5. Remarks

- An intensive development plan for **"Wind Corridor" or "Solar Park"** had not been mentioned in the NPSEP when this Interim Report 2 was prepared. However, it is noted that the development of these solar potential may be considered in the future based on results of WB study mentioned above.
- From the viewpoint of scale merit, it is expected that the large scale development will contribute to the lowering of generation cost, and the scheme of public and private partnership, such as power system development by NTDC and power plants construction by IPPs may be applicable.
- Key points of RE involvements are **to secure the stability of power system which is a mission for the power system operator.** Especially, integration of variable renewable energy (VRE) such as solar and wind is the most essential issue. **Thus RE introduction shall be promoted by the suitable manner under the initiative of the power system operator, NTDC.**

第 2 回ビデオ会議

The Project for the Study of Upgrading National Power System Expansion Plan in The Islamic Republic of Pakistan

2^{nd} online discussion

December, 2020

Japan International Cooperation Agency
NEWJEC Inc.

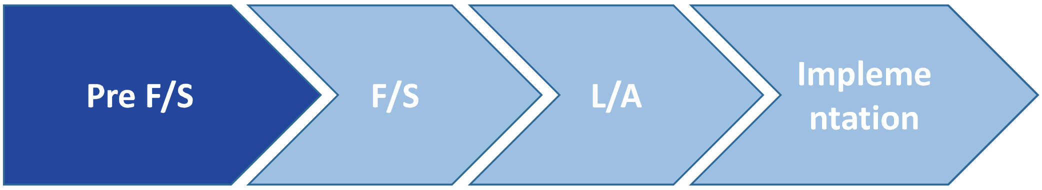
Overview of the candidate projects for Preliminary Feasibility Study (Pre F/S)

Contents

1. Objective of Pre Feasibility Study

- ✓ To find a potential project for yen-loan in the future
- ✓ To collect of information which is necessary to implement a feasibility study (F/S) for the formation of a loan project
- ✓ JICA will decide the implementation of the F/S
- ✓ Finally, JICA will decide the implementation of the project.

Steps for a loan project



2. Prerequisites for selection of candidate projects

Followings are the prerequisites and its reason for selection of the candidate projects.

Viewpoint	Prerequisite	Reason
Necessity	The projects on the NTDC's requirement list	Due to the inability to conduct sufficient site survey under the Covid-19 constraint
Finance	Finance has not been arranged yet	To formulate new loan program
Development period	Within 5 to 10 years	Considering the urgency of necessity, together with the required period for formation of loan program
New/Existing	Excluding project at new site	Due to the inability to conduct sufficient land use survey under the Covid-19 constraint
Location	Excluding remote area	For ensuring safety

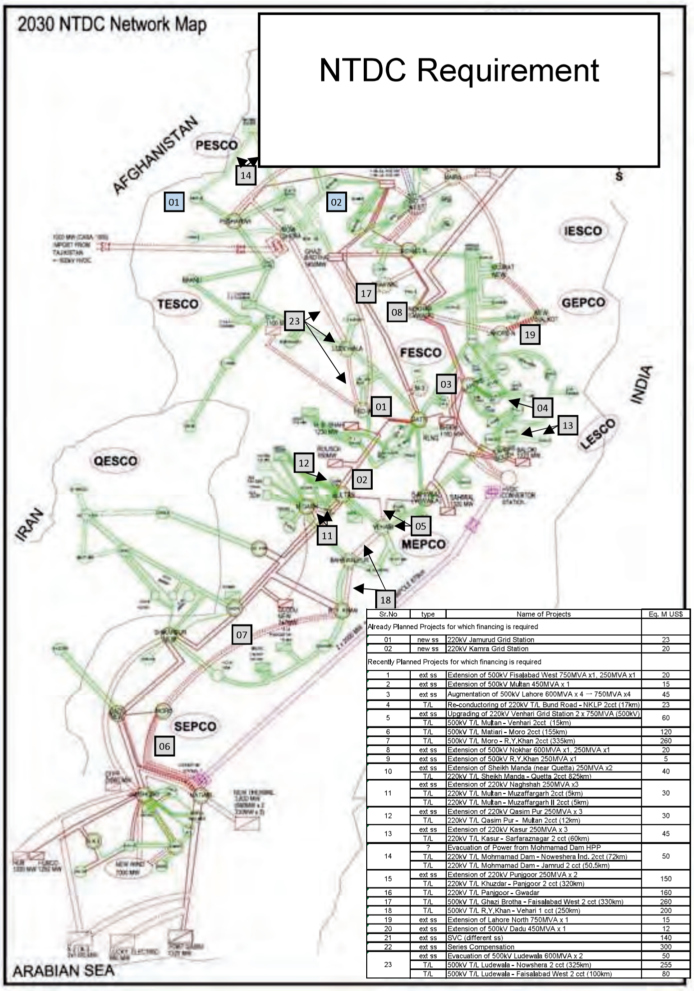
3. Approach to select candidate projects

Outline of power system expansion plan till 2030

No.	Key projects
1	T/Ls connecting hydropower stations in north and existing bulk power system
2	T/Ls connecting thermal power and renewable power stations in south and existing bulk power system
3	T/Ls and substations to supply power in major power demand area

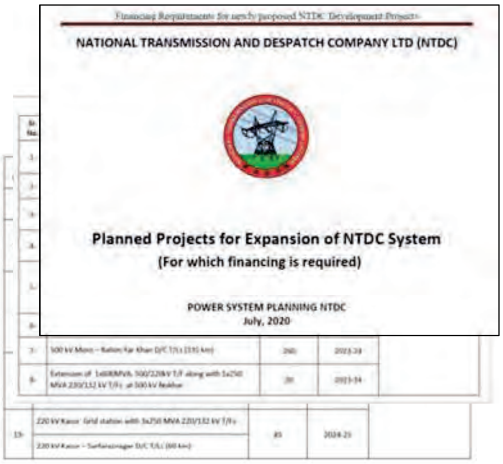
Projects of category no. 1 and 2 depend on the development of the power generation expansion. Especially, hydropower and coal thermal power development had not been developed smoothly in Pakistan. Therefore projects related to category 1 and 2 should be excluded.

No.	Conclusion
1	Candidate projects are selected in the 2030's power system expansion plan related to the power supply system in major power demand area. Namely, "Lahore", "Multan", "Faisalabad"
2	Three (3) projects are selected for Pre F/S in the conclusion no. 1. Mitigation of environmental impact and application of advanced technologies are considered.



Sr.No	type	Name of Projects	Eq. M US$
Already Planned Projects for which financing is required			
01	new ss	220kV Jamurud Grid Station	23
02	new ss	220kV Kamra Grid Station	20
Recently Planned Projects for which financing is required			
1	ext ss	Extension of 500kV Fisalabad West 750MVA x1, 250MVA x1	20
2	ext ss	Extension of 500kV Multan 450MVA x 1	15
3	ext ss	Augmentation of 500kV Lahore 600MVA x 4 → 750MVA x4	45
4	T/L	Re-conductoring of 220kV T/L Bund Road - NKLP 2cct (17km)	23
5	ext ss	Upgrading of 220kV Venhari Grid Station 2 x 750MVA (500kV)	60
	T/L	500kV T/L Multan - Venhari 2cct (15km)	
6	T/L	500kV T/L Matiari - Moro 2cct (155km)	120
7	T/L	500kV T/L Moro - R.Y.Khan 2cct (335km)	260
8	ext ss	Extension of 500kV Nokhar 600MVA x1, 250MVA x1	20
9	ext ss	Extension of 500kV R.Y.Khan 250MVA x1	5
10	ext ss	Extension of Sheikh Manda (near Quetta) 250MVA x2	40
	T/L	220kV T/L Sheikh Manda - Quetta 2cct 825km)	
11	ext ss	Extension of 220kV Naghshah 250MVA x3	30
	T/L	220kV T/L Multan - Muzaffargarh 2cct (5km)	
	T/L	220kV T/L Multan - Muzaffargarh II 2cct (5km)	
12	ext ss	Extension of 220kV Qasim Pur 250MVA x 3	30
	T/L	220kV T/L Qasim Pur - Multan 2cct (12km)	
13	ext ss	Extension of 220kV Kasur 250MVA x 3	45
	T/L	220kV T/L Kasur - Sarfaraznagar 2 cct (60km)	
14	?	Evacuation of Power from Mohmamad Dam HPP	50
	T/L	220kV T/L Mohmamad Dam - Noweshera Ind. 2cct (72km)	
	T/L	220kV T/L Mohmamad Dam - Jamrud 2 cct (50.5km)	
15	ext ss	Extension of 220kV Punjgoor 250MVA x 2	150
	T/L	220kV T/L Khuzdar - Panjgoor 2 cct (320km)	
16	T/L	220kV T/L Panjgoor - Gwadar	160
17	T/L	500kV T/L Ghazi Brotha - Faisalabad West 2 cct (330km)	260
18	T/L	500kV T/L R.Y.Khan - Vehari 1 cct (250km)	200
19	ext ss	Extension of Lahore North 750MVA x 1	15
20	ext ss	Extension of 500kV Dadu 450MVA x 1	12
21	ext ss	SVC (different ss)	140
22	ext ss	Series Compensation	300
23	ext ss	Evacuation of 500kV Ludewala 600MVA x 2	50
	T/L	500kV T/L Ludewala - Nowshera 2 cct (325km)	255
	T/L	500kV T/L Ludewala - Faisalabad West 2 cct (100km)	80

4. Project list of NTDC's requirement



5. Candidate projects for Pre F/S 〈List〉

No.	Area (Objective)	Facility	Project summary
1.	Lahore (Reinforce ment)	T/L	(i) Bund Rd-NKLP 220kV Underground cable (UGC) 15km 2cct.
		S/S	(i) Lahore 500kV Trf replacement (600MVA x 4 -> 750MVA x 4) (ii) Nokhar 500kV, 220kV Trf ext. (600MVA, 250MVA each)
2.	Multan (Reinforce ment)	T/L	(i) Venhari – π Branch 500kV OHL 37km 2cct. (ii) Multan P/S - Qasimpur 220kV UGC 11km 2cct.
		S/S	(i) Multan 500kV Trf ext. (450MVA x 1) (ii) Venhari 500kV Trf ext. (750MVA x 2) (iii) Qasimpur 220kV Trf ext. (250MVA x3)
3.	Faisalabad (Reinforce ment)	T/L	(i) Ludewala – Faisalabad West 500kV OHL 94km 2cct (ii) Ludewala – Nowshera 500kV OHL 262km 2cct.
		S/S	(i) Ludewala 500kV upgrade (new 500kV S/S Construction) (ii) Faisalabad West 500kV ,220kV Trf ext. (750MVA,250MVA each)

Project 1

Project 1: Outline of Lahore area projects

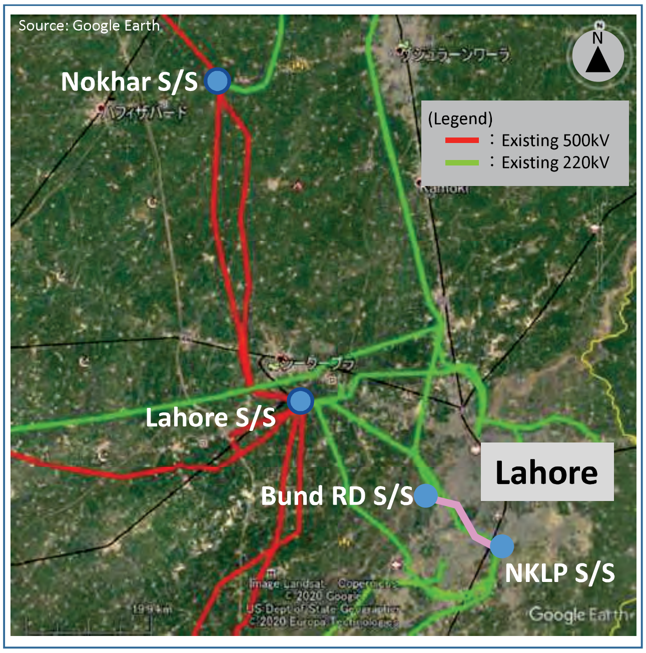
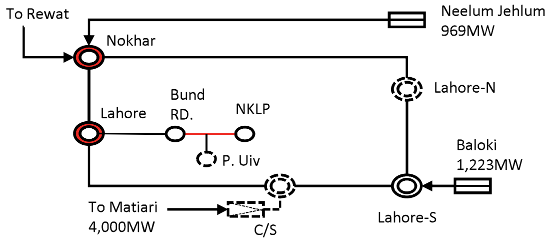


Fig. Location of projects

(1) Objective

Reinforcement of power supply in Lahore



(2) Outline of system expansion

	T/L	Voltage	Line length	Facility
(i)	Bund RD – NKLP	220 kV	15 km	UGTL 2cct

	S/S	Facility
(i)	Lahore	500kV AIS, 750MVA 500/220kV Trf×4
(ii)	Nokhar	500kV AIS, 600MVA 500/220kV Trf×1 250MVA 220/132kV Trf x 1

(3) Environmental impact

Survey	T/L	S/S	Remark
Assessment of impact	N/A	N/A	ROW: 50m (500kV) 30m (220kV)

(4) Estimation of project cost

Construction Cost
152MUSD（T/L 69MUSD, S/S 83MUSD）

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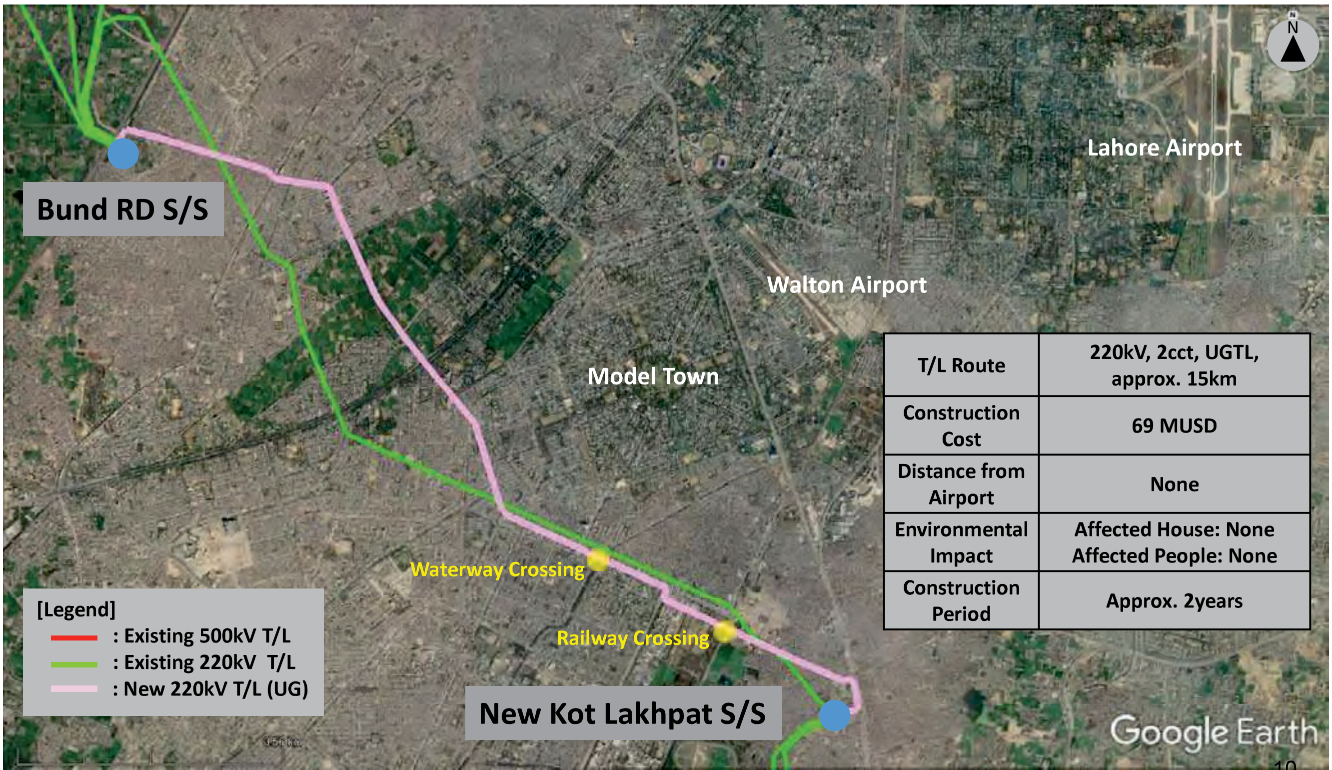
Route of UGTL (Bund RD S/S - New Kot Lakhpat S/S)

The below figure shows the route of OHTL between Bund RD S/S and New Kot Lakhpat S/S.



T/L Route	220kV, 2cct, UGTL, approx. 15km
Construction Cost	69 MUSD
Distance from Airport	None
Environmental Impact	Affected House: None Affected People: None
Construction Period	Approx. 2years

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Project#1-1 : 500kV Lahore S/S Trf. Replacement Work *(Site Investigated)*

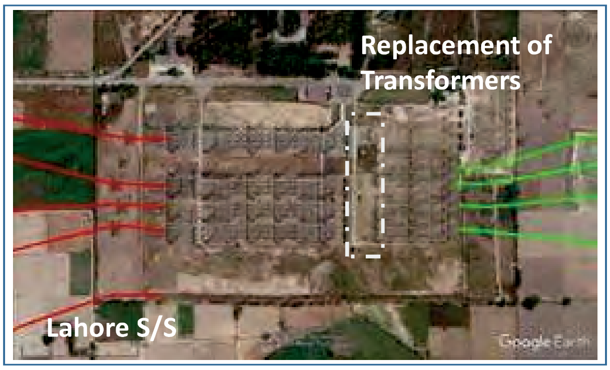

Fig. 1-1.1: Scope on Satellite Image

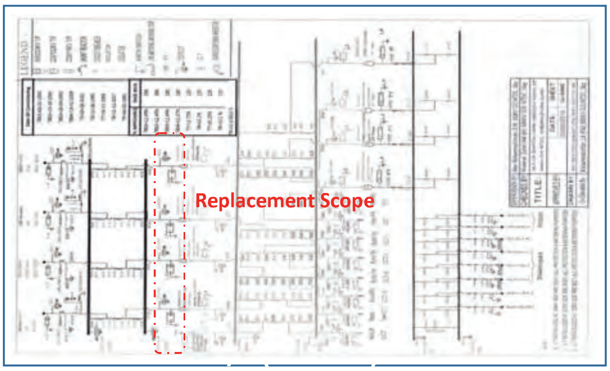

Fig. 1-1.2 : Scope on Single Line Diagram

[Work Description]

- ☑Increase Capacity (+ 600MVA)
  - ▹ All 600MVA x 4 banks ⇒ 750MVA x 4 banks
    Total 2,400MVA ⇒3,000MVA
- ☑Related Facilities (need to modify)
  - ▹ Gantry, Strings & Insulators
  - ▹ Embedded bases, ▹ Fire Fighting
  - ▹ Prot.&Ctrl Panels, etc.
- ☑Expected Schedule : 30M

[Concern]

- ☑ Transportation
  - ▹ Distance : 1,000km from Karachi
  - ▹ Gravity restriction : less than 0.3G
- ☑ Replacement Schedule
  - ▹ Method of Minimum Shutdown

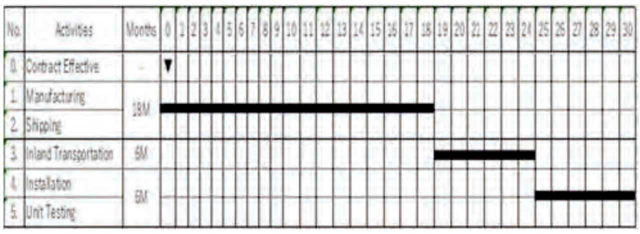

Fig. 1-1.3 : Expected Schedule

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Project#1-2 : 500kV Nokhar S/S Trf. Extension Work *(Desk Research Only)*

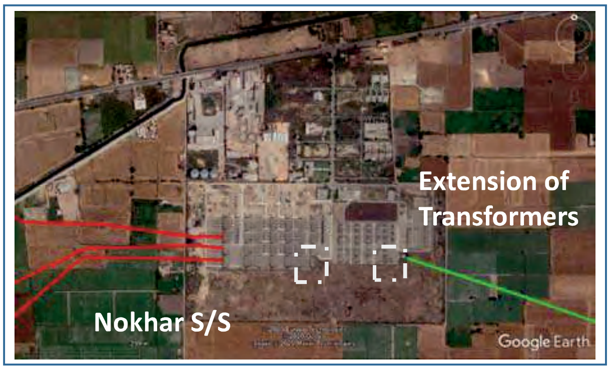

Fig.1-2.1 Scope on Satellite Image

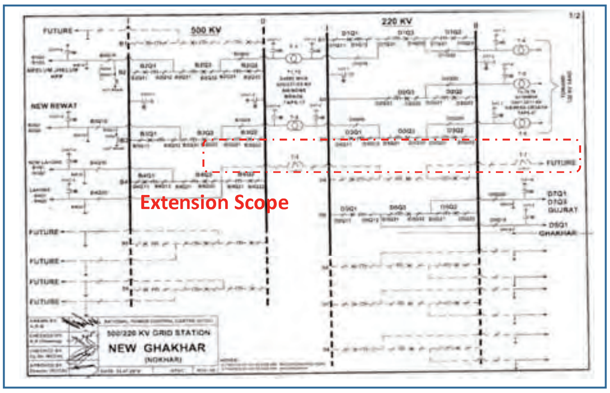

Fig.1-2.2 Scope on Single Line Diagram

[Work Description]

- ☑Increase Capacity
  - ▹ 600MVA, 500kV x 1 bank Extension
  - ▹ 250MVA, 220kV x 1 bank Extension
- ☑Related Facilities (need to modify)
  - ▹ 500kV & 220kV Switchgears : 1 Dia each
  - ▹ Gantry, Strings & Insulators
  - ▹ Embedded bases, ▹ Fire Fighting
  - ▹ Prot.&Ctrl Panels, etc.
- ☑Expected Schedule : 24M

[Concern]

- ☑ Safety
  - ▹ Work near the live existing facilities

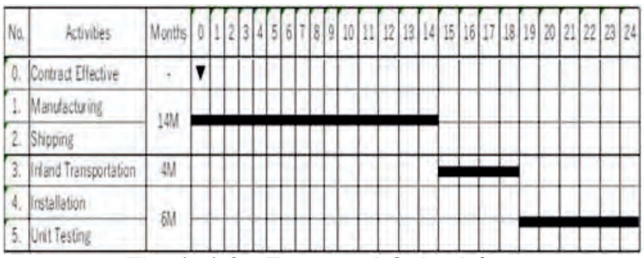

Fig. 1-1.3 : Expected Schedule

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Project 2

Project 2: Outline of Multan area projects

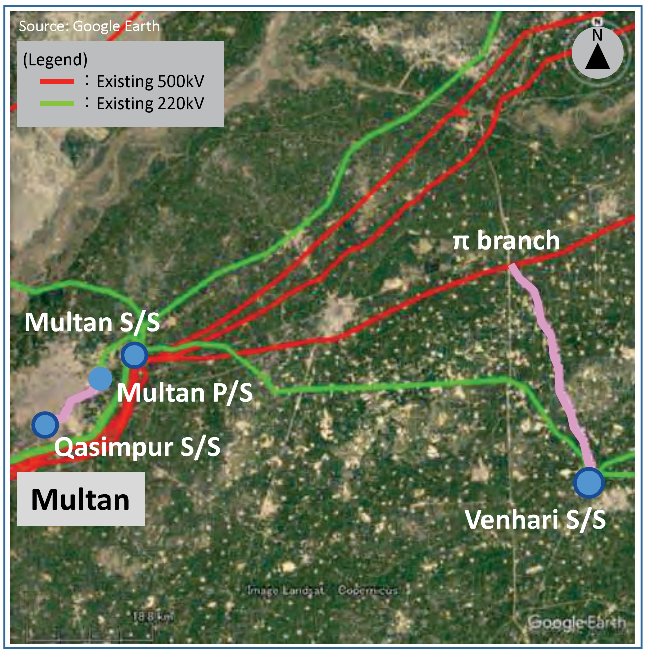
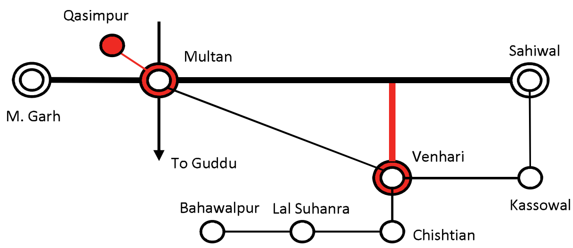


Fig. Location of projects

(1) Objective

Reinforcement of power supply in Multan



(2) Outline of system expansion

	T/L	Voltage	Line Length	Facility
(i)	Venhari – Pi branch	500 kV	37 km	OHTL 2cct
(ii)	Multan – Qasimpur	220kV	11 km	UGTL 2cct

	S/S	Facility
(i)	Multan	500kV AIS, 450MVA 500/220kV Trf × 1
(ii)	Venhari	500kV AIS, 750MVA 500/220kV Trf × 2
(iii)	Qasimpur	220kV AIS, 250MVA 220/132kV Trf × 3

(3) Environmental impact

Survey	T/L	S/S	Remark
Assessment of impact	Less than 200 people	small	ROW: 50m (500kV) 30m (220kV)

(4) Estimation of project cost

Construction Cost
156MUSD（T/L 73MUSD, S/S 83MUSD）

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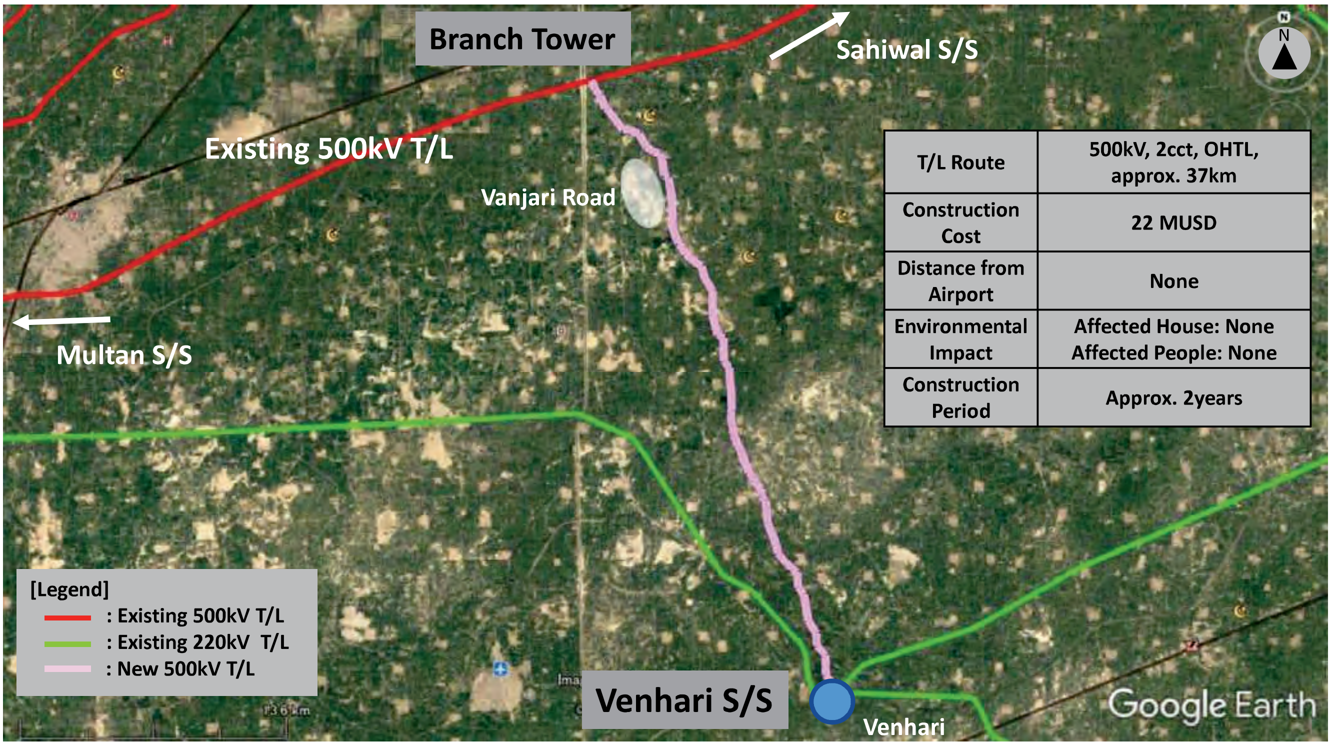
Route of OHTL (Venhari S/S - Branch Tower)

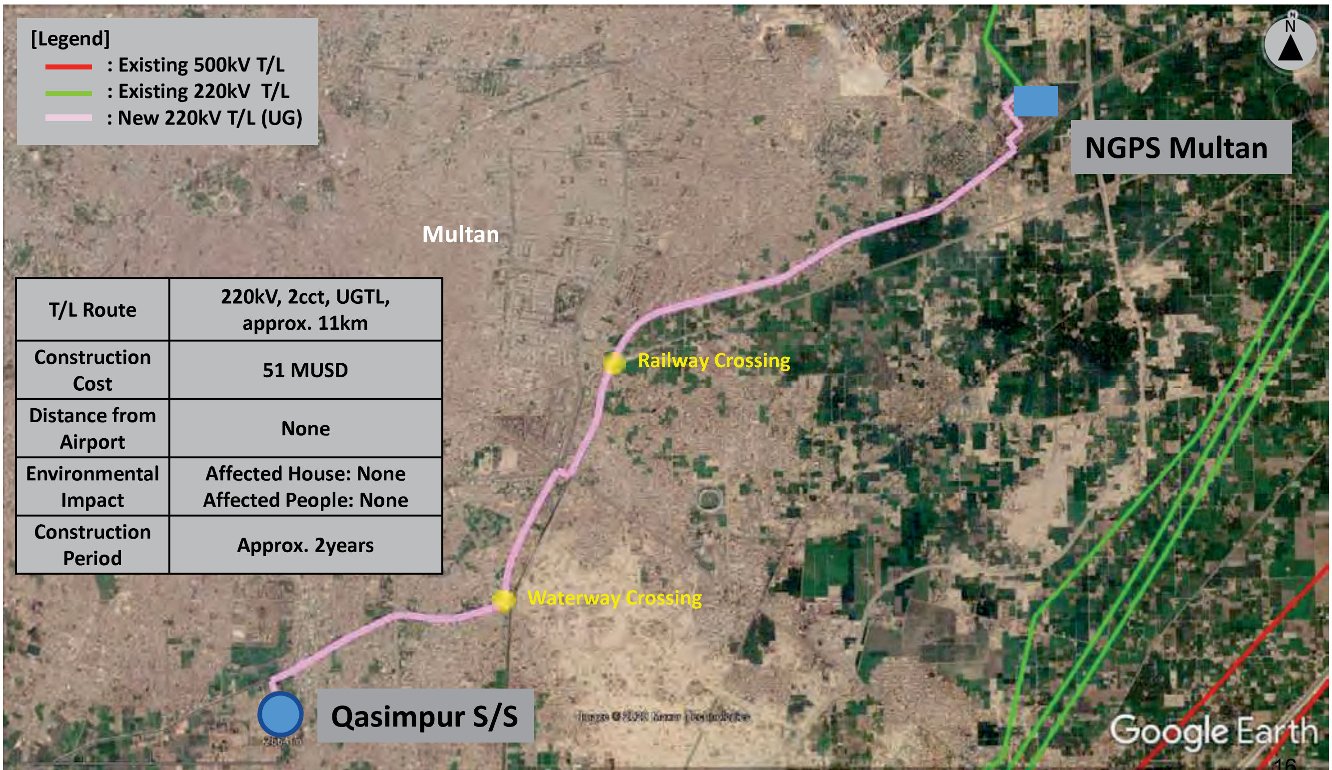
The below figure shows the route of OHTL between Venhari S/S and Branch Tower.



T/L Route	500kV, 2cct, OHTL, approx. 37km
Construction Cost	22 MUSD
Distance from Airport	None
Environmental Impact	Affected House: None Affected People: None
Construction Period	Approx. 2years

Route of UGTL (NGPS Multan – Qasimpur S/S)

The below figure shows the route of OHTL between NGPS Multan and Qasimpur S/S.



T/L Route	220kV, 2cct, UGTL, approx. 11km
Construction Cost	51 MUSD
Distance from Airport	None
Environmental Impact	Affected House: None Affected People: None
Construction Period	Approx. 2years

Project#2-1 : 500kV Multan S/S Trf. Extension Work *(Desk Research Only)*

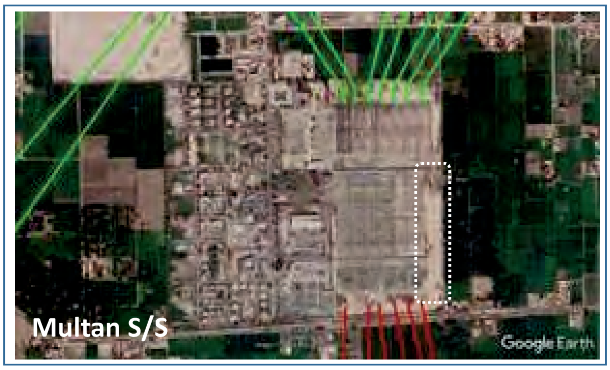


Fig.2-1.1 Scope on Satellite Image

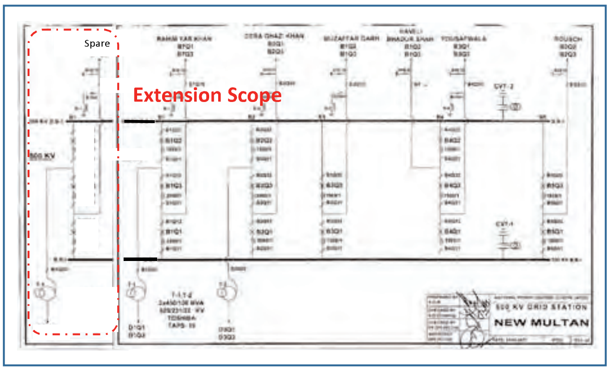


Fig.2-1.2 Scope on Single Line Diagram

[Work Description]
- ☑Increase Capacity
  - ▹ 450MVA, 500kV x 1 bank Extension
- ☑Related Facilities (need to modify)
  - ▹ 500kV & 220kV Switchgears : 1 Dia each
  - ▹ Gantry, Strings & Insulators
  - ▹ Embedded bases, ▹ Fire Fighting
  - ▹ Prot.&Ctrl Panels, etc.
- ☑Expected Schedule : 20M

[Concern]
- ☑ Safety
  - ▹ Work near the live existing facilities
- ☑ Extension Space
  - ▹ Availability is to be confirmed (seem to be available)

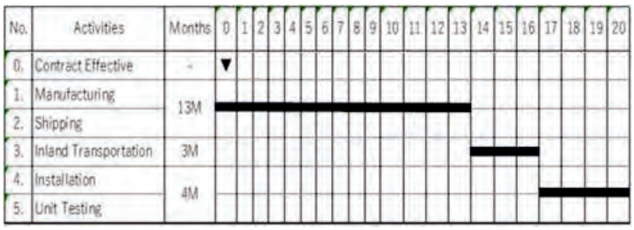


Fig. 2-1.3 Expected Schedule

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Project#2-2 : 500kV Venhari S/S Trf Extension Work *(Desk Research Only)*

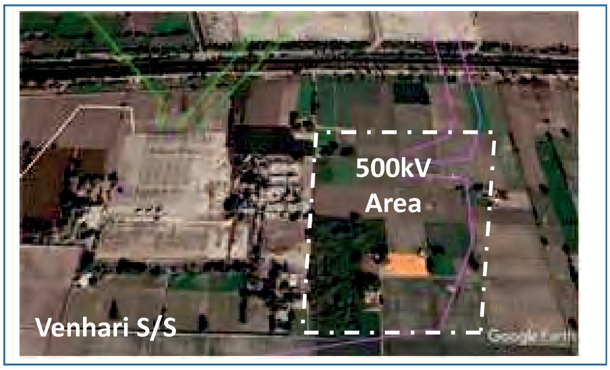

Fig.2-2.1 Satellite Image of 500kV S/S yard

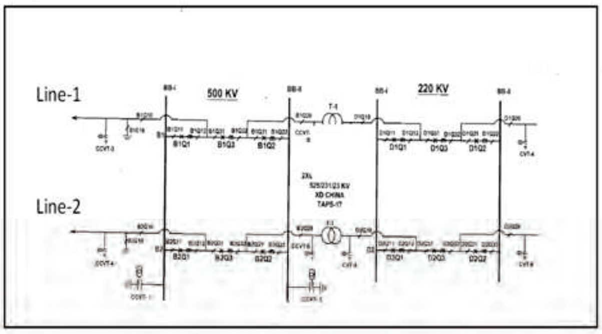

Fig.2-2.2 S.L.D. at New Construction.

[Precondition]
- ☑ Trf. Extension after 500kV upgrading
- ☑ Location of 500kV yard & BoQ are assumption (vide.Fig.2-2.1&Fig.2-2.2)

[Work Description]
- ☑Increase Capacity
  - ▹ 750MVA, 500kV x 2 banks Extension
- ☑Related Facilities (need to modify)
  - ▹ 500kV & 220kV Switchgears : 1 Dia each
  - ▹ Gantry, Strings & Insulators, ▹ Embedded bases,
  - ▹ Fire Fighting, ▹ Prot.&Ctrl Panels, etc.
- ☑Expected Schedule : 24M

[Concern]
- ☑ Safety
  - ▹ Work near the live existing facilities

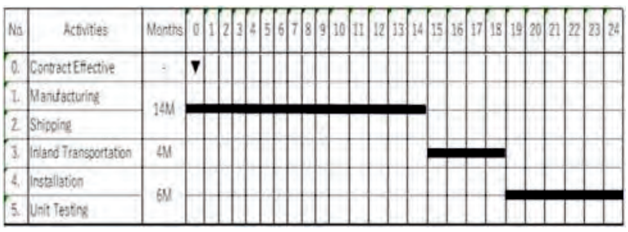

Fig. 2-2.3 Expected Schedule

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Project#2-3 : 220kV Qasimpur S/S Trf Extension Work *(Desk Research Only)*

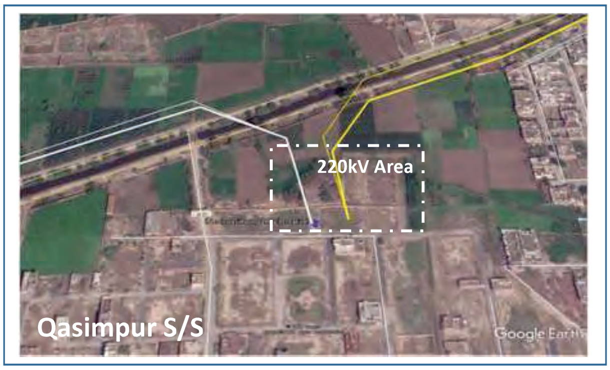


Fig.2-3.1 Satellite Image of 220kV S/S yard

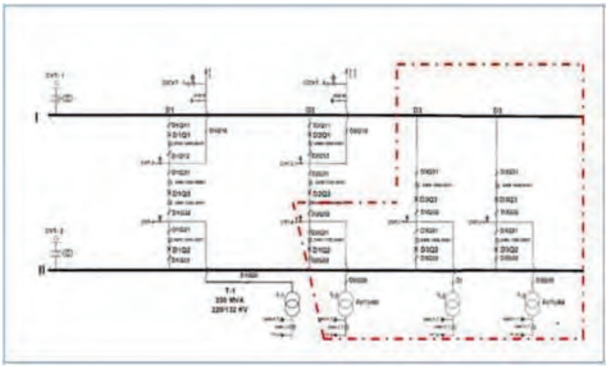


Fig.2-3.2 Scope on Single Line Diagram

[Precondition]

☑ Trf. Extension after new construction

☑ Location of Substation yard & BoQ are assumption (vide.Fig.2-3.1&Fig.2-3.2)

[Work Description]

☑Increase Capacity

- ▻ 250MVA, 220kV x 3 banks Extension

☑Related Facilities (need to modify)

- ▻ 220kV Switchgears : 2 Dias + 1 feeder
- ▻ Gantry, Strings & Insulators, ▻ Embedded bases,
- ▻ Fire Fighting, ▻ Prot.&Ctrl Panels

☑Expected Schedule : 24M

[Concern]

☑ Safety

- ▻ Work near the live existing facilities

No.	Activities	Months	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.	Contract Effective	-	▼																								
1.	Manufacturing	14M																									
2.	Shipping																										
3.	Inland Transportation	4M																									
4.	Installation	6M																									
5.	Unit Testing																										

Fig. 2-3.3 Expected Schedule

Project 3

Project 3: Outline of Faisalabad area projects

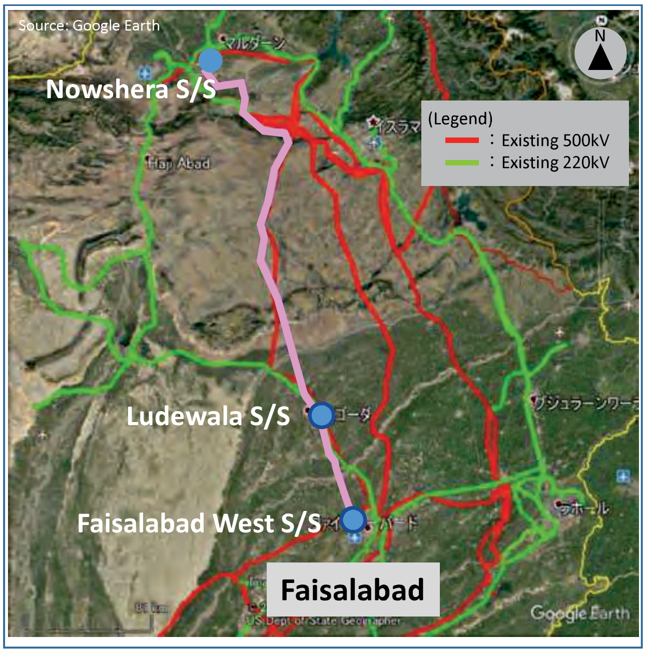
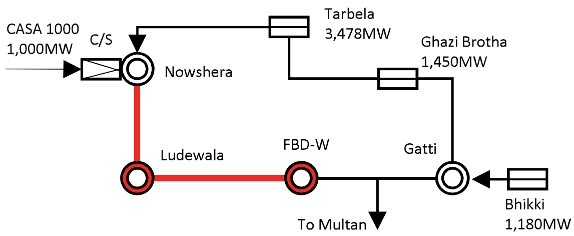


Fig. Location of projects

(1) Objective

Reinforcement of power supply in Faisalabad



(2) Outline of system expansion

	T/L	Voltage	Line Length	Facility
(i)	FBD West – Ludewara	500 kV	94 km	OHTL 2cct
(ii)	Ludewara - Nowshera	500kV	262 km	OHTL 2cct

	S/S	Facility
(i)	Ludewala	500kV AIS, 1-1/2 Bus 2dia + 1dia (Aux.) 600MVA 500/220kV Trf×2 220kV AIS (existing) 1-1/2 Bus 2dia expansion
(ii)	FSB-W	500kV AIS, 750MVA 500/220kV Trf×1 250MVA 220/132kV Trf x 1

(3) Environmental impact

Survey	T/L	S/S	Remark
Assessment of impact	Less than 200 people	small	ROW: 50m (500kV) 30m (220kV)

(4) Estimation of project cost

Construction Cost
306MUSD（T/L 196MUSD, S/S 110MUSD）

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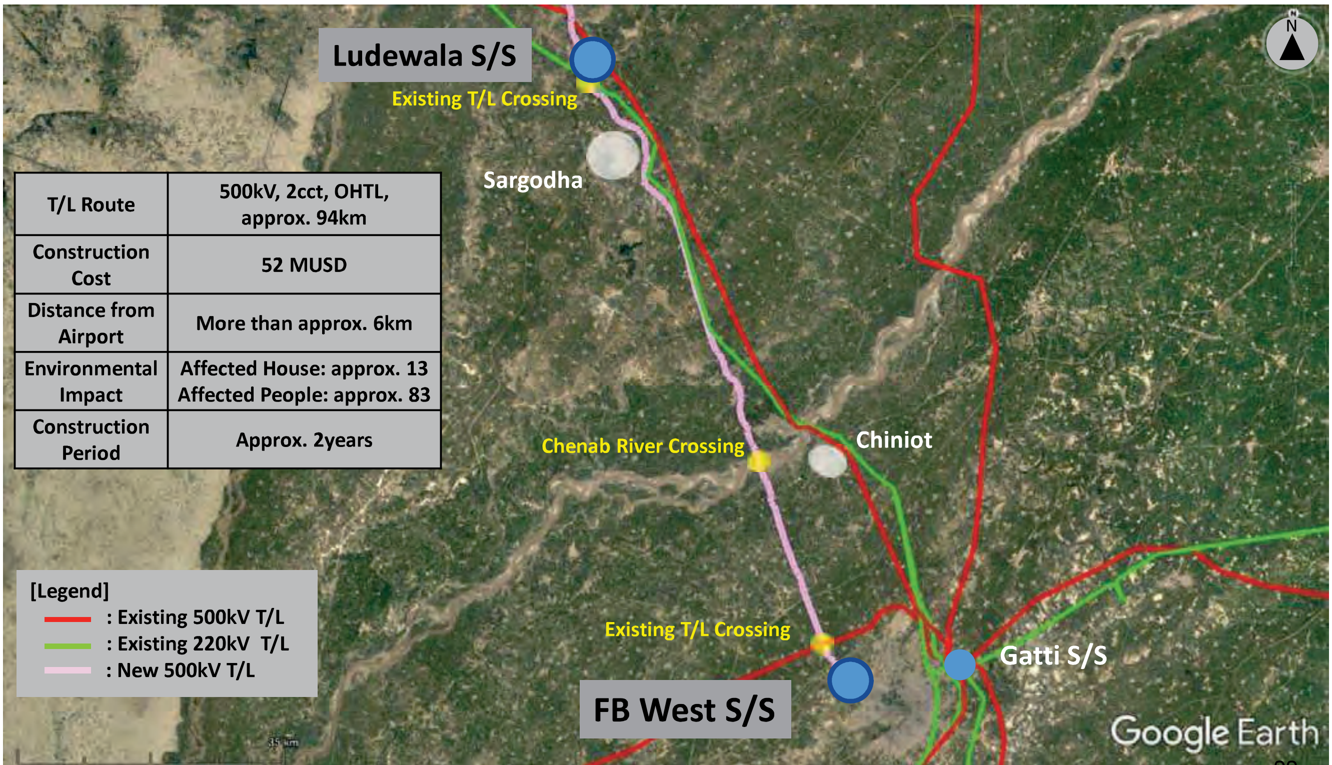
Route of OHTL (Faisalabad West S/S - Ludewala S/S)

The below figure shows the route of OHTL between Faisalabad West S/S and Ludewala S/S.



T/L Route	500kV, 2cct, OHTL, approx. 94km
Construction Cost	52 MUSD
Distance from Airport	More than approx. 6km
Environmental Impact	Affected House: approx. 13 Affected People: approx. 83
Construction Period	Approx. 2years

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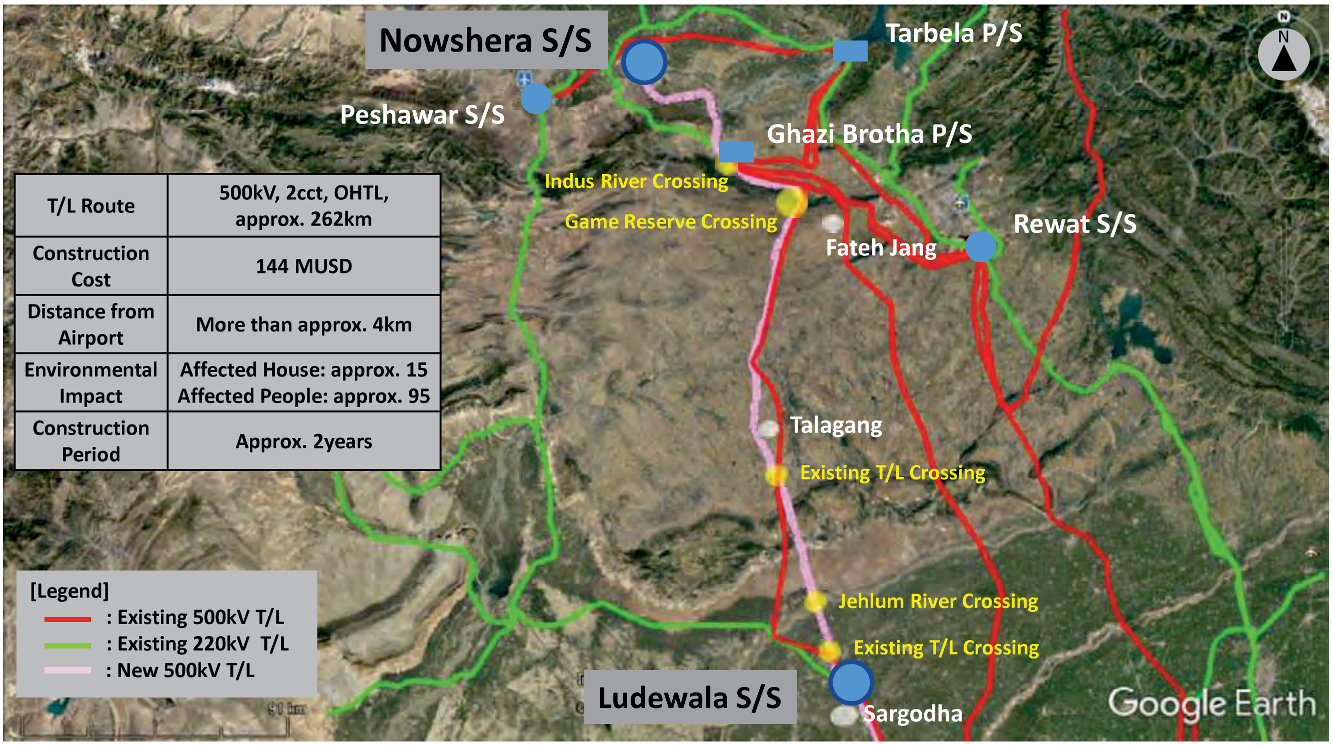
Route of OHTL (Ludewala S/S – NowsheraS/S)

The below figure shows the route of OHTL between Ludewala S/S and NowsheraS/S.



T/L Route	500kV, 2cct, OHTL, approx. 262km
Construction Cost	144 MUSD
Distance from Airport	More than approx. 4km
Environmental Impact	Affected House: approx. 15 Affected People: approx. 95
Construction Period	Approx. 2years

Project#3-1 : 220kV Ludewala S/S 500kV Upgrading Work *(Desk Research Only)*

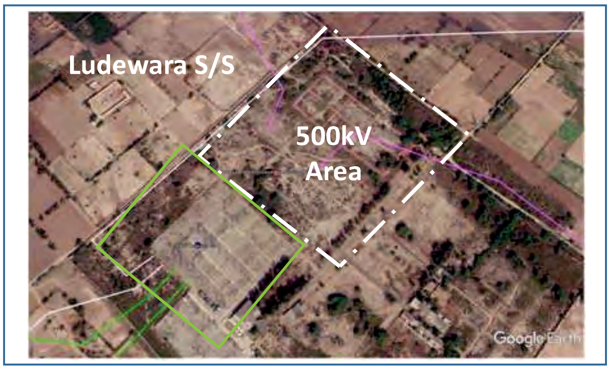


Fig.3-1.1 Satellite Image of 500kV S/S yard

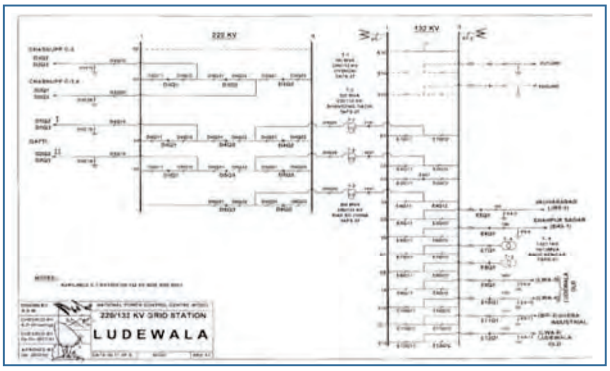


Fig.3-1.2 Existing 220kV Single Line Diagram

[Precondition]

- ☑ 500kV upgrading Work (FTK) near 220kV Existing
- ☑ Location of 500kV yard is assumption (vide.Fig.2-2.1)

[Work Description]

- ☑Increase Capacity
  - ▹ 600MVA, 500kV x 2banks
  - ▹ 500kV Switchgears : 4 Dias
  - ▹ Civil & Architecture / BOP
- ☑Related Facilities (need to modify)
  - ▹ 220kV Switchgears : 2 Dias
  - ▹ Gantry, Strings & Insulators, ▹ Embedded bases
  - ▹ Fire Fighting, ▹ Prot.&Ctrl Panels
- ☑Expected Schedule : 28M

[Concern]

- ☑ Safety
  - ▹ Work near the live existing facilities

No.	Activities	Months	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
0.	Contract Effective	-	▼																												
1.	Manufacturing	16M																													
2.	Shipping																														
3.	Inland Transportation	4M																													
4.	Installation	8M																													
5.	Unit Testing																														

Fig. 3-1.3 Expected Schedule

Project#3-1 : 220kV Ludewala S/S 500kV Upgrading Work *(Desk Research Only)*

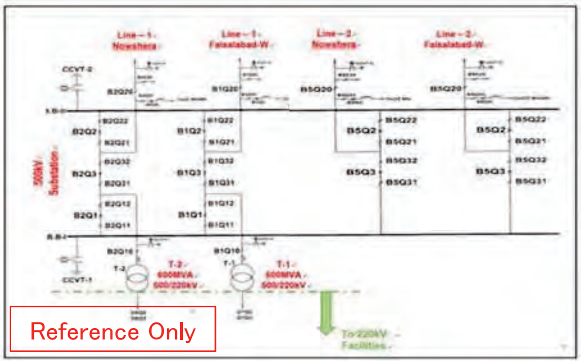


Fig.3-1.4 500kV Expected Single Line Diagram

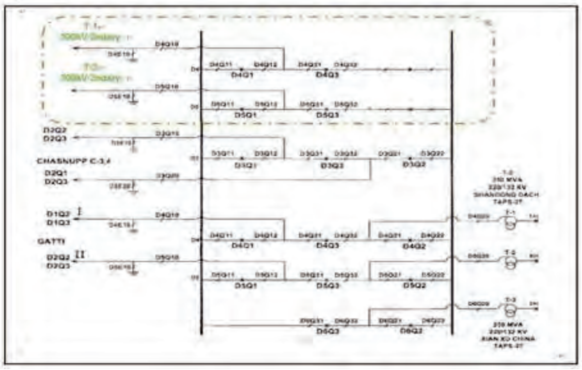


Fig.3-1.5 220kV S.L.D. after upgrading

[Precondition]
- ☑ 500kV upgrading Work (FTK) near 220kV Existing
- ☑ Location of 500kV yard is assumption. (vide.Fig.2-2.1)

[Work Description]
- ☑Increase Capacity
  - ▻ 600MVA, 500kV x 2banks
  - ▻ 500kV Switchgears : 4 Dias
  - ▻ Civil & Architecture / BOP
- ☑Related Facilities (need to modify)
  - ▻ 220kV Switchgears : 2 Dias
  - ▻ Gantry, Strings & Insulators, ▻ Embedded bases
  - ▻ Fire Fighting, ▻ Prot.&Ctrl Panels
- ☑Expected Schedule : 28M

[Concern]
- ☑ Safety
  - ▻ Work near the live existing facilities

No.	Activities	Months	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
0.	Contract Effective	-	▼																												
1.	Manufacturing	16M		━	━	━	━	━	━	━	━	━	━	━	━	━	━	━	━												
2.	Shipping																														
3.	Inland Transportation	4M																		━	━	━	━								
4.	Installation	8M																						━	━	━	━	━	━	━	━
5.	Unit Testing																														

Fig. 3-1.3 Expected Schedule

Project#3-2 : 500kV Faisalabad West S/S Trf Extension Work *(Desk Research Only)*

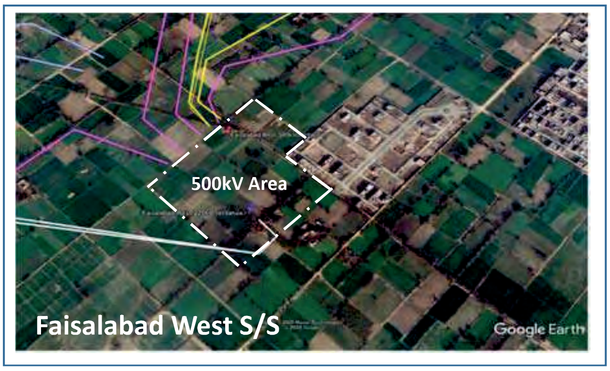


Fig.3-2.1 Satellite Image of 500kV S/S yard

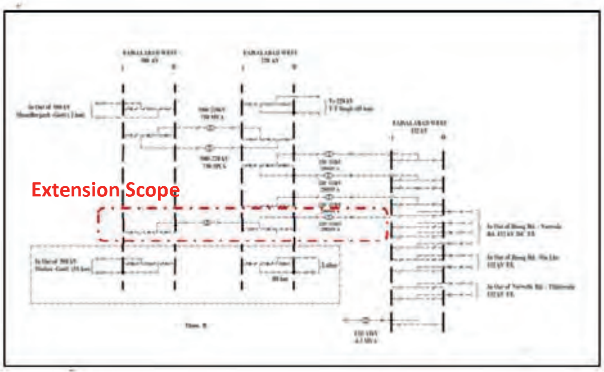


Fig.3-2.2 Scope on Single Line Diagram

[Precondition]
- ☑ Trf. Extension after 500kV upgrading
- ☑ Location of 500kV yard & BoQ are assumption (vide.Fig.2-2.1&Fig.2-2.2)

[Work Description]
- ☑Increase Capacity
  - ▻ 750MVA, 500kV x 1 bank Extension
  - ▻ 250MVA, 220kV x 1 bank Extension
- ☑Related Facilities (need to modify)
  - ▻ 500kV & 220kV Switchgears : 1 Dia each
  - ▻ Gantry, Strings & Insulators, ▻ Embedded bases
  - ▻ Fire Fighting, ▻ Prot.&Ctrl Panels
- ☑Expected Schedule : 24M

[Concern]
- ☑ Safety
  - ▻ Work near the live existing facilities

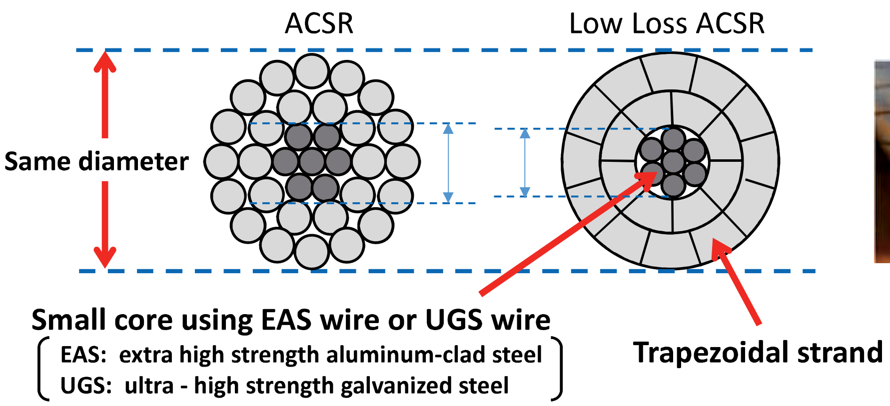
No.	Activities	Months	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.	Contract Effective	-	▼																								
1.	Manufacturing	14M		━	━	━	━	━	━	━	━	━	━	━	━	━	━										
2.	Shipping																										
3.	Inland Transportation	4M																━	━	━	━						
4.	Installation	6M																				━	━	━	━	━	━
5.	Unit Testing																										

Fig. 3-2.3 Expected Schedule

Applicable Advanced Technology

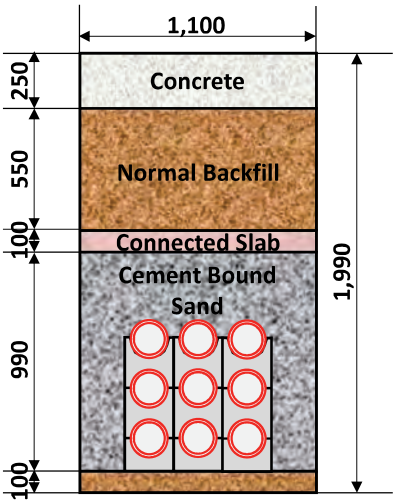
Low Loss Conductor

- ✓ Low Loss ACSR has more cross-section area of aluminum than ACSR.
  Therefore, it is possible to reduce electrical resistance and loss by applying Low Loss ACSR.
- ✓ Low Loss ACSR will be applied in T/L between Tarbela P/S and Burhan S/S.



PFP Pipe

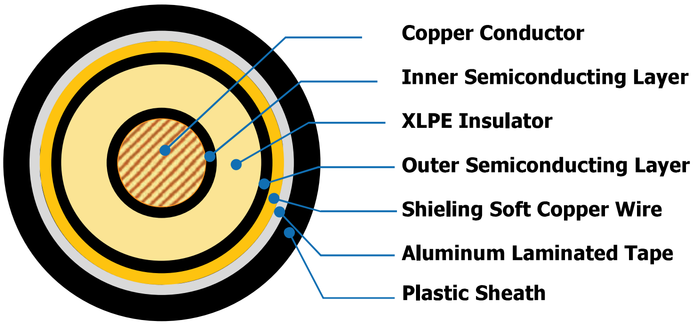
- ✓ In case of applying the pipe method, it is possible to determine the construction section flexibly. So, the impact on third parties is small.
- ✓ PFP pipes have the strength, the water resistance, the flexibility and an excellent record in Japan.

Cross Section	Photo of Installation of PFP Pipe
	

*PFP: Polycon Fiber Reinforced Plastics

Cable

- ✓ In case of applying the pipe method, it is not necessary to use cables with metal sheaths.
- ✓ So, it is possible to apply XLPE cables with an aluminum laminated tape, which has an excellent workability and is inexpensive.



*XLPE: Cross - linked Polyethylene

5. Candidate projects for Pre F/S 〈Summary〉

No.	Area (Objective)	Facility	Project summary	Advanced technology	Project cost (MUSD)
1.	Lahore (Reinforcement)	T/L	(i) Bund Rd-NKLP 220kV Underground cable (UGC) 15km 2cct.	PFP piping + XLPE cable	69
		S/S	(i) Lahore 500kV Trf replacement (600MVA x 4 -> 750MVA x 4) (ii) Nokhar 500kV Trf new (600MVA, 250MVA each)		55 28
2.	Multan (Reinforcement)	T/L	(i) Venhari – π Branch 500kV OHL 37km 2cct. (ii) Multan P/S - Qasimpur 220kV UGC 11km 2cct.	PFP piping + XLPE cable	22 51
		S/S	(i) Multan 500kV Trf new (450MVA x 1) (ii) Venhari 500kV Trf new (750MVA x 2) (iii) Qasimpur 220kV Trf new (250MVA x3)		18 37 28
3.	Faisalabad (Reinforcement)	T/L	(i) Ludewala – Faisalabad West 500kV OHL 94km 2cct (ii) Ludewala – Nowshera 500kV OHL 262km 2cct.	Low loss conductor	52 144
		S/S	(i) Ludewala 500kV upgrade (new 500kV yard) (ii) Faisalabad West 500kV Trf new (750MVA,250MVA each)		82 28

第 3 回ビデオ会議

Key subjects for discussion

Revised 16/12/2020

	Subject	Content
1	Concept of bulk power system	UHV backbone system which connects northern and southern power generation to the central demand area
	Renewable Energy	How to deal with RE in the power system expansion plan
2	Pre Feasibility study	3 projects are proposed based on NTDC's priority list
3	Strategic Environmental Assessment	Result of SEA in the power system expansion plan
	T/L corridor (North)	Result of transmission line corridor study based on GIS data in north (large hydropower plant to grid) and in south (large coal-fired power plant to grid)
	T/L corridor (South)	
3.5	Economic and Financial Analysis	Estimates of wheeling cost based on long term power system expansion plan DEC18
4	HVDC	Modeling of HVDC system which is a key technology of UHV backbone system DEC23
	Wrap-up	Additional discussion of the subjects if necessary

Request for the comments on the Technical Document

Request:

- Comments on the Technical Documents
- SLDs, Layouts of S/Ss and routes of T/Ls for Pre-F/S

Deadline: 23rd December 2020 (4th discussion)

The Project for the Study of Upgrading National Power System Expansion Plan in The Islamic Republic of Pakistan

3rd Online Discussion

December 16, 2020

Japan International Cooperation Agency
NEWJEC Inc.

The Project and the Strategic Environmental Assessment

USUI Shunji

Japan International Cooperation Agency
NEWJEC Inc.

CONTENTS

1. Strategic Environmental Assessment
2. Methodology of the SEA
3. Result of the SEA

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CONTENTS

1. Strategic Environmental Assessment
2. Methodology of the SEA
3. Result of the SEA

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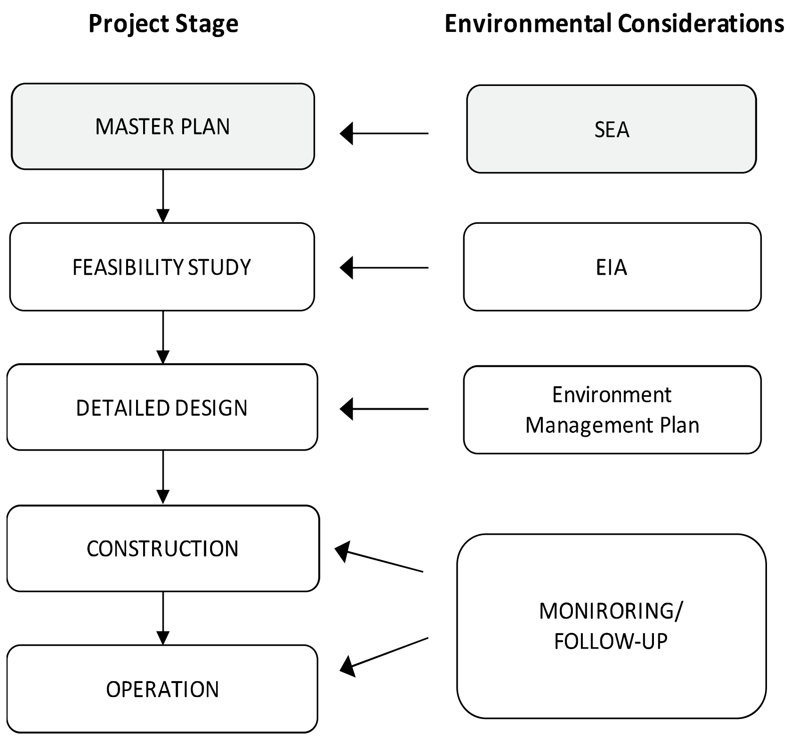
1.1 Strategic Environmental Assessment

- JICA's "Guidelines for Environmental and Social Considerations (2010)" : All master plan studies are required to implement a strategic environmental assessment.
- Applying Strategic Environmental Assessment (OECD, 2006): A range of "analytical and participatory approaches that aim to integrate environmental considerations into policies, plans and programmes and evaluate the inter linkages with economic and social considerations.

1.2 Strategic Environmental Assessment



1.3 Strategic Environmental Assessment

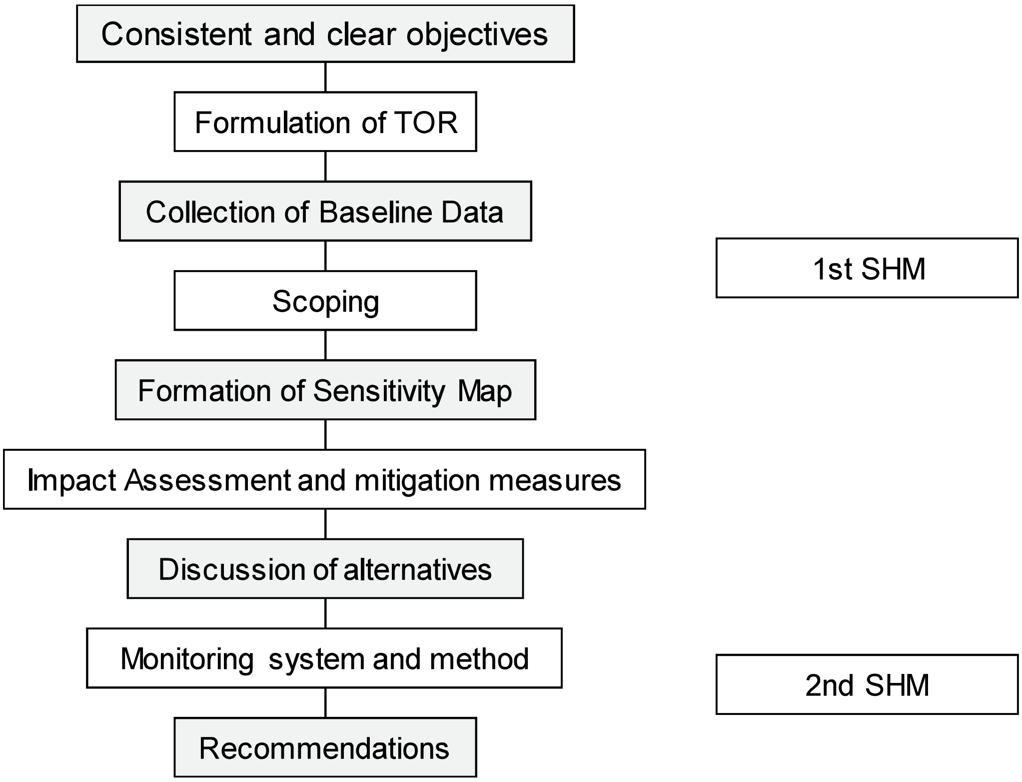
Benefits of the implementation of SEA

- to avoid / minimize negative impacts at early stage of project;
- to involve stakeholders to make the formulation process more effective in terms of better decision-making for evaluation of the master plan; and,
- to enhance capacity of counterpart agency and other related agencies for undertaking environmental and social considerations from early stage of development project.

CONTENTS

1. Strategic Environmental Assessment
2. Methodology of the SEA
3. Result of the SEA

2.1 Methodology of the SEA: Flow



2.2 Methodology of the SEA Scoping: tentative items

Item	SEA
Protected areas	✓
Ecosystem	✓
Topography and geology	✓
Involuntary resettlement	✓
Land use and utilization of local resources	✓
Existing social infrastructures and services	✓
Cultural heritages	✓

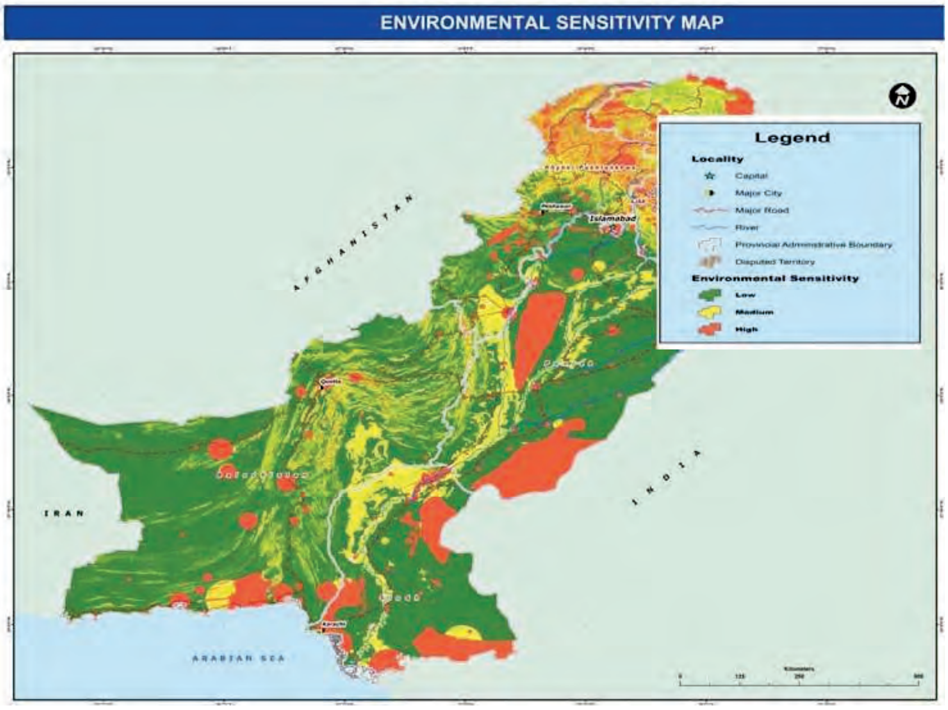
CONTENTS

1. Strategic Environmental Assessment
2. Methodology of the SEA
3. Result of the SEA

3.1 Results of the SEA

Item	SEA
Protected areas	✓
Ecosystem	✓
Topography and geology	✓
Involuntary resettlement	✓
Land use and utilization of local resources	✓
Existing social infrastructures and services	✓
Cultural heritages	✓

3.2 Sensitivity Map



It should be noted that this Sensitivity Map is exclusive for the Project and cannot be used as a Sensitivity Map for other projects or general information

3.2 Sensitivity Map

The important point is that "red areas (places that are expected to have big impacts)" do NOT mean "places that cannot be developed".

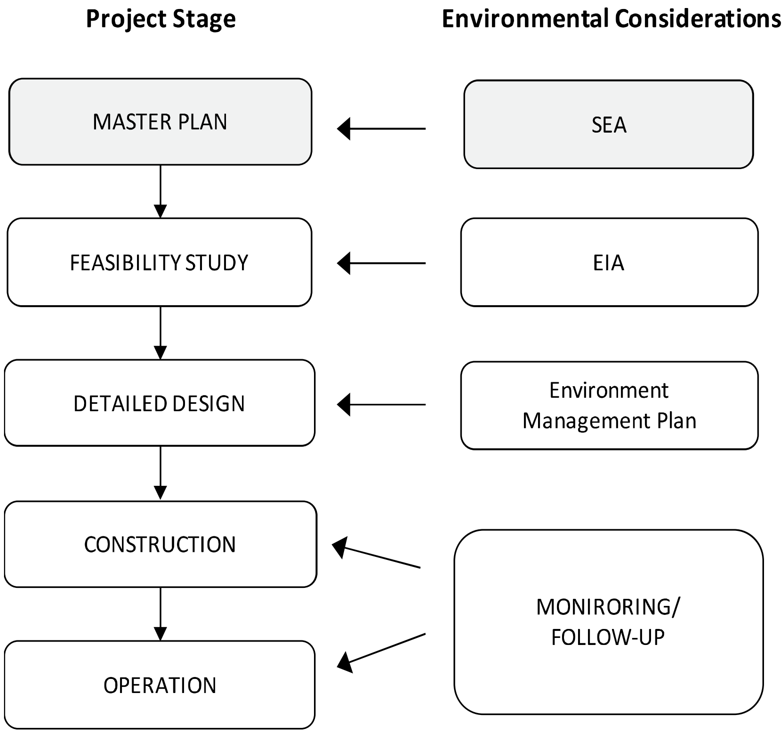
The purposes of the map are:

(1) to visualize the magnitude of the impacts;

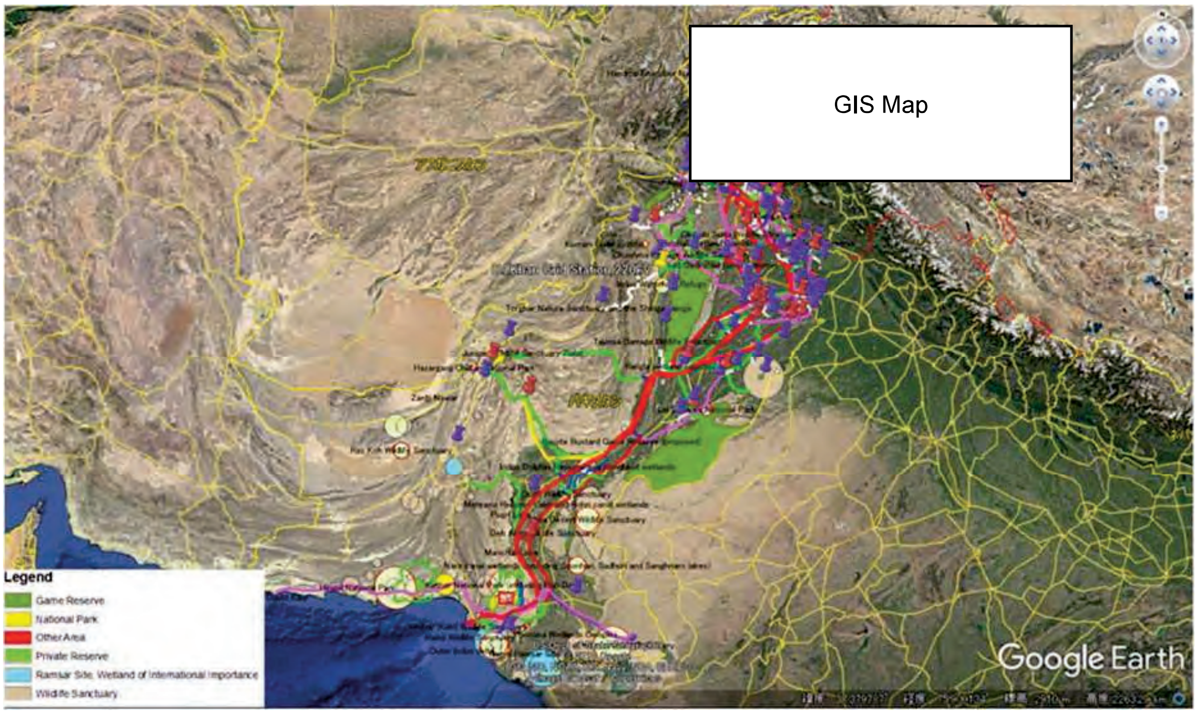
(2) to make government officials, developers, and local residents recognize that it is necessary to pay sufficient attention to the impacts on the environment; and,

(3) to promote sufficient environmental and social considerations for the formulation and implementation of plans.

3.2 Sensitivity Map

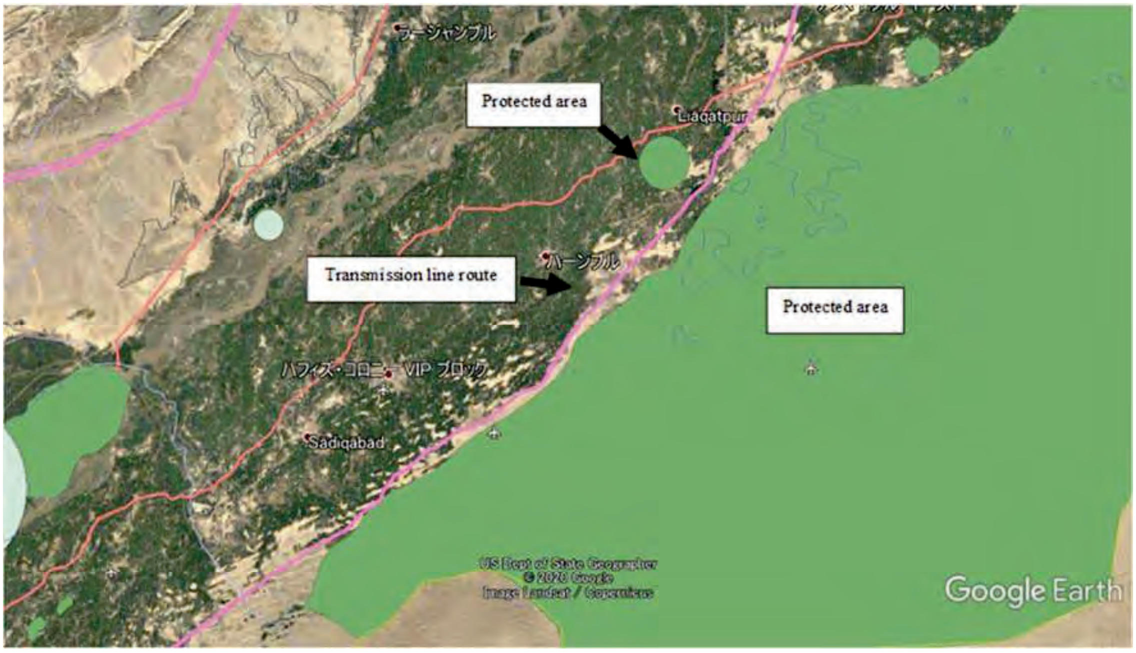


3.3 Overall



Superposition of transmission line routes and items of the environmental and social considerations on Google Map

3.4 Protected areas

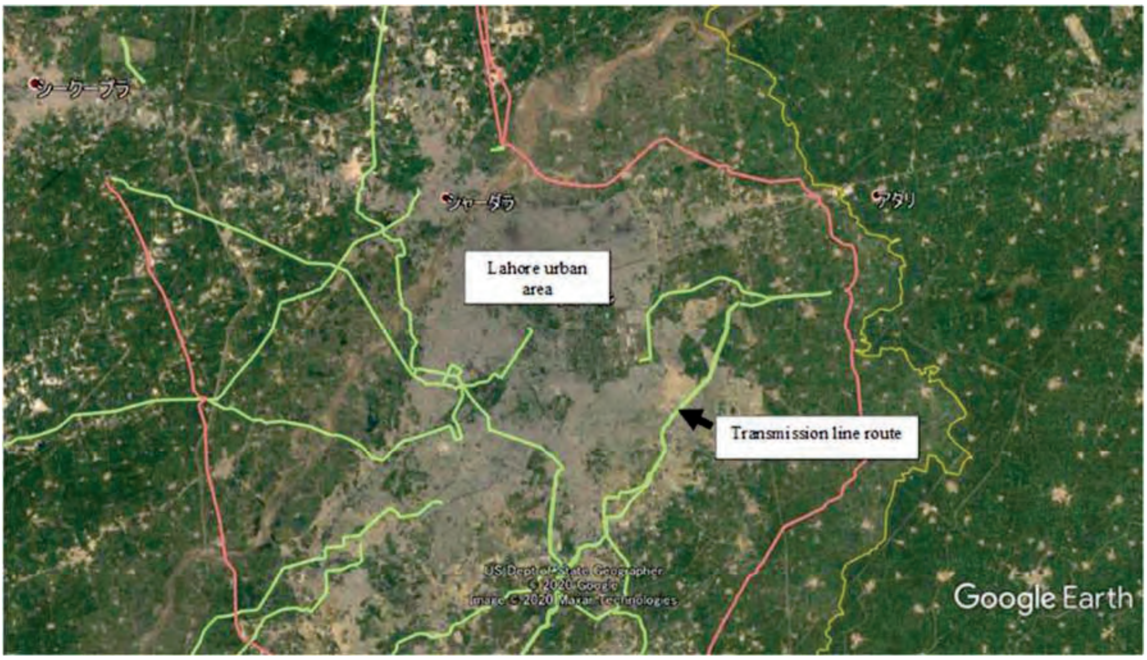


Avoiding protected areas as much as possible

3.4 Protected areas

- The routes to avoid protected areas are selected as much as possible.
- The area dimensions of some protected areas are shown in circles because their boundaries are not clear. It is particularly necessary for these protected areas with unclear boundaries to investigate the boundaries at the time of project implementation and avoid them.

3.5 Densely populated areas



Avoiding densely populated area such as Lahore urban area as much as possible

3.5 Densely populated areas

- The routes are planned to avoid densely populated areas.
- Some routes must pass through the urban areas. Regarding such routes, mitigation measures such as undergrounding transmission lines under a road are considered.

3.6 Alternatives

Evaluation item	Alternative 1 Status quo	Alternative 2 Evaluating multiple transmission line route options for individual projects	Alternative 3 Implementing a SEA
Technical aspects	No technical problems.	No technical problems.	No technical problems.
Economic aspects	It is economically inefficient.	The route options are limited. It is also difficult to consider comprehensive route options with other projects. It is, therefore, economically inefficient.	It is economically efficient because it can avoid major route changes and unexpected plan changes at individual project levels.
Environ-mental aspects	It is difficult to take drastic measures such as avoiding protected areas.	It is difficult to take drastic measures such as avoiding protected areas.	The major impacts can be minimized and/or mitigated to avoid areas that may be affected by the Project as much as possible. Furthermore, it is easy to take mitigation measures at the time of EIA.

بہت بہت شکریہ

Thank you for listening.

ありがとうございました。

The Project for the Study of Upgrading National Power System Expansion Plan

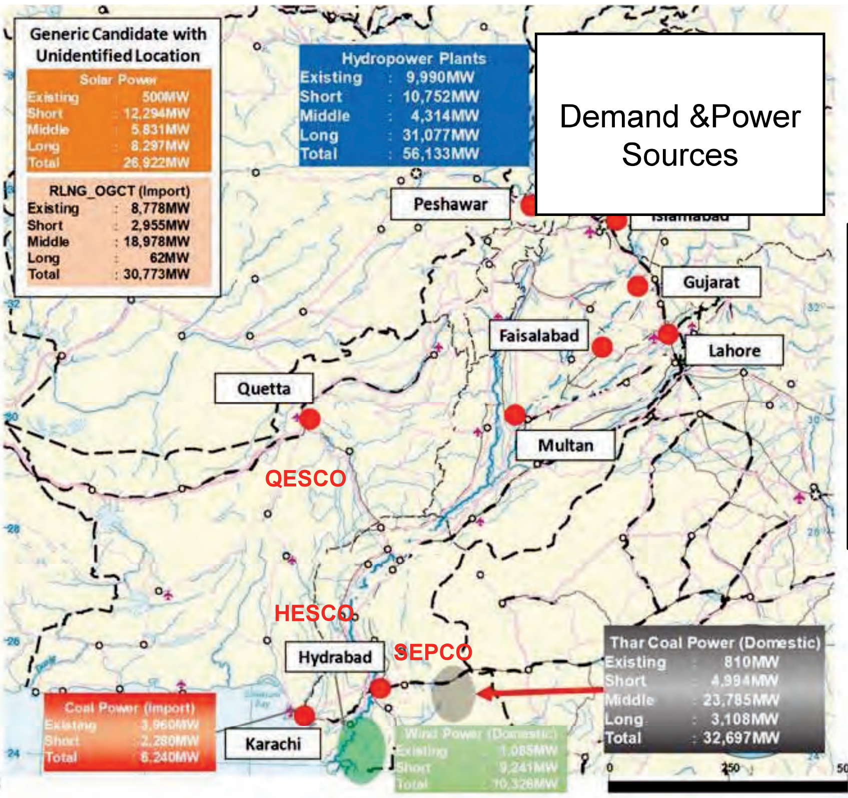
Analysis of New Transmission Routes in Southern Power - Central

December 16, 2020

Japan International Cooperation Agency
NEWJEC Inc.

CONTENTS

1. Perceptions of demand and power supply in 2047



A total of 51.2 GW will be installed until 2047 in southern area including HESCO, SEPCO and QESCO.

- 32.7 GW from the Thar coal field
- 10.3 GW from the Sindh wind corridor
- 6 GW of imported coal-fired power around Karachi
- 2.2 GW of nuclear power

The total demand in the southern region is only about 15.5 GW in HESCO, SEPCO and QESCO.
Most of the power generation in the southern region is expected to be consumed in the central region.

Effective transmission of generated power from south to central area is one major topic.

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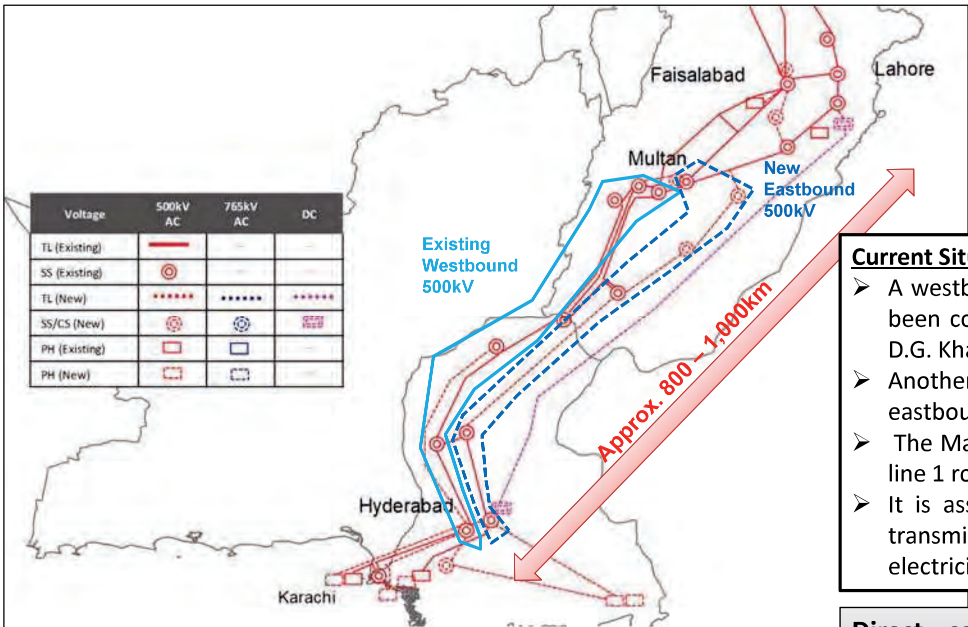
1. Perceptions of demand and power supply in 2047



Current Situation of Power System in Southern Area

- A westbound 500 kV transmission line system has already been constructed for Jamshoro-Dadu-Shikarpur-R.Y. Khan-D.G. Khan.
- Another 500 kV transmission line system with one eastbound route is expected to be augmented by 2030.
- The Matiari CS-Lahore South CS ±660kV DC transmission line 1 route is under construction.
- It is assumed that the two southern to central 500 kV transmission lines will be able to supply these regions with electricity until 2047.

Direct connection from new power sources to demand center is required.

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2. Study on the construction of the Southern Power Source-Central region power grid
(1) DC and AC

- The transmission of electricity from the southern part of the country to the central part of the country will cover a distance of about 800 km to 1000 km. Generally, DC is more cost effective than AC in case of the transmission line length over 400-500km.
- The power supply in the middle of the section can be handled by the planned bulk transmission system, and it is not necessary to consider it in the new bulk system.
- The AC transmission line covers long transmission distances and therefore, its stability, including voltage drop, is of concern.

It is desirable to use DC transmission lines from the viewpoint of cost and supply reliability.

2. Study on the construction of the Southern Power Source-Central region power grid
(2) Location of the power converter station

- For the converter stations in the southern region, the 660kV DC transmission line, which is under construction, is located at Matiari.
- Although it is about 200 km away from the domestic coal-fired power in the already developed Thar coal field, it will be able to consolidate the power generated from the imported coal-fired power near Karachi and the wind corridor in Sindh state.
- For the newly planned new bulk system, the main source of supply is envisaged to be the domestic coal-fired power from the Thar coal field. Therefore, it will be more efficient to have the converter station in the southern part of the country alongside the Thar field.
- It is preferable to distribute the supply-side converter stations in the major demand areas, rather than concentrating it in one location.

Converter stations will be located near the Thar coal fields and at Lahore, Faisalabad and Multan.

2. Study on the construction of the Southern Power Source-Central region power grid
(3) Voltage Class and Number of Circuits

- As a high-capacity transmission method, the National Power System Expansion Plan for 2011 plans a 37.2 GW power supply capacity and eight routes of ±600 kV DC transmission lines.
- In terms of UHV DC transmission projects, there has been remarkable development in China and India since 2010. In China, 13 of ±800kV DC transmission line projects are in operation as of 2019, four ±1000kV DC transmission line projects are under construction and six are awaiting approval.
- In our discussions with NTDC, concerns were expressed that the construction of eight transmission lines would be expensive in terms of environmental impact and cost, and as of 2020, the ±800 kV DC and ±1000 kV DC transmission lines will be in the practical stage, and the grid configuration will be considered in light of these voltage classes as well.
- Considering the existing and on-going power system, it is necessary to construct the evacuation route for approx. 30GW from Thar coal plants. Thus, ±1000 kV DC transmission lines with two circuits are considered.

±1000 kV DC transmission lines with two circuits are proposed.

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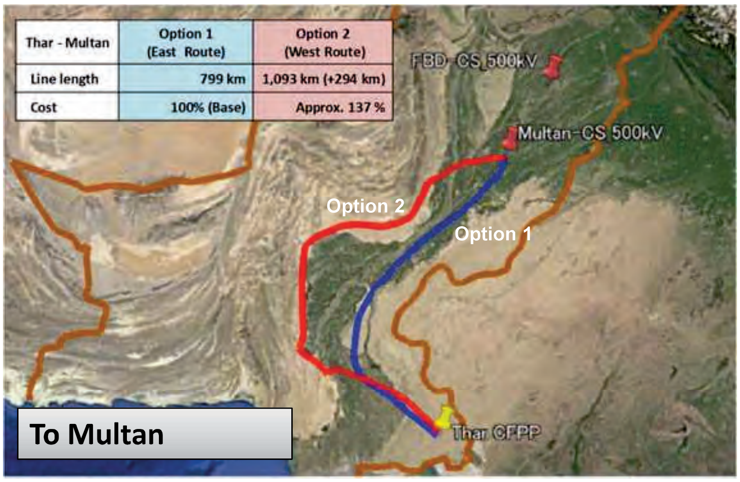
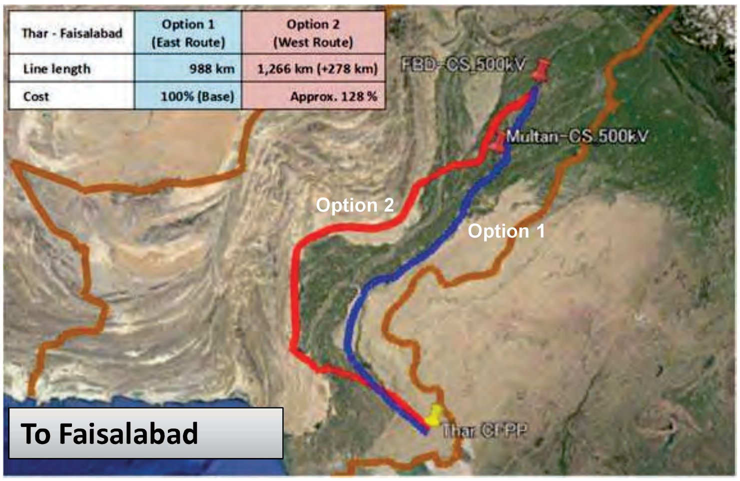
2. Study on the construction of the Southern Power Source-Central region power grid
(4) Transmission routes

Thar - Multan	Option 1 (East Route)	Option 2 (West Route)
Line length	799 km	1,093 km (+294 km)
Cost	100% (Base)	Approx. 137 %



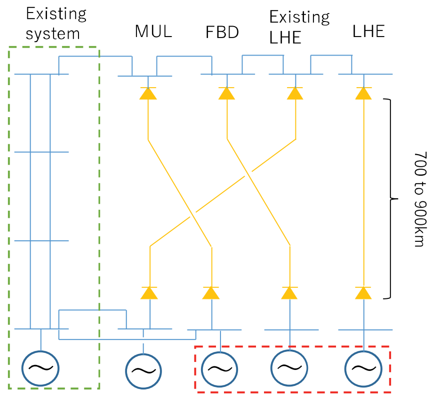
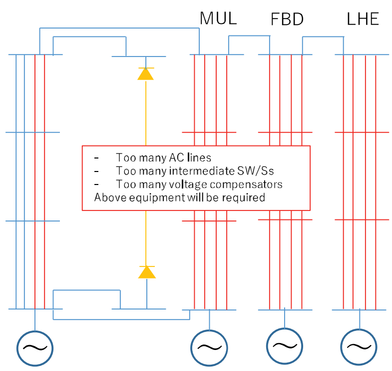
Thar - Faisalabad	Option 1 (East Route)	Option 2 (West Route)
Line length	988 km	1,266 km (+278 km)
Cost	100% (Base)	Approx. 128 %



- The eastward route (option 1) and the westward route (option 2) across the Indus River were considered using the Sensitivity Map.
- The distance of transmission lines **increased by about 28% or 37%**, though the option 2 avoided the residential and agricultural areas.
- **Therefore, it was decided to adopt option 1; the eastbound route of the study in this report.**
- It should be noted that **the selection of the transmission route in the future F/S level study** needs to be made after comprehensively considering the impacts on natural and social environments.

8

3. Result of pre-study

	HVDC	AC 500 or 765 or 1000kV
System Diagram		
Reliability	+++	+ Power transmission clearly difficulty in terms of static stability
Feasibility	+++ 3 routes	+ More than ten times of DC routes
Cost	+++	+
Total Evaluation	+++	+

good
+++
↕
+

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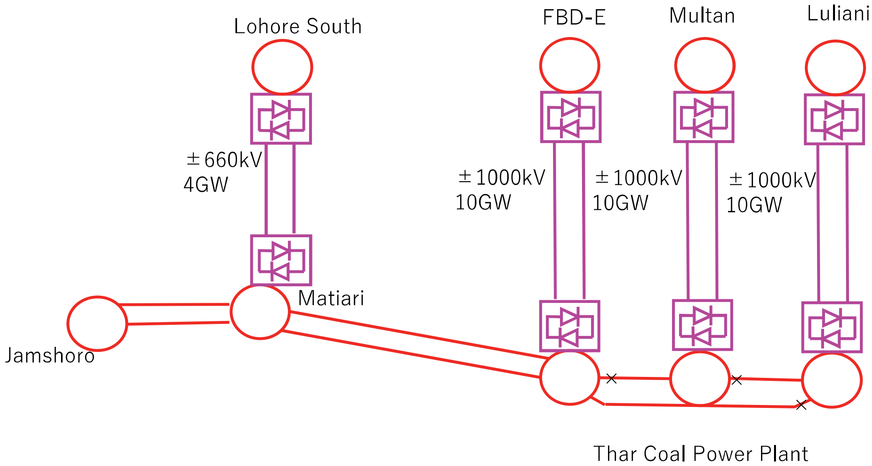
3. Result of pre-study



The DC system was adopted as a result of evaluation in terms of reliability, feasibility and cost. The concept is to secure as much power as possible through the existing AC system in the event of a single-route failure, in addition to regular power transmission.
The following four routes of DC transmission lines will be adopted as the new bulk system in the central region from the power supply in the southern region.

1. Matiari - Lahore South ±660kV DC transmission line - under construction
2. Thar - Luliani (Lahore) ±1,000kV DC transmission line - planned this time
3. Thar - Faisalabad ±1,000kV DC transmission line - planned this time
4. Thar-Multan ±1,000kV DC transmission line - planned this time

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第 3.5 回ビデオ会議

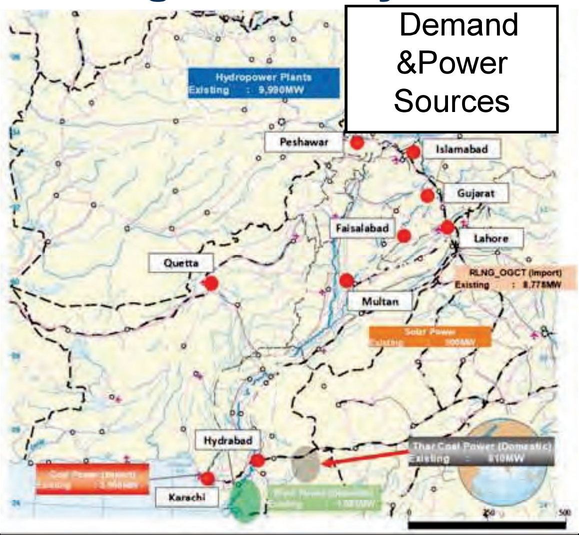
The Project for the Study of Upgrading National Power System Expansion Plan

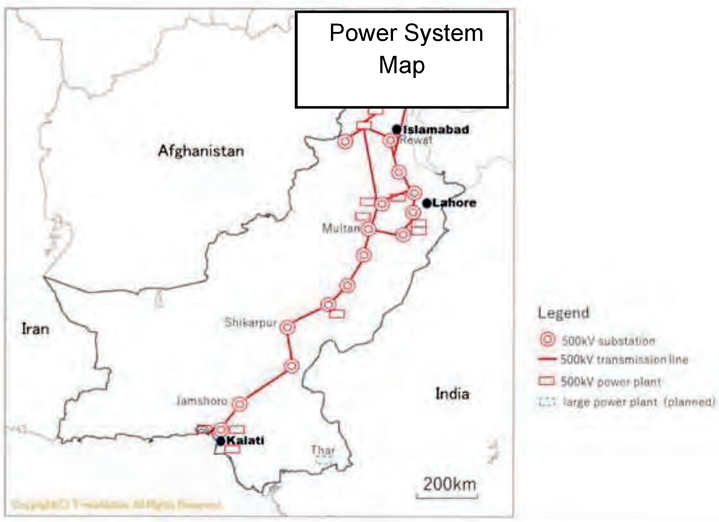
Outline of NPSEP

December 18, 2020

Japan International Cooperation Agency
NEWJEC Inc.

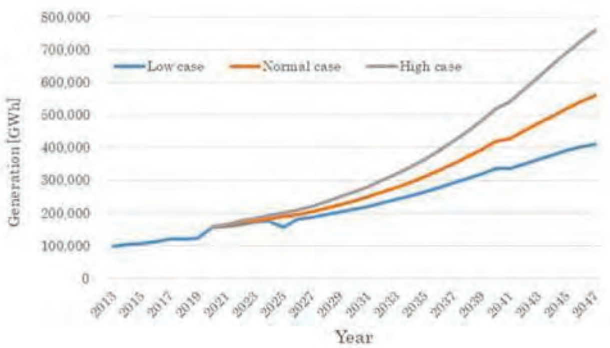
1. Existing Power System

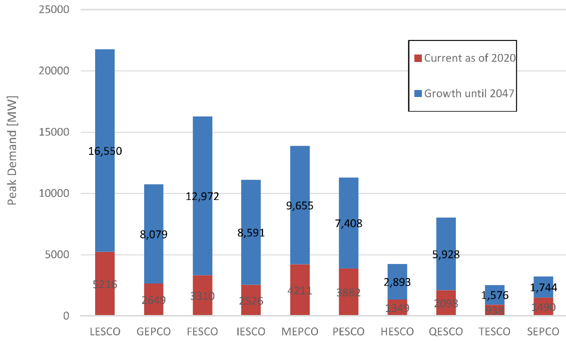




- The distance between northern capital city Islamabad and southern city Karachi is about 1,150 km, and the northern and southern area are connected by 500kV transmission lines which are the backbone of 500kV power system.
- Northern hydro power plants (Tarbela hydro power plant 4,888MW, etc.) and southern thermal power plant (Port Qasim coal thermal power plant 1,320MW, etc.) are connected to 500kV power system, the generation power is transmitted to the main consumption area, Lahore located in northern-middle area.
- Un even distribution of generation sources and concentration of the power demand is the one of unique characteristic.

2. Understandings of IGCEP2047
(1) Concentration of the Power Demand in the Central Area





- In terms of electricity demand in the NTDC's jurisdiction, the Punjab province, which is located in the middle of the country, accounts for 62.6 GW out of the total demand of 103.0 GW, with LESCO, FESCO, MEPCO and GEPCO. If the jurisdiction of PESCO and IESCO is included in this, the total demand reaches 85.0 GW.
- These jurisdictions include Lahore, Faisalabad, Multan, Gujarat, Peshawar, Islamabad and other large cities, which pose a challenge to the efficient transmission of power from the power plants to the demand areas and the supply of power in the metropolitan areas.

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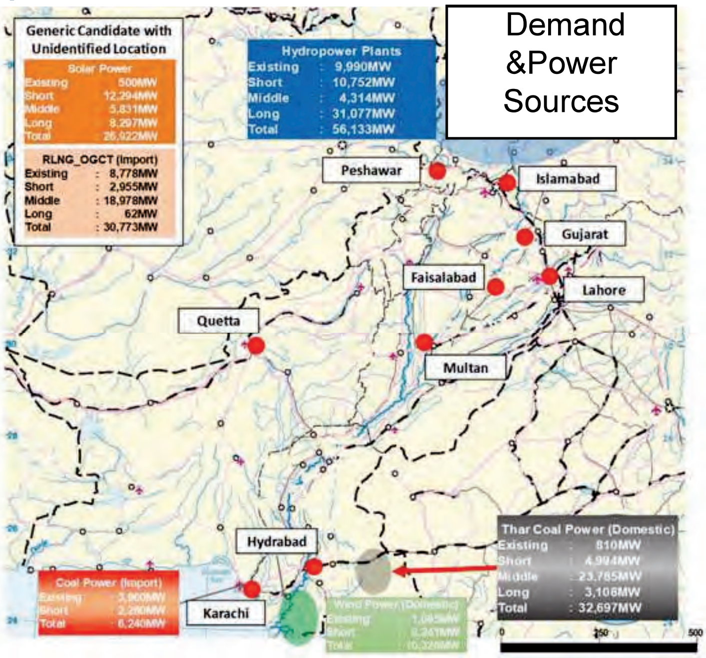
2. Understandings of IGCEP2047
(2) Un even Distribution of Power Sources



- The most important features of the power generation development plan in Pakistan are the development of abundant hydropower reserves in the north and coal-fired development in the Thar coalfield, the fourth largest reserve in the world, in the south.
- By 2047, hydro development will amount to 46 GW, with most of it located in the northern mountainous region The construction of these northern hydropower-to-demand transmission lines is envisaged to be a major development in an alpine region unlike any other in the world.
- Domestic coal-fired power development in the southern Thar coalfield is planned at 32 GW. In addition, the wind corridor in Sindh is envisaged to be developed at around 9 GW.

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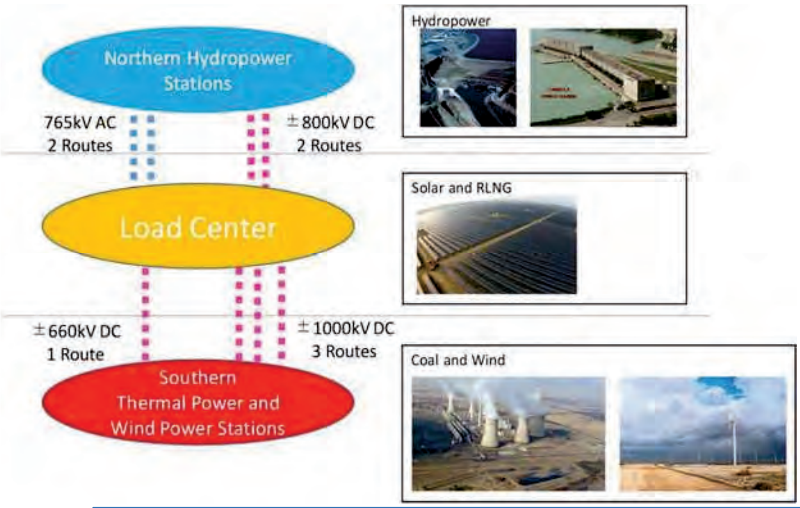
3. Basic Concept for the NPSEP2047

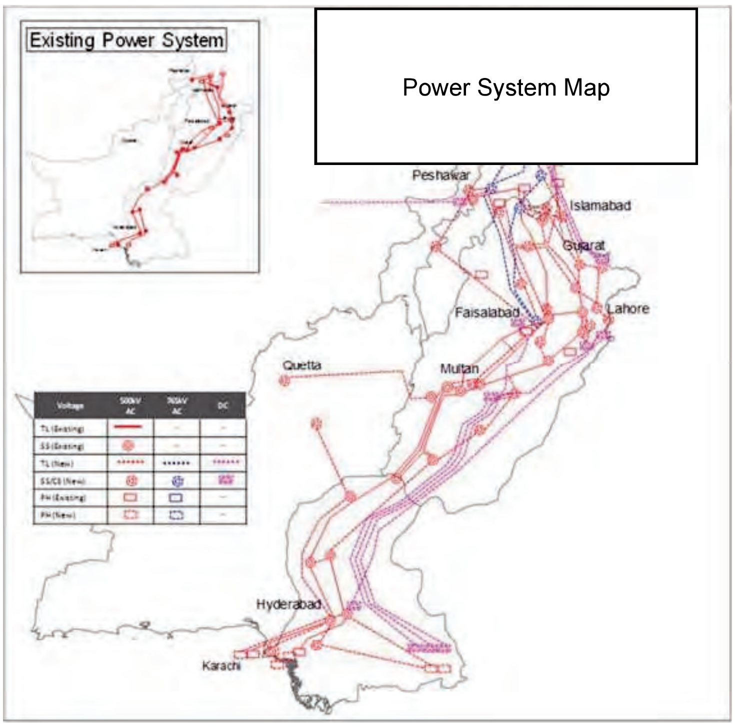


Item	Feature
Simple and reliable power system	A simple grid structure with a longitudinal traverse from north to central demand area and south to central demand area, making grid operation easy Critical urban demand is firmly supported by UHV transmission from northern and southern sources to achieve a high level of reliability. Back-up is ensured even in the event of a failure, such as a disruption of the northern or southern route due to weather conditions
Incremental upgrade by DC transmission system	The general advantage of DC transmission is the flexible ability to add converters when transmission capacity shall be increased. Power development projects, including those for northern hydropower and southern thermal power plants, are subject to unexpected delays and changes in plans, whereas DC transmission is flexible and can be ramped up incrementally. It is economically advantageous.

Concept of "the Large Scale Power Sources and UHV Transmission Lines"

- Considering the focal characteristics in power demand and power generation from IGCEP2047 Draft, ***"the Large Scale Power Sources and UHV Transmission Lines"*** is proposed for the basic concept of the National Power System Expansion Plan.

4. Outline of the Power System in 2047



UHV Transmission Lines

(Northern Hydro)

- Two routes of 765kV AC transmission lines (Manshera SS-Islamabad West SS and Mardan North-Faisalabad West)
- Two routes of ±800 kV DC transmission lines (Chilas CS-New Sialkot CS)

(Southern Thermal Power, Renewable Energy)

- One ±660 kV DC transmission line route

(Matiari CS-Lahore South CS)

- 3 routes of ±1000kV DC transmission lines (Thar CSs-Luliani CS, Faisalabad CS and Multan CS)

- In addition to the UHV transmission system, the construction of a grid that allows for the decentralized deployment of solar and RLNG-fired power near the demand areas, as the bulk power system by 2047 is also planned.
- In large cities, we will construct highly reliable 500kV power systems based on a circular structure to achieve high power supply reliability.
- The power supply in rural areas such as TESCO and QESCO will be strengthened through the construction and enhancement of new 500 kV/220 kV systems, where demand is expected to grow.

The Project for the Study of
Upgrading National Power System
Expansion Plan

Outlook for Wheeling Cost in the Power System Expansion Plan

December 18, 2020

Japan International Cooperation Agency
NEWJEC Inc.

CONTENTS

1. Financial model
2. Premises in running the model
3. Estimates of wheeling cost

FYI:

– Average wheeling tariff levels, fiscal 2013 – 2019
– Transmission tariff comparison in Pakistan, EU, and Japan

1. Financial model

Financial model based on the NTDC financial statements

- A financial model was constructed to estimate the future cost structure and financial conditions of the NTDC.
- The model was compiled based on the financial statements of the NTDC between fiscal 2016 and 2019.

Simulation of the financial statements in the future

- Financial statements after fiscal 2019 were simulated by adding up necessary annual investment estimated by the power system planning WG.

Future wheeling cost

- Future wheeling costs were calculated from foreseeable revenue and expenses.

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2. Premises (1/3)

Fund procurement

- The ratio of debt to equity is 2:1.

Debt finance

- As debt finance, loans provided by bi- and multilateral institutions are used.
- Borrowing conditions: maturity of 17 years, grace period of three years, and interest rate of 14% p.a..

Equity finance

- The average Return on investment (ROI) was 15.2% between fiscal 2016 and 2019, the rounded figure of 15% is used in the model.
- Although financial cost of equity finance is not exempted from taxes, a certain level of ROI is to be included in the wheeling cost from the viewpoint of business operation.

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2. Premises (2/3)

Currency values

- In the model, all currency values are in actual (nominal) terms. On the other hand, investment cost is estimated in 2019 constant (real) terms and dollar-denominated.

GDP deflator

- To convert real prices to nominal ones, the study used the GDP deflators available in the IMF World Economic Outlook.

Exchange rate

- A long-term outlook for exchange rates is very difficult to due to the current economic downturn and turmoil caused by the Coronavirus pandemic.
- In the time horizon of the 2020s, future exchange rates are estimated under the premise that the value of the rupee against the dollar will stay stable in real terms. In other words, the exchange rate for the rupee against the dollar in nominal terms will be adjusted by the difference between GDP deflators in Pakistan and the United States.
- Beyond 2030, the rupee exchange rate will be assumed to remain at the same rate in 2029.

2. Premises (3/3)

Cost items

Operation and maintenance (O&M)

- Personnel expenses: the increase in personnel expenses is 7% p.a..
- Maintenance, repair, and others: two percent of the value of operating assets is appropriated.

Depreciation: the depreciation period is 25 years.

Interest on loans: 14% a year

3. Estimates of wheeling cost (1/3)

Investment cost for transmission facilities, fiscal 2020 - 2047

(Unit: millions of 2019 US$)

	FY2020-2030	FY2031-2040	FY2041-2047	Total
Transmission line	4,680	3,804	1,165	9,648
Substation	6,741	8,715	3,231	18,687
Total	11,421	12,519	4,395	28,335

Source: Compiled by the power system planning working group.

- Above figures are estimated by the power system planning WG.
- Currency values are in real terms (2019 constant US$).

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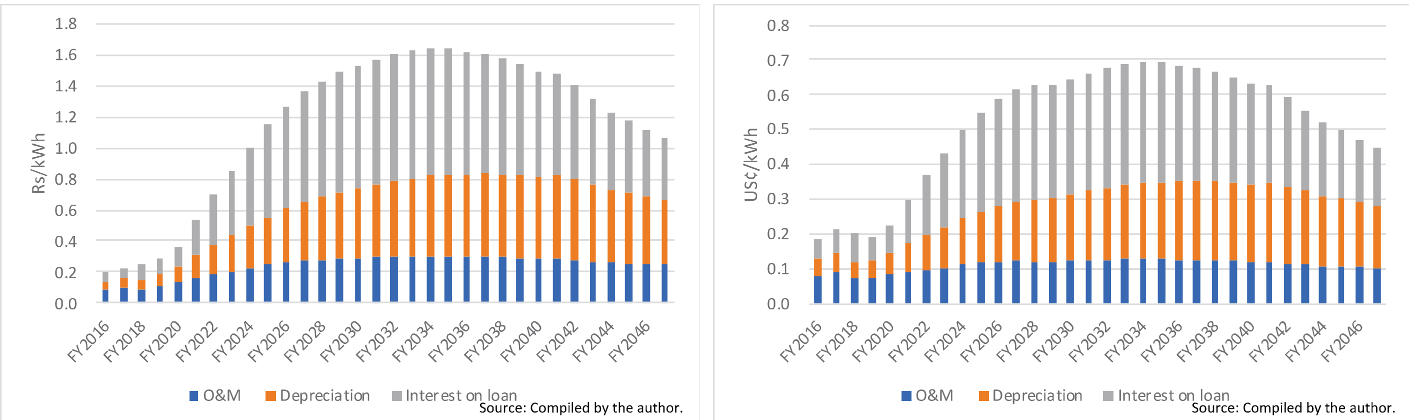
3. Estimates of wheeling cost (2/3)

Wheeling cost excluding ROI



- Obviously, interest payment (in other words, finance cost) is very heavy.
- Why will the cost decline beginning in the late 2030s? It is because the redemption of loans borrowed during the 2020s will be finished and interest payment for these loans will also terminate.
- Investment after fiscal 2041 will be almost halved as compared to that in the 2030s, and the cost will further decline.
- Especially, interest payment will markedly decrease in line with the termination of the redemption of loans.

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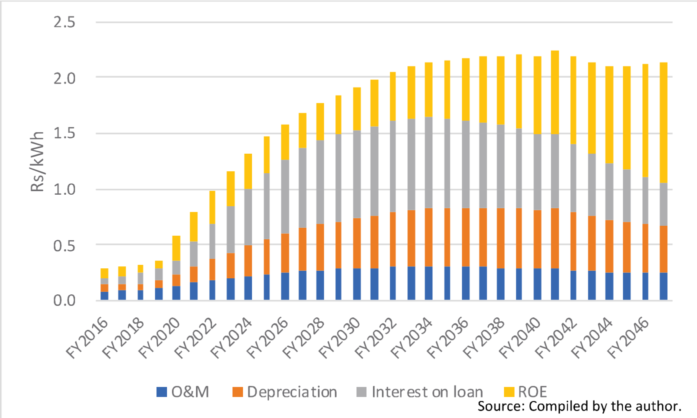
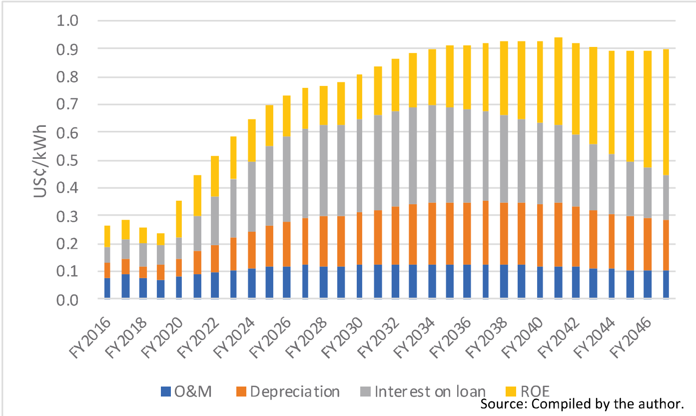
3. Estimates of wheeling cost (3/3)

Wheeling cost including ROI



Source: Compiled by the author.



Source: Compiled by the author.

- Shareholders' equity will increase proportionally in line with the progress of investment.
- Dividends for shareholders are not deductible as cost, and are paid from profit after tax.
- From the bushiness operation viewpoint, dividends are still part of the financial cost, and ROI should be reflected in the cost calculation.
- Unlike payment for interest on loans, the ROI portion in the total cost will continue to increase.

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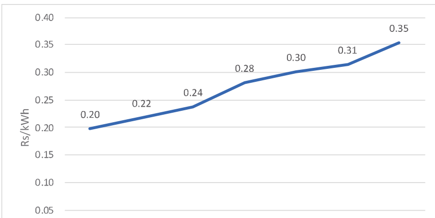
FYI (1/2): Average wheeling tariff levels, fiscal 2013 - 2019



Source: Compiled by the author using NTDC statistics.

(Unit: mil Rs, GWh, Rs/kWh)

	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Wheeling charges	16,782	19,836	22,236	27,546	31,326	36,744	41,989
Unit supplied to Discos by CPPA	84,424	91,190	93,843	98,248	104,330	117,139	118,838
Average tariff levels	0.20	0.22	0.24	0.28	0.30	0.31	0.35

Source: Compiled by the author using NTDC statistics and financial reports.

- Makeup of current operating costs is not well balanced (i.e., 57% salaries, wages and other benefits, 40% depreciation, and only 4% repairs and maintenance).
- It seems that money is not being sufficiently allocated to repairs and maintenance and new investment.
- The technical audit conducted by the USAID reported that there were many problems in maintenance and facility conditions.

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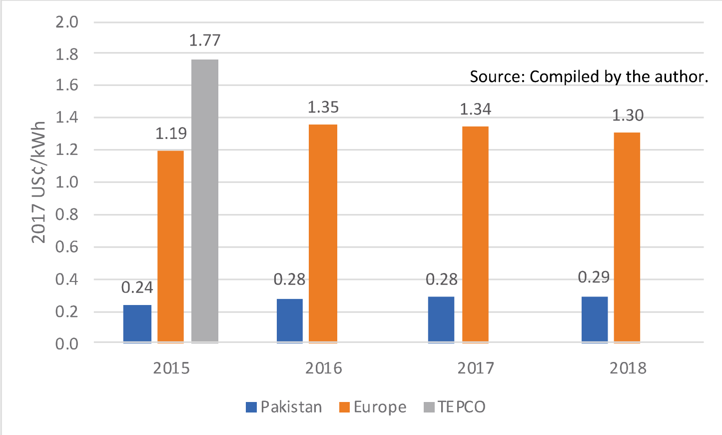
FYI (2/2): Transmission tariff comparison in Pakistan, EU, and Japan



- All figures are 2017 constant prices, which are adjusted by using GDP deflators and exchange rates in 2017.
- Europe consists of 36 countries.
- The figure of Tokyo Electric Company (TEPCO) in Japan is the approved tariff for special high voltage customers (more than 20kV and more than 2000kWh) in 2015, but the exchange rate used is the 2017 period average.

Pakistan

	FY2015	FY2016	FY2017	FY2018
NTDC tariffs, Rs/kWh	0.24	0.28	0.30	0.31
NTDC tariffs, constant Rs of 2017/kWh	0.25	0.29	0.30	0.31
NTDC tariffs, constant US¢ of 2017/kWh	0.24	0.28	0.28	0.29
GDP deflator, calendar year	258.126	261.547	272.855	277.556
Exchange rate to US$, end of calendar year	102.77	104.77	105.46	138.71

Source: Compiled by the author using NTDC and IMF statistics.

Europe

(Unit: 2017 €/MWh)

	2015	2016	2017	2018
TOS	2.45	3.58	3.50	2.89
Non-TOS	8.07	8.40	8.36	8.64
Total	10.52	11.98	11.86	11.53

TSO costs: infrastructure, system services and losses

Non-TSO costs: renewable energy support, regulatory levies, stranded costs, etc.

Source: ENTSO (2018), ENTSO-E Overview of Transmission Tariffs in Europe, Synthesis 2018

(Unit: 2017 US¢/kWh)

	2015	2016	2017	2018
TOS	0.28	0.40	0.40	0.33
Non-TOS	0.91	0.95	0.94	0.98
Total	1.19	1.35	1.34	1.30

USD1 = € 0.8852 in 2017 (period average)

Source: Compiled by the author.

Japan

Approved wheeling tariffs in December 2015

(Unit: ¥/kWh)

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kasnsai	Chugoku	Shikoku	Kyushu	Okinawa
Low voltage, 200V and less than 50kWh	8.76	9.71	8.57	9.01	7.81	7.81	8.29	8.61	8.30	9.93
High voltage, 6000V, and 50 - 2,000kWh	4.17	4.50	3.77	3.53	3.77	4.01	3.99	4.04	3.84	5.20
Special high voltage, more than 20kV and more than 2000kWh)	1.85	1.98	1.98	1.85	1.83	2.02	1.62	1.79	2.09	3.01

Source: METI

(Unit: US¢/kWh)

	Hokkaido	Tohoku	Tokyo	Chubu	Hokuriku	Kansai	Chugoku	Shikoku	Kyushu	Okinawa
Low voltage, 200V and less than 50kWh	7.81	8.66	7.64	8.03	6.96	6.96	7.39	7.68	7.40	8.85
High voltage, 6000V, and 50 - 2,000kWh	3.72	4.01	3.36	3.15	3.36	3.58	3.56	3.60	3.42	4.64
Special high voltage, more than 20kV and mere than 2000kWh)	1.65	1.77	1.77	1.65	1.63	1.80	1.44	1.60	1.86	2.68
USD1 =	¥112.17	in 2017 (period average)								

Source: Compiled by the author.

第 4 回ビデオ会議

The Project for the Study of
Upgrading National Power System
Expansion Plan

Overview of HVDC Basic Technology

December, 2020

Japan International Cooperation Agency
NEWJEC Inc.

1

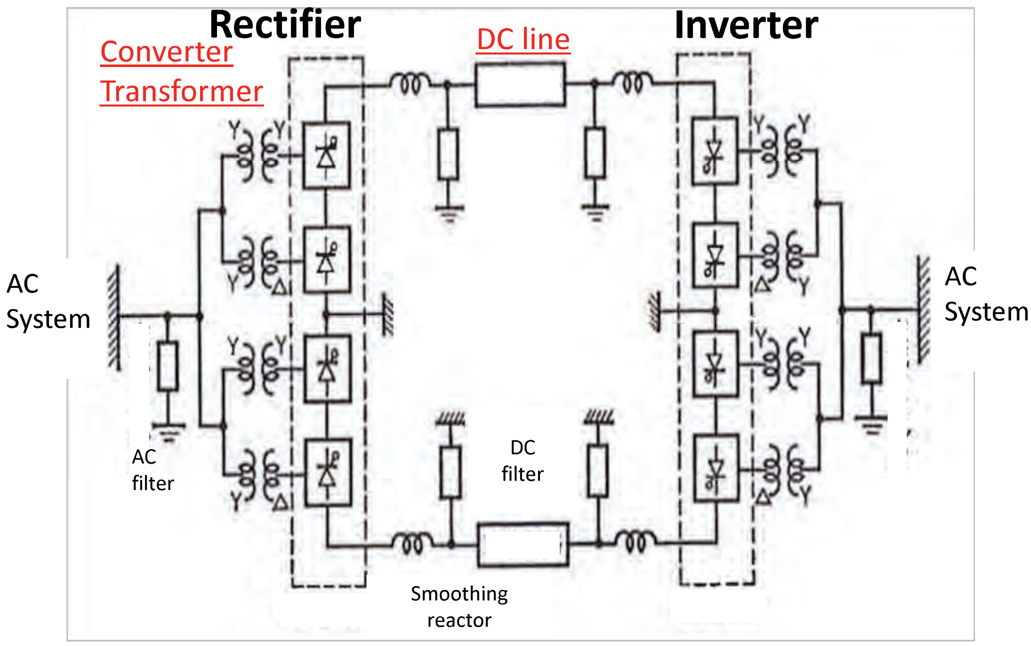
Contents

2

1. Modeling of HVDC System

3

Configuration of HVDC System



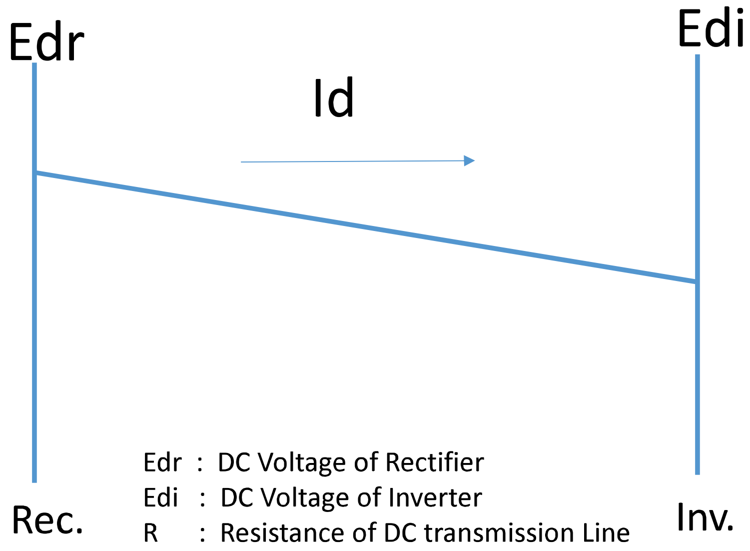
Basic Specification (Sample)
10GW 1000km ±1000kV Bi-pole 1cct
Direct Current（Id) 5kA

Basic design of HVDC will be done
For Converter Transformer and
DC Line

4

Basic Equation for direct current (Id)

(0) $Id = (Edr - Edi)/R$



DC current is decided from the difference between Ed of rectifier and Ed of inverter, and the value is calculated from equation (0)

Basic Equation for Rectifier

(1) $En = Vn * r$ — En: Rated AC Voltage of Converter Vn:Rated Voltage of AC System
r: Ratio of Converter Transformer

(2) $Ea = En / t$ — Ea : AC Voltage of Converter t:Tap of Converter Transformer

(3) $Ed = 3\sqrt{2}/\pi * Ea * \cos\alpha - 3/\pi * X * Id$ ($3\sqrt{2}/\pi = 1.35$)

Ed : DC Voltage α :Control Angle Id :DC Current
X:Commutating Reactance =Converter Transformer Reactance

(4) $\beta = 180 - \alpha$ — β :Control Lead Angle

(5) $u = \arccos(\cos\alpha - \sqrt{2} * X * Id/Ea) - \alpha$ — u : Overlapping Angle

(6) $\gamma = 180 - \alpha - u \ (= \beta - u)$ — γ : Margin Angle

(7) $P = 3\sqrt{2}/\pi * Ea * Id * (\cos(\alpha+u) + \cos\alpha)/2$ — P :AC Active Power

(8) $Q = 3\sqrt{2}/\pi * Ea * Id * \sin\arccos((\cos(\alpha+u) + \cos\alpha)/2)$ — Q: AC Reactive Power

(9) $S = \sqrt{P * P + Q * Q}$ — S: Apparent Power =Capacity of Converter Transformer

Basic Equation for Inverter

(1) En=Vn ＊ r — En: Rated AC Voltage of Converter Vn:Rated Voltage of AC System, r: Ratio of Converter Transformer

(2) Ea=En / t — Ea : AC Voltage of Converter t:Tap of Converter Transformer

(3) $Ed = 3\sqrt{2}/\pi * Ea * \cos\gamma - 3/\pi * X * Id$ ($3\sqrt{2}/\pi = 1.35$)

Ed : DC Voltage γ :Margin Angle Id :DC Current
X:Commutating Reactance =Converter Transformer Reactance

(4) $\beta = 180 - \alpha$ — β :Control Lead Angle

(5) $u = \arccos(\cos\gamma - \sqrt{2} * X * Id/Ea) - \gamma$ — u : Overlapping Angle

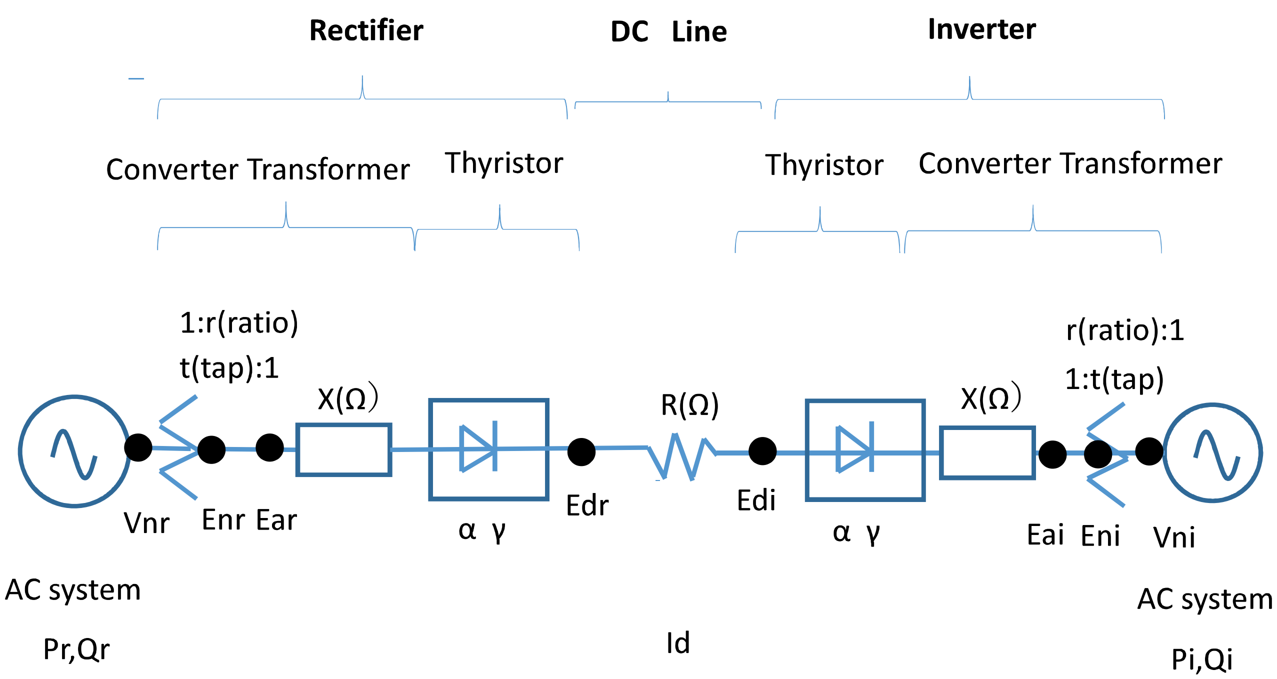
(6) $\gamma = 180 - \alpha - u\ (= \beta - u)$ — γ : Margin Angle

(7) $P = 3\sqrt{2}/\pi * Ea * Id * (\cos(\gamma+u) + \cos\gamma)/2$ — P :AC Active Power

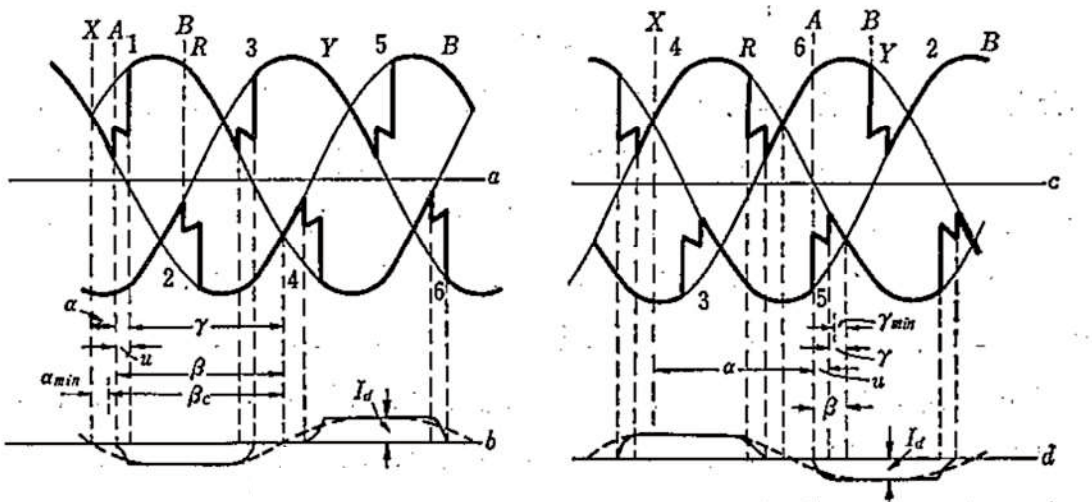
(8) $Q = 3\sqrt{2}/\pi * Ea * Id * \sin\arccos((\cos(\gamma+u) + \cos\gamma)/2$ — Q: AC Reactive Power

(9) $S = \sqrt{P * P + Q * Q}$ — S: Apparent Power=Capacity of Converter Transformer

Outline of HVDC Basic System



Definition of each angle



(a) (b)

$\beta = 180 - \alpha$

$\gamma = \beta - u$

Rectifier

Inverter

Control Angle: $\alpha \geqq 20$

Margin Angle: $\gamma \geqq 20$

For stable operation of HVDC, α and γ is preferable over 20 in general.

Study Flow for Converter Transformer Capacity

1. Setting of DC current Id (the design value)

2. Setting of control angle α tentatively, ex. 20 of rectifier and 150 of inverter

3. Setting of tentative commutating reactance X based on 1.5 times of HVDC capacity

4. Adjusting AC voltage Ea tentatively by the tap of converter transformer for matching the DC voltage Edr and Edi to the desirable value

5. Adjusting control angle of inverter for matching the calculated DC current Id to the design value

6. Resetting commutating reactance X based on the capacity of converter transformer equal to the calculated apparent power S.

7. By repeating 4-6, matching the calculated DC current Id to the design value.

8. By this flow, the capacity and the commutating reactance of converter transformer can be decided

Study result of HVDC parameter (per mono-pole)

Rectifier

En:833kV
t : 0.977
α : 20

Ed : 1000kV

Inverter

En:833kV
t :1.020
α : 142
γ : 20

Ed: 955kV

Adjust

Id 5kA (=(1000kV-955kV)/9Ω)

P 5GW
Q 2.7GVar
S 5.7GVA

Modeling

If γ is under 20, converter transformer tap of inverter is adjusted for changing the Ea

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Modeling (Study result)

(1) Basic

10GW 1000km ±1000kV Bi-pole 1cct

Direct Current (Id) **5kA**

(2) Design of converter transformer (per mono-pole)

En:833kV

S: **5.7GVA**

X= 0.14(typical %impedance)× (833kV×833kV)/(5.7GVA×1000)=**17Ω**

(3) Design of transmission line

TACSR 810sq case : 1659A 0.0363Ω/km

4conducters :**6636A**

4conducters ×1000km : **9Ω**

Basic design of HVDC system can be carried out based on this procedure.
Detail designs including auxiliary equipment and dynamics control will be done at next stage

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2. Hardware of HVDC T/L & Converter

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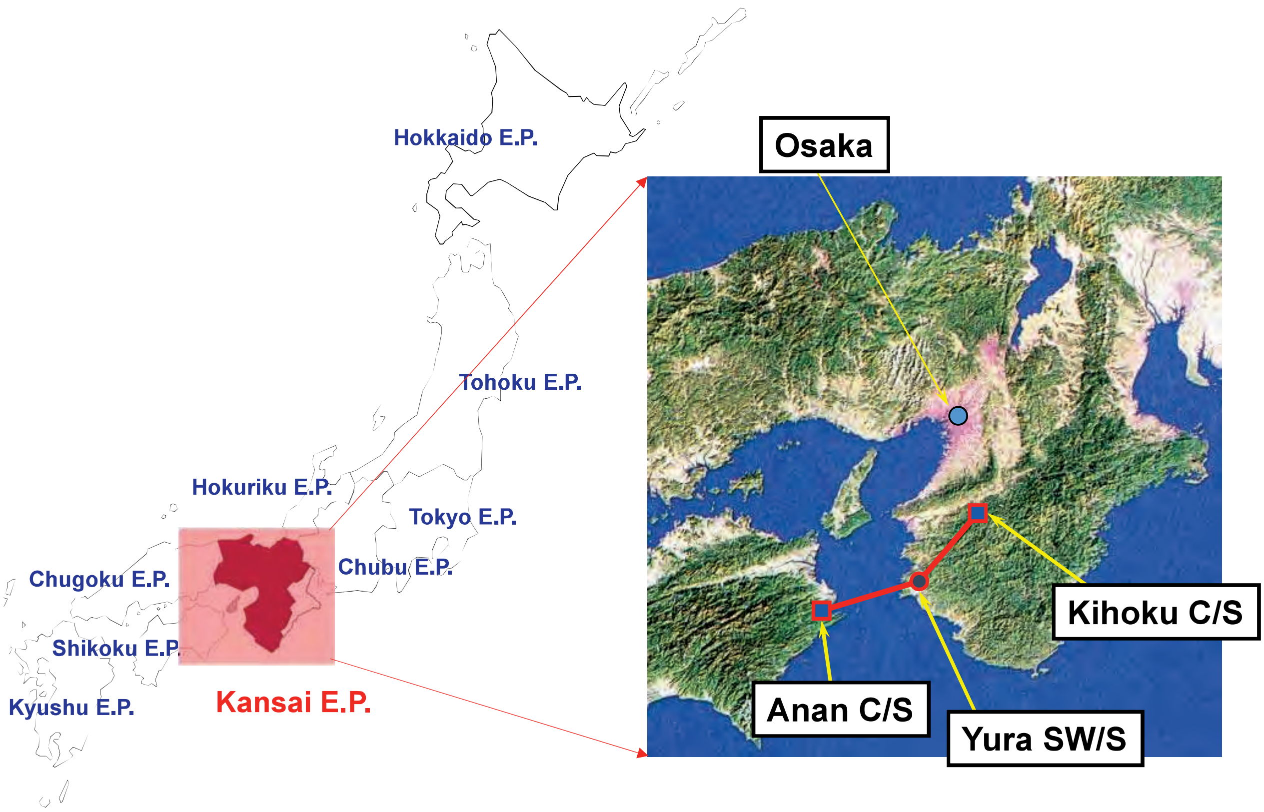
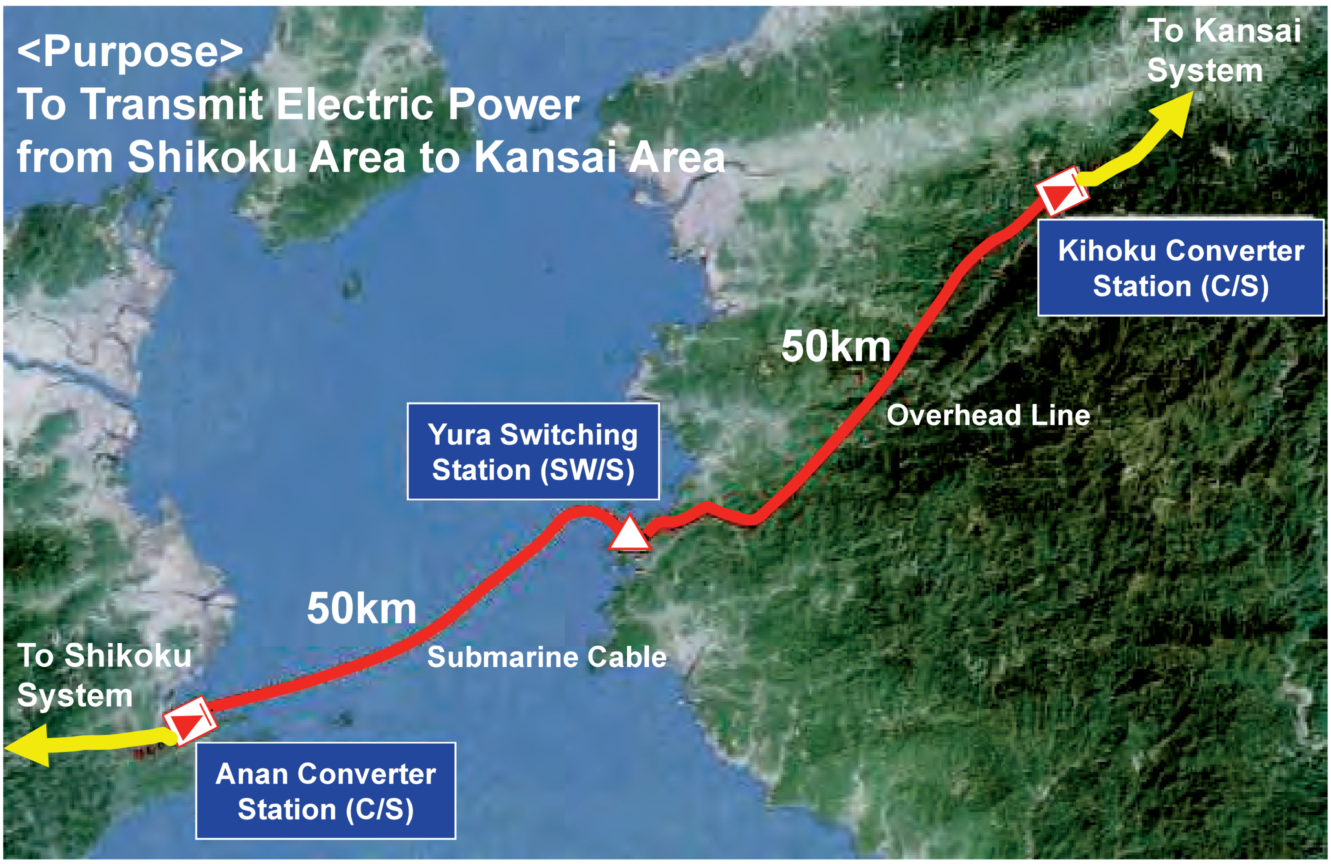
(1)HVDC between Anan and Kihoku (Japan)

Location of DC ± 500kV T/L between Anan and Kihoku



Outline of DC ± 500kV T/L between Anan and Kihoku



Outline of DC ± 500kV T/L between Anan and Kihoku

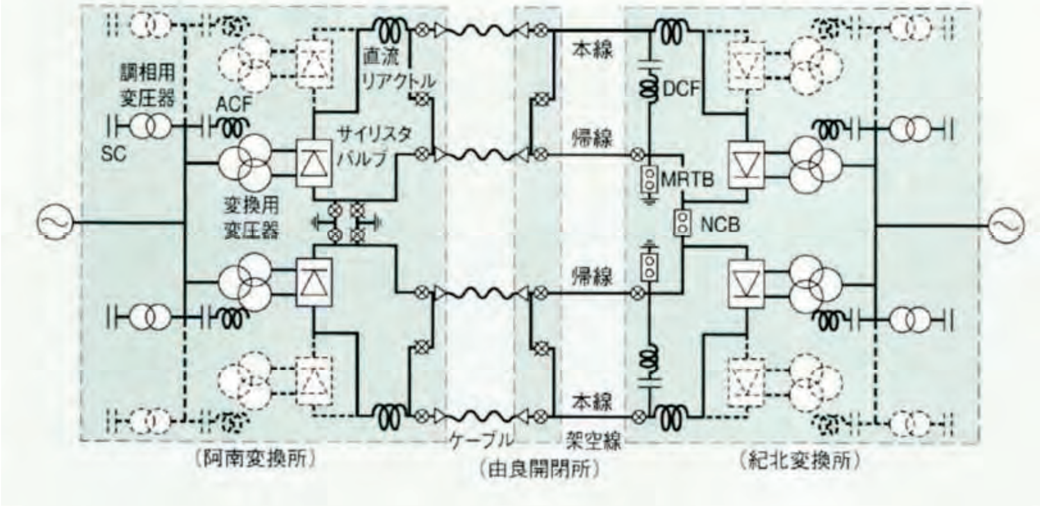
Name of T/L	Anan-Kihoku DC Trunk Line
Line Length	Approx. 102km Overhead Line: 50.9km Submarine Cable: 50.7km
Power Transmission System	DC Bipolar System with Metallic Return
Voltage	±250kV (Max. Voltage±500kV)
Transmission Capacity	1,400MW (Designed for 2,800MW)
Section of OHTL	From Yura Switching Station to Kihoku Converter Station

Kihoku Converter Station

Single Line Diagram of Kii Channel HVDC System

Converter Transformer

DC Line



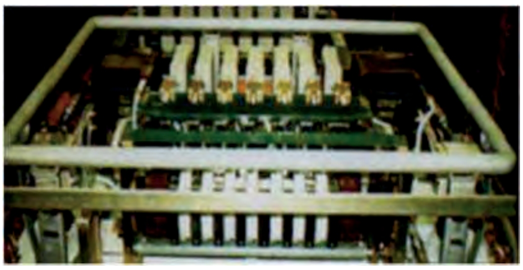
Anan Converter Station

Kihoku Converter Station

Yura Switch Station

Thyristor Valve of Kihoku Converter Station

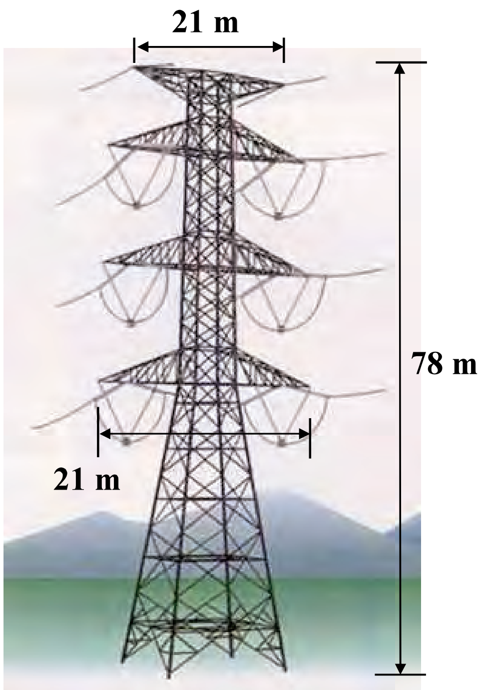
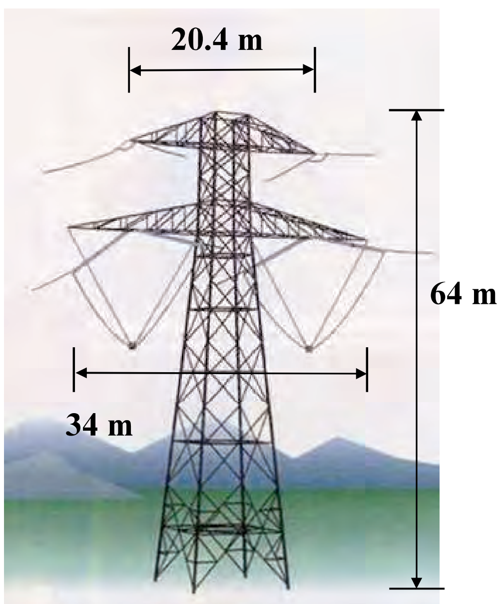
700MW Thyristor



Module of Thyristor Valve
8kV 3,500A

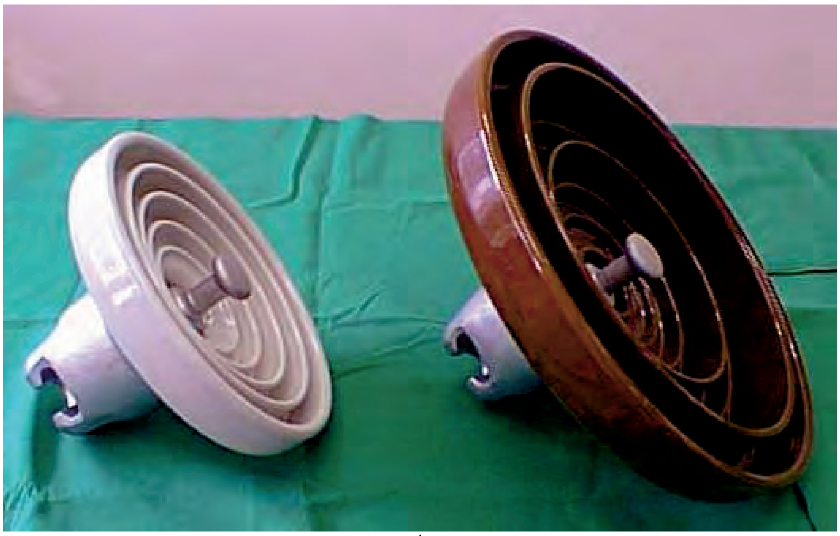
Converter Transformer of Kihoku Converter Station (872MVA)

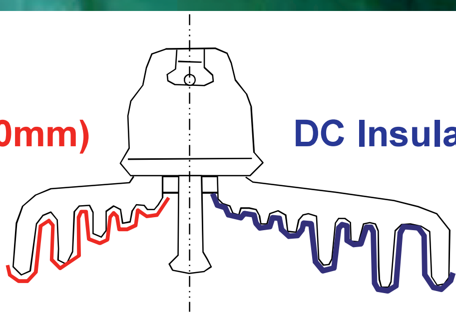
Comparison with AC 500kV T/L and DC ±500kV T/L

AC 500kV T/L	DC ±500kV T/L
	
Weight: 65t	**Weight: 40t**

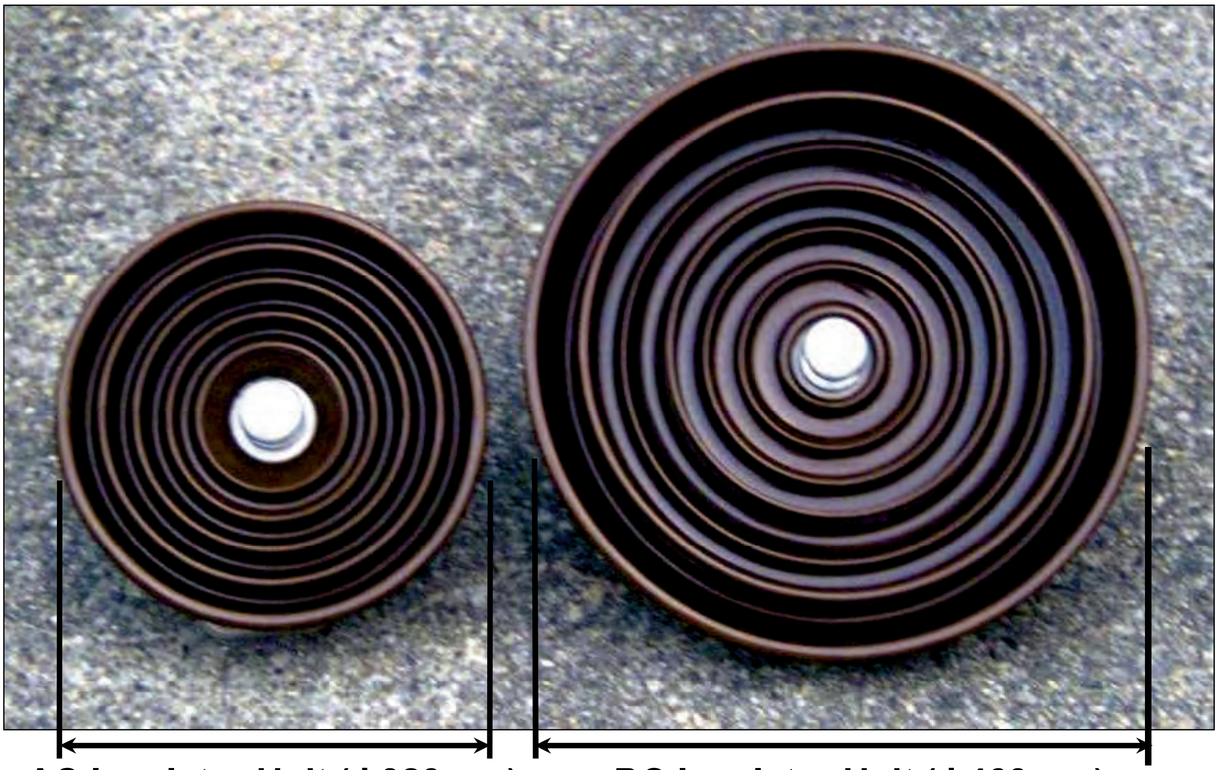
Development of DC Suspension Insulator (Φ460mm)

Comparison with AC and DC Suspension Insulator Units





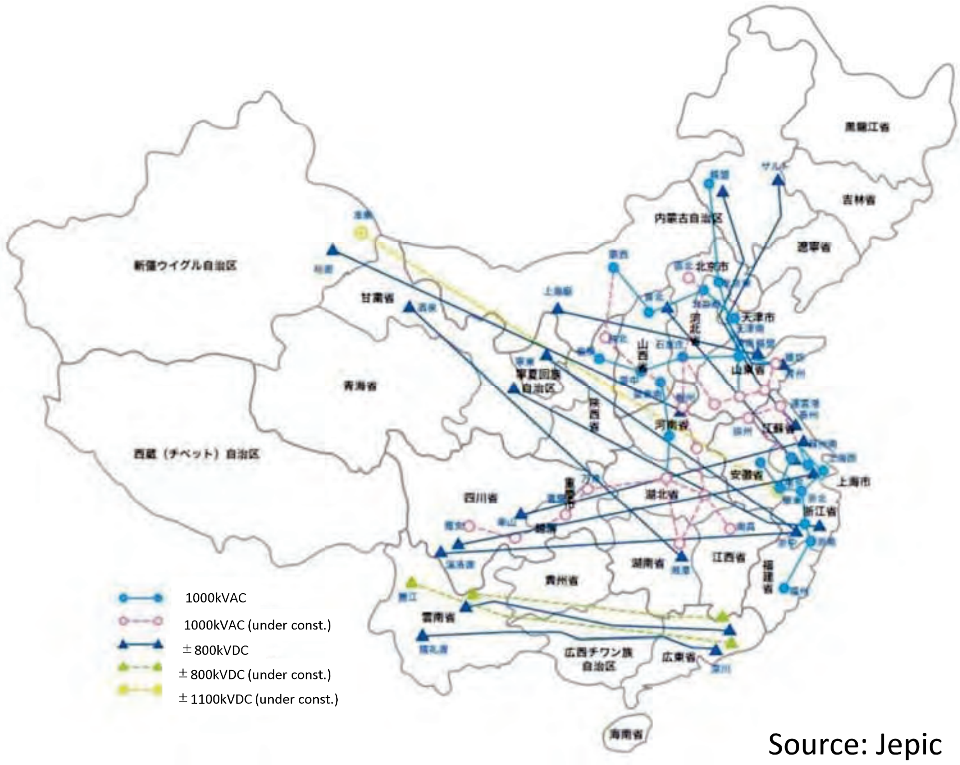
Comparison with AC and DC Suspension Insulator Units



AC Insulator Unit (Φ320mm)　DC Insulator Unit (Φ460mm)

(2)HVDC in China

Outline of UHV project in China (2018)



Source: Jepic

HVDC ±800kV Line (Oct.2017)

Source: Jepic

HVDC ± 1100kV Line under construction (Jan.2018)

Source: Jepic

添付資料　4

NTDC への提供データリスト

添付資料 4　NTDC への提供データリスト

Field	Items
01_Power System Analysis	01_01_Demand Allocation 01_02_Input Data for Generators 01_03_Preparation of Input Data for PSSE 01_04_PSSE Data for NTDC 01_05_Output of Analysis
02_Transmission and Substation	02_01_List of SS and TL 02_02_Google Earth Data of SS and TL 02_03_Power System Map
03_Transmission Line Corridor for Northern Hydropower	03_001_Power Plants 03_002_NTDC ongoing TL 03_100_Admin Boundary 03_101_River 03_102_Elevation 03_103_Slope 03_104_Road 03_200_SEA 03_300_TLs in Corridor 03_999_Google Earth Files
04_Strategic Environment Analysis	04_01_Ramsar Site 04_02_IBA 04_03_Protected Areas 04_04_Settlement Boundaries 04_05_Seismic Zones 04_06_Heritage Sites 04_07_Flood 04_08_Airport Buffers 04_99_Sensitivity Map
05_Economic and Financial Analysis	05_01_IRR Calculation for Pre FS 05_02_Financial Model for MP