), 300A or 630A (line)
Rated short-time withstand current	31.5kA

Source: JICA Study Team

(f) 115kV shunt capacitor

Table 8.3-7 Basic Specification of 115kV Shunt Capacitor

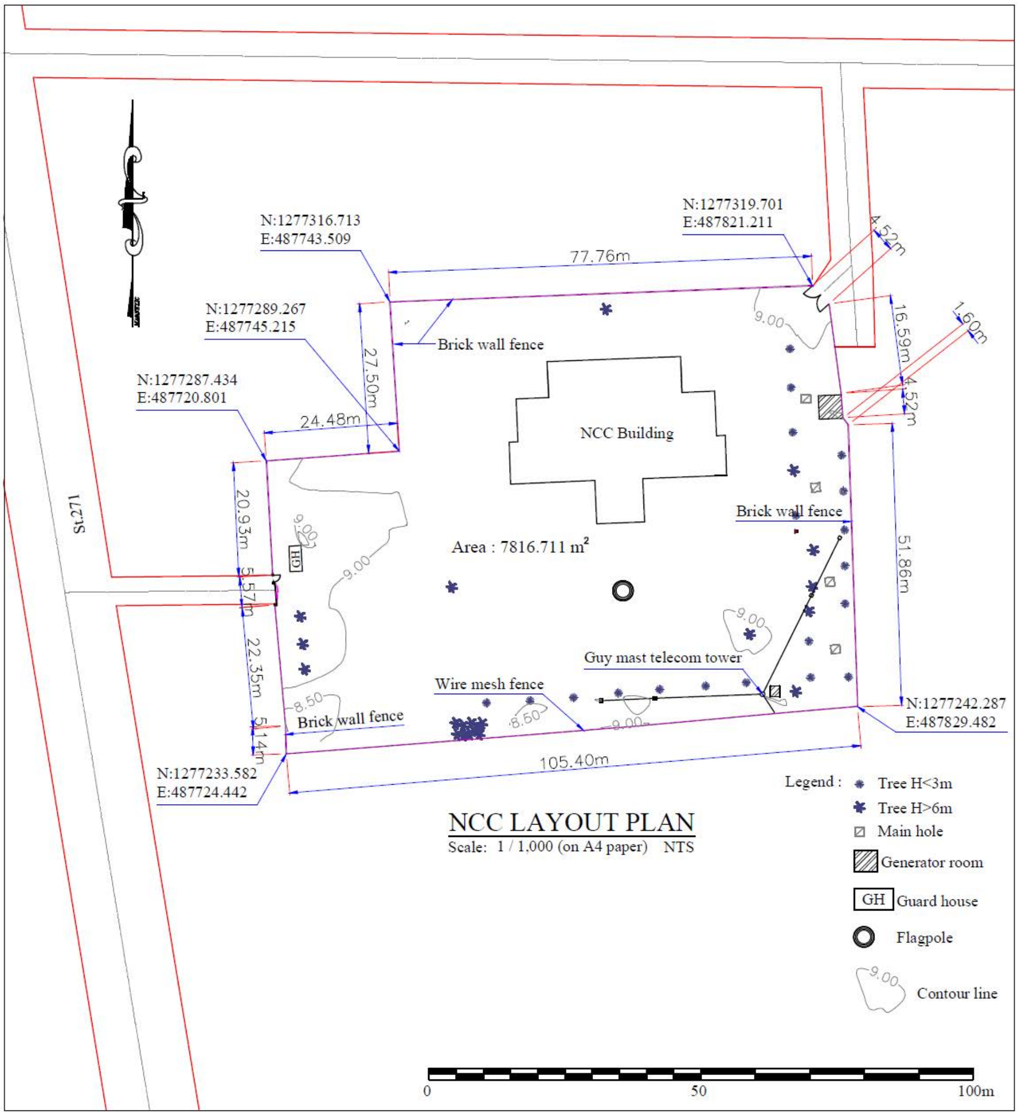
	Basic specification
Type	Can Type
Rated voltage	115 kV
Rated capacity	30MVar

Source: JICA Study Team

(3) New GIS substation at NCC

(a) Location

According to the result of the field survey, the location is a south part of the NCC. Fig. 8.3-1 shows a survey map of candidate site, whose size is approximately 30m × 105 m.



Source: JICA Study Team

Fig. 8.3-1 GIS Substation Site at NCC

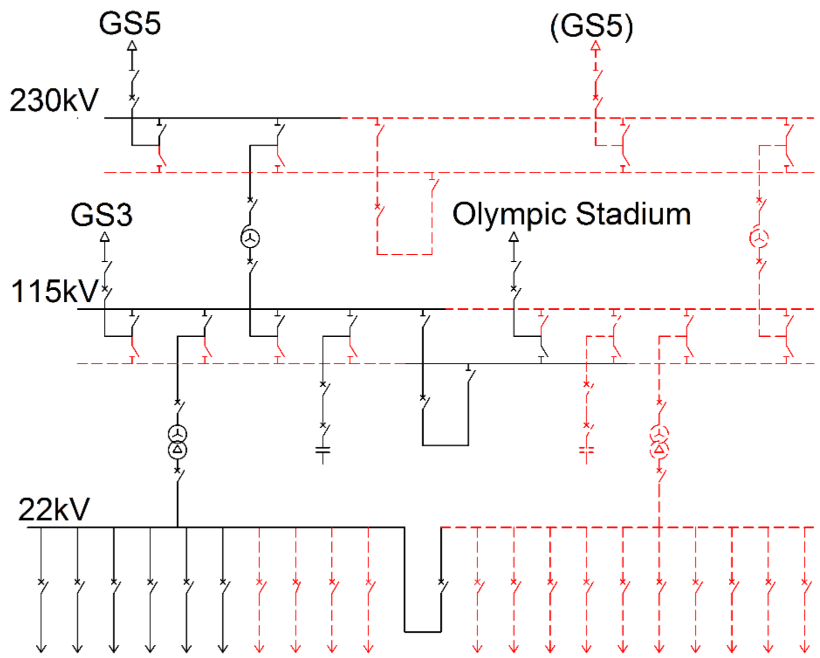
(b) Equipment & layout

Table 8.3-8 Substation Equipment (NCC)

	Number of equipment
230kV GIS bus	Single bus (Double bus in the future)
230kV line	1 lines (2 lines in the future)
230kV/115kV Transformer (300MVA)	1 banks (2 banks in the future)
115kV GIS bus	Single bus (Double bus in the future)
115kV line	2 lines (4 lines in the future)
115kV/22kV Transformer (75MVA)	1 bank (2 banks in the future)
115kV Shunt capacitor	1 unit (1 unit in the future)
22kV line	6 lines (20 lines in the future)

Source: JICA Study Team

In addition, Fig. 8.3-2 shows the single line diagram of the substation.



Source: JICA Study Team

Fig. 8.3-2 Single Line Diagram of Substation at NCC

For placement on site within a limited area, while ensuring access or passage for the instrument of future expansion of the space required for installation and maintenance work, the equipment arrangement design aims to be compact.

Equipment except the distribution transformer is disposed in the substation building.

Inside the building, interconnection transformer is located on the Ground floor, 230kV GIS is located on the 1st floor, 22kV SWG and 115kV GIS are located on the 2nd floor, and control room and others are located in the 3rd floor. And shunt capacitor is placed on the rooftop. In addition, since the carrying path of NCC site is narrow, it is proven that carrying the three-phase one body tank by Schnabel trailer, which is a land transport of normal 230kV normal three-phase transformer, is difficult. As for surrounding NCC, extension of the carrying path is impossible for the urban area. In order to solve this transport problem, specific three-phase structure should be adopted. In general, specific three-phase structure transformer is divided into three tanks for each phase, transported by a low bed trailer and assembled on-site. Installation area of the transformer to be increased slightly compared to the normal three-phase one, but can be sufficiently placed in NCC site. On the other hand, since there is a possibility that the reinforcing road and traffic control is not required by low-floor trailer transportation, the cost benefit of transport is large.

1) Main gate carrying path

2) Rear gate carrying path

Fig. 8.3-3 NCC Carrying Path

Appendix-5-1-1 shows the equipment layout image of the substation at NCC site.
Appendix-5-1-2 and 5-1-3 shows the layout image in the NCC substation building.

(c) Construction schedule

The construction schedule of the substation is shown below.

Table 8.3-9 Construction Schedule (NCC)

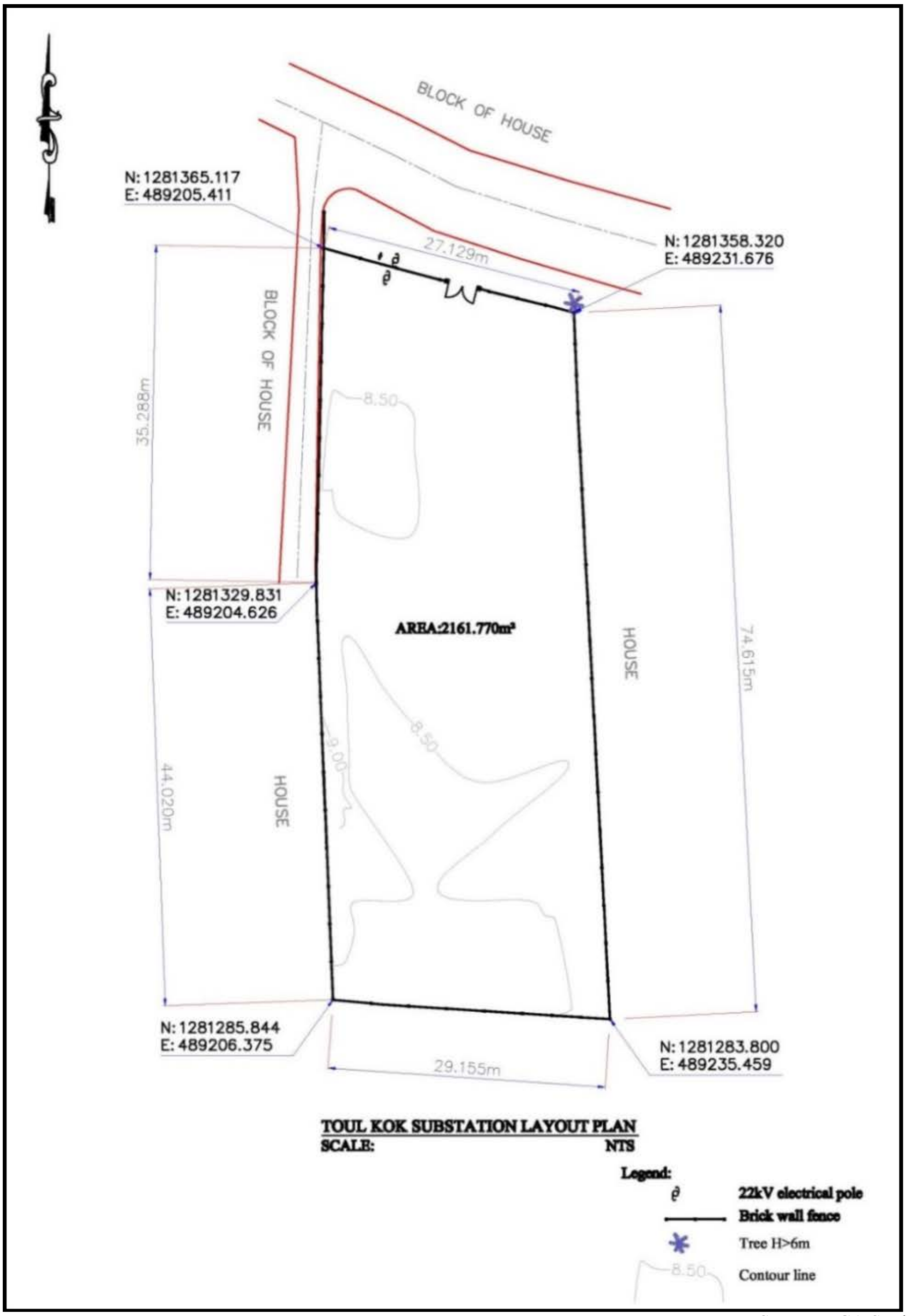
Year	First year												Second year												Third year					
Order	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
Detail Designing	■	■	■	■																										
Building construction work					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■							
Manufacturing & Transportation					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Installation work																			┅	┅ (Foundations)										
GIS(230kV,115kV)																					■	■			■	■	■			
Main Transformer																						■	■	■	■	■				
Distribution Transformer																				■	■	■								
115kV Shunt Capacitor																									■					
22kV Switchgear																							■	■	■					
Control system, Relay																								■	■	■	■			
Testing & Commissioning																									■	■	■	■	■	
Energizing																														▲

Source: JICA Study Team

(4) New GIS substation at the Toul Kork site

(a) Location

According to the result of the field survey, the location is facing the main road in the region and the route of the transmission line between GS5 and GS1. Fig. 8.3-4 shows a survey map of candidate site whose size is approximately 25m ×75 m.



Source: JICA Study Team

Fig. 8.3-4 Survey Map of Toul Kork Substation

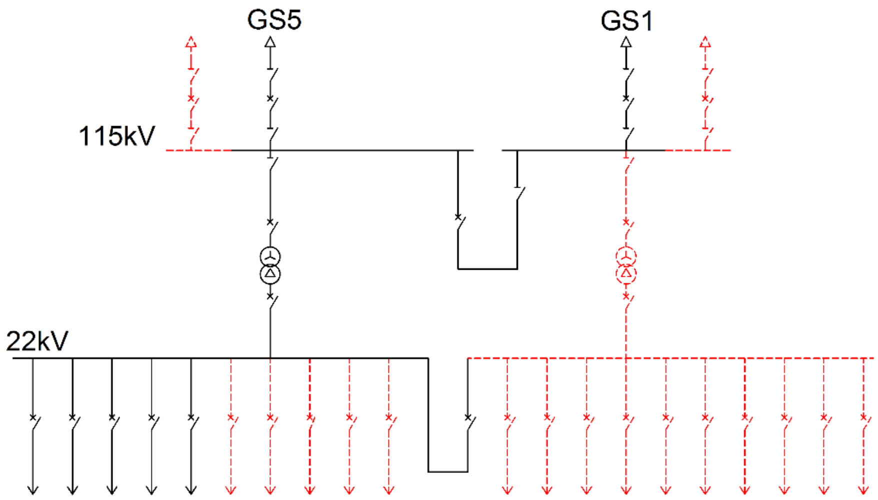
(b) Equipment & layout

Table 8.3-10 Substation Equipment (Toul Kork)

	Number of equipment
115kV GIS bus	Single bus
115kV line	2 lines (4 lines in the future)
115kV/22kV Transformer 50MVA	1 bank (2 banks in the future)
22kV line	5 lines (20 lines in the future)

Source: JICA Study Team

In addition, Fig. 8.3-5 shows the single line diagram of the Toul Kork substation.



Source: JICA Study Team

Fig. 8.3-5 Single Line Diagram of Substation at Toul Kork

For placement on site within a limited area, while ensuring access or passage for the instrument of future expansion of the space required for installation and maintenance work, the equipment arrangement design aimed to be compact.

Equipment except the distribution transformer and steel-tower is disposed in the substation building.
Inside the building, 115kV GIS are located on the Ground floor, 22kV switchgear is located on the 1st floor, and control room and others are located on the 2nd floor.

For the reduction of the steel tower site area, single lead-in steel tower is adopted. At the steel tower arm-on, the substation lead-in power cable is connected with the overhead transmission line.

Appendix-5-2-1 shows the equipment layout image of the substation at Toul Kork site.
Appendix-5-2-2 shows the layout image of the Toul Kork substation building.

(c) Construction schedule

The construction schedule of the substation is shown below.

Table 8.3-11 Construction Schedule (Toul Kork)

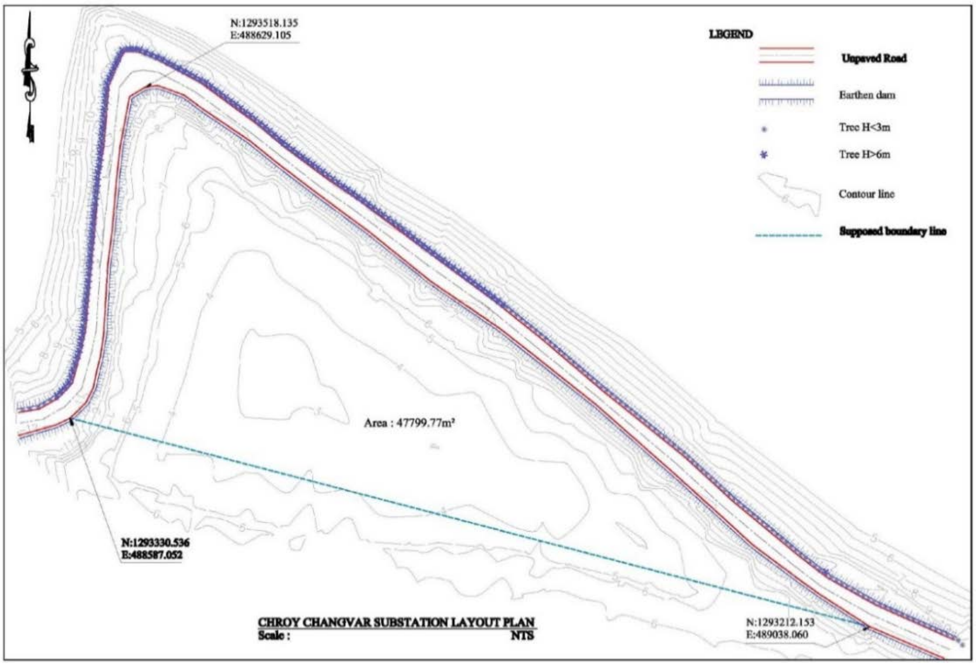
Year	First year												Second year											
Order	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Detail Designing	■	■	■	■																				
Building construction work					■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Manufacturing & Transportation					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Installation work																□	□	□	□	(Foundations)				
Steel structure																	■	■						
115kV GIS																				■	■			
Distribution Transformer																		■	■	■				
22kV Switchgear																			■	■				
Control system, Relay																				■	■	■		
Testing & Commissioning																				■	■	■	■	
Energizing																								▲

Source: JICA Study Team

(5) New AIS substation at site of Chroy Changvar

(a) Location

For the site selection of Chroy Changvar substation, EDC is negotiating with the company that is doing large-scale development of Chroy Changvar district. Substation site will be selected near the lowland where is facing the pond on the north side of the large-scale development area.



Source: JICA Study Team

Fig. 8.3-6 Candidate Area of Chroy Changvar Substation

In addition, EDC has a plan for 230kV step-up at Chroy Changvar substation in the future. Therefore, conditions for site selection are as follows.

• 115kV transmission line route can be secured.
• To ensure the site area required for AIS substation
• The access from the 230kV system is easy.
• To ensure the site area in consideration of 230kV step-up

Since vast vacant land (low wetland) was available around the predetermined Chroy Changvar substation site, JICA Study Team studied as follows on the assumption that these requirements are satisfied.

EDC is planning to ensure the land satisfy to all of these requirements.
(Example of the required land size is approximately 180m × 180m.)

Fig. 8.3-7 Circumstances of Chroy Changvar Substation Candidate Area

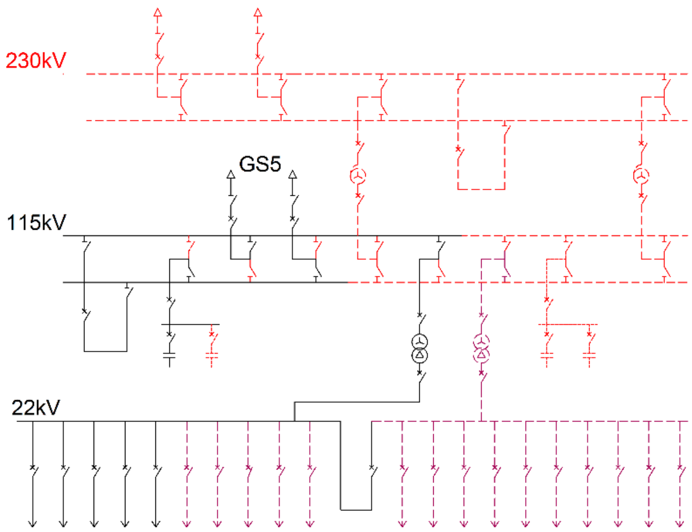
(b) Equipment & layout

Table 8.3-12 Substation Equipment (Chroy Changvar)

	Number of equipment
230kV bus	0 Bus (Double bus in the future)
230kV line	0 lines (4 lines in the future)
230kV/115kV Transformer (300MVA)	0 banks (2 banks in the future)
115kV bus	Single bus (Double bus in the future)
115kV line	2 lines (6 lines in the future)
115kV/22kV Transformer (75MVA)	1 bank (2 or 3 banks in the future)
115kV Shunt capacitor	1 unit (4 units in the future)
22kV line	4 lines (20 lines in the future)

Source: JICA Study Team

In addition, Fig. 8.3-8 shows the single line diagram of the Chroy Changvar substation.



Source: JICA Study Team

Fig. 8.3-8 Single Line Diagram of Substation at Chroy Changvar

The equipment layout was designed to be compact satisfying the following conditions.

- Ensuring the space for the installation work
- Ensuring the space for the future expansion (230kV step-up and 115kV Transmission line expansion)
- Ensuring the access and passage
- Ensuring the space required for the maintenance

Appendix-5-3 shows the equipment layout image of the substation at Chroy Changvar site.

(c) Construction schedule

The construction schedule of the substation is shown below.

Table 8.3-13 Construction Schedule (Chroy Changvar)

Year	First year												Second year											
Order	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Detail Designing	■	■	■	■																				
Building construction work					■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Manufacturing & Transportation					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
Installation work																□	□	□	□	(Foundations)				
Steel structure																		■	■	■				
115kV Switchgear																				■	■			
Distribution Transformer																		■	■	■				
115kV Shunt Capacitor																					■			
22kV Switchgear																			■	■				
Control system, Relay																				■	■	■		
Testing & Commissioning																				■	■	■	■	
Energizing																								▲

Source: JICA Study Team

8.3.2 Modification of GS3 and GS5

(1) GS3

(a) Present conditions and expandability

GS3 was originally designed in consideration of the future expansion of a maximum six (6) 115kV transmission line feeder bays in total. Since the two bays out of the six bays are currently being used for transmission line feeders going to GS1 and to CEP IPP power plant. Additionally in Phase 1, one bay is planning to be used for transmission line feeder going to Olympic Stadium GIS substation.

The remaining three (3) feeder bays are currently not in use although some feeder bays are now equipped with an unused switchgear which can be removed.

1) 115kV Switchgear installation position

2) 115kV Shunt capacitor installation position

Fig. 8.3-9 Vacant Space for Expansion in GS3

(b) Outline of the modifications

In GS3, switching equipment that is installed to connect the Olympic Stadium substation in phase 1 is modified for connection to the NCC substation. In addition, a shunt capacitor (30MVar) 1 unit is installed as a phase modifying equipment.

In addition to the above additional installation of equipment, the following items will be necessarily installed or modified under this Project.

1) 115kV Shunt capacitor control, switching and protection (GS3)
2) Modification of existing Substation Control System
3) SCADA and telecommunication equipment for the transmission line system change

(c) Outline of technical data of equipment

Table 8.3-14 Basic Specification of 115kV Switchgear and Shunt Capacitor

		Basic specification
115kV Switch gear	Rated voltage	115 kV
	Bus bar configuration	Single Bus-bar Type
	GIS or AIS	AIS
	Rated current	1,250A: Shunt capacitor
	Rated short-time withstand current	31.5kA
115kV Shunt capacitor	Type	Can Type
	Rated voltage	115 kV
	Rated capacity	30MVar

Source: JICA Study Team

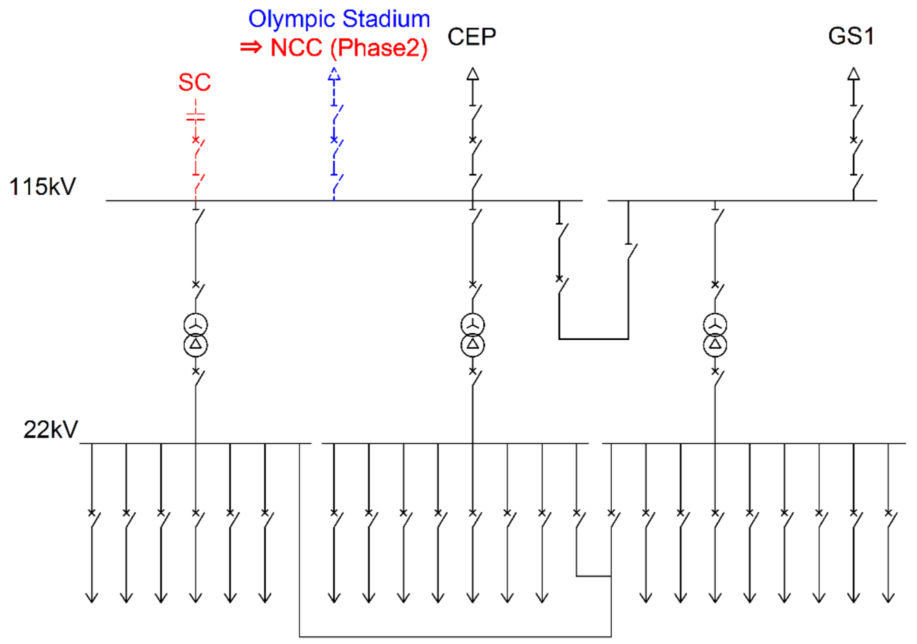
(d) Expanding equipment & layout

Table 8.3-15 Expanding Equipment

	Number of expanding equipment
115kV Shunt capacitor	1 unit

Source: JICA Study Team

In addition, Fig. 8.3-10 shows the single line diagram of the substation.



Source: JICA Study Team

Fig. 8.3-10 Single Line Diagram of GS3

Appendix-5-4 shows the equipment layout image of GS3.

(e) Implementation Schedule

The implementation schedule for the modification of GS3 is presented below.

Table 8.3-16 Construction Schedule (GS3)

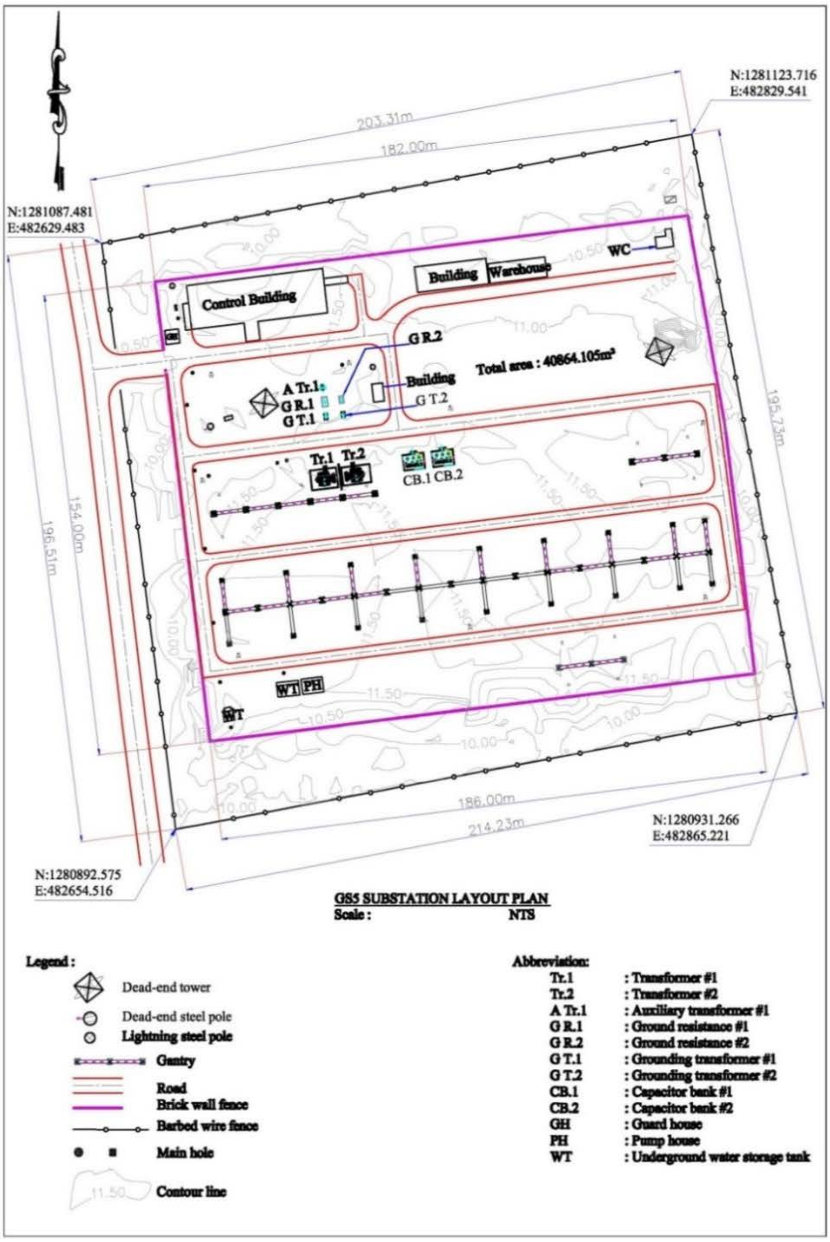
Year	First year												Second year											
Order	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Detail Designing	■	■																						
Manufacturing & Transportation			■	■	■	■	■	■	■	■	■	■	■	■	■									
Installation work														□	□	(Foundations)								
Steel structure															■									
115kV Shunt Capacitor																■								
Switchgear (115kV)															■	■								
Control system, Relay																■	■							
Testing & Commissioning																	■	■						
Energizing																			▲					

Source: JICA Study Team

(2) GS5

(a) Present conditions and expandability

Because GS5 has a structure in which distribution transformers is installed in the 115kV switchyard, 230kV bay does not exist.
Despite 6 of the 15 bays of 115kV is free, there are only 5 times of a square which can be arranged in a side-by-side of 230kV AIS bus bay in unused space on the north side of these 6 free bays.
On the other hand, according to the acquisition of a vacant land on the east side, the expandability would be secured. In that case, 230kV AIS bus bay is about 8 times of a space which can be arranged side-by-side.



Source: JICA Study Team

Fig. 8.3-11 Survey Map of GS5

(b) Outline of the modifications

i) 230kV/115kV main transformer : 2 units

In order to 115kV system enhancement, two main transformers (300MVA × 2) will be installed.

ii) 230kV switchgear: 6 bays

Total 6 bays
The followings will be additionally installed.
In order to be connected to the SPP and NPP, 230kV overhead transmission feeder bay × 2.
In order to be connected to the NCC, 230kV underground transmission cable bay ×1.
230kV Bus-tie bay ×1.
230kV/115kV main transformer primary bay ×2.

iii) 115kV shunt capacitor: 2 units

In order to 115kV reactive power supply, two shunt capacitors (30MVA × 2) will be installed.

iv) 115kV switchgear: 6 bays

Total 6 bays
The following will be additionally installed.
In order to be connected to the Chroy Changvar, 115kV overhead transmission feeder bay × 2.
115kV Bus-tie bay ×1.
115kV phase modifying equipment bay ×1.
230kV/115kV main transformer secondary bay ×2.

In addition, since EDC decided that EDC will purchase a vacant land, it was possible to perform the modification using AIS facilities that were expected to benefit in all costs, maintenance and operation than GIS one.

1) GS5 115kV bus north side

2) Vacant land east of GS5

Fig. 8.3-12 230kV AIS Equipment Expansion Candidate Area of GS5

In addition to the above additional installation of switchgear, the following items will be necessarily installed or modified under this Project.

1) 230kV bus, transmission line feeder and transformer control and protection

2) 115kV bus, transmission line, transformer and shunt capacitor control and protection
3) Modification of existing Substation Control System
4) SCADA and telecommunication equipment for the new transmission line system

(c) Outline of technical data of equipment

i) 230kV/115kV main transformer

Table 8.3-17 Basic Specification of 230kV/115kV Main Transformer

	Basic specification
Type	YN Auto d1
Rated voltage	230 kV / 115 kV
Rated capacity (Primary/secondary)	300MVA

Source: JICA Study Team

ii) 230kV Switchgear

Table 8.3-18 Basic Specification of 230kV Switchgear

	Basic specification
Rated voltage	230kV
Bus bar configuration	Double bus-bar Type
GIS or AIS	AIS
Rated current	2,000A
Rated short-time withstand current	40kA

Source: JICA Study Team

iii) 115kV Shunt capacitor

Table 8.3-19 Basic Specification of 115kV Switchgear

	Basic specification
Type	Can Type
Rated voltage	115 kV
Rated capacity	30MVar

Source: JICA Study Team

iv) 115kV Switchgear

Table 8.3-20 Basic Specification of 115kV Switchgear

	Basic specification
Rated voltage	115kV
Bus bar configuration	Double bus-bar Type
Insulation type	AIS
Rated current	1,250A: Transmission line / 2,000A: MTr secondly
Rated short-time withstand current	31.5kA

Source: JICA Study Team

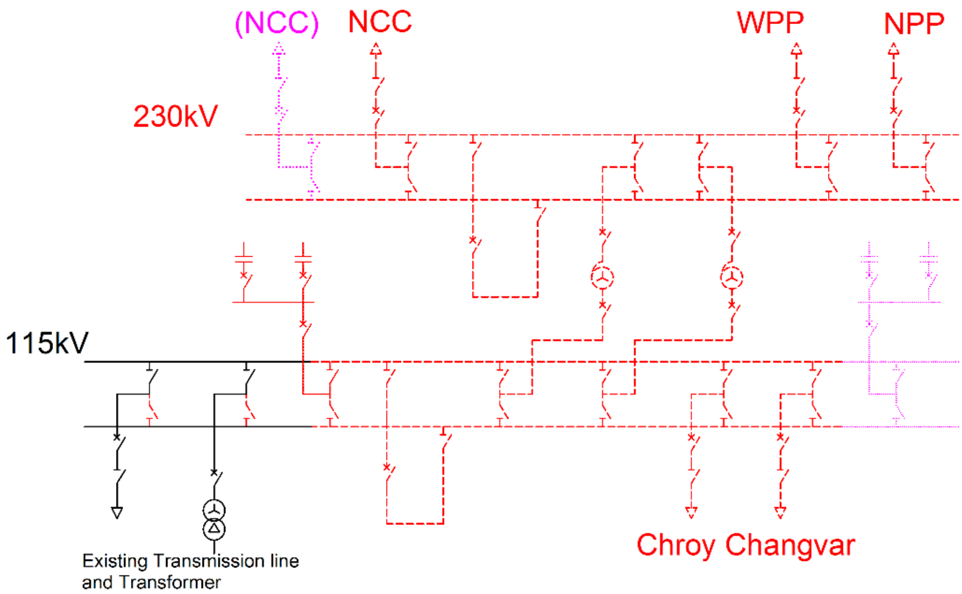
(d) Expanding equipment & layout

Table 8.3-21 Expanding Equipment (GS5)

	Number of equipment
230kV AIS bus	Double bus
230kV line	3 lines (2 Transmission line, 1 power-cable)
230kV/115kV Transformer (300MVA)	2 Banks
115kV Shunt capacitor	2 units (4 units in the future)
115kV AIS bus	Expansion to Double bus (Existing Single bus)
115kV line	2 lines

Source: JICA Study Team

In addition, Fig. 8.3-13 shows the single line diagram of the substation.



Source: JICA Study Team

Fig. 8.3-13 Single Line Diagram of GS5

From the point of view of project cost reduction, EDC would like to install 230kV AIS extension by land acquisition than installing 230kV GIS to the existing vacant lot. Therefore, site extension is adopted.

Appendix-5-5 shows the equipment layout image of the substation at GS5.

(e) Implementation Schedule

The implementation schedule for the modification of GS5 is presented below.

Table 8.3-22 Construction Schedule (GS5)

Year	First year												Second year												Third year					
Order	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
Detail Designing	■	■	■	■																										
Building construction work					■	■	■	■	■	■	■	■	■	■	■	■	■	■												
Manufacturing & Transportation					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■										
Installation work																□	□	□	□	(Foundations)										
Steel Structure																			■	■	■									
Switchgear (230kV,115kV)																						■	■	■	■	■				
Main Transformer																						■	■	■						
115kV Shunt Capacitor																									■	■				
Control system, Relay																								■	■	■	■			
Testing & Commissioning																									■	■	■	■	■	
Energizing																														▲

Source: JICA Study Team

8.4 DISTRIBUTION FACILITY

8.4.1 Outline of Distribution Facility

Distribution facility is connected between a distribution substation and a customer, such as house, building, and factory, and it consists of a pole, conductor, and transformer and so on.

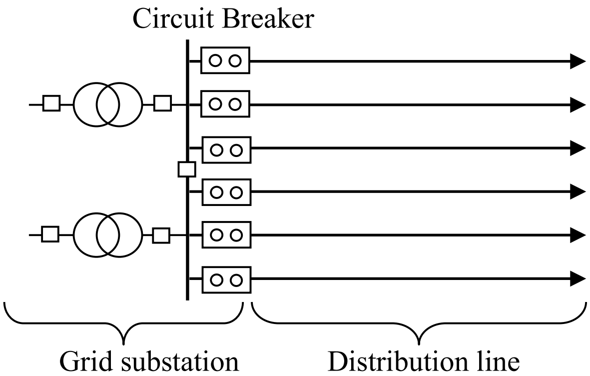
In Phnom Penh, a certain supply capacity is secured in present situation because distribution facilities are already constructed. On the other hand, power demand is expected to grow significantly in the future because the large-scale development projects are planned in many places.

Under such a situation, it is important to utilize existing distribution lines effectively and to expand new distribution lines in order to respond the power demand in the future.

Fig. 8.4-1 State of Phnom Penh City

(1) Configuration of distribution line

There are 6 (six) grid substations in around Phnom Penh City and electric power is supplied by distribution lines from each grid substation. Distribution line circuit breaker is installed in each line, and the amount of power supply is about 10MW in case that the capacity of circuit breaker is 300A.



Source: JICA Study Team

Fig. 8.4-2 Example of Connection

(2) Voltage level

Voltage level of distribution line can be roughly divided into low voltage and medium voltage mainly, and voltage in Phnom Penh City is shown in Table 8.4-1.

Table 8.4-1 Voltage Level of Distribution Line

Classification	Voltage
Medium voltage	22kV
Low voltage	400V, 230V

Source: JICA Study Team

(3) Power distribution system

Power distribution system is mainly divided into overhead line and underground line. Overhead line is common system in Cambodia, but the underground line has been adopted in the center of Phnom Penh City. In case of the new distribution line, it is necessary to select the power distribution system based on the current state.

Fig. 8.4-3 Overhead Line

Fig. 8.4-4 Underground Line (under construction)

8.4.2 Standards of Power Distribution Facility and Construction

(1) Standards of power distribution facility

Design Standards of EDC based on the power technical standard and power technical standard detailed regulation are as follows.

(a) Concrete Pole

The standard of pole is shown in Table 8.4-2. Length of pole is 7.5~14m, and strength is 2~10kN. Embedment of more than 1/6 of the length of a pole is required at the construction work, in addition, reinforcement by foundation block is required depending on the angle of distribution line and soil coefficient.

Method of reinforcement by foundation block is shown in Fig. 8.4-6.

Fig. 8.4-5 Example of Concrete Pole

Table 8.4-2 Standard of Concrete Pole

Concrete pole table			
Length	**Strength**	**Installation depth**	**Foundation block**
7.5 m	2 kN	1.25 m	
9 m	2 kN	1.50 m	0.60 x 0.40 m
9 m	5 kN	1.50 m	0.70 x 0.45 m
9 m	8 kN	1.50 m	0.85 x 0.70 m
12 m	3 kN	2.00 m	0.60 x 0.40 m
12 m	6 kN	2.00 m	0.75 x 0.50 m
12 m	9 kN	2.00 m	0.90 x 0.75 m
14 m	4 kN	2.35 m	0.70 x 0.45 m
14 m	6.5 kN	2.35 m	0.80 x 0.50 m
14 m	10 kN	2.35 m	1.00 x 0.75 m

Source: Design standard distribution networks, EDC

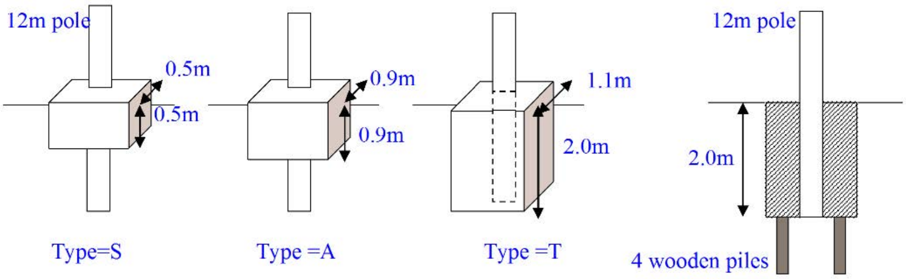


Fig. 8.4-6 Method of Reinforcement

Source: Design standard distribution networks, EDC

(b) 22kV distribution line

Conductors and cables conformed by IEC or ICEA (Insulated Cable Engineers Association) are adopted at 22kV distribution lines.

In general, bare conductors are adopted for overhead line, and cables are adopted for underground line.

In case of overhead line, insulated conductors or cables are adopted in order to ensure the clearance between distribution line and other structure.

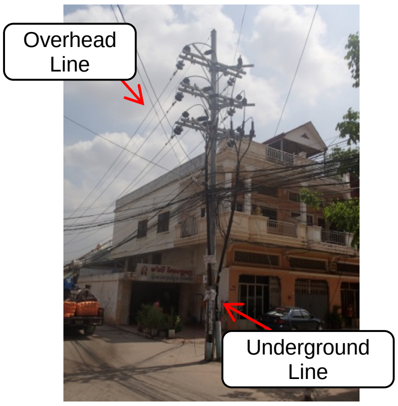


Fig. 8.4-7 Example of 22kV Distribution Line

i) 22kV overhead bare conductor

Table 8.4-3 22kV Overhead Bare Conductor

MV overhead line conductors				
	Bare conductors			
Type	240 mm^2 AAC	150 mm^2 AAC		70 mm^2 AAC
EDC nomenclature				
Photograph				
Implementation range	MV overhead network			
Standards	IEC 61089			

Source: Design standard distribution networks, EDC

ii) 22kV overhead insulated conductor

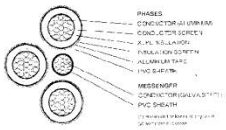
Table 8.4-4 22kV Overhead Insulated Conductor

MV overhead line conductors					
	Partial insulated conductor				
Type	240 mm^2		150 mm^2		70 mm^2
EDC nomenclature					
Photograph					
Implementation range	MV overhead network				
Standards	ICEA S-66-524				

Source: Design standard distribution networks, EDC

iii) 22kV overhead cable

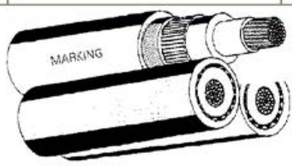
Table 8.4-5 22kV Overhead Cable

MV overhead line conductors				
	Aerial Bundled Cable			
Type	240 mm^2	150 mm^2	70 mm^2	
EDC nomenclature				
Photograph				
Implementation range	MV overhead network			
Standards	IEC 60502			

Source: Design standard distribution networks, EDC

iv) 22kV underground cable

Table 8.4-6 22kV Underground Cable

MV underground cables			
	MV twisted underground cable		
Type	3 x 240 mm^2 Alu	3 x 150 mm^2 Alu	3 x 70 mm^2 Alu
EDC nomenclature EDC	0840 1178	0840 1014	
Photograph			
Implementation range	MV underground network		
Standards	IEC 60502		

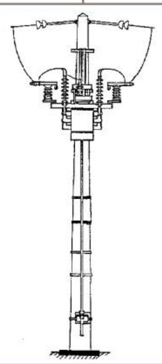
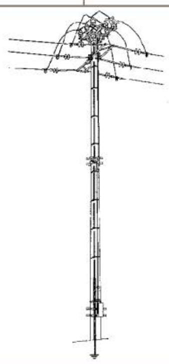
Source: Design standard distribution networks, EDC

(c) Line switch

There are some kinds of distribution line switch. LBS (Load Break Switch) and DS (Disconnecting Switch) are pole mounted type, and switchgear is indoor type.

i) Pole mounted type

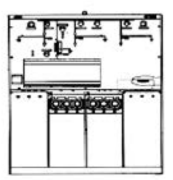
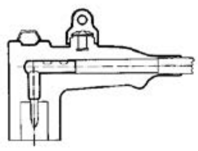
Table 8.4-7 Pole Mounted Type Switch

Overhead MV switches				
Type	630 A	400 A	200 A	
EDC nomenclature				
Photograph				
Implementation range	On the main feeder.		spur line.	
Standards	IEC 60420		IEC 60420	

Source: Design standard distribution networks, EDC

ii) Indoor type

Table 8.4-8 Indoor Type Switch and Cable Terminal

Ring main units and 630 A plug-in connector			
	RMU 2S + T	RMU 2S + 2T	MV plug-in connector
EDC nomenclature			a) 630 A = b) 200 A =
Photograph			
Implementation range	Load break switches ensuring incoming / outgoing feeder sectioning and transformer protection	Load break switch ensuring incoming / outgoing feeders sectioning and protection for two transformers	Plug-in connector for MV single core cables on ring main units
Standards	IEC 60298, 60265, 60129, 60694, 60420, 60056		IEC

Source: Design standard distribution networks, EDC

Fig. 8.4-8 Pole Mounted Type Switch

Fig. 8.4-9 Indoor Type Switch

(2) Standard of construction

(a) Clearance

i) Minimum height of the overhead line

Minimum height of overhead line is different depending on voltage, conductor type, construction area, and crossing a road or not.

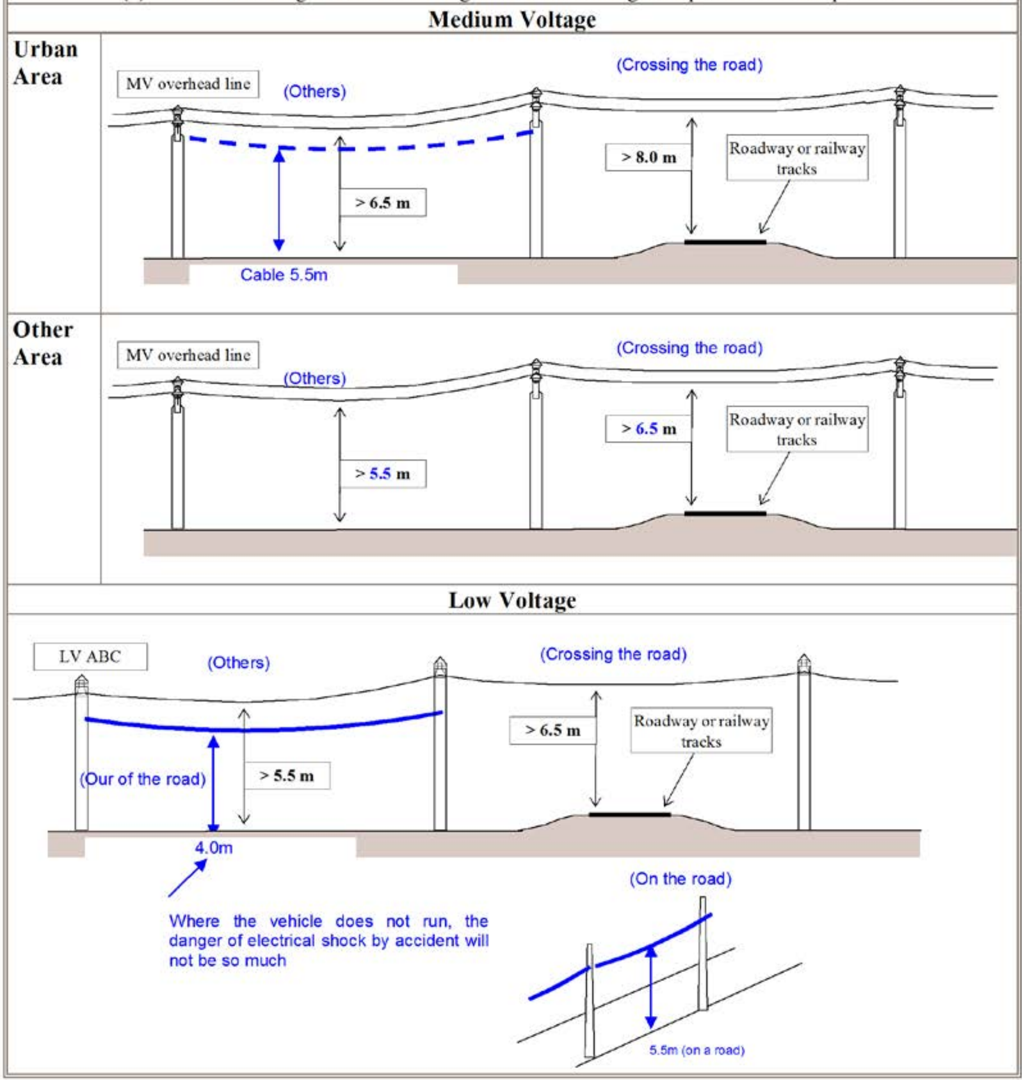
For example, to construct a 22kV overhead insulated conductor in Phnom Penh, it is necessary to ensure a height of 8.0m or more at a road crossing point, at other point, it is necessary to ensure a height of 6.5m or more.

Table 8.4-9 Minimum Height of the Overhead Line

The minimum height of the Overhead line

	LV Overhead line	MV Overhead line		
		Urban Area		Other Area
		Cable	Others	
Crossing a road	6.5m	8.0m	8.0m	6.5m
Others	5.5m(*)	5.5m	6.5m	5.5m

(*)The minimum height of the low voltage conductor is mitigated up to 4.0m on the place out of the road.



Source: Design standard distribution networks, EDC

ii) Clearance between overhead line and others

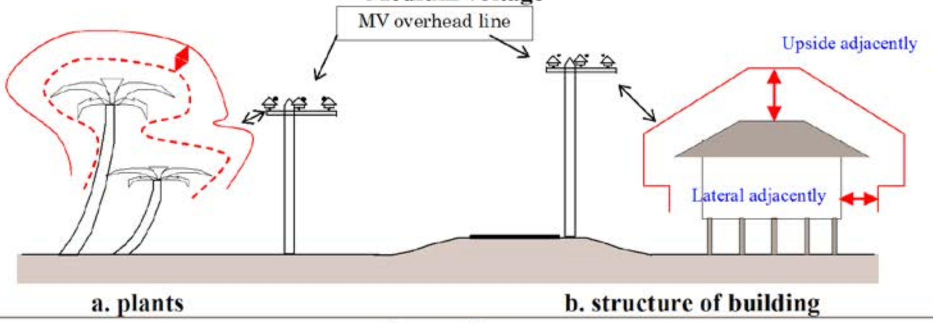
It is necessary to ensure a clearance between overhead line and a plant or a structure such as house and building.

For example, it is necessary to ensure a clearance more than 1.5m away from the side of a large building to construct 22kV overhead insulated conductor around a building.

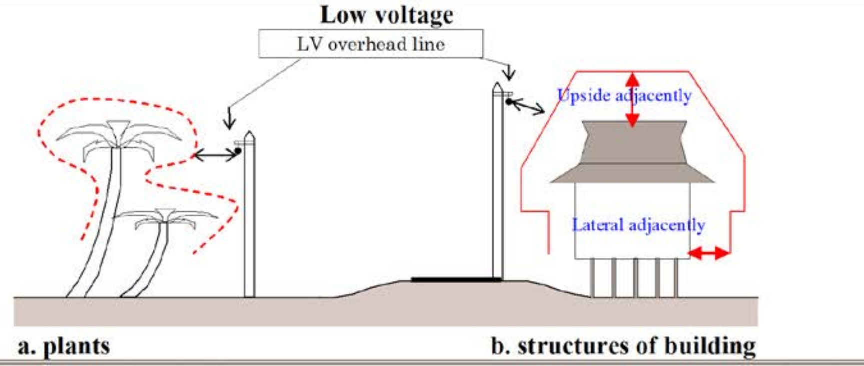
Table 8.4-10 Clearance between Overhead Line and Others

Clearance between overhead line and others					
				LV	**MV**
Structures of building	Upside adjacency	With the possibility for persons to climb on	Bare conductor		3.0m
			Insulated conductor	2.0m	2.5m
			Cable	1.0m	1.2m
		Others	Bare conductor	-	3.0m
			Insulated conductor	1.2m	1.5m
			Cable	0.4m	0.5m
	Lateral and downside adjacency		Bare conductor	-	3.0m
			Insulated conductor	1.2m	1.5m
			Cable	0.4m	0.5m
Plants			Bare conductor	-	2.0m
			Insulated conductor	Shall not contact directly	
			Cable	Shall not contact directly	

Medium voltage



Low voltage



Source: Design standard distribution networks, EDC

iii) Adjacency and crossing of 22kV overhead line

It is necessary to ensure a clearance between 22kV and other lines.

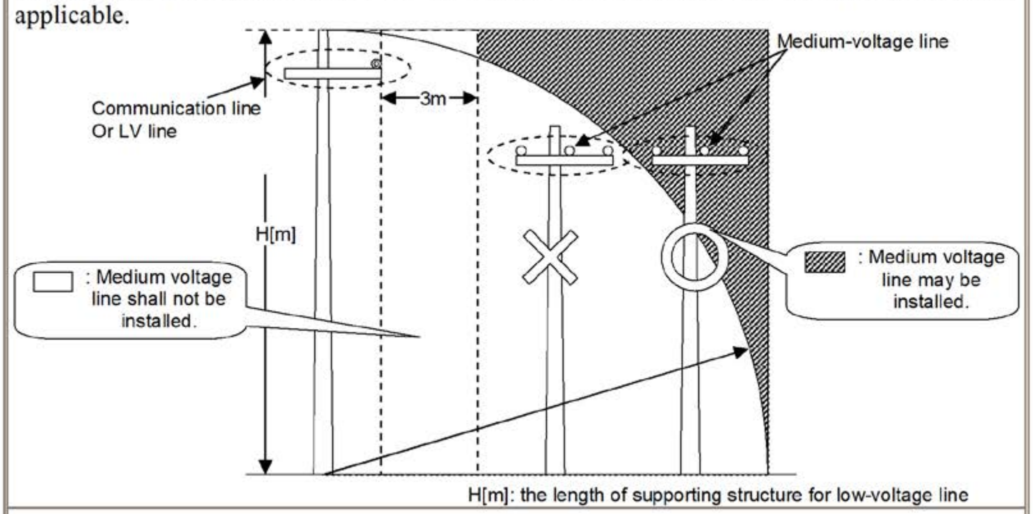
For example, in case of 22kV insulated conductor or cable, it is necessary to ensure a clearance more than 0.5m between each line.

Table 8.4-11 Adjacency and Crossing of 22kV Overhead Line

Adjacency and Crossing of MV

Other objects		Direction of adjacency or crossing	Clearance: Insulated Conductor	Clearance: Cable	Clearance: Others
Medium voltage line	Insulated Conductor	Lateral adjacency	0.5m or more	0.5m or more	2.0m or more
	Cable	Lateral adjacency	0.5m or more	0.5m or more	2.0m or more
	Others	Lateral adjacency	2.0m or more	2.0m or more	2.0m or more
Low voltage line		Downside adjacency	1.0m or more	0.5m or more	2.0m or more
		Upside adjacency and crossing	(*1)	0.5 or more	(*1)
Communication line		Downside adjacency	1.0m or more	0.5m or more	2.0m or more
		Upside adjacency and crossing	(*2)	0.5 or more	(*2)

(*1)(*2) If the MV line keeps the horizontal clearance of 3.0m or more with LV line or communication line, LV line or Communication line does not come in contact with the MV line when the supporting structure of the LV line or Communication line collapsed, this not be applicable.



Source: Design standard distribution networks, EDC

(b) Underground line

i) Standard construction and depth of burial

Direct burial system is standard for underground line.

Depth of burial is 1.2m or more at the point receiving pressure from vehicles and other objects, and 0.6m or more at other point.

However, it is necessary to use pipes in case that an underground line crosses a major road, or in case a depth shown in Table 8.4-12 cannot be obtained.

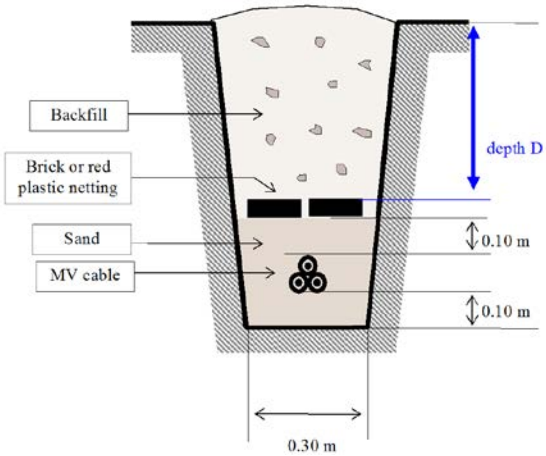


Fig. 8.4-10 Standard Construction

Source: Design standard distribution networks, EDC

Table 8.4-12 Depth in Case of Direct Burial System

Depth in case of direct burial system	
Installation position	**Depth**
At a place where there is a danger of receiving pressure from vehicles or other objects	D = 1.2 m or more
Other place	D = 0.6 m or more

Source: Design standard distribution networks, EDC

ii) Clearance between underground line and other electrical lines

It is necessary to ensure 0.15m or more between low voltage line and low voltage line. And it is necessary to ensure 0.3m or more between medium voltage line and other lines.

Table 8.4-13 Clearance between Underground Line and Other Electrical Lines

Clearance between plural underground lines		
New line	Other electrical lines	
	Low-voltage	Medium-voltage
Low-voltage	0.15m	0.3m
Medium-voltage	0.3m	0.3m

Source: Design standard distribution networks, EDC

iii) Clearance between underground line and other buried object

In the case of 22kV underground line, it is necessary to ensure 0.6m or more from the communication line, 1.0m or more from the gas pipe, 0.3m or more from water supply and sewerage.

Table 8.4-14 Clearance between Underground Line and Other Lines

Clearance between plural underground lines				
New line	Other electrical lines			
	Communication line	Gas	Water	Sewerage
Low-voltage	(* 0.1)0.3m	Shall not contact directly		
Medium-voltage	(* 0.1)0.6m	1.0m	0.3m	0.3m

(*) Approval of the owner of the communication line shall be required

(Source: Design standard distribution networks, EDC)

8.4.3 Basic Concept of Expansion of Distribution Line

(1) Measures associated with the new substation

At present, it is in situation that buildings are under construction in many places in Phnom Penh City, it should be prioritized to utilize the existing distribution lines, such as loads divides, in order to respond to the increase in electricity demand due to the development of those relatively small.

On the other hand, power demand is expected to increase 10% on average per year after year 2014 due to the large-scale development plans. Power demand is expected to increase rapidly at candidate sites of new substation (① NCC, ② Toul Kork area, ③ Chroy Changvar area), because large-scale development plans are concentrated in these areas.

Therefore, it is necessary to extend the distribution equipment with tuned to these development plans.

Scale	Countermeasure	Timing of implementation
Small	Utilizing the existing distribution lines (for example, loads divides)	Correspondence of each time
Large	Planned expansion of distribution line	With tuned to the development plan

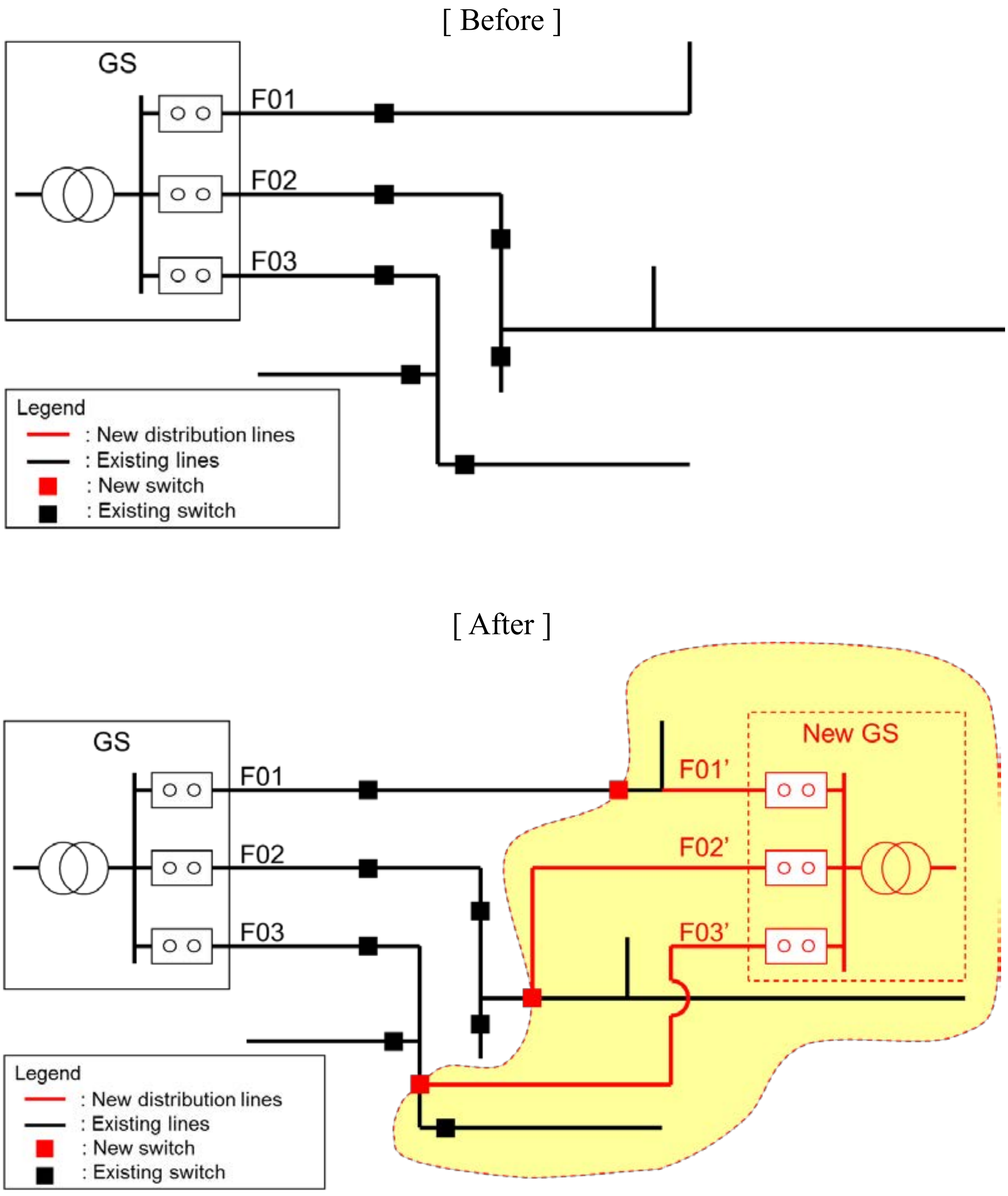
However, JICA Study Team could not confirm the situation that a large-scale development plan is progressing specifically at the field survey.

Therefore, in this Study, the priority is to divide loads, and to improve the power supply capacity and supply reliability with tuned to the new grid substation.

(2) Method of loads divides

The method of loads divides is shown in Fig. 8.4-11 based on concept of Section 8.4.4 (1).

In that way, electric power supplied by the existing grid substation will be reduced and reserve margin will be increased and power interchange form the other feeder is possible, so the supply reliability will be improved.



(Source: JICA Study Team)

Fig. 8.4-11 Image of Method of Loads Divides with tuned to the New Substation

(3) Measures associated with the new transmission line

As the results of the first field survey, there is a possibility that the new transmission line will be the same route as the existing distribution line. In this case, countermeasure work will be required in order to ensure the clearance between new transmission line and existing distribution line. For example, it is necessary to change conductors to cables and make the supporting point lower as shown in Fig. 8.4-13.

In addition, in case that sufficient clearance between cable and existing structures will not be ensured, it is necessary to consider underground cable or route changes by reconstructing pole.

Therefore, it is necessary to perform optimum measures depending on the surrounding circumstances, after determining the route of the transmission line to be established, it is necessary to examine measures again.

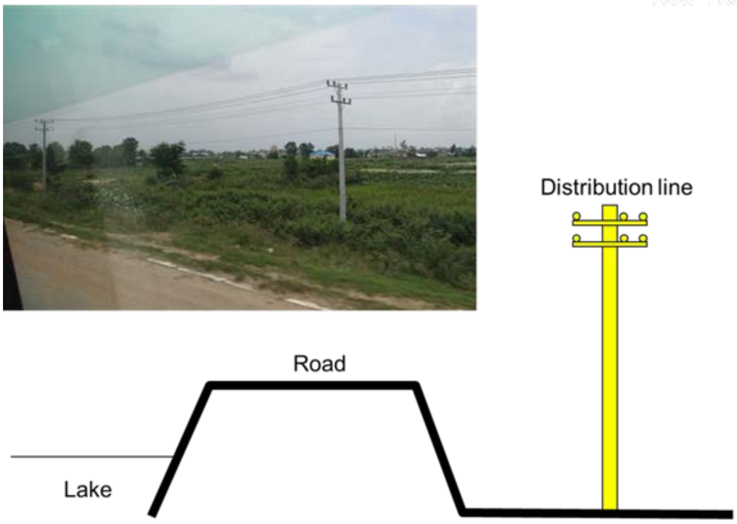
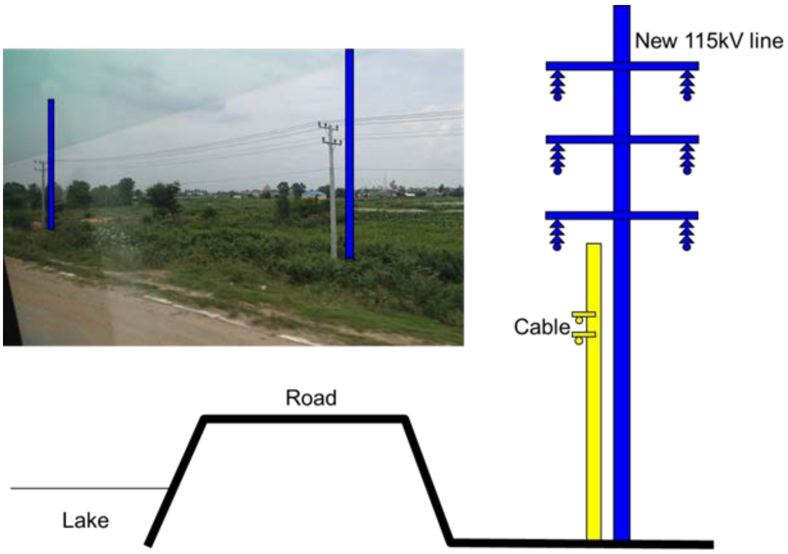


Fig. 8.4-12 Current Situation



Source: JICA Study Team

Fig. 8.4-13 Example of Countermeasure Work

8.4.4 Method of Examination of New Distribution Line Route

JICA Study Team investigated the route of new distribution line in the following steps, based on Design Standard Distribution Networks of EDC and information get through the field survey.

- Step 1 : Study of candidates for connection points of existing distribution line
- Step 2 : Study of distribution system (Overhead/Underground)
- Step 3 : Study of new distribution line route from new GS to candidates of connection points

However, JICA Study Team has examined what can be expected possibly carried out under certain assumptions in this preliminary design. Eventually, it is necessary to design in details after getting the approval of the use of land, and checking the status of existing buried objects such as water supply etc.

(1) Study of candidates for connection points of existing distribution line (Step1)

JICA Study Team has selected connection points that can be expected to divide loads or improve supply reliability. And JICA Study Team has taken into consideration to make effective use of existing facility when selecting the connection point.

(2) Study of distribution system (Overhead/Underground) (Step2)

JICA Study Team investigated the distribution system based on the design criteria of EDC and the status of existing distribution line at new substation candidate sites around.

(3) Study of new distribution line route from new GS to candidate of connection points (Step3)

JICA Study Team investigated the new distribution line route between from new GS to candidate of connection points selected by step 1. And JICA Study Team has also taken notice of following basic points to consider.

[Basic points to consider]

- To construct in public land such as public road
- To shorten the route length for economy
- To construct along the wide road and avoid the place where many people and cars are concentrated such as market, in consideration of construction work and maintenance work.

8.4.5 Preliminary Design

(1) NCC

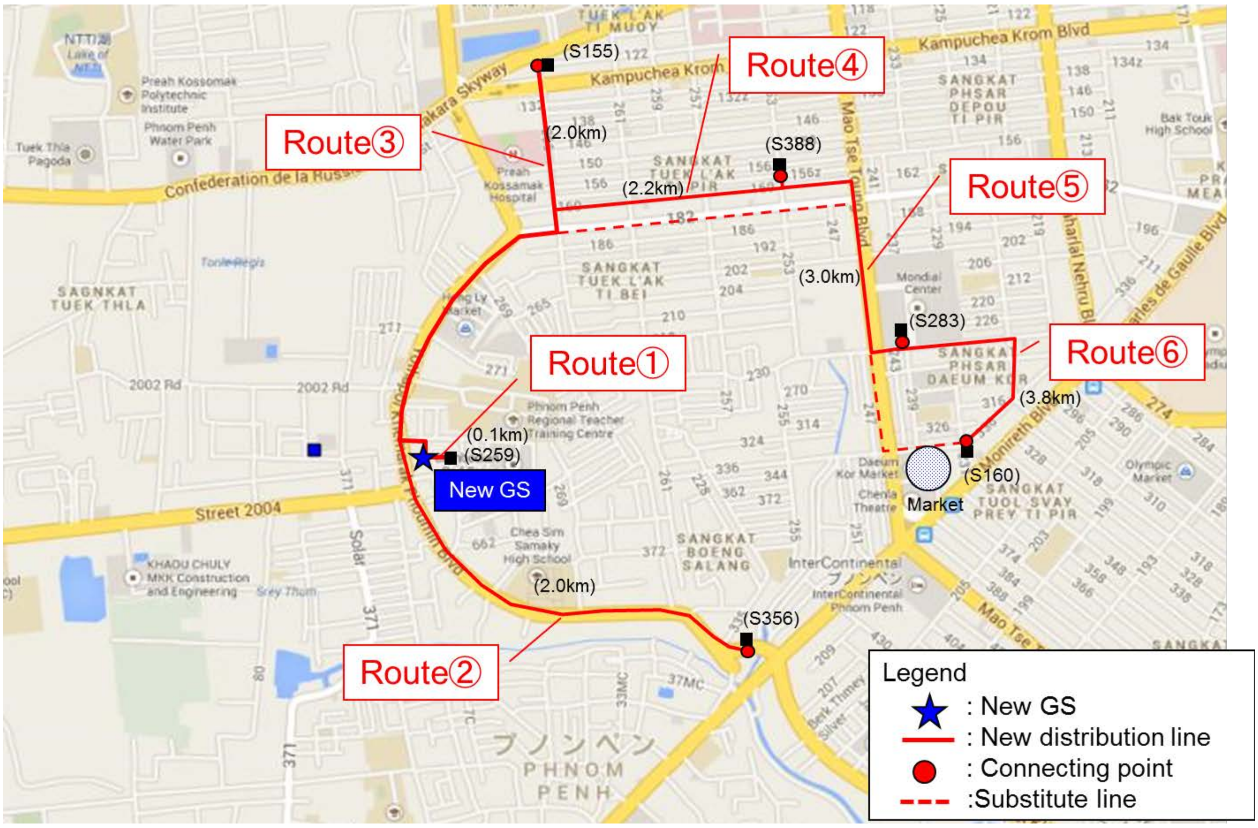
JICA Study Team designed to expand six new distribution lines, and connection point is indoor switchgear. In addition, JICA Study Team selected underground distribution system based on existing line.

One line will be laid in land of NCC to improve the supply reliability for NCC. Other five lines will be in land of the road, in this case, permission by municipality having jurisdiction over the road is necessary.

Table 8.4-15 Candidate Connection Point (NCC GS)

	Candidate connection point*	Distribution system (OH/UG)	Approximately route length[km]	Remarks
①	S259	UG	0.1	Backup for supply to NCC
②	S356	UG	2.0	
③	S155	UG	2.0	
④	S388	UG	2.2	
⑤	S283	UG	3.0	
⑥	S160	UG	3.8	

*S: Substation (Source: JICA Study Team)



 (Source: JICA Study Team)

Fig. 8.4-14 Route of Distribution Line (NCC GS)

(2) Toul Kork

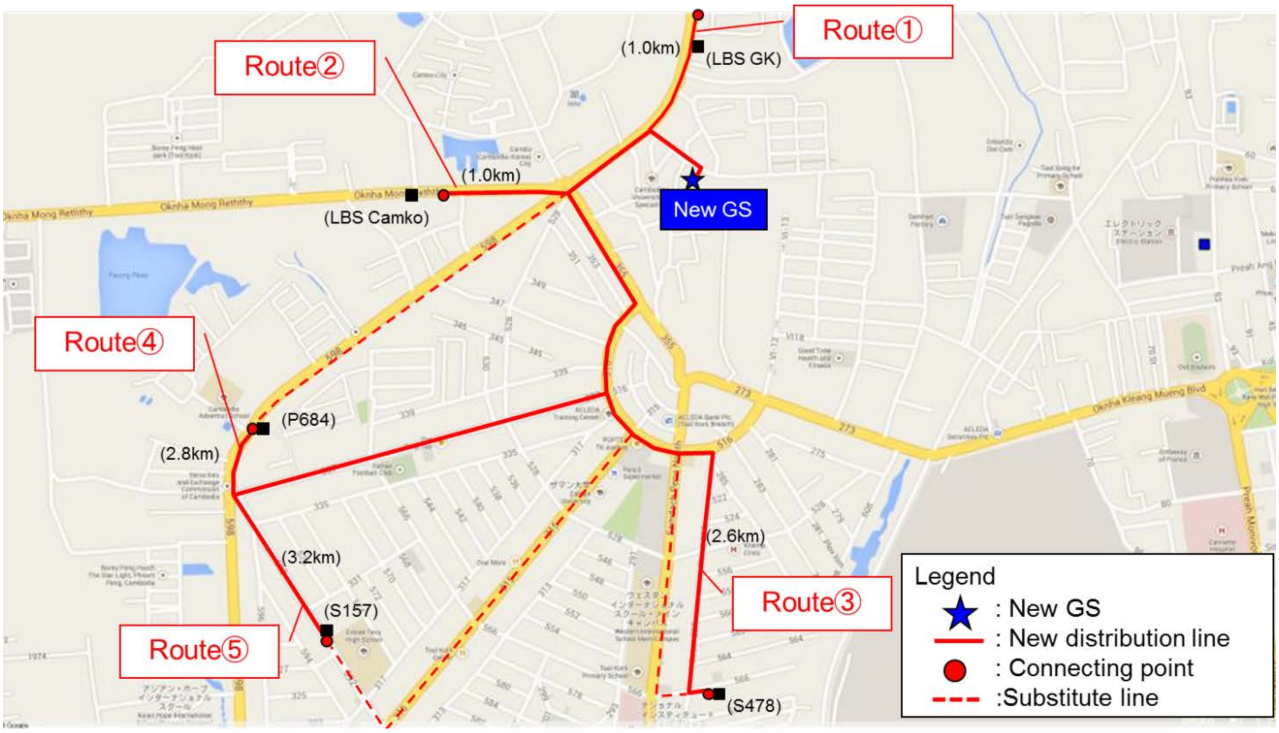
JICA Study Team designed to expand five new distribution lines, and connection point is overhead line or indoor switchgear. In addition, JICA Study Team selected underground distribution system based on existing line. In case of connecting to overhead line, distribution system will be changed from underground system to overhead system at near the site of connection point, after that it will be connected to overhead line.

All five lines will be laid in land of the road, and permission by municipality having jurisdiction over the road is necessary.

Table 8.4-16 Candidate Connection Point (Toul Kork GS)

	Candidate connection point*	Distribution system (OH/UG)	Approximately route length[km]	Remarks
①	Around LBS_GK	UG+OH	1.0	
②	Around LBS_Camko	UG+OH	1.0	
③	S478	UG	2.6	
④	Around P684	UG+OH	2.8	
⑤	S157	UG	3.2	

*S: Substation Source: JICA Study Team



©2014 Google Source: JICA Study Team

Fig. 8.4-15 Route of Distribution Line (Toul Kork GS)

(3) Chroy Changvar

JICA Study Team designed to expand five new distribution lines, and connection point is overhead line or indoor switchgear. Basically, distribution line is overhead system, but a part of them is underground system based on existing line.

Almost lines will be laid in land of the road, and the permission by municipality having jurisdiction over the road is necessary. However, around site of candidate new GS is all private land and there is no public land such as road, therefore the permission by owner of private land for construction of distribution line is necessary too.

Chroy Changvar is the area where REE (Rural Electricity Enterprise) given a license by EAC (Electricity Authority of Cambodia) can supply and retail electricity, therefore distribution lines which owner is not EDC are installed. These distribution lines are supplied from GS1 and GS6 now, therefore supply should be changed from existing GS to new GS. Furthermore, connection point between EDC grid and REE line should be changed by discuss with REE.

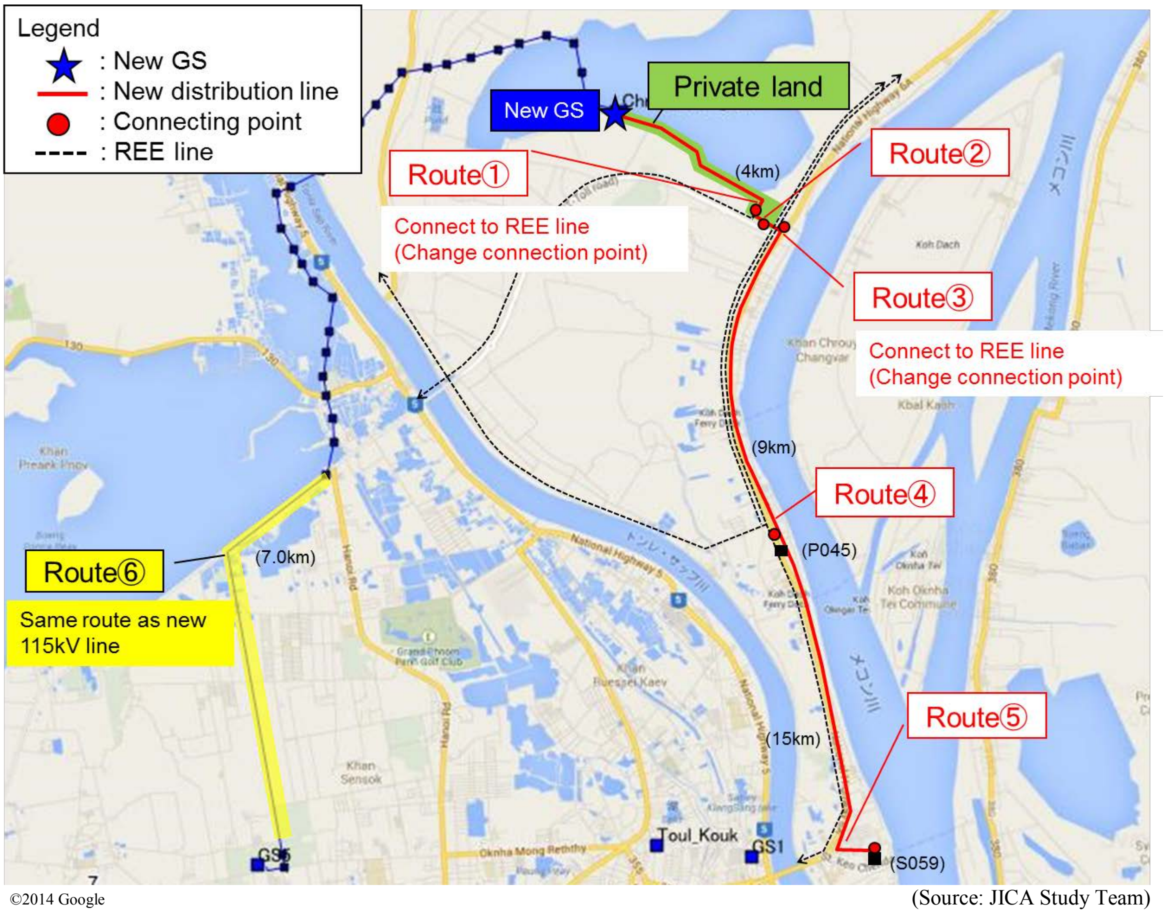
In addition, modification work of existing distribution line will be necessary because a part of new 115kV transmission lines will be installed at same route as distribution line.

Table 8.4-17 Candidate Connection Point (Chroy Changvar GS)

	Candidate connection point*	Distribution system (OH/UG)	Approximately route length [km]	Remarks
①	Around the intersection between national road 6A and Toll road	OH	4.0	Construct in private land and public road. Connect to REE line. (Change connection point)
②	Around the intersection between national road 6A and Toll road	OH	4.0	Construct in private land and public road.
③	Around the intersection between national road 6A and Toll road	OH	4.0	Construct in private land and public road. Connect to REE line. (Change connection point)
④	Around P045	OH	9.0	Construct in private land and public road.
⑤	S059	OH+UG	15.0	Construct in private land and public road.
⑥	—	OH	7.0	Same route as new 115kV line.

*S: Substation, P:Pole mounted transformer

Source: JICA Study Team



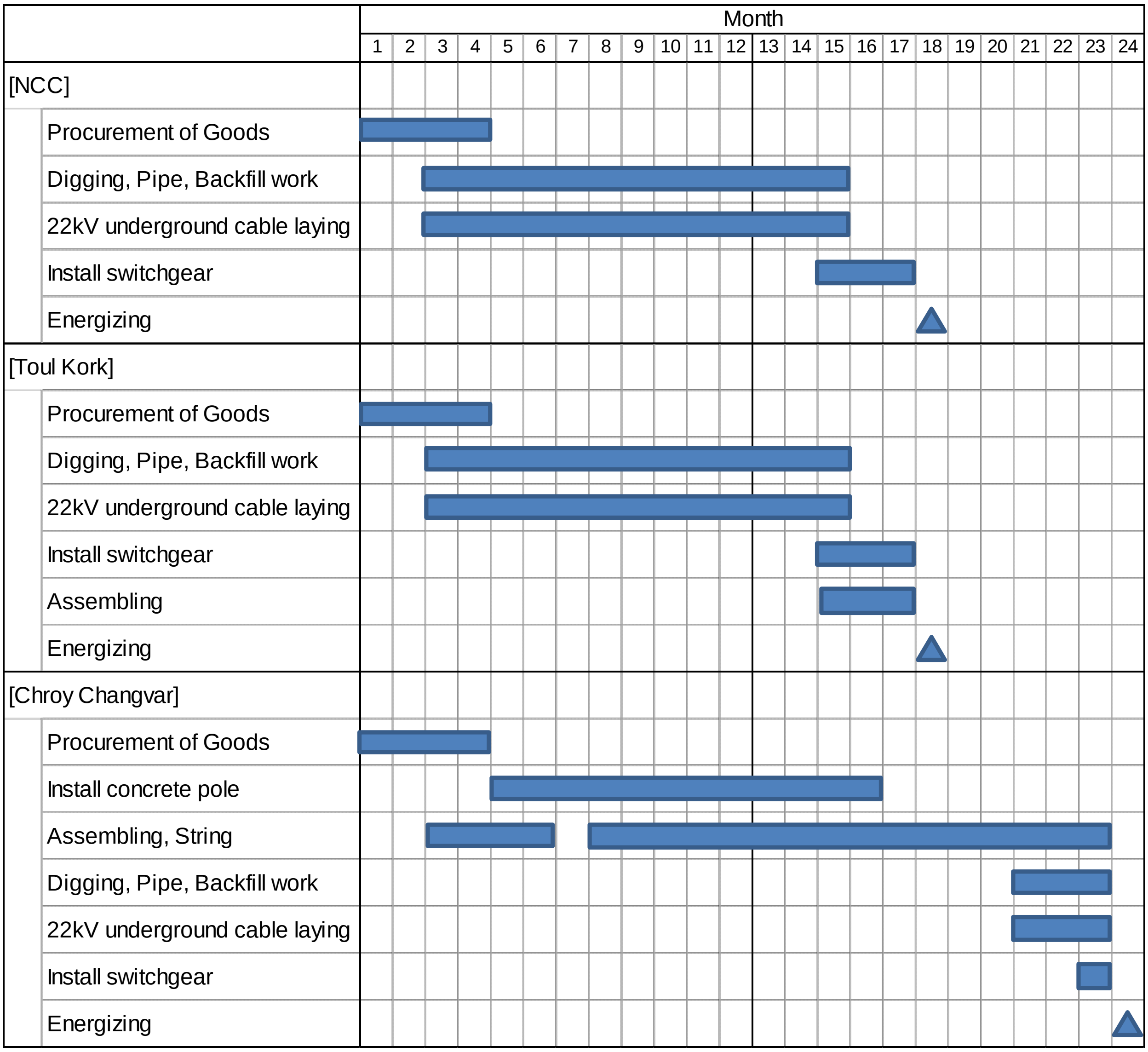
(Source: JICA Study Team)

Fig. 8.4-16 Route of Distribution Line (Chroy Changvar GS)

8.4.6 Construction Schedule

Construction schedule is shown in Table 8.4-18.

Table 8.4-18 Construction Schedule



Source: JICA Study Team

CHAPTER 9

PROJECT IMPLEMENTATION AND O/M ORGANIZATION

CHAPTER 9 PROJECT IMPLEMENTATION AND OPERATION AND MAINTENANCE ORGANIZATION

9.1 EDC's Financial Status

Table 9.1-1 shows the balance sheets for 2009 to 2012 from the EDC's annual reports. The table is added with the liquidity ratios and own equity ratios calculated by the study team. The liquidity ratio shows the continuous improvement during the period, and exceeded 150% in 2012. This means that EDC owns current asset enough to cover short-term debts, which is an index of financial healthiness of EDC. Throughout the period, the own equity ratio was kept at around 40%, showing the company's effort to keep the balance between the debt and the equity under expansive conditions.

Table 9.1-1 EDC's Balance Sheet

(Unit: Cambodian Riel 1,000)

	2009	2010	2011	2012
ASSETS	1,377,817,340	1,854,458,690	2,265,827,452	2,967,276,566
Non-current assets	791,072,614	1,261,333,433	1,428,131,911	1,847,187,790
Property, plant and equipment	790,960,747	1,066,646,944	1,226,183,735	1,652,736,044
Intangible assets	111,867	401,132	292,514	195,993
Other non-current assets		194,285,357	201,655,662	194,255,753
Current assets	586,744,726	593,125,257	837,695,541	1,120,088,776
Cash and cash equivalents	153,350,951	289,457,512	408,817,458	578,738,523
Trade and other receivables	150,873,266	186,275,785	287,024,944	373,215,974
Inventories	79,074,471	117,391,960	141,853,139	168,134,279
Other receivables	203,446,038			
EQUITY				
Assigned capital	614,393,127	662,390,444	680,173,081	680,185,054
Retained earnings		159,775,668	309,565,644	512,017,298
Accumulated losses	-23,343,787			
LIABILITIES				
Non-current liabilities	391,288,665	528,834,132	677,283,540	1,061,124,393
Borrowings	330,724,570	458,220,206	591,915,355	958,626,156
Customer deposits	59,898,913	68,164,789	78,258,708	89,724,146
Provision for retirement benefit	665,182	864,135	1,356,918	1,961,385
Deferred tax liability-net	-	1,585,002	5,752,559	10,812,706
Current liabilities	395,479,335	503,458,446	598,805,187	713,949,821
Borrowings	94,906,670	200,234,757	169,485,555	145,177,973
Finance Lease Liability	42,701,150	13,651		
Trade and other payables	234,557,571	272,301,325	408,479,660	536,924,009
Income tax	23,313,944	30,908,713	20,839,972	31,847,839
TOTAL EQUITY AND LIABILITIES	1,377,817,340	1,854,458,690	2,265,827,452	2,967,276,566
Liquidity Ratio	97%	118%	140%	157%
Own Equity Ratio	43%	44%	44%	40%

Source: EDC Annual Report, modified by Study Team for consistency

Table 9.1-2 is the profit and loss statement for the same period. EDC's revenue has been increasing along with the expanding electricity sales. The profit has been expanding accordingly. After 2009, both the revenue and profit almost doubled. On the side of expenditures, the cost of purchase of power is prominent. The prices of power purchase from surrounding countries can be a risk factor to EDC's finance. Interview to EDC revealed that there was no particular risk hedge measure taken for currency exchange rate fluctuation, but it set the upper limit on price of power purchases from IPPs (Independent Power Producer(s)). Also, the increase of salaries is significant, which reflects almost 10 % annual increase of man powers in recent years and its management policy "to provide its employee with competitive remuneration and benefits to ensure good living conditions ".

Table 9.1-2 Profit and Loss Statement

(Unit: Cambodian Riel 1,000)

	2009	2010	2011	2012
Revenue				
Electricity sales	1,215,763,623	1,577,667,850	1,808,509,354	2,253,164,604
Connection service fees	10,574,579	12,866,750	15,691,822	17,665,928
Other income	4,989,068	8,498,287	18,025,953	11,649,917
Operating expenses				
Purchased power	-875,453,346	-1,144,613,037	-1,348,820,232	-1,681,832,803
Fuel costs	-61,018,894	-32,782,648	-60,830,107	-69,308,114
Import duty	-10,596,794	-31,262,376	-35,821,899	-40,305,082
Salaries and other benefits	-29,764,019	-47,764,116	-65,436,166	-84,249,349
Other operating expenses	-34,410,007	-44,093,732	-48,368,994	-56,247,420
Depreciation(&Amortization)	-36,663,509	-40,111,790	-49,683,369	-58,872,605
Amortization			-108,618	-96,521
Foreign Exchange Loss net		-7,284,996		
Operating profit	183,420,701	251,120,192	233,157,744	291,568,555
Net finance costs	-19,768,955	-23,385,520	-40,710,828	-33,847,806
Profit before income tax	163,651,746	227,734,672	192,446,916	257,720,749
Income tax expense	-34,315,556	-44,615,217	-42,656,940	-55,269,095
Net profit for the year/total	129,336,190	183,119,455	149,789,976	202,451,654

Source: EDC Annual Report, modified by Study Team for consistency

Finally, the cash flow for the same period is shown in Table 9.1-3. In 2012, Cambodian Riel 140 billion was invested in physical assets, out of net inflow of Cambodian Riel 300 billion. This investment activity still left Cambodian Riel 170 billion in the year. Considering the further increase of electricity demand and resulting sales, EDC will likely be able to continue its investment activity no less than in 2012 for coming years. For 2012, the increase of borrowing was expansive, so was the repayment. However, as pointed out with the Balance Sheet, the equity and debt have been in balance, showing the EDC’s effort to keep the financial position to be able to invest, supported by expansive demand for electricity.

Table 9.1-3 EDC's Cash Flow

(Unit: Cambodian Riel 1,000)

	2009	2010	2011	2012
Cash flow from operating activities				
Profit before income tax	130,229,827	227,734,672	192,446,916	257,720,749
Adjustments for:				
Depreciation and amortization		40,111,790	49,791,987	58,969,126
Revenue from transfer of assets from customers			-9,010,141	-
Loss on disposal of property, plant and equipment		2,544,085	598,173	1,596,196
Foreign expense		-12,941,938	-2,065,749	-7,865,808
Interest expense		23,385,520	37,707,767	34,482,370
Addition/reversal of allowance for bad and doubtful debts			-4,292,253	2,756,808
Allowance for retirement benefits		198,953	492,783	604,467
Allowance for inventory obsolescence		1,412,521	3,994,905	510,572
Reversal of Impairment Loss on Trade Receivables		-894,261		
Changes in:				
Trade and other receivables		-22,923,945	-31,620,486	-45,899,808
Inventories		-44,973,693	-67,392,929	-80,909,003
Other non-current assets		-9,904,251	-7,370,305	7,399,909
Trade and other payables		37,743,754	51,011,287	136,209,876
Customer deposits		8,265,876	10,093,919	11,465,438
Net cash generated from operations		249,759,083	224,385,874	377,040,892
Interest paid		-5,421,736	-14,509,745	-42,247,897
Income tax paid	-14,507,858	-35,435,446	-48,558,124	-31,814,007
Interest received	238,251	1,304,092		
Net cash generated from operating activities	115,960,220	210,205,993	161,318,005	302,978,988
Cash flows from Investing activities				
Purchases of property, plant and equipment	-15,435,505	-92,213,377	-68,884,618	-140,145,212
Proceeds from sale of property, plant and equipment	357,908	4,765,678	7,057,087	2,371,434
Decrease in Other Assets		7,480,619		
Purchases of Intangible Assets	-20,950	-357,010		
Net cash used in investing activities	-15,098,547	-80,324,090	-61,827,531	-137,773,778
Cash flow from financing activities				
Proceeds from borrowings	6,872,146	6,235,352	22,909,596	74,269,593
Payments on borrowings	-181,088		-3,040,124	-69,565,711
Government grants			-	11,973
Payments on finance lease		-10,694		
Net cash generated from financing activities	6,929,309	6,224,658	19,869,472	4,715,855
Net increase in cash and cash equivalents	107,552,731	136,106,561	119,359,946	169,921,065
Cash and cash equivalents at beginning of the year	45,798,220	153,350,951	289,457,512	408,817,458
Cash and cash equivalents at end of the year	153,350,951	289,457,512	408,817,458	578,738,523

Source: EDC Annual Report, modified by Study Team for consistency

9.2 EDC's Project Organization and O&M Organization

9.2.1 Current Project Organization and O&M Organization

(1) Head office

At present, EDC and the IPPs generate power, and the EDC transmits and distributes power exclusively to the Phnom Penh metropolitan area. The following is an organizational chart of EDC.

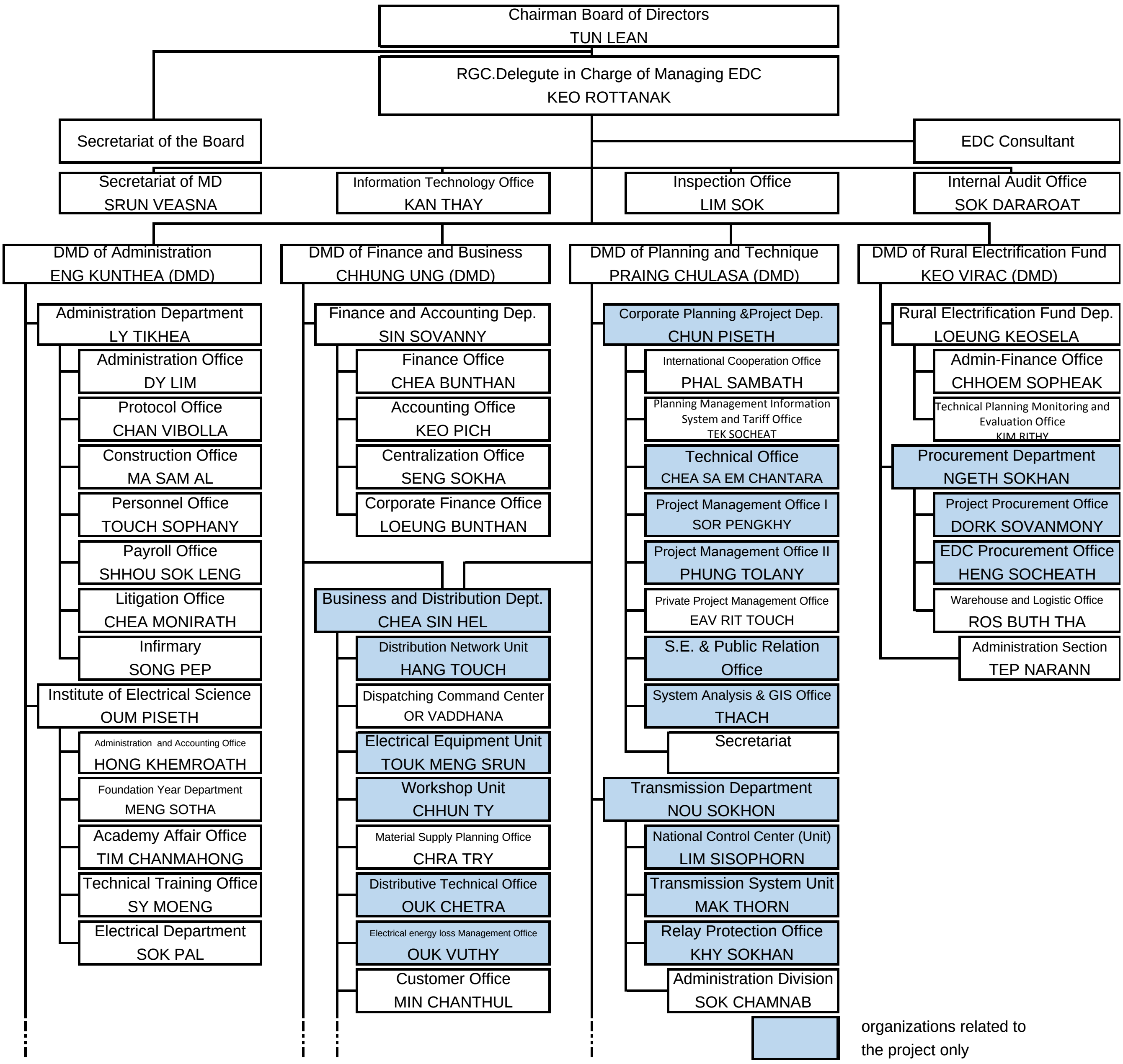


Fig. 9.2-1 Organizational Chart of EDC (organizations related to the project only)

(2) Project Organization

The PMO (Project Management Office)-I or II under the Corporate Planning & Project Department manages the projects funded by international organizations.

(3) O&M Organization

The O&M of the existing substation (GS1, GS2, GS3, GS4) are carried out by the substation head + operator (each 3 operators of 4 groups), and a total of 13 staff (excluding the security guard).

The SCADA (Supervisory Control and Data Acquisition) system has already been introduced into all substations, and NCC (National Control Center) has the equipment that can acquire operational data and information on the substation directly from NCC. However, the signal is not transferred by the difference of the protocol of the SCADA system between NCC and the substations. Because the counter test has not been executed even if the data and information can be taken into the NCC SCADA system, these are inaccurate and untrustworthy. Therefore, the NCC SCADA system does not function.

About this protocol problem, the Chinese consultant employed by EDC conducted the investigation and already prepared the countermeasure.

9.2.2 Proposal for the Project and O&M Organizations

(1) Project implementation

Given that EDC promotes a lot of Projects, EDC will decide which organization executes this Project immediately before this Project starts. However, it is assumed that PMO will be in charge for this Project.

JICA Study Team believes that the PMOs have enough capacity to implement the project with the technical advice of a consultant, since they have been doing the same kind of work. It is necessary to consider that there is no engineer who is well versed in 230kV/115kV underground cable at EDC because this equipment is the first time to set up in Cambodia except Phase 1 project which is under selection of the Consultant. Concretely, EDC establishes a system to acquire a sufficient amount of technical knowhow by participating in the construction of the Project and the engineer who can become the person in charge of O&M of the 230kV/115kV underground cable in the future is arranged in the PMO of this Project.

Moreover, to achieve good technical skills, overseas training in Japan is recommended at the construction stage. In Japan, there is many experience about maintenance of 230kV/115kV underground cable. Therefore if EDC engineers take training by Power Company in Japan, improvement in technical skill is expectable. This training will be conducted by the Consultant at construction stage.

(2) O&M

It is expected that the Transmission Dept. and Business and Distribution Dept. of EDC will be responsible for the O&M of the new facilities after construction is completed. The Transmission Department was separated from the former Transmission and Distribution Department in 2007. They have enough experience in the maintenance of the distribution system, but, limited experience in transmission system maintenance work.

Given that 230kV/115kV underground cable is basically laid underground, daily checks and patrols are unnecessary, and a special organization for O&M is unnecessary. However, it is important to grasp the buried position and depth accurately from the perspective of checking the relation between the other underground structures and to take proper action in the event of some abnormality. It is necessary to acquire information on the construction dug up near the location laid underground at an early stage so that the underground cable may evade the risk of being affected by other construction work, and to urge the execution of countermeasures for those who execute construction.

Same as the Phase 1, it is advisable that 13 staff should be assigned arranged at the newly established substation for O&M as well as the existing substations. The O&M of substation are planned by the substation head + operator (each 3 operators of 4 groups).

Moreover, Technology Transfer including capacity building at site is recommended at the construction stage. This training will be conducted by the Consultant at construction stage.

CHAPTER 10

EVALUATION OF PROJECT

CHAPTER 10 EVALUATION OF PROJECT

10.1 Quantitative Evaluation

10.1.1 Benefit of Project

The effects to be realized by this Project were already discussed in Chapter 3; to alleviate insufficiency of distribution transformer capacity in the Phnom Penh system, to improve the stability of the whole Phnom Penh power system, and to reduce system losses, etc., among which the alleviation of the insufficiency of distribution transformer capacity has the most notable quantitative effect. This effect was chosen to be the subject of the evaluation of the benefit brought about by the Project.

The electricity demand in the Phnom Penh system has been, and will be increasing at a very high rate. Before the expected completion of this Project in 2020, there will be the increase of the capacity of distribution transformers scheduled to be in place including those of Phase 1 Project. Even after the completion of this Project, the demand will soon exceed the augmented capacity.

Under such a circumstance, the estimation of the effect on the increase of energy sales made possible by this Project required a modeling of the working of transformers in three substations to be constructed by the Project. This model is explained by the illustration shown in Fig. 11.1-1, where MW_0: transformer capacity without the Project, MW_1: transformer capacity with the Project, and abc: daily duration curve.

Transformers installed by the Project will work, just after the completion of the Project, for three hours at around each of two daily demand peaks. The energy distributed through the transformers is shown in the shaded area in the figure. The demand will be increasing: the installed transformers will work for twelve hours sometime later, and will eventually reach full capacity operation. This process is assumed to unfold during the period between 2020 and 2030, and thereafter, transformers are assumed to be working constantly at full capacity.

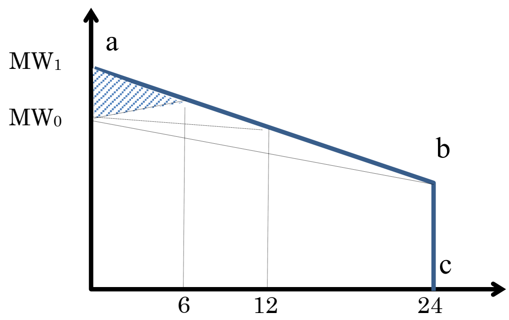


Fig. 10.1-1 Model of Energy Sales Increase

Source: JICA Study Team

On the basis of this assumption, the effect of the Project was calculated for the period between 2020 to 2030, which is shown in the table below, where; a. power demand, b. energy demand, c. additional energy to be distributed through three transformers installed by the Project, and d. additional energy to be delivered to customers (additional energy sold). Between c and d, distribution loss 3% was considered.

Table 10.1-1 Additional Energy Sold by the Project

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
a. Power Demand (MW)	954	1,061	1,169	1,277	1,387	1,496	1,652	1,809	1,967	2,126	2,285
b. Energy Demand (GWh)	5,767	6,414	7,065	7,721	8,381	9,045	9,988	10,936	11,890	12,849	13,813
c. Additional energy distributed through three new transformers (GWh)	222	277	333	388	443	665	887	1,109	1,330	1,552	1,774
d. Additional energy sold (GWh)	215	269	323	376	430	645	860	1,075	1,291	1,506	1,721

Source: JICA Study Team

10.1.2 Financial and Economic Evaluation

(1) Financial Evaluation

In financial evaluation, the benefit is defined by the increase of sales for additional energy delivered to customers by the Project, and the cost consists of expenses incurred for the implementation and operation of the Project, and expenses for the purchase of additional energy with which additional sales will be possible. The financial viability of the Project is evaluated in terms of FIRR (Financial Internal Rate of Return). The conditions of the evaluation are as follows;

Project Period	30 years (consisting of 5-year construction and 25-year operation periods),
Income	energy sales, sold for KHR 782 per kWh (obtained by the electricity sales divided by energy sold, figures from EDC Annual Report, energy sold is subject to 3% distribution loss),
Cost	energy purchase cost, for US¢ 10.5 per kWh (energy purchased allows for 7% transmission loss), annual O&M (Operation and Maintenance) cost of equipment installed: 3% of project cost less taxes (subject to inflation) depreciation straight line method, 20 years,
Inflation	4.4% p.a.
tax	corporate income tax 20%.

Where necessary, the exchange rates between currencies as shown in Chapter 9 were applied.

Unit cost of energy purchase, US¢ 10.5 per kWh, was assumed in the following manner;

As of 2014, the prices of energy from IPP (Independent Power Producer)-hydro and IPP-thermal (coal) are US¢ 8.0 and US¢ 11.0 per kWh, respectively. The price of IPP-thermal is likely to rise due to the price hike of imported coal. Annual rise of IPP thermal price was assumed to be 3%, on the basis of coal price change forecast by IEA[1].

EDC has set the upper limit of IPP thermal energy purchase price at US¢ 13.0 per kWh. If we apply 3% p.a. rise on 2014 IPP-thermal energy price US¢ 11.0, it will exceed US¢ 13.0 in 2020, when the project is expected to start operation. Therefore, IPP-thermal energy purchase price for the project is assumed at US¢ 13.0 per kWh.

[1] World Energy Outlook 2013, International Energy Agency

According to the Power Development Master Plan that EDC is currently preparing, EDC will be securing energy mostly from IPP-hydro and IPP-thermal in 2020 and onward, and their proportions will be approximately 50:50. The unit cost of energy purchase was thus derived from the average of IPP-hydro price and IPP-thermal price for 2020, US¢ 10.5 per kWh.

To meet the fast growing demand, EDC will have to largely depend on ongoing and under-planning IPP projects for securing energy in coming years. However, in the long run, more risk-prone hydro development may fall behind schedule, which pushes up the proportion of IPP-thermal in the energy procurement. Sensitivity analysis discussed later deals with this risk, assuming that the proportion of IPP-thermal increases from 50 % in 2020 to 80% in 2030 and stays thereafter. The (weighted) average cost of energy purchase would be US¢ 12.0 per kWh in 2030.

Cash flow was calculated for the conditions mentioned above, and FIRR defined by the return on the own fund (Equity IRR) and by the return on the whole investment cost (Project IRR) were obtained.

Equity IRR, which shows the financial return on the own fund spent by the project proponent, was calculated at 25.0 %. According to the interview to EDC, the electric utility is able to secure fund from its main bank at an interest rate of 7% p.a. Taking this as the cost of capital, Equity IRR 25.0% is well above the cost of capital. Therefore, the Project is judged to be financially viable.

Meanwhile, the Project IRR, which is the return on the Project as a whole without identifying financing sources, for the same conditions otherwise, was 12.9%. This means that if the interest rate of the loan secured for part of the initial investment cost of the project was lower than 12.9 %, the return on its own fund (that is Equity IRR) will always be above 12.9 %. This is also a strong indication that the Project will be financially sound.

A series of sensitivity tests was conducted for the cash flow analysis discussed above. The following adverse conditions were considered in the tests,

a) overrun of project cost +10%
b) downward deviation of energy sales -10%
c) price hike of imported energy proportion of IPP-thermal gradually rises from 50% in 2020 to 80% in 2030
d) simultaneous occurrence of the above three conditions

The results are shown in the table below. In either setting, Equity IRR exceeds the deemed cost of capital, 7%, suggesting the financial robustness of the Project. NPV (Net Present Value) of the Project, obtained with an SDR (Social Discount Rate) 12.0%, base year 2014, for each condition is also shown in the table.

Table 10.1-2 Sensitivity Test of FIRR

	Equity IRR	Project IRR	NPV (US$ million)
Original conditions	25.0 %	12.9 %	131.3
a) overrun of project cost +10%	23.3 %	11.9 %	119.9
b) downward deviation of expected sales -10%	23.2 %	11.8 %	106.8
c) increase of energy purchase cost (thermal proportion rises to 80%)	22.5 %	10.9 %	89.5
d) simultaneous occurrence of a, b, c	18.8 %	8.8 %	57.4

Source: JICA Study Team

(2) Economic Analysis

In economic analysis, economic viability of a project is evaluated through comparison of economic cost and economic benefit of the project.

To obtain economic cost of the Project, the following adjustments were made to the financial cost used in the financial analysis;

value added tax (VAT)	:	not included in the economic cost as it is a transfer within the Cambodian economy,
foreign currency portion of project cost	:	the estimated cost was deemed to be "border price basis" and used as they were, except that the import tax was deducted,
local currency portion of project cost	:	to be converted to "shadow price basis" by multiplying the Standard Conversion Factor (SCF) 0.9,
land acquisition cost and compensation	:	these costs were deemed to represent the opportunity costs of relevant assets, and used as they were,
O&M cost, management cost of EDC	:	the estimated costs were used as they were.

On the other hand, the economic benefit of the Project was estimated by an alternative method, in the following manner.

This Project will involve transmission lines, substations and distribution lines, and the only plausible alternative to the Project was diesel-powered privately owned generating equipment. The Project is then deemed to realize the benefit by replacing the energy generated with less efficient private diesel units.

The cost of such diesel generation was studied somewhere else: one of such examples of recent years is an ADB's study[2] where the unit cost was estimated at US$0.47/kWh for non-household users. However, this study was for the rural areas of Cambodia, and may possibly lead to too high an estimate. Meanwhile, the final report of the Phase 1 project preceding this Project used US$0.20/kWh in the economic analysis as a cost of the alternative, having made reference to the contract tariff in the PPSEZ (Special Economic Zone in Phnom Penh), US$0.193/kWh. A private electricity service for PPSEZ has a certain size, and probably includes provision of distribution

2 Proposed Loan and Administration of Loan Kingdom of Cambodia: Medium-Voltage Sub-Transmission Expansion Sector Project, Report and Recommendation of the President to the Board of Directors, Project Number: 42361, November 2012, Asian Development Bank

network. These characteristics of PPSEZ are good attributes to be deemed as an alternative to this Project. The latest annual report of EAC[3] shows the licensed tariff of Colben Energy PPSEZ Limited which operates in PPSEZ, to be US$0.2016/kWh for the year 2013. This tariff was used as a cost of alternative energy to the Project, therefore, the unit benefit of the Project, in the economic analysis.

The economic cost and benefit were calculated in the method discussed above, and compared to obtain the EIRR (Economic Internal Rate of Return).

As a result, EIRR was obtained at 17.5 %. The SDR, against which EIRR is compared, should be 12%, considering the present economic development status of Cambodia. The obtained EIRR 17.5% is well above SDR 12%. Therefore, the Project is expected to be economically viable.

The sensitivity test was conducted for the EIRRs. The same adverse conditions as in the financial analysis were considered. The results are shown in the table below. Under either condition, the EIRR was shown to exceed 12%. In summary, the Project is considered to remain economically efficient, and expected to contribute the economy of the country under various unfavorable conditions.

Table 10.1-3 Sensitivity Test of EIRR

	EIRR
Original conditions	17.5 %
a) overrun of project cost +10%	15.6 %
b) downward deviation of expected sales -10%	16.2 %
c) increase of energy purchase cost (thermal proportion rises to 80%)	15.5 %
d) simultaneous occurrence of a, b, c	12.5 %

Source: JICA Study Team

10.1.3 Estimation of Impact on CO_2 Emission

One of the benefits of the Project is a reduction of system losses. The energy equivalent to the reduction of system losses is the avoided production of energy realized by the Project. Therefore, CO_2 that was to be emitted in relation to the production of the energy is the reduction of CO_2 emission due to the Project.

In order to compare a system loss when the Project is carried out with a system loss when the Project is not carried out, the result shown in Fig. 3.3-11 was first assumed to be a state when the Project is carried out. On the other hand, as the case where the Project is not carried out, it assumed that new distributing substations do not exist, and analysis was carried out where the load of the substations is allocated to existing distributing substations (overload is ignored). When annual energy losses are calculated from the result, they become the following values and the difference is 16,180MWh.

without Project	annual energy loss	= 149,979 MWh
with Project	the same	= 133,799 MWh

3 The Annual Report on Power Sector of the Kingdom of Cambodia 2014 Edition, Electricity Authority of Cambodia

There is an example of the study on CO_2 emission factor for EDC's power grid published[4] by a Japanese research institute IGES (Institute for Global Environmental Strategies). However, the study period for Phnom Penh grid was 2007-2009, after which the import of power has grown greatly. Further, the power demand for Phnom Penh grid for 2020 is forecast to be four times as large as in 2009.

The emission factor obtained in the aforementioned study cannot be used as it is. The study's result was modified to be used in the assessment here, as below.

a) The generated energy of power stations connected to Phnom Penh grid in 2008 was largest at 1,227GWh, and the emission factor for the year was 0.6951 t-CO_2/MWh (GES study report),
b) The demanded energy in 2020 was estimated to be 5,767GWh in this report,
c) The difference of energy in a) and b) above is assumed to be filled with imported power from Vietnam, whose CO2 emission is 0.429t-CO2/MWh (IEA report[5]),
d) using the energy in a) and b) above to weight-average the emission factors (0.6951 and 0) to obtain the emission factor for 2020.

CO_2 emission factor for 2020 = 0.6951 × [1227/5767] + 0.429× [(5767-1227)/5767]
= 0.4856 t-CO_2/MWh

Using this factor, the reduction of CO_2 emission by the Project was calculated to be 7,857 t-CO_2 per year, as shown in the table below.

4 Grid Emission Factor of the Phnom Penh Electricity Grid, 2011, Institute for Global Environmental Strategies
5 CO_2 Emissions from Fuel Combustion, International Energy Agency, 2013

Table 10.1-4 Reduction of CO_2 Emission by the Project (as of 2020)

Calculation Result Sheet : New or Existing			
	Preparatory Survey for Phnom Penh Transmission and Distribution System Expansion Project in Cambodia (Phase 2)		
Reduction of GHG emission by the Project (t-CO_2/y)			$ER_y = BE_y - PE_y$ (t-CO_2/y)
1. Baseline Emission $BE_y = BL_y \times EF_{BL,y}$			
BE_y	Baseline Emission : Emission of GHG without improvement of efficiency by the Project	72,830	t-CO_2/y
BL_y	Energy Loss before the Project	149,979	MWh/y
$EF_{BL,y}$	CO2 Emission factor of power grid in question	0.486	t-CO_2/MWh
2.Project Emission $PE_y = PL_y \times EF_{BL,y}$			
PE_y	Project Emission : Emission of GHG with improvement of efficiency by the Project	64,973	t-CO_2/y
PL_y	Energy Loss after the Project	133,799	MWh/y
$EF_{BL,y}$	CO2 Emission factor of power grid in question	0.486	t-CO_2/MWh
3. Reduction of emission due to the Project $ER_y = BE_y - PE_y$ (t-CO_2/y)			
ER_y	Reduction of emission due to the Project	7,857	t-CO_2/y
BE_y	Baseline Emission : Emission of GHG without improvement of efficiency by the Project	72,830	t-CO_2/y
PE_y	Project Emission : Emission of GHG with improvement of efficiency by the Project	64,973	t-CO_2/y

10.2 Proposal of Operation and Effect Indicators

10.2.1 Proposal of Operation and Effect Indicators

As operation and effect indicators for performing an ex-post valuation, three indicators shown in Table 10.2-1 are proposed.

Table 10.2-1 Operation and Effect Indicators to Propose

Indicator	Function	Purpose	
		As Operation Indicator	As Effect Indicator
a) Facility availability factor [%]	Maximum load[MW]/ (Rated capacity of the facility [MVA] * power factor)	To evaluate whether the distributing substation is operated proper	To evaluate whether the facility availability factor has been improved by the proper value after the Project
b) Outage times [times/year]	Annual outage times in the Project area occurred by fault at installed connection transformer and continuation of outage more than one minute	To evaluate whether reliability is kept proper	To evaluate whether reliability has been improved by the proper value after the Project
c) Electricity supply [MWh]	Annual electric energy transmitted from the target transformer	To check that the distributing substation is utilized efficiently.	To evaluate the increased energy

Source: JICA Study Team

Besides, it can be targeted at connection and distribution transformers and transmission lines regarding the facility availability factor and the electricity supply. However, since the power flow of the facility of those other than distributing transformers depends on the operation conditions of the system at the evaluation time greatly. For example, the power flow changes with operation status (opening-and-closing status) of 115kV transmission lines. Therefore, they are unsuitable as indicators and the facility availability factor and the electricity supply of only a distributing transformer are proposed as indicators here.

10.2.2 Targeted Values of Operation and Effect Indicators

The targeted values are set up aiming at the two-year back (2022) of the project completion.

The targeted values of operation and effect indicators are shown in Table 10.2-2. Besides, the facility availability factor was calculated by making the demand estimate value in 2022 of each substation into a maximum load value.

Table 10.2-2 Targeted Values of Operation and Effect Indicators

Indicator	Facility	Standard value	Targeted value	Remarks
a) Facility availability factor [%]	NCC* S/S (115/22kV)	—	98%	- Power factor 95% - The demand forecast value in 2022 of JICA Study Team is used for the maximum load. (69.5 at NCC, 70.3 at Toul Kork and 119.7 at Chroy Changvar) - Assumed that 75MVA transformer at Chroy Changvar S/S will be extended by 2022.
	Toul Kork S/S (115/22kV)	—	99%	
	Chroy Changvar S/S (115/22kV)	—	84%	
b) Outage times [times/year]	GS5 (230/115kV)	—	0	—
	NCC S/S (230/115kV)	—	0	—
c) Electricity supply [MWh]	NCC S/S (115/22kV)	—	89,104	Targeted value is distributed proportionally with the demand forecast value in 2022, after computing 3 substation sum total value by the method described in Section 11.1.
	Toul Kork S/S (115/22kV)	—	90,119	
	Chroy Changvar S/S (115/22kV)	—	153,383	

* NCC : National Control Center

Source: JICA Study Team