TSEP 2024-34 Addendum

Introduction

As per PC 4 of the Grid Code, System Operator (SO) in coordination with the Transmission Network Operators (TNOs) shall prepare and develop an Integrated System Plan (ISP) i.e., Indicative Generation Capacity Expansion Plan (IGCEP) and Transmission System Expansion Plan (TSEP), on an annual basis. Furthermore, SO shall prepare IGCEP and share the results with the National Grid Company (NGC) and other TNOs to enable them in the timely preparation of TSEP.

Consequently, NGC shall prepare a centralized TSEP in coordination with other TNOs and submit the same to SO. Once submitted by NGC, SO shall review TSEP and submit the same to NEPRA for approval, along with the IGCEP, as part of the ISP.

In compliance to above, ISP 2024-34 was developed and submitted to the Authority on 30th April, 2024, however, the Authority gave certain directions including some additional scenarios and consultation among concerned power sector entities.

Based on the output of revised IGCEP 2025-35, the proposed list of projects (Appendix-II) was compared with the previous one i.e., IGCEP 2024-34. On analysing the list, certain key differences were observed i.e., delay in CODs of mega hydro power projects like 2160 MW Dasu Hydro Power Project (HPP), 800 MW Mohmand HPP, 4500 MW Diamer Basha HPP, and inclusion of 3109 MW of REs owing to market based induction. The timelines of power evacuation schemes and relevant network reinforcements for above said power projects have been changed / adjusted in this addendum accordingly.

It is to highlight here that the country-level as well as spatial load forecast (Appendix-I) used for TSEP 2024-34 and revised IGCEP 2025-35 is consistent. Despite the fact, the DISCOs have observed a steep decline in their network-connected consumption owing to prevailing economic conditions, and drastic increase in net-metering and roof top solar PV. In this regard, the long-term planner is of the view that this sudden decline is a short-term phenomenon and it should not impact long-term expansion decisions at this stage. Nevertheless, this trend warrants close monitoring over the coming years, and if it persists, appropriate adjustments may be incorporated into future network expansion and investment planning.

The needs assessment conducted under the revised IGCEP 2025–2035 identified a significant change concerning power exports from National Grid to K-Electric. Subsequently, the export to K-Electric is envisaged to reach 3,456 MW by 2035, compared to the previously proposed 2,050 MW.

In view of the above, a detailed cost comparison analysis between generation from already planned 620 MW of REs and increased export from National Grid will be carried out by K-Electric in due course of time. In addition to this, extensive studies will also be carried out both by K-Electric and NGC to assess system reinforcement requirements. Therefore, as of now, the increased quantum of export of power to K-Electric has not been considered in this addendum.

Way Forward

Grid Code obligates SO to develop a detailed Grid Code Operating Procedure (GCOP) clearly indicating the information that shall be submitted by each User, their deadlines and the processes that shall follow such submission. GCOP should be prepared and followed in true spirit to avoid any inconvenience in ISP process.

Study Analysis

Only those scenarios have been studied/revised in which the timelines of generation projects have been changed as compared to IGCEP 2024-34 previously submitted to the Authority. Only sensitivity analysis has been carried out in load flow by shifting the timelines of the said generation projects. Following scenarios have been studied:

- Peak Load Summer (June) 2027
- Peak Load Summer (June) 2029
- Peak Load Summer (July/August) 2034

Analysis of Summer Peak – June 2027

Peak Load Summer (June) 2027 scenario has been revised because of the change in timelines of Dasu and Mohmand HPPs. Previously 3 units of Dasu HPP (360 MW each) and all 4 units of Mohmand HPP (200 MW each) were considered. Now, in the revised scenario of June 2027, only 1 unit of Dasu HPP (360 MW) and no impact of Mohmand HPP has been considered.

The power flow plots for normal and N-1 contingency conditions, showing 500 and 220 kV networks are attached as Exhibit #1-14. The results of the load flow study show that there is no adverse impact of this generation shift and system remains stable under both normal and N-1 contingency conditions.

Analysis of Summer Peak – June 2029

Peak Load Summer (June) 2029 scenario has been revised because of the change in timelines of Diamer Basha HPP. Previously 5 units of Diamer Basha HPP (375 MW each) were considered. Now, in the revised scenario of June 2029, no impact of Diamer Basha HPP has been considered.

The power flow plots for normal and N-1 contingency conditions, showing 500 and 220 kV networks are attached as Exhibit #15-23. The results of the load flow study show that there is no adverse impact of this generation shift and system remains stable under both normal and N-1 contingency conditions.

Analysis of Summer Peak – July/August 2034

Previously, the ultimate spot year of IGCEP was 2033-34 which has now been changed as 2034-35. Therefore, this new scenario Peak Load Summer (July/August) 2034 has been studied. In this scenario, all 12 units of Basha HPP (375 MW each) have been considered. Moreover, approximately 1400 MW of candidate wind power plants are optimized in IGCEP, due to dispatch of 03 imported CFPPs as per merit order. Out of this 1400 MW wind, 800 MW and 500 MW wind power plants have been assumed in 132 kV network of QESCO and in Jhimpir area, respectively, thus requiring no reinforcement. For remaining 100 MW wind power, there is no margin available in existing Jhimpir network and upgradation of Jhimpir-II grid station from 220 kV to 500 kV voltage level along with associated transmission lines would be required. As the said upgradation for only 100 MW wind power is not a feasible option, therefore, this 100 MW wind power has not been considered in the case. It can be considered in future when more wind power gets optimized in IGCEP along with the said upgradation.

The power flow plots for normal and N-1 contingency conditions, showing 500 and 220 kV networks are attached as Exhibit #24-37. The results of the load flow study show that the system remains stable under both normal and N-1 contingency conditions.

All load flow study exhibits are attached in Appendix-3.

Transmission Development/Expansion Plan

Table 1: Power Dispersal & Import/Export projects

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Dasu HPP	Dasu HPP (Phase-1: 2160 MW) – Mansehra	765	D/C	157	Jun-2026
2	K-2/K-3 NPP	In/Out of Port Qasim CFPP – Matiari S/C at K-2/K-3 NPP	500	D/C	102	May/Jun-2025
3	Tarbela 5th Ext. HPP	Tarbela 5th Ext. HPP – Islamabad West	500	D/C	55	Aug-2025
		Tarbela 5th Ext. HPP – Tarbela		S/C	2	
4	HVDC Convertor Station at Nowshera (Azakhel)	HVDC Bi-pole Line from Tajikistan to Nowshera Azakhel (CASA-1000)	±500 kV DC		113	C/S: Jun-2025 T/L: Sep-2025
5	Mohmand HPP	Mohmand HPP – Jamrud	220	D/C	65	2027-28
		Mohmand HPP – Nowshera Industrial			70	
6	Gwadar	Gwadar – Pak Iran Border	220	D/C	75	2027-28

Table 2: 765 kV Grid Stations/Switching Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
1	Mansehra	Mansehra – Islamabad West	D/C	97	2x1200	Jun-2026
2	Upgradation of Islamabad West from 500 kV to 765 kV				3 x 1200	Jan-2027

Table 3: 500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
1	Nowshera (Azakhel)	In/Out of Tarbela – Peshawar S/C at Nowshera Azakhel	D/C	12	2 x 750	G/S: Sep-2025 T/L: May-2025
2	Lahore North	Lahore North – Lahore South CS	D/C	68	4 x 750	G/S : 1st ATF 750MVA: Apr-2024 (Energized) Remaining: Aug-2025 T/L: Already Completed
		Lahore North – Nokhar	D/C	45		
3	Maira Switching Station(S/S)	Maira – Suki Kinari HPP	D/C	156 (75 + Remaining 81 km)		S/S: Jun-2025 T/Ls: 2026-27
		Maira – Islamabad West	D/C	135		
		Karot HPP – Maira	D/C	15		
4	Allama Iqbal Industrial City (AIIC)-FIEDMC	In/Out of Gatti - Ghazi Brotha S/C at AIIC	D/C	2	2 x 750 (500/132 kV)	T/L: May-2024 G/S: Oct-2025
5	Islamabad West	In/Out of Ghazi Brotha HPP – Rewat D/C at Islamabad West	2 x D/C	5.9	3 x 750	Jan-2027
7	Upgradation of Vehari from 220 kV to 500 kV Voltage Level	In/Out of Multan – Sahiwal S/C at Vehari	D/C	35	2 x 750	2026-27
6	Sialkot New	Sialkot New – Lahore North	D/C	55	2 x 750	2027-28
8	Chakwal New	In/Out of AIIC – Ghazi Brotha/Tarbela S/C at Chakwal New	D/C	3	2 x 500 (500/132 kV)	2027-28
		In/Out of Gujranwala – Rewat S/C at Chakwal New	D/C	30		

Table 4: 220/132 kV Grid Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
1	Zhob	Zhob – D.I Khan	D/C	220	2 x 160	G/S: Jun-2025 T/L: Already Completed
2	Lahore North	In/Out of Ghazi Road/Ravi – K.S.K D/C at Lahore North	2 x D/C	15	3 x 250	G/S: Aug-2025 T/L: Already Completed
		In/Out of Lahore Old – Ravi S/C at Lahore North	D/C	14		
3	Dhabeji SEZ	In/Out of Gharo – Jhimpir S/C at Dhabeji SEZ	D/C	10	2 x 160	G/S: Aug-2025 T/L: Aug-2025
4	Mirpur Khas New	In/Out of the Hala Road – Jamshoro S/C at Mirpur Khas New	D/C	67	2 x 250	G/S: Aug-2025 T/L: Apr-2026
5	Jauharabad	In/Out of C-1/C-2/C-3/C-4 – Ludewala D/C at Jauharabad	2 x D/C	6	2 x 250	Oct-2025
6	Pilot Battery Energy Storage System (BESS) at Jhimpir-I					Oct-2025
7	Quaid-e-Azam Business Park (QABP)	In/Out of Bandala – KSK D/C at QABP	2 x D/C	3	2 x 250	G/S: Dec-2025 T/L: Already Completed
8	Swabi	Swabi – Nowshera	D/C	55	3 x 250	G/S: Dec-2025 T/L: Jun-2025
9	Haripur New	In/Out of Mansehra – ISPR S/C at Haripur New	D/C	2	3 x 250	G/S: Dec-2025 T/L: Jun-2025
10	Arifwala	In/Out of Yousafwala – Kassowal D/C at Arifwala	2 x D/C	25	2 x 250	2026-27

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
11	Nowshera (Azakhel)	In/out of Shahibagh – Chakdara S/C at Nowshera	D/C	2		2026-27
		In/out of Shahibagh – Nowshera Industrial S/C at Nowshera	D/C	12		
12	Sunder Industrial	In/Out of Kot Lakhpat – Sarfraz Nagar S/C at Sunder Industrial	D/C	2	2 x 250	2026-27
13	Gharo				2 x 250	2026-27
14	Islamabad West	In/Out of Tarbela – ISPR S/C at Islamabad West	D/C	12.5	3 x 250	Jan-2027
		In/Out of Haripur – ISPR S/C at Islamabad West	D/C	21		
15	H. Faqirian	H. Faqirian – Ludewala	D/C	88	2 x 250	2026-27
16	Mastung	Mastung – Sibbi	D/C	147	3 x 160	2026-27
17	Jamrud	Jamrud – Peshawar	D/C	45	2 x 250	2026-27
18	Nagshah	In/Out of 220 kV Multan – M. Garh New S/C at Nagshah	D/C	5	3 x 250	2026-27
		In/Out of 220 kV Multan – M. Garh-II at S/C Nagshah	D/C	5		
19	Zero Point	In/Out of 220 kV I.S.P.R – Mansehra S/C at Zero Point	D/C	22.5	2 x 250	2026-27
		In/Out of 220 kV Islamabad University – Rawat S/C at Zero Point	D/C	4		
20	Punjab University	In/Out of Bund Road – New Kot Lakhpat D/C at Punjab University	2 x D/C	1	3 x 250	2027-28
21	Gujranwala-II	Gujranwala-II – Nokhar	D/C	80	2 x 250	2027-28
22	Sialkot New	Sialkot New – Sialkot (Sahuwala)	D/C	12	3 x 250	2027-28
		Sialkot New – Gujranwala-II	D/C	36		

Table 5: Transmission Lines for System Reinforcement

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Second Source of Supply to Jaranwala Road	In/Out of Trimmu RLNG - FBD West S/C at Sammundri Road	220	D/C	35	T/L: Oct-2024 220 kV Line Bay: 2026-27
		Sammundri Road to Jaranwala Road (Including 2 km U/G cable)		D/C	23	2026-27
2		Faisalabad West – Lalian New	220	D/C	56	T/L: Aug-2025 220 kV Line Bay: 2026-27
3		Reconductoring of Tarbela – Burhan D/C on twin bundled Rail conductor	220	D/C	35	2025-26
4	Reinforcement of Sahiwal Area	Sahiwal – Sahiwal PP	500	S/C	11.6	2026-27
		2x500 kV line bays				
5	Second Source of Supply to 500 kV Sheikh Muhammadi	OHL line from Peshawar to In/Out point of Nowshera using the same right of way	500	D/C	29	2026-27
		500 kV line bay at Sheikh Muhammadi				
		Nowshera - Ghazi Brotha (By-passing of 500 kV Tarbela – Ghazi Brotha – Chakwal S/C from Ghazi Brotha)	500	D/C	52	
6		Reconductoring of Bund Road – Kot Lakhpat D/C T/L (Partially on U/G cable)	220	D/C	17	2026-27
7	Second Source of Supply to Hala Road	In/Out of Jamshoro – T.M. Khan S/C at Hala Road	220	D/C	21	2026-27
		In/Out of Jamshoro – T.M. Khan S/C at Hala Road Part-II on Composite Tower			3	

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
8	Interlinking of Dharki, Rahim Yar Khan, Bahawalpur and Chishtian Grid Stations	Dharki – Rahim Yar Khan	220	D/C	105	2026-27
		Rahim Yar Khan – Bahawalpur		D/C	150	
		In/Out of Chishtian – Vehari S/C at Lal Sohanra		D/C	80	
9		Reconductoring of Burhan – ISPR D/C on twin bundled Rail conductor	220	D/C	27.5	2026-27
10		In/Out of one circuit of the proposed Islamabad West -Ghazi Brotha D/C T/L at Faisalabad West	500	D/C	277	2027-28

Table 6: Extension/Augmentation of 500/220 kV and 220/132 kV Transformers

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
1	Nokhar	Extension of 4th Transformer	500/220	1 x 600	Dec-2025
2	Lahore (Sheikhupura)	Replacement of 1x450 MVA Transformer with1x600 MVA	500/220	1 x 600	2026-27
3	Faisalabad West	Extension of 3rd Transformer	500/220	1 x 750	
4	Multan	Replacement of old 1x450 MVA Transformer with new one	500/220	1 x 450	
5	Dadu	Extension of 3rd Transformer	500/220	1 x 450	
6	Sheikh Muhammadi (Peshawar)	Extension of 4th Transformer	500/220	1 x 450	2028-29

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
7	New Kot Lakhpat	Extension of 4th Transformer	220/132	1 x 250	May-2025
8	Islamabad University	Extension of 3rd Transformer	220/132	1 x 250	
9	Sibbi	Extension of 3rd Transformer	220/132	1 x 160	Jun-2025
10	Loralai	Extension of 3rd Transformer	220/132	1 x 250	
11	T.M. Khan	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	
12	Hala Road	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	
13	Jamshoro	Extension of 3rd Transformer	220/132	1 x 160	
14	Yousafwala	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1 x 250	2024-25
15	Nokhar	Augmentation of 3x160 MVA Transformers with 3x250 MVA	220/132	3 x 250	Dec-2025
16	R.Y. Khan	Extension of 3rd Transformer	220/132	1 x 250	2026-27
17	Allai Khwar	Extension of 3rd Transformer	220/132	1 x 160	2026-27
18	Guddu	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2026-27
19	Yousafwala	Augmentation of 3x160 MVA Transformers with 3x250 MVA	220/132	3 x 250	2026-27
20	Guddu	Extension of 3rd Transformer	220/132	1 x 250	2027-28

Table 7: Projects for Voltage Control and Reliability Improvement

Sr. No.	Name of Project	Project Description	Expected Completion Date
1	Reactive Power Compensation at 220 kV and 132 kV Grid Stations	96 MVAR Switched Shunt each at 132 kV Ravi, Ghazi Road, Wapda Town, Punjab University, Lahore North, Lalian New, Nishatabad, Nokhar, KAPCO, Piranghaib, Bahawalpur, Sahuwala, Jaranwala Road, Yousafwala, Vehari, Mastung and 220 kV Kala Shah Kaku	2026-27
2	Mitigation of high fault level at 132 kV Burhan	16 Ohm inter bus Current Limiting Reactor (CLR) between 132 kV bus bars of Burhan 220/132 kV Grid station	2026-27
3	246 MVAR SVS at 132 kV Quetta Industrial	96 MVAR Switched Shunt	2027-28
		±150 MVAR STATCOM	
4	196 MVAR SVS at 132 kV Khuzdar	96 MVAR Switched Shunt	2027-28
		±100 MVAR STATCOM	

Table 8: Newly Proposed Power Dispersal & Import/Export projects

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Basha HPP	Basha HPP – Dasu HPP with 111 MVAR Line Reactors at both ends	765	D/C	75	2032-33
		Mansehra – Lahore North with 222 MVAR Line Reactors at both ends	765	D/C	350	2033-34
		In/Out of one circuit of the proposed Basha HPP – Dasu HPPD/C T/L at Mansehra with 222 MVAR Line Reactors at Basha HPP and Mansehra ends	765	D/C	157	2033-34
		Basha HPP – Suki Kinari HPP with 111 MVAR Line Reactors at Basha HPP end	500	D/C	190	2032-33
		50% Series Compensation of D/C T/Line from Basha HPP to Suki Kinari HPP	500	D/C		
		In/Out of one circuit of the proposed Maira–Karot HPP D/C T/L at Lahore North with 111 MVAR Line Reactors at Maira, Karot and Lahore North ends	500	D/C	240	
		Basha HPP – Maira Switching Station with 111 MVAR Line Reactors at both ends	500	D/C	350	2033-34
		50% Series Compensation of D/C T/Line from Basha HPP to Maira Switching Station	500	D/C		
2	Balakot HPP	In/Out of Maira – Suki Kinari HPP S/C at Balakot HPP	500	D/C	2	2027-28
3	C-5 NPP	In/Out of Ludewala–Nowshera S/C at C-5 NPP with 111 MVAR Line Reactors at C-5 NPP end	500	D/C	19.25	2030-31
		C-5 NPP– Ludewala with 111 MVAR Line Reactors at both ends		S/C	150	

Table 9: Newly Proposed 765, 500 & 220 kV Grid Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
			765 kV			
1	Upgradation of Lahore North from 500 kV to 765 kV (Part of scope of work of Basha HPP)				3x1200	2033-34
			500 kV			
1	Upgradation of Okara from 220 kV to 500 kV	In/Out of one circuit of Yousafwala – Sahiwal CFPP D/C at Okara	D/C	15	2x750	2027-28
		Okara – Lahore South CS	D/C	70		
2	Upgradation of Ludewala from 220 kV to 500 kV	In/Out of proposed Nowshera – Ghazi Brotha S/C at Ludewala with 111 MVAR Line Reactors at Nowshera, Ludewala and Ghazi Brotha ends	D/C	325	2x750	2027-28
		Ludewala – Faisalabad West with 111 MVAR Line Reactors at Ludewala end	D/C	100		
3	Upgradation of Gujrat from 220 kV to 500 kV	In/Out of Maira – Lahore North S/C at Gujrat	D/C	52.5	2x750	2032-33
4	Lahore East	In/Out of Lahore South CS – Lahore North D/C at Lahore East	2 x D/C	60	2x750	2032-33
			220 kV			
1	DHA Prism	In/Out of Ghazi Road – Lahore South S/C at DHA Prism	D/C	1	2x250	2027-28
2	Burewala	Burewala – Vehari	D/C	30	2x250	2027-28
		Burewala – Arifwala	D/C	40		

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
3	Lodhran	In/Out of M. Garh – Bahawalpur D/C at Lodhran	2 x D/C	20.5	3 x 250	2032-33
4	Lahore East	In/Out of Ghazi Road – Shalimar S/C at Lahore East	D/C	22.7	3 x 250	2032-33

Table10: Newly Proposed Transmission Lines for System Reinforcement

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Reinforcement of South to North transmission interface	In/Out of one circuit of the proposed Sialkot New – Lahore North D/C T/L at Maira	500	D/C	235	2027-28
2		Matiari – Moro with 111 MVAR Line Reactors at Moro end	500	D/C	142	2028-29
		Moro – R.Y. Khan111 MVAR Line Reactors at both ends	500	D/C	337	
3		Reconductoring of 220 kV D/C T/Line from KSK to Bund Road Grid Station	220	D/C	27	2028-29
4		Nishatabad – Gatti 3rd circuit	220	S/C	2.2	2032-33

Table 11: Newly Proposed Extension/Augmentation of 500/220 kV and 220/132 kV Transformers

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
1	Muzaffargarh	Extension of 3rd Transformer	500/220	1 x 600	2025-26
2	R. Y. Khan	Extension of 3rd Transformer	500/220	1 x 600	2032-33
3	Sialkot New	Extension of 3rd Transformer	500/220	1 x 750	2032-33
4	D. I. Khan	Extension of 3rd Transformer	220/132	1 x 250	2027-28
5	Faisalabad West	Extension of 4th Transformer	220/132	1 x 250	2032-33
6	Zhob	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2032-33
7	Dadu	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2032-33

Table 12: Newly Proposed Projects for Voltage Control and Reliability Improvement

Sr. No.	Name of Project	Project Description	Expected Completion Date
1	Reactive Power Compensation at 220 & 132 kV Grid Stations	96 MVAR Switched Shunt each at 220 kV Lahore South and 132 kV Sarfraz Nagar	2026-27
2	Bus Reactors at 500 & 220 kV Grid Stations	• 2x111 MVAR at 500 kV Shikarpur • 111 MVAR each at 500 kV Sheikh Muhammadi, Rewat, Faisalabad West and D.G. Khan • 60 MVAR each at 220 kV Zhob, D.M. Jamali and Loralai	2026-27
3	Reactive Power Compensation	96 MVAR Switched Shunt at 132 kV switchyard of proposed 220/132 kV Burewala	2027-28

Sr. No.	Name of Project	Project Description	Expected Completion Date
4	STATCOM at 500 kV Grid Stations	±400 MVAR each at 500 kV Dadu, Guddu, M. Garh, R.Y. Khan and Sheikhupura	2028-29
5	STATCOM at 500 & 220 kV Grid Stations	±400 MVAR each at 500 kV Faisalabad West and 220 kV Chishtian	2032-33
6	Reactive Power Compensation at 132 kV Grid Stations	96 MVAR Switched Shunt each at 132 kV R. Y. Khan, Lodhran and Islamabad University	2032-33
7	Bus Reactor	60 MVAR Bus at 220 kV Mirpur Khas	2032-33
8	Switchgear replacement	Replacement of switchgear equipment at 500 kV Gatti	2032-33
9	Switchgear replacement	Replacement of switchgear equipment at 500 kV Lahore	2032-33

Note:

- The expected CODs of some of the projects have been revised as compared to previous version of TSEP 2024-34 submitted to NEPRA on 30-04-2024 due to generation shift in IGCEP.
- The expected CODs of a few projects have been revised as compared to the previous version of TSEP 2024-34 submitted to NEPRA on 30-04-2024 due to unavailability of financing for the projects or physical progress, as experienced at present.
- As conflict exists between load demand of respective DISCOs and load demand prepared by System Operator (SO), the requirement of projects beyond 2026-27 will be checked/revalidated after resolution of the conflict.

The following table illustrates the existing and planned NTDC transformation and transmission system capacity.

Table 13: Existing and Planned Transformation and Transmission System Capacity of NTDC

Year	765 kV			500 kV			220 kV			±660 kV	±500 kV
	No. of G/S	T/F Cap. (MVA)	T/L Length (km)	No. of G/S	T/F Cap. (MVA)	km (T/L)	No. of G/S	T/F Cap. (MVA)	T/L Length (km)	T/L Length (km)	T/L Length (km)
2024-25 (Up to April 2025)	-	-	-	19	26,700	9,198	50	39,160	12,131	2x886	-
2034-35	3	9,600	1,672	29	48,550	15,413	66	56,880	15,153	2x886	2x113

There are additional 500 kV and 220 kV grid stations owned and operated by other entities but are part of NTDC integrated system:

- 500 kV Tarbela and Ghazi Brotha having 500/220 kV transformation capacities of 1350 MVA and 1200 MVA respectively.
- 220 kV Mangla, KAPCO and Bahria town having transformation capacities of 414 MVA, 500 MVA and 63 MVA respectively.

The geographical maps showing NTDC network configuration in different years are attached as Appendix-4.

Cost Estimates of the Transmission Plan

A summary of category wise aggregated scope of work of the new transmission expansion and reinforcement projects, identified in addition to the already planned/ongoing projects, and the corresponding cost estimates are presented below:

Table 14: Ongoing/Already Planned Transmission Projects

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	1,396.22
2	765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	2,217.73
3	Transmission Lines for System Reinforcement	698.18
4	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	166.09
5	Projects for Voltage Control and Reliability Improvement	122.01
Total		**4,600.23**

Note: *For ongoing projects, PC-1 cost has been used. The prevalent exchange rate of 1US$ = 280.70 PKR has been assumed for cost calculations.*

Table15: Newly Proposed Transmission Projects

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	3,145.13
2	765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	1,143.16
3	Transmission Lines for System Reinforcement	961.33
4	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	65.30
5	Projects for Voltage Control and Reliability Improvement	730.91
Total		**6,045.83**

Note: *The prevalent exchange rate of 1US$ = 280.70 PKR has been assumed for cost calculations.*

NTDC

Transmission System Expansion Plan
(TSEP 2024-34)
April 2024

TRANSMISSION SYSTEM EXPANSION PLAN (TSEP) 2024-34

April 2024

Striving for Reliable Grid

Power System Planning, NTDC

EXECUTIVE SUMMARY

In fulfillment of its Grid Code requirement, NTDC is obligated every year to submit a ten-year Transmission System Expansion Plan (TSEP) to the Regulator (NEPRA) for its bulk transmission network (220 kV and above voltage levels). TSEP shall primarily determine the following:

- Power evacuation schemes for upcoming generation projects
- System reinforcement/expansion for removal of transmission constraints and to meet future load demand
- Cross-border import/export of power
- System stability improvement and voltage support

Like the previous year, the activity has been jointly undertaken by the NTDC planning engineers in the lead, and the USAID's Power Sector Improvement Activity (PSIA) project team in a support role. TSEP has been developed based on the Indicative Generation Capacity Expansion Plan 2023-34 (IGCEP 2024) and the substation-wise demand forecasts at the system and each DISCO level.

Three spot years, i.e., 2026-27, 2028-29 and 2033-34 have been selected to develop power flow network models (base cases) considering different operating conditions.

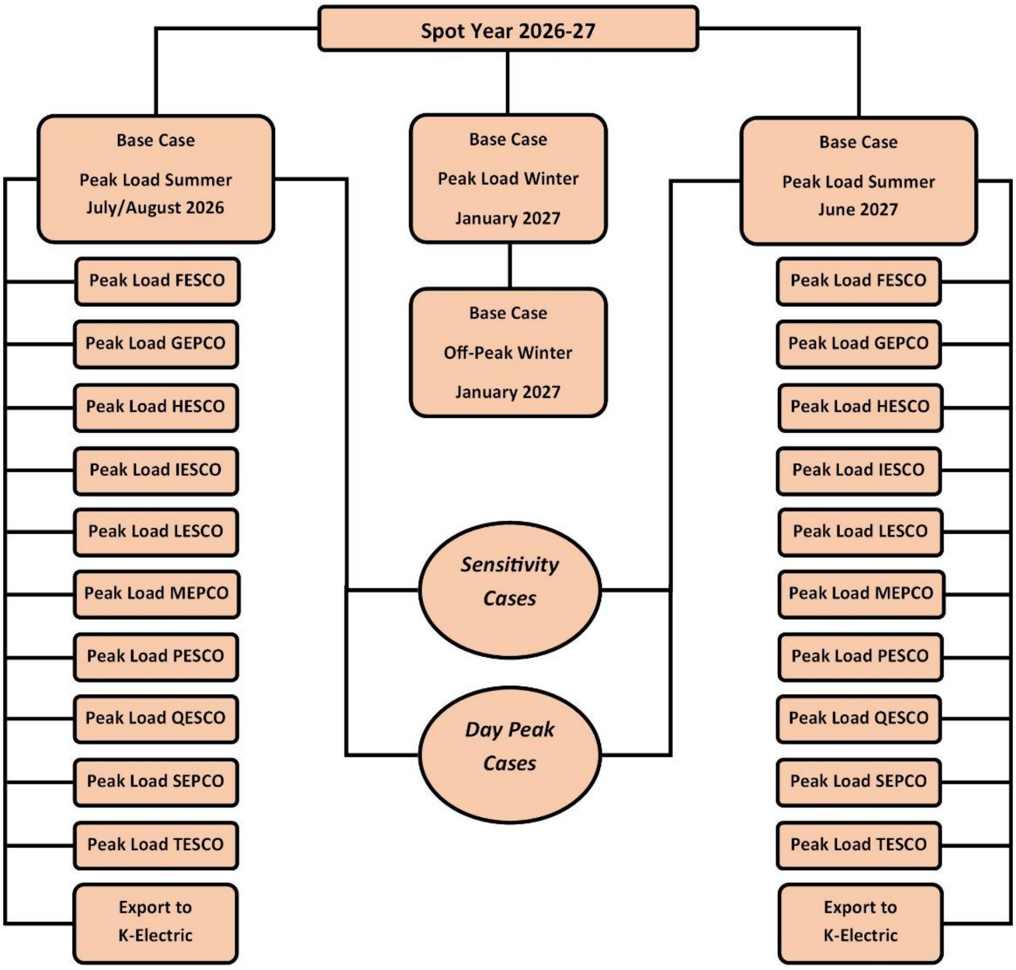
Standard analytical techniques were employed for transmission planning studies using state of the art Siemens-PTI's software tool PSSE®. Extensive power flow, short-circuit and stability analyses have been performed to identify the transmission development/expansion and investment requirements in the next 10 years.

Most of the under construction and committed transmission projects expected to commission in the next three years have been incorporated in the base cases developed for 2026-27. In addition, some network reinforcements and system operational measures have been proposed on the basis of multiple sub-studies in order to optimize system performance while considering the following objectives:

- To identify generation interconnection schemes to ensure evacuation of power from new generation plants to the load centers.
- To determine the expansion/reinforcement requirements to meet the latest load demand of the DISCOs.
- To assess system short circuit levels and to propose remedial measures to keep the fault currents within their ratings.
- To ascertain that the integrated power system is transiently stable when subjected to fault conditions.
- To determine reactive power compensation requirements for voltage support & system stability.
- To prepare costing of the proposed transmission projects
- Recommendations for improvement of system performance

A comprehensive approach has been followed for the analysis of the updated base cases developed in meeting the above objectives, such as peak demands of each DISCO and peak/off-peak system conditions. Figure A, illustrates the process for developing power flow base cases for each study year to capture all the possible system operating scenarios, especially the boundary conditions. As can be seen, at least twenty-five (25) power flow cases are required for each study (spot) year. Simulations were carried out for normal system and N-1 contingency operating conditions to determine adequacy of the proposed transmission facilities under each seasonal pattern of power flow conditions. The analyses considered system peak demand as well as respective peak demand of each DISCO, one at a time, so that adequacy of the bulk and secondary transmission requirements (for NTDC and DISCO networks) can be ascertained.

Figure A: Process for development of power flow models/base cases



The following operating conditions have been analyzed for all the spot years, i.e., 2026-27, 2028-29 and 2033-34:

- Peak Load Summer July/August (high hydro and high demand)
- Peak Load Summer June (low hydro as compared to July and high demand)
- Peak and off-Peak Load Winter (low hydro and low demand)
- Day-Peak Load Summer (high solar)

Many new projects for network expansion and reinforcement have been identified based on a detailed analysis of all the above-mentioned system operating conditions. A summary of category wise aggregated scope of work of the new transmission expansion and reinforcement projects, identified in addition to the already planned/ongoing projects, and the corresponding cost estimates are presented in Tables A and B.

Table A: Ongoing/Already Planned Transmission Facilities

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	741.46
2	765 kV Grid Stations/Switching Stations and Associated Transmission Lines	185.10
3	500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines	397.83
4	220/132 kV Grid Stations and Associated Transmission Lines	780.93
5	Transmission Lines for System Reinforcement	654.24
6	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	62.49
7	Projects for Voltage Control and Reliability Improvement	390.01
Total		**3,212.06**

Note: *For ongoing projects, Cost to be incurred in future is used in the above table. The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

Table B: Newly Proposed Transmission Facilities

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	2,551.13
2	765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	1,086.68
3	Transmission Lines for System Reinforcement	1,217.90
4	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	54.94
5	Projects for Voltage Control and Reliability Improvement	665.45
Total		**5,576.1**

Note: *The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

The general conclusions and recommendations based on system studies performed are given as follows:

1. Installation of 2x48 MVAR switched shunt capacitors at132 kV bus bars of 220/132 kV substations where needed. The proposed solution will not only improve the voltage profile and reduce loading on transformers but also help in minimizing the use of expensive/out of merit generation. A list of substations that urgently need steady state reactive support is provided in this report. NTDC shall expedite this project on an urgent basis for economical and secure operation of the system.

   In addition, timely completion of Vehari 500 kV and Nagshah 220/132 kV grid stations is instrumental in eradicating dependance of secure system operation on KAPCO or other generation in the vicinity. Therefore, these projects should be expedited on priority basis.

2. To improve the system performance and to eradicate dependance of north to south interface power transfer limit on the intermediate generating stations (Guddu, Muzaffargarh, KAPCO, etc.), installation of dynamic reactive support has been studied in parallel with an international

consultant CESI under the project titled "System Studies for Review of Grid System Performance" and some potential sites for installation of ±400 MVAR STATCOM each, have been initially identified and included in the TSEP.

3. Expedite implementation of 500/132 kV Chakwal New and 765/500/220/132 kV Islamabad West substations and reinforce supply network to Faisalabad West substation by connecting it to Ghazi Brotha/Islamabad West through new 2x500 kV circuits in line with upcoming generation in the north. These developments are very crucial and any delay in these projects would stress the system making it vulnerable to voltage instability and causing severe overloading on multiple circuits/transformers. Therefore, it is strongly recommended that these projects should be completed on a fast-track basis.

4. The existing south to north power transfer interface is not capable of transmitting full generation available in the south, including the 1845 MW wind generation. Reinforcement of south to north transmission interface is inevitable to avoid any curtailment of power in the south. Accordingly, 500 kV D/C Matiari-Moro-R. Y. Khan OHL is included in the plan and shall be built on priority basis.

5. Although, a comprehensive interconnection scheme for Diamer Basha HPP has been proposed, however, there might be slight changes in this scheme since another consultancy project is being initiated to review and finalize the power evacuation plan for Basha HPP based on detail routes survey, soil investigation, high altitudes, engineering considerations, tower spotting, etc.

6. The following switchgear ratings have been proposed for the existing (as per requirements) and future substations after carrying out extensive short circuit analysis and by suggesting operational measures/network re-configuration:

    - 40 kA short circuit ratings for 132 kV voltage level.
    - 50 kA short circuit rating for 220 kV and 500 kV voltage levels.
    - 63 kA short circuit rating shall be used for substations or power plants connected at 220 kV or 500 kV level where the use of 63 kA rating is unavoidable due to network requirements.
    - 50-63 kA short circuit rating for 765 kV voltage level

7. The results of transient stability studies reveal that the system is transiently stable for all the credible contingencies analyzed, however, a few contingencies, under certain operating conditions, cause post-disturbance oscillations on the system, which need to be further investigated. The under-execution study project "System Studies for the Grid System Performance and Proposals for System Stability Improvement" has also made some recommendations in this regard. In addition, the following remedial measures are recommended:

    - Validation of dynamic models and control parameters of generators, exciters, governors, and Power System Stabilizers through measurements and where possible, check response of these validated models against actual events. Also, develop appropriate dynamic load models since contribution of the air-conditioning load on the system has increased significantly and voltage recovery has become challenging under certain contingencies.
    - Installation/commissioning of Power System Stabilizers (PSS) at some of the existing power plants and all new power plants. System Operator should carry out the required system studies to identify appropriate locations for PSS installations and

supervise tuning of these PSSs to avoid any inter-area or local area oscillations on the integrated power system.

- Installation of Dynamic System Monitors (DSM) at all 500/220 kV substations for real time recording. Also, install PMUs at key substations to improve observability of the system for better control. Installation of these devices would help in performing diagnostic/post-mortem analysis and for improving the dynamic system model.

8. Installation of dynamic reactive power compensation devices, such as STATCOM, in the QESCO area to address its voltage stability issues. Phase-wise additions are recommended and to start with, it is proposed to install 150 MVAR STATCOM and 96 MVAR Switched Shunt at Quetta and 100 MVAR STATCOM and 96 MVAR Switched Shunt at Khuzdar by 2026-27.

9. Evaluate and initiate a process of converting the old power plants, which are close to the load centers, into synchronous condenser instead of decommissioning them. In this regard, the key stakeholders including CCPA, IPPs and GENCOs shall be consulted to come up with a way forward enabling NTDC to use this potential of ancillary service with possible amendments in the tariff structure and contracts.

10. Adopt higher equipment ratings and standardize development plans, as recommended below.

    - 500/220 kV transformers shall be 750 MVA and 220/132 kV transformers shall be 250 MVA.

    - The 500/220 kV, 500/132 kV and 220/132 kV substations should be standardized to have three transformers each feeding main load centers. In remote areas where load demand is relatively low, a two-transformers configuration can be used initially but the layout of the substations should have provision to install up to 4th transformer in the future, as and when required.

    - Reconductoring or replacement of existing 220 kV lines of single conductor to twin-bundled conductors or HTLS in order to increase the line capacity. This shall be decided on case-to-case basis. Quad bundled 220 kV lines for specific use may also be considered.

    - 220/132 kV grid stations in thickly populated areas can be of GIS type connected with the main grid through XLPE cables of standard sizes.

11. The connection of line reactors shall be standardized with provision to use the line reactors as bus reactors when the respective line is switched-off.

12. Enhancement in knowledge base of planning and operation teams through structured capacity building training programs. These teams need to prepare themselves to meet challenges related to excessive penetration of VRE resources, appropriate application of FACTS devices, use of new software tools, such as PSCAD for transient studies, etc.

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TABLES

FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND DEFINITIONS

ADB	Asian Development Bank
AEDB	Alternative Energy Development Board
Cct-km	Circuit-kilometer
DISCO	Distribution Company
DSM	Demand Side Management
GDP	Gross Domestic Product
GENCO	Generation Company
HPP	Hydel (or Hydro) Power Project
HSFO	High-Sulphur Furnace Oil
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEEE	Institute of Electrical and Electronic Engineers
kA	Kilo-Ampere
KESC	Karachi Electric Supply Company
km	Kilo meter
kV	Kilo Volt
MMcfd	Million cubic feet per day
MOU	Memorandum of Understanding
MT	Metric Tons
MVA	Mega volt-amperes
MWh	Megawatt-hour or 1,000 kilowatt-hours
NEPRA	National Electric Power Regulatory Authority
NPP	National Power Plan, prepared by Acres International Limited in 1994
NTDC	National Transmission and Despatch Company
OGDCL	Oil and Gas Development Company Limited
P.P.	Power Project
PAEC	Pakistan Atomic Energy Commission
PARCO	Pak-Arab Refining Company
PPIB	Private Power and Infrastructure Board
PPL	Pakistan Petroleum Limited
PQA	Port Qasim Authority
PSO	Pakistan State Oil
PSS/E	Power System Simulation
RFO	Residual Furnace Oil
SIL	Surge Impedance Load
SNGPL	Sui Northern Gas Pipeline Limited
SSGCL	Sui Southern Gas Company Limited
SYPCO	Generation planning software (System Production Costing)
TAVANIR	The Iranian Electric Utility
WAPDA	Water and Power Development Authority

1. INTRODUCTION

In fulfillment of the Grid Code requirement, NTDC is obligated to submit a ten-year Transmission System Expansion Plan (TSEP), with the IGCEP, to the Regulator (NEPRA). After finalization of the IGCEP-2024, the TSEP activity has been jointly undertaken by the NTDC planning engineers and the USAID's Power Sector Improvement Activity (PSIA) project team. NTDC led this activity with a significant support from the PSIA team that assisted in developing alternative reinforcement/expansion plans for different operating scenarios, provided technical expertise in resolving many constraints in the existing transmission system and assisted in report development.

1.1 OBJECTIVES

The main objective of this activity is to develop a comprehensive transmission expansion plan, comprising of new substations and transmission lines as well as extension/augmentation of existing substations considering the committed and expected generation additions and demand requirements up to the horizon year 2033-34. This will also include generation interconnection of mega projects along with detailed analyses for system performance improvement. Three spot years (2026-27, 2028-29 and 2033-34) have been selected for detailed analysis to ascertain system expansion requirements to cover different time spans up to the horizon year.

The TSEP is being developed to fulfill the following:

- To determine the expansion/reinforcement requirements to meet with the expected load demand of the ten DISCOS following the reliability criteria as per the approved Grid Code for the transmission system.
- To identify generation interconnections, i.e., transmission requirements to ensure evacuation of power from new generation plants to the load centers.
- To assess system short circuit levels and to propose remedial measures and/or any change in switchgear rating to keep the fault currents within their ratings.
- To ascertain that the integrated power system is transiently stable when subjected to fault conditions on the bulk power (220 kV, 500 kV and 765 kV AC and HVDC) network.
- To determine reactive power compensation requirement to keep the voltage profile within the stipulated limits under maximum and minimum load conditions and to avoid any voltage collapse situation in general.
- To propose Grid Solutions to minimize the use of expensive generation, where possible.
- To develop a comprehensive cost basis and to determine stage-wise investment requirements (high level estimates) for the proposed expansion plan.

1.2 RELIABILITY CRITERIA

The Grid Code bounds NTDC to comply with the following planning and performance criteria:

Steady State:

Adequacy and steady-state system performance assessment of transmission facilities shall be based on equipment nominal loading, congestion management, short circuit levels and voltage regulation.

The results of steady-state power flow studies shall be deemed acceptable if they do not result in any voltage violations or overloads based on predetermined loading limits for Normal (N-0) and contingency (N-1) conditions.

The permissible loading limits for OHL/cables and transformers under normal operation is 80%, however, under contingency conditions, the permissible loading limits are 100% and 110 % for lines and transformers, respectively.

Dynamic/Transient Conditions:

The integrated power system shall remain stable under the following disturbances:

a) Permanent three-phase fault on any primary transmission line and associated components, cleared normally in 5 cycles.

b) A single-phase to ground fault with a "Stuck Breaker" condition, with delayed clearing in 12.5 cycles after fault initiation

The robustness of the proposed transmission expansion plan has been tested against criterion (a) whereas criterion (b) needs to be applied at the detailed design stage of generating stations and their interconnection schemes with the national grid. Should there be any stability concerns, appropriate mitigation measures shall be identified and incorporated into the system improvement plans for future years.

Grid Frequency Variations:

The nominal frequency of the NTDC transmission system is 50 Hz, which shall be maintained within the normal operating limits of 49.8 Hz to 50.2 Hz.

Grid Voltage Variations:

Normal operating conditions: Voltage variations for nominal system voltages up to 500 kV level shall remain within the bandwidth of +8% to –5%.

Contingency operating conditions: Voltage variations for nominal system voltages up to 500 kV level shall be in the range of ±10%.

The upper voltage limit of the nominal 765 kV level is 800 kV and the lower limit shall not be below 5% under normal and contingency conditions.

Short Circuit Levels:

Maximums short circuit calculations shall be performed for each study year. Adequacy of fault interrupting capability and short circuit withstand capacity shall be ensured.

1.3 NTDC POWER NETWORK

The existing NTDC transmission network is shown in Figure 1-1. The primary (backbone) network mainly consists of 500 kV overhead lines (OHLs), which run from North to South making a typical longitudinal network. The North has an enormous hydro potential, whereas the thermal and RE generations are distributed in the South and middle of the country.

The main load centers of the country are in the top half area that constitutes about 75% share of the total demand. The system peak demand occurs in summer when the hydro power generation output is high. However, this hydro generation output is low during winter and shoulder months and the demand is mostly met with thermal power generation. Accordingly, there are two distinct patterns of power flow in the system. In summer, power flows from North to South and in winter, it flows from South to North. This necessitates installation of Long HVAC (500 kV or above) and HVDC lines to carry power for both the power flow patterns.

Maintaining a reasonable voltage profile, both in summer and winter months, is quite challenging. Although, the DISCOS are required to maintain their power factor within a specified limit (above 0.95 pf at the common coupling points with the NTDC network), however, there are frequent incidents where these limits are violated and cause extra reactive power burden on the NTDC transmission system. Also, long lines, with generation sources away from load centers, necessitate the installation of reactive power compensation devices (sources and sinks) for secure and reliable operation of the integrated power system. Besides, dynamic VAR compensation devices such as SVCs, STATCOM, SVS and other FACTS devices play a vital role for maintaining voltage stability and can enhance the power transfer capability of South to North transmission interface. Therefore, optimal reactive power compensation is a potential issue and needs to be evaluated thoroughly.

1.4 INTERCONNECTION/TIE-LINES WITH OTHER ENTITIES

KE Electricity Network (K-Electric)

K-Electric (KE) is supplying power to the Karachi area. Although it is an independent entity, it shall be considered in the country's transmission system expansion plan. From 2024-25 onwards, NTDC agreed to export 2050 MW to KE and supply of this power has been assumed in the generation capacity expansion plan (IGCEP-2024). Correspondingly, KE has provided its available transmission network model for all the spot years which were incorporated into the NTDC load flow base cases for the TSEP related system studies.

Interconnection with Tajikistan (CASA)

NTDC will be having a 1000 MW HVDC interconnection with Tajikistan which is expected to be commissioned by August 2027. This import of power is considered in the TSEP.

DISCOs Connections

NTDC is currently supplying power to ten Distribution Companies which are managing their 132 kV and below networks and meeting demand requirements of their respective areas. Each DISCO is responsible of developing its network expansion plan, however, NTDC and DISCOs teams worked together to review, simulate, and verify system reinforcement and expansion requirements within each DISCO network to be considered in the TSEP.

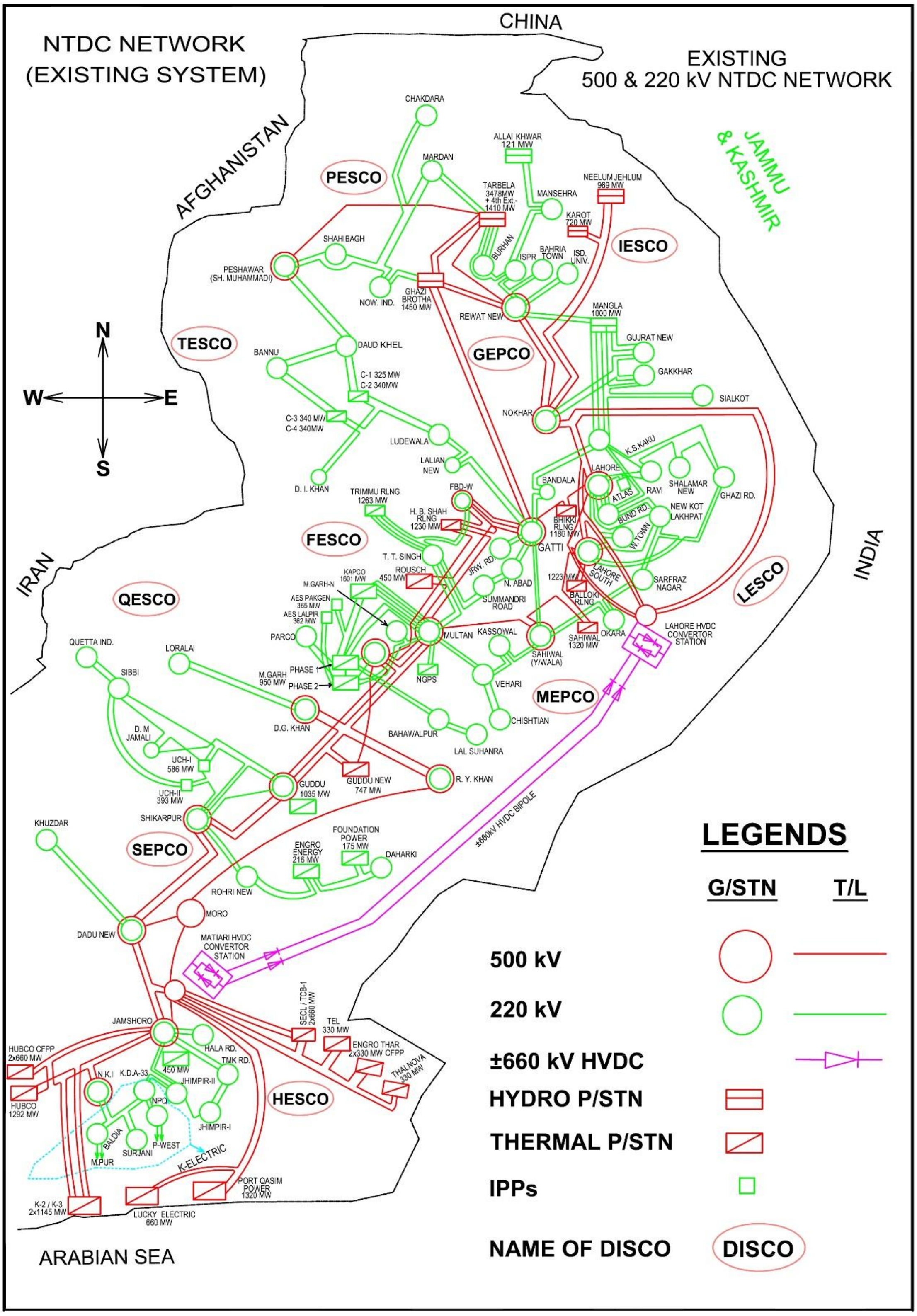
Interconnection with Iran

Currently NTDC has a 132 kV link from Iran feeding 80 MW to Gwadar area and another link (220 kV OHL energized at 132 kV) feeding an additional 100 MW to the area. These links will be operated in isolated mode and are considered in the TSEP. The under construction 220/132 kV grid station will be commissioned by 2027-28.

Provincial Grid Companies (PGCs)

There are few PGCs which are in the process of developing their own networks. At this stage, they do not have any transmission plan developed and accordingly, their representation in TSEP is minimal. However, their generation projects, which are identified in the IGCEP-2024, have been considered in the TSEP along with their interconnection to the grid. Any update on their transmission network development, if made available, would be considered in the next TSEP.

Figure 1-1: Existing 500/220 kV NTDC System



2. INPUT DATA AND ASSUMPTIONS

2.1 DEMAND FORECAST 2023-34

The spatial demand forecast is used for developing transmission reinforcement and expansion plans for DISCOs and NTDC up to the year 2033-34. DISCO-wise load flow base cases have been combined to make composite cases for identifying NTDC's transmission expansion requirements for multiple intermediate (spot) years and for the horizon year 2033-34. Table 2-1 shows the peak demand forecasts (low demand scenario) used for the analysis. The detailed demand forecast results are presented in Appendix A. The demand under the normal scenario is considerably lower as compared to last year's forecast used for the analysis. This would be achievable considering an energy conservation drive by NEECA and other entities which is targeted on reducing the air conditioning load within the demand.

Table 2-1: System Peak Demand Forecasts 2023-2034

Name	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027	2027-2028	2028-2029	2029-2030	2030-2031	2031-2032	2032-2033	2033-2034
LESCO	5488	5607	5760	5949	6163	6253	6529	6766	6905	7119	7257	7453
GEPCO	2390	2486	2615	2763	2923	3028	3212	3388	3515	3684	3816	3996
FESCO	3186	3014	3158	3347	3563	3729	3989	4233	4455	4730	4964	5182
IESCO	2819	2834	2877	3011	3160	3249	3416	3577	3687	3831	3932	4061
MEPCO	4418	4607	4804	5025	5265	5407	5675	5914	6063	6285	6438	6676
PESCO	2672	2737	2887	3006	3134	3180	3288	3392	3444	3540	3587	3691
HESCO	1226	1248	1268	1298	1332	1338	1371	1388	1404	1424	1426	1446
QESCO	1114	1196	1244	1299	1361	1399	1459	1514	1545	1590	1614	1674
TESCO	533	543	558	575	594	600	619	634	639	650	654	667
SEPCO	1006	1023	1051	1083	1118	1130	1165	1192	1199	1218	1223	1246
Coincidence Factor (%)	88.4	93.5	93.2	92.8	92.5	92.1	92.0	92.0	92.0	92.0	92.0	89.02
System Demand Without Export to KE	22615	24422	25243	26226	27316	27869	29165	30365	31170	32313	33098	33111
Export to KE	1064	1100	2050	2050	2050	2050	2050	2050	2050	2050	2050	2050
System Demand With Export to KE	**23679**	**25522**	**27293**	**28276**	**29366**	**29919**	**31215**	**32415**	**33220**	**34363**	**35148**	**35161**

Note: T&T losses do not include HVDC loss

2.2 IGCEP 2023-34

The Generation Planning team of System Operator (SO) has developed the Indicative Generation Capacity Expansion Plan (IGCEP) based on the above-mentioned demand forecast. A detailed list of the generation additions in the base case is attached as Appendix B and summarized in Table 2-2. Generation interconnection schemes and power evacuation facilities are identified in the TSEP to connect the new generation facilities to the load centers. In addition, system-wide transmission reinforcement and expansion requirements are assessed after rigorous transmission system studies.

Table 2-2: Summary of Generation Additions in IGCEP

Fiscal Year	Coal Fired Steam Imported Coal	Coal Fired Steam Local Coal	Nuclear	HPP	Solar Utility MWp	Net Meter MWp	Solar KE MWp	Wind NTDC	Wind KE	Bagasse	Per Year Committed Capacity Addition	Per Year Total Capacity Addition	Cumulative Capacity Addition
2024	0	0	0	10	150	0	0	0	0	0	0	160	160
2025	660	0	0	1,145	132	240	0	0	0	32	0	2,209	2,369
2026	0	0	0	1,694	0	241	0	0	0	30	0	1,965	4,334
2027	0	0	0	1,958	1,200	215	0	0	0	0	0	3,373	7,707
2028	300	0	0	2,380	1,350	223	0	100	0	0	100	4,453	12,160
2029	0	0	0	1,910	0	186	0	0	0	0	100	2,196	14,356
2030	0	0	0	2,625	0	191	0	0	0	0	100	2,916	17,272
2031	0	0	1,200	82	0	205	0	0	0	0	100	1,587	18,859
2032	0	0	0	0	0	92	0	0	0	0	100	192	19,051
2033	0	0	0	0	0	303	0	0	0	0	100	403	19,454
2034	0	0	0	0	0	211	0	0	0	0	100	311	19,765
Total	**960**	**0**	**1,200**	**11,805**	**2,832**	**2,107**	**0**	**100**	**0**	**62**	**700**	**19,765**	

Table 2-3 provides a list of major power plants that are already committed or are under construction. Correspondingly, the transmission interconnection and power evacuation schemes/plans for each of these power plants have been identified and summarized in the table below.

Table 2-3: Major Committed Power Plants and Connectivity Schemes

S. No.	Project Name	Capacity (MW)	Type	Power Evacuation Plan	Expected Commissioning
1	Suki Kanari	884	Hydro	Interim Arrangement: Loop in-out of N. Jhelum – Karot 500 kV circuit at Suki Kinari	2023-24
				500 kV D/C OHL from Suki Kanari to the proposed Maira 500 kV switching station and from Maira to Islamabad West	2026-27
2	Tarbela 5th Extension	1,530	Hydro	500 kV S/C from Tarbela 5th to existing Tarbela 500 kV D/C from Tarbela 5th to Islamabad West	2024-25
3	Dasu	2160	Hydro	765 kV D/C OHL from Dasu to Mansehra Switching station 765 kV D/C OHL from Mansehra to Islamabad West	2025-26
4	Mohmand Dam	800	Hydro	220 kV D/C OHL from Mohmand Dam to Nowshera Ind. Substation 220 kV D/C OHL from Mohmand Dam to the proposed Jamrud Substation	2026-27
5	Balakot	300	Hydro	In-out of one circuit of D/C 500 kV Suki Kinari to Maira at Balakot	2027-28
6	Diamer Basha	4500	Hydro	765 kV D/C OHL from Basha to Dasu 500 kV D/C OHL from Basha to Suki Kanari with 50% series compensation	2027-28
				In-out one circuit of D/C 765 kV Basha-Dasu OHL at Mansehra 765 kV D/C OHL from Dasu HPP to Lahore North 500 kV D/C OHL from Basha to Maira switching station with 50 % series compensation	2028-29
7	C-5 NPP	1200	Nuclear	In-out of 500 kV Nowshera-Ludewala S/C at C-5 NPP 500 kV S/C from C-5 NPP to Ludewala	2029-30

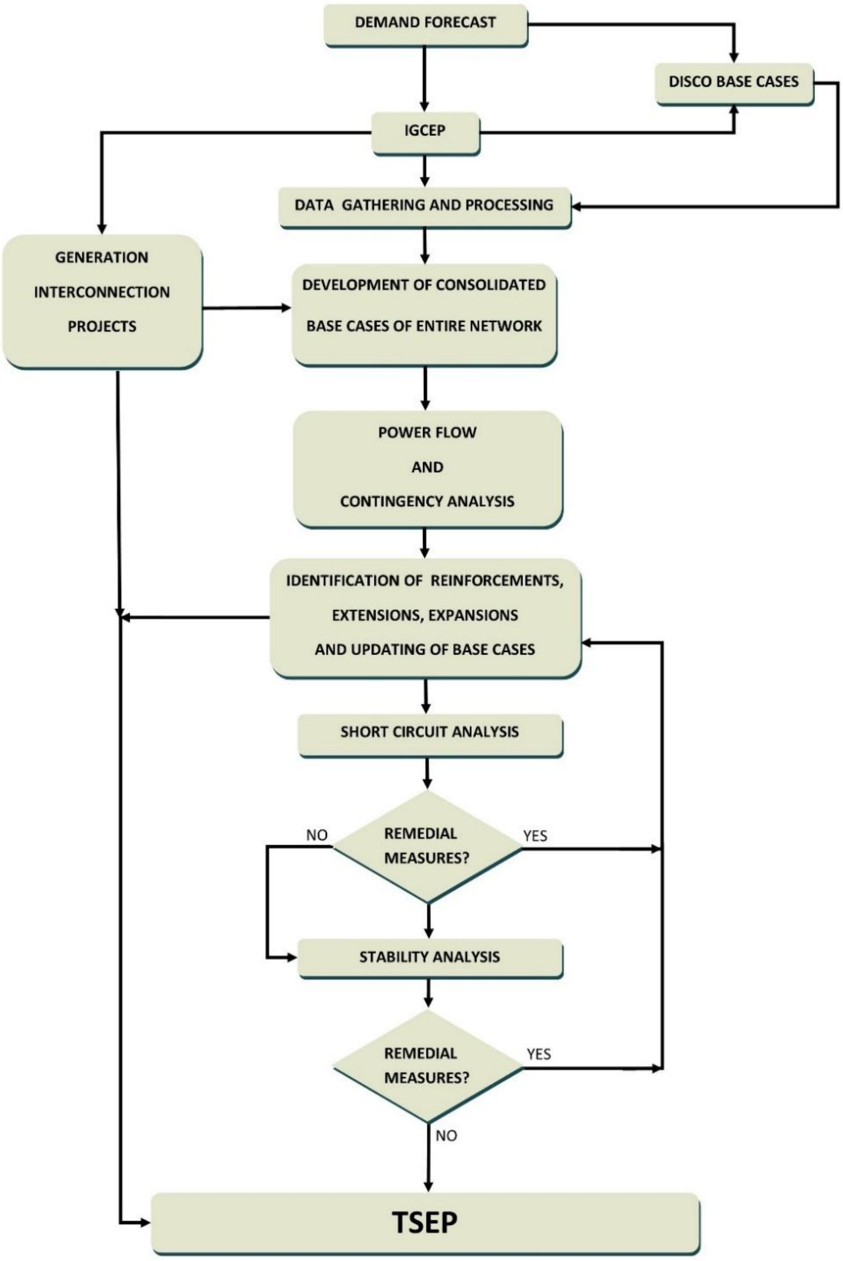
2.3 COMMITTED TRANSMISSION EXPANSION PROJECTS

Many transmission system reinforcements and expansion projects are already envisaged based on earlier studies and the TSEP-22 (Phase I). These reinforcements are deemed necessary to remove transmission bottlenecks and to meet the system demand reliably. In general, most of these projects are expected to be commissioned between 2022-26 and have been considered in the TSEP 24. A general review of these projects was carried out during the study process and necessary adjustments were made, where required. Resultantly, these transmission projects were incorporated into power flow base cases developed for the TSEP related system studies.

3. APPROACH AND METHODOLOGY

This TSEP corresponds to the IGCEP 2024 that annunciates a generation development sequence for a period from 2024 to 2034. This generation expansion plan has been appropriately incorporated into the TSEP, which will be based on results of the extensive system studies carried out for the three spot years comprising 2026-27, 2028-29 and 2033-34. The development of load flow base cases, simulations, and analyses for the first spot year primarily considered the committed and under construction generation and transmission projects, whereas the optimized generation projects in the base scenario are largely incorporated in the next two study years. Accordingly, transmission system reinforcement and expansion requirements have been determined to reliably supply power to the respective load centers (DISCOs) and power exchange through the national and international tie-lines, such as with KE and Tajikistan.

Figure 3-1: Process for Development of Transmission System Expansion Plan (TSEP)



3.1 BASE CASES DEVELOPMENT

Power flow base cases to represent future operating scenarios were developed using the existing network topology of 2024. Each DISCO developed its own load flow base cases to represent operating scenarios of 2026-27 and 2028-29. Subsequently, NTDC and DISCO teams worked together to review, simulate and verify the system reinforcement and expansion requirements within the DISCO network. Finally, the respective load flow cases for each DISCO were incorporated into the NTDC load flow case (2026-27 and 2028-29) to form a single power flow base case for each spot year. The following data inputs formed the bases for development of the study cases:

- PMS based Load Forecast (base case)
- Indicative Generation Expansion Plan (IGCEP) 2024 (base case)
- Existing transmission network data files in the PSS/E format
- All the ongoing and committed/planned transmission expansion envisaged up to the year 2026-27 for removing the existing bottlenecks, congestions, over loadings, grid code violations and firm capacity breaches of substations.

Table 3-1 shows the existing installed capacities, their respective availabilities and future generation additions as per the IGCEP 2024. The generation dispatch used in the load flow base cases is derived from this table based on the merit order and seasonal availability of power from each type of power plant. This sequence of generation addition is used in the power flow analysis.

Table 3-1: Generation Capacity Additions up to 2033-34

Power Plants Category	Exist. Inst. Cap. (MW)	Capacity Addition (MW)										
		2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30	2030-31	2031-32	2032-33	2033-34
Hydro (WAPDA)	9,459	0	88	1600	1950	1080	1905	2625				
GENCO 1	450		660									
GENCO 2	1,367											
GENCO 3	1,476											
Nuclear	3,530								1200	-	-	
IPPs Hydro	1,221	10.2	1056.9	94.3	8	300	5.2	0	82.25	0	0	0
IPPs Thermal	19,239					300						
IPPs Bagasse	368	0	32	30	0	0	0	0	0	0	0	0
Wind (NTDC)	1,845	0	0	0	0	100	0	0	0	0	0	0
New Technology		0	0	0	0	100	100	100	100	100	100	100
Solar	500	150	131.52	0	1200	1350	0	0	0	0	0	0
Sub-Total NTDC	39,454	160	1,968	1,724	3,158	3,230	2,010	2,725	1,382	100	100	100
Solar KE	100	0	0	0	0	0	0	0	0	0	0	0
Wind KE		0	0	0	0	0	0	0	0	0	0	0
Thermal KE	3,210											
Sub-Total KE	3,310	0	0	0	0	0	0	0	0	0	0	0
CASA						1000						
Total	42,764	160.2	1968.42	1724.3	3158	4230	2010.2	2725	1382.25	100	100	100
Net Metering		0	240	241	215	223	186	191	205	92	303	211
Retirements	0	546	136	0	2133	233	1177	167	743	0	660	1733
Yearly Total	42,764	-386	2,072	1,965	1,240	4,220	1,019	2,749	844	192	-257	-1,422
Cumulative total	**42,764**	**42,379**	**44,451**	**46,416**	**47,656**	**51,876**	**52,896**	**55,645**	**56,489**	**56,681**	**56,424**	**55,002**

For the starting sport year, load flow base cases for the spot year 2026-27 have been developed by the DISCOs and reviewed by NTDC. These include necessary reinforcements required to meet the demands of DISCOs. The corresponding 220 kV and 500 kV expansion requirements of the NTDC network were determined and included in the 2026-27 base cases, which formed part of the transmission reinforcement and expansion plan for the TSEP 2024.

Similarly, load flow base cases for the spot year 2028-29 are developed by updating the base cases of the spot year 2026-27 with all the DISCOS networks expansion requirements included to meet the forecasted demand in their respective areas. The corresponding 220 kV and 500 kV expansion requirements of the NTDC network are determined and added in the 2026-27 base cases to develop the base cases of 2028-29. These expansion requirements for NTDC would also form part of the transmission reinforcement and expansion plan for the TSEP 2024.

However, for the spot year of 2033-34, the DISCOs' network assumed in June 2029 has only been considered and no additional expansion in DISCOs network is included. Loads at the existing substations are increased linearly as per the expected demand of each DISCO and in case any 220/132 kV substation exceeds its firm capacity, the remaining load is lumped at the respective 220 kV bus. NTDC network requirements are then determined, including transmission lines, substations, reactive power compensation, etc., to meet the expected demand in a secure and reliable manner and accordingly, base cases for the horizon year 2033-34 are developed for analysis.

3.2 STUDIES APPROACH AND METHODOLOGIES

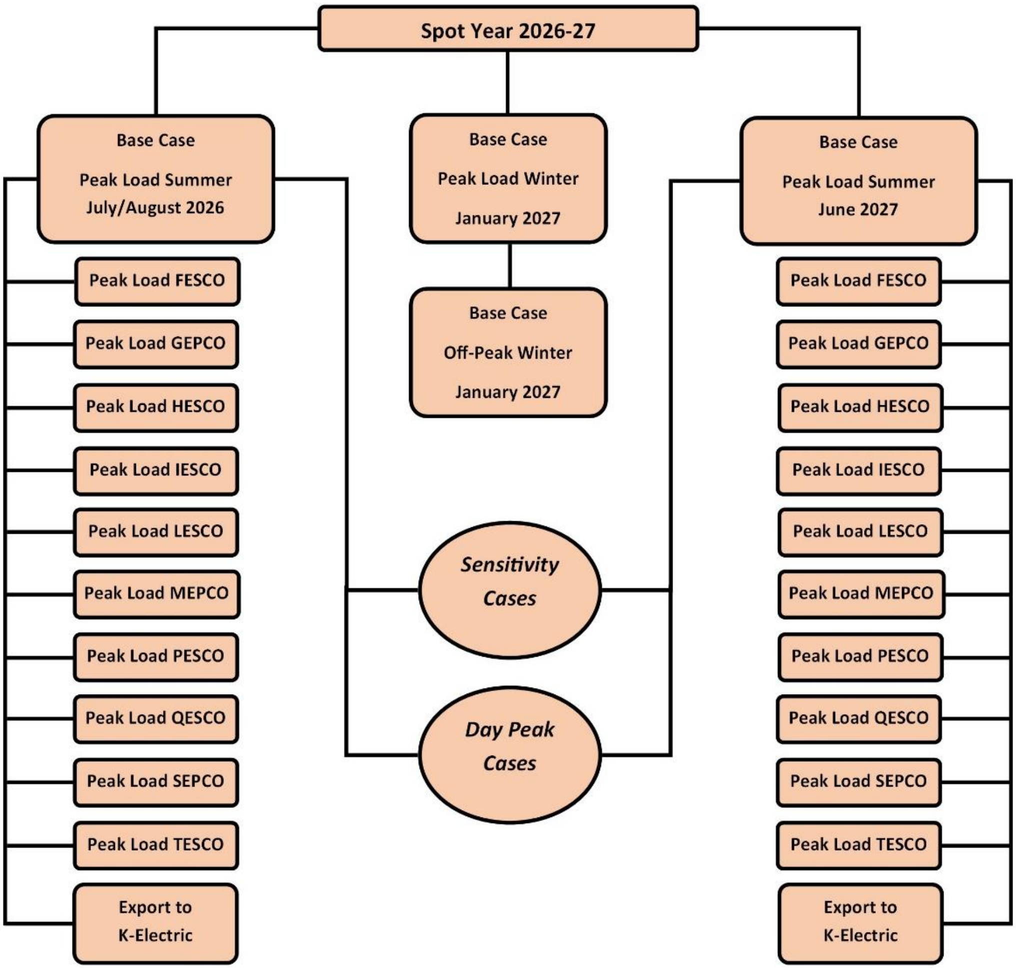
Standard analytical techniques for transmission planning studies (load flow, short circuit, and transient stability analyses) have been employed using the state of art software PSS/E® of Siemens-PTI.

The following operating conditions (base cases) have been analyzed for each study year.

- Peak Load Summer July/August (high hydro and high demand)
- Peak Load Summer June (low hydro as compared to July and high demand)
- Peak and off-Peak Load Winter (low hydro and low demand)
- Day-Peak Load Summer (high solar)

It is noted that there are ten associated peak demand cases, which correspond to each summer base case, i.e., one case for exclusive peak demand of each DISCO. The purpose is to study and analyze each operating condition and to ensure that adequate transmission reinforcements are in place for secure operation of the integrated power system. Figure 3-2 illustrates the process for developing power flow cases for each study year. As can be seen, at least twenty-five (25) power flow cases are required for each study (spot) year. Simulations have been carried out for normal (N-0) and contingency (N-1) operating conditions to determine adequacy of the proposed transmission facilities under each seasonal pattern of power flow conditions. The analyses considered system peak demand as well as respective peak demand of each DISCO, one at a time, so that adequacy of the bulk and secondary transmission requirements (for NTDC and DISCO networks) can be ascertained.

Figure 3-2: Process for development of power flow cases



Short circuit analysis has been carried out for calculating maximum three-phase and single-phase fault currents for all the spot years using IEC 909 employed in PSS/E® software. Detailed analysis has been performed for Lahore, Faisalabad and Islamabad areas to determine the appropriate remedial measures to keep the short circuit levels within the existing breakers ratings.

Transient stability analysis has been carried out for the 765, 500 & 220 kV network for all the spot years employing the following standard disturbance:

- 3-phase fault at bus bar, cleared in 5 cycles with outage of the heavily loaded circuit emanating from the bus bar.

Post fault behavior of the system was monitored for rotor angles, power swings, voltage recovery and frequency deviation to check transient stability of the integrated power system.

4. ISSUES AND PROPOSED SOLUTIONS - 2026-27

Following main issues were analyzed and remedial/operational measures have been proposed in addition to determining the transmission expansion requirements for secure operation of the integrated power system:

a. High short-circuits levels in Lahore, Islamabad, Faisalabad, and Multan areas
b. Reactive power compensation requirements
c. Out of merit/expensive generation operation
d. Reinforcement of NTDC network in Peshawar, Sahiwal, Islamabad and Faisalabad areas
e. Indigenous generation and south to north transmission interface capacity enhancement
f. Hydro power integration

These are reviewed again in this TSEP keeping in view the progress on the ongoing projects and the implementation status of the progress on the proposed projects.

4.1 HIGH SHORT CIRCUIT LEVELS

In TSEP 2022, a detailed investigation was carried out to identify and minimize the high short-circuit levels prevailing in the existing substations and mitigation measures were proposed to resolve these issues. This was re-evaluated in TSEP 2024 and due to delay of some projects like the Punjab University 220/132 kV substation, the proposed grouping of Lahore 132 kV ring has been revised. The remaining measures are the same and are summarized as follows:

- Split the 220 kV bus at Lahore 500/220 kV substation as per Figure 4-1.
- Develop a direct 220 kV link from Lahore North 500/220 kV to Bund Road 220/132 kV substations after by-passing the KSK 220 kV bus. This will eliminate the short-circuit in-feed from Mangla/Gatti to Lahore North and can easily be achieved by opening the four circuit breakers (D5Q1, D5Q2, D6Q1and D6Q2) at the KSK 220/132 kV substation.
- Split 132 kV busbar of Wapda Town 220/132 kV substation. No additional splitting of 132 kV busbars is proposed at 220/132 kV substations supplying the Lahore ring.
- Segregate the 132 kV network into isolated groups (at 132 kV level) fed by two to three 220/132 kV source substations, as shown Figure 4-2.
- Splitting of 132 kV buses at a few 132/11 kV substations of different DISCOs.

Figure 4-1: Splitting of 220 kV bus of Lahore 500/220/132 kV Substation.

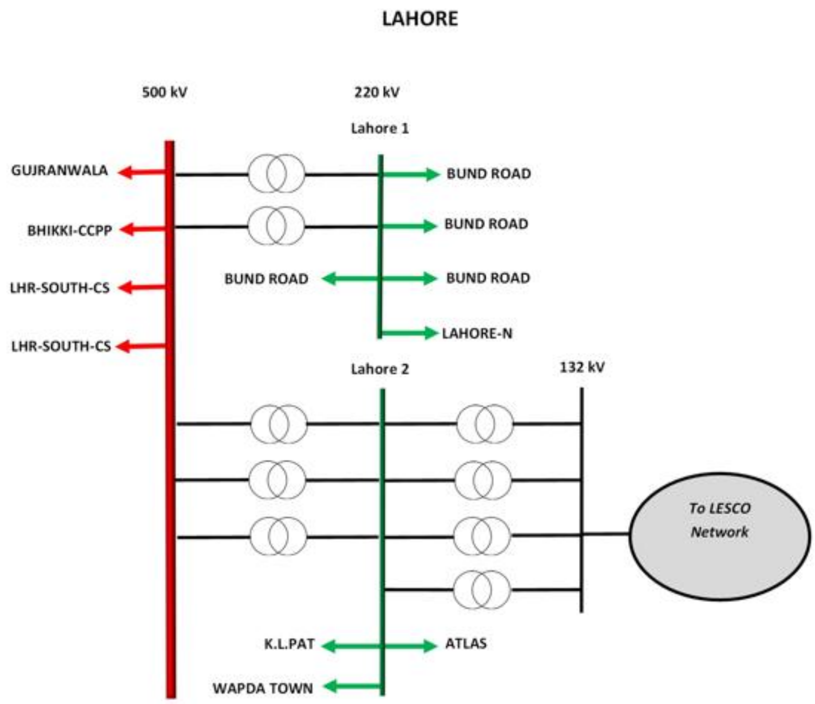


Figure 4-2 shows the proposed grouping of the Lahore ring. This grouping of the network will not only limit the short-circuit levels but also improve the power flow control and loading of 220/132 kV transformers.

Figure 4-2: Proposed 132 kV Grouping of Lahore Ring

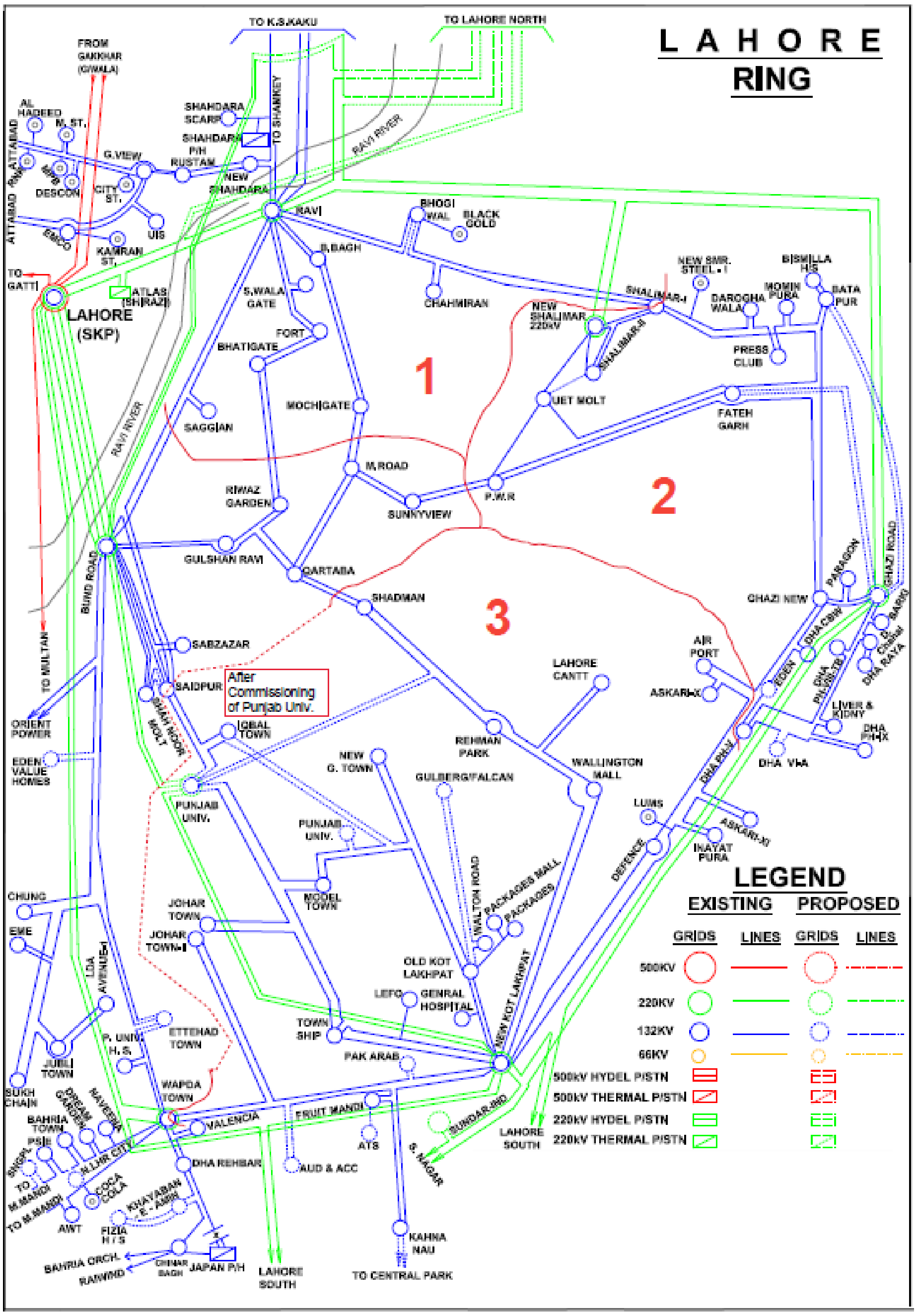


Table 4-1 shows the normally open points recommended for network operation. Whereas Table 4-2 presents the busbar splitting at 132 kV level in LESCO to achieve the proposed grouping.

Table 4-1: Normally open points at 132 kV level in LESCO

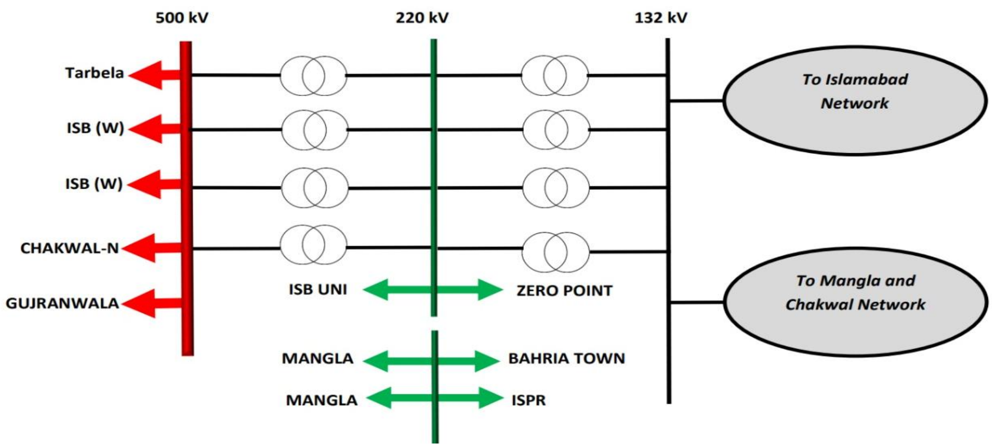
Normally Open Points				
Sr. No.	From Bus		To Bus	
	Number	Name	Number	Name
1	4115	PWR	4114	Sunny View
2	4113	Mclaod Road	4112	Mochi Gate
3	4137	Qartaba	4138	Shadman
4	4104	Airport	4096	Ghazi New
5	4097	DHA Phase V	4283	Askari XI
6	4117	Saidpur	4076	Ravi
7	4073	Saggian	4116	Bund Road
8	4080	Bhati gate	4136	Rewaz garden

Table 4-2: Bus bar splitting at 132 kV level in LESCO

Bus Splitting			
Sr. No.	Main Bus	Splitted Bus	Elements shifted to splitted bus
1	Shalamar-1	Shalamar-2	Chahmirn, Bogiwal and Karol
2	Wapda Town	Wapdatwn2	ADD&ACCNTS Johar Twn-II PU H/S
3	Saidpur	Saidpur2	A.I.Town 220 Punjab Uni

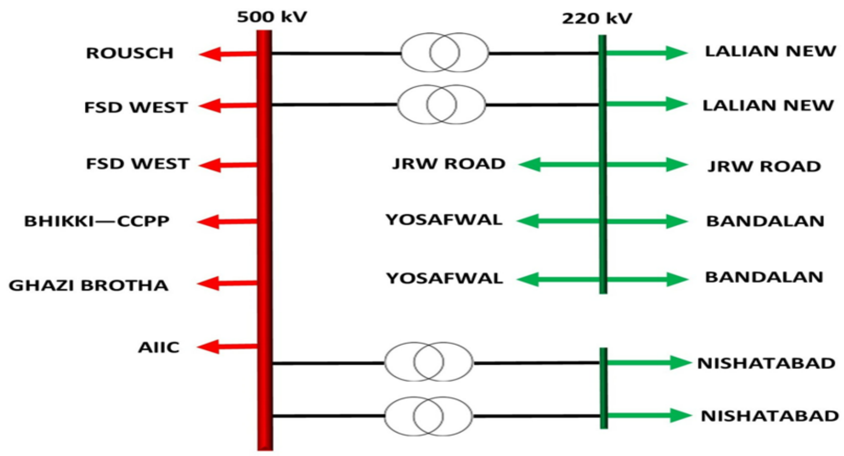
To limit the short-circuit levels in Islamabad, Rawat and Burhan area, it is proposed to split the 220 kV bus at Rawat New, as shown in Figure 4-3, to establish a direct 220 kV link between Mangla and ISPR/Bahria Town through the split bus. This will reduce the fault levels at Rawat, Mangle, ISPR and Burhan 220 kV buses. The fault levels are also high at 132 kV buses of Rawat and ISPR, it is proposed to open two 220/132 kV and one 500/220 kV transformer at ISPR and Rawat grid stations, respectively. Alternatively, some 132 kV links can be kept as open points to limits the fault levels at these grid stations.

Figure 4-3: Splitting of 220 kV bus of Rawat New 500/220/132 kV Substation



Similarly, to reduce high short-circuit levels at Gatti 500/220 kV and Nishatabad 220/132 kV substations, it is proposed to split the 220 kV bus at Gatti, feeding Nishatabad through two 500/220 kV transformers from Gatti, as show in **Figure 4-4**.

Figure 4-4: Splitting of 220 kV bus at Gatti 500/220 kV Substation



4.2 GRID SOLUTIONS FOR EXPENSIVE GENERATION

Currently, many expensive generation plants are dispatched out of merit due to transmission constraints, especially during the summer months. A significant attention has been given to this issue in the TSEP and solutions are proposed to minimize, or even to eliminate, out of merit dispatch of generation. In general, the expensive generation is required to overcome the overloading of transformers and transmission lines and voltage control issues in the load centers. The commissioning of the under-construction network reinforcement projects will minimize the need for running some of the expensive generation, particularly, in LESCO, MEPCO and IESCO areas. However, to avoid out of merit dispatch of most of the remaining plants, it is proposed to add steady state shunt compensation as per Table 4-3. It is important to mention that if execution/completion of these projects is delayed then the need of out of merit/expensive generation would persist.

Table 4-3 also includes proposed reactive power addition at various 220/132 kV substations, 2x48 MVAR Switched Capacitor (SW) each, to control the steady state voltage profile of the 220 kV network and to reduce the loading of 220/132 kV transformers. This compensation will not only improve the voltage profile of the system but also enhance system voltage stability in the case of delay in commissioning of the planned Ghazi Brotha/Islamabad West to Faisalabad West 500 kV double circuit line.

Table 4-3: Proposed Switched Shunt Capacitors

Substation Name	Compensation (MVAR)	Remarks
Ravi	96	This compensation is required to improve the voltage profile of Lahore ring under steady state and contingency conditions
Ghazi Rd	96	
Wapda Town	96	
Punjab Univ.	96	
Lahore North	96	
Lahore South	96	
KSK	96	In addition to improving voltage profile in Lahore, Faisalabad and Gujranwala areas, it will also help in maintaining system voltage in case Faisalabad West to Ghazi Brotha 500 kV double circuit line is delayed
Lalian	96	
Nishatabad	96	
Nokhar	96	
Jaranwala Rd.	96	
Vehari	96	
KAPCO	96	This compensation is required to minimize the use of expensive/out of merit generation at KAPCO & Nandipur CCPP
Piranghaib	96	
Bahawalpur	96	
Sahuwala	96	
Yousafwala	96	
Sarfaraz Naggar	96	

Table **4-4** presents a summary of under-construction transmission reinforcement solutions and the proposed reactive power compensation necessary to eliminate the need for out of merit dispatch of expensive generation.

Table 4-4: Transmission Solutions for Expensive Generation

Name of Plant	Region	Alternative/Proposed Transmission Solution	Expected COD
Nishat Chunian	LESCO	1. Augmentation of 220/132 kV Transformers at Lahore and Wapda Town Substations.	June 2024
Atlas	LESCO	2. Extension of 220/132 kV Transformer at NKLP Substation.	June 24
Nishat Power	LESCO	3. Replacement of 1x450 MVA T/F with 1x600 MVA T/F at 500/220 kV Lahore Substation.	2026-27
KEL	LESCO	4. Lahore North 500/220/132 kV Substation	August /2024
Saba	LESCO	Reactive Power Compensation in LESCO Region (5x96 MVAR at 132kV bus bars of NTDC substations as mentioned Table 4-3 above)	2026-27
Halmore	LESCO		
Sapphire	LESCO		

Name of Plant	Region	Alternative/Proposed Transmission Solution	Expected COD
Orient	LESCO		
KAPCO	MEPCO	1. Reactive Power Compensation in MEPCO Region (4x96 MVAR at 132kV bus bars of NTDC substations as mentioned Table 4-3 above) 2. 3rd 500/220 kV transformer at M' Garh 3. Upgradation of Vehari 220/132 kV Substation to 500 kV 4. Nagshah 220/132 kV Substation	2026-27 2025-26 2026-27 2026-27
HUBCO Narowal	GEPCO	1. Re-conductoring of 132kV Sahuwala to Ghuinke T/L from Lynx to Rail conductor 2. Gujranwala-II 220/132 kV Substation	2024-25 2026-27
Nandipur	GEPCO	1. Reactive Power Compensation in GEPCO Region (Approx. 96 MVAR at 132 kV Level) 2. Sialkot 500/220/132 kV Substation	2026-27 2026-27
Saif	LESCO	1. Augmentation (Stage-wise) of Yousafwala 220/132kV Transformers 2. Arifwala 220/132 kV Substation	2024-25 & 2026-27 2026-27
AGL	IESCO	1. Islamabad West 765/500/220/132 kV Substation	2026-27

In addition to the above, the following points relevant to the analysis must be noted.

- To minimize use of KAPCO generation, 3rd 500/220 kV transformer at M'Garh is proposed to be installed on priority. This will, however, limit the requirements of local generation to about 250 MW which will persist till the commissioning of 500/220 kV Vehari and 220/132 kV Nagshah substations. Alternatively, around 600 MW would be required from Lal-pir and Pak-gen power plants in case KAPCO contract is not extended.

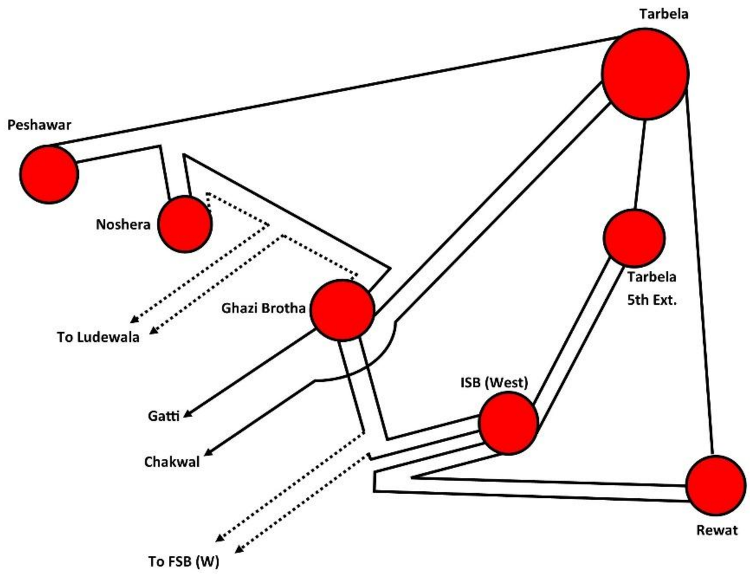
4.3 REINFORCEMENT OF PESHAWAR, FAISALABAD AND SAHIWAL AREAS

In TSEP 2022, re-configuration of the 500 kV network in Peshawar, Islamabad/Ghazi Brotha areas was proposed. This is shown in Figure **4-5.** This configuration has been adopted and its implementation plan has been developed, accordingly.

Initially, it was anticipated that the proposed plan related to the dispersal of power from Tarbela 5th extension and Dasu power project will be in place, particularly Islamabad West 765/500/220/132 kV substation. However, it seems that commissioning of this project will be delayed which will limit the dispersal of power from these generation projects. These limitations were also studied to quantify the impact of unavailability of these projects and to develop interim arrangements. Consequently, 765/500/220/132 kV Islamabad West as well as 500/132 kV Chakwal substations are not considered in the base case of July/August 2026.

Similarly, a new 500 kV circuit from Yousafwala to Sahiwal CFPP was proposed and is included in the implementation plan. This can be implemented as an interim arrangement and may be modified later as per the requirements of any new expansion in the area.

Figure 4-5: 500 kV Network Reconfiguration of Peshawar & Islamabad Areas



4.4 REACTIVE POWER COMPENSATION AND NETWORK REINFORCEMENT IN QESCO AREA

QESCO's power network is unique in nature due to long lightly loaded lines with scattered loads. Operating this network in synchronism with the national grid is very challenging and results in various steady state and dynamic voltage stability issues. To address these issues, by 2025, the following reactive power compensation projects were proposed in TSEP 2022 and re-confirmed in TSEP 2024:

- Installation of 150 MVAR STATCOM and 96 MVAR Switched Shunt Capacitors at 132 kV Quetta Industrial.
- Installation of 100 MVAR STATCOM and 96 MVAR Switched Shunt Capacitors at 132 kV Khuzdar.

4.5 WIND CAPACITY ASSESMENT AND INTEGRATION OF NEW RE PROJECTS

In line with TSEP activities, a detailed wind integration study was performed to optimize the timeline, location, and the generation interconnection requirements for the selected wind power generation as per IGCEP 2022. This study report is attached as Appendix C. This study has two parts. The first part was focused on understanding the generation trends in wind power and assessing the transmission requirements for evacuation of the existing generation in the South. The second part aimed at developing the power evacuation scheme for the future generation proposed in IGCEP 2022. Some key conclusions of this report are utilized for the development of TSEP 2024, which are documented here for reference.

In TSEP 2022 (Phase 1), studies were performed assuming the average availability of wind (51%). This assumption is thoroughly reviewed by analyzing the data available on wind intermittency in the respective wind corridors. Hourly wind generation data of the Jhimpir corridor available with NTDC is used to perform a statistical analysis to define the wind generation profiles during the year. Table 4-5 shows the fraction of time for which a typical 100 MW wind power plant is expected to remain in certain generation ranges. In addition, the capacity factor and the maximum ramp-up and ramp-down rates associated with this typical 100 MW wind power generation are also highlighted.

Table 4-5 : Power generation statistics associated with a typical 100 MW wind power plant

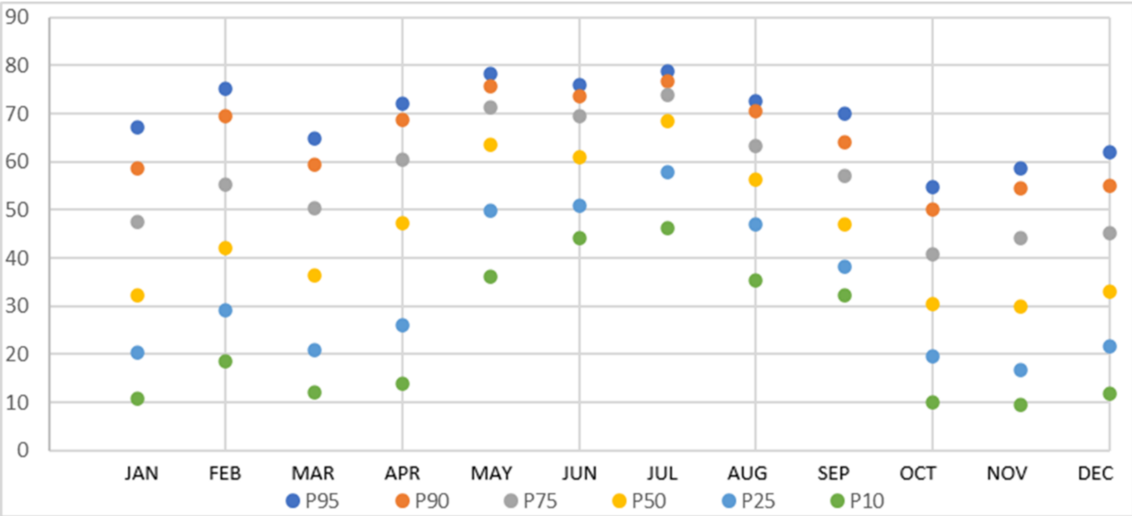
PERIOD		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Expected percentage of time Wind Generation is	Below 10 MW	9%	4%	8%	4%	2%	0%	0%	0%	0%	10%	11%	9%	5%
	Above 50 MW	21%	34%	26%	45%	75%	77%	85%	69%	42%	10%	16%	16%	43%
	Above 75 MW	3%	5%	1%	3%	12%	7%	19%	1%	1%	0%	0%	0%	4%
Capacity Factor (%)		34	43	36	44	59	60	65	54	48	31	31	33	45
Maximum Ramp-up Rate for 100 MW wind Plant (MW/h)		22	18	23	29	17	14	11	13	20	22	25	16	29
Maximum Ramp-down Rate for 100 MW wind Plant (MW/h)		25	34	31	27	29	12	12	12	21	24	21	30	34

It can be seen that wind generation remains considerably high during the summer months (i.e. from May to September) with capacity factors above 50%. Highest capacity factor of 65% is observed in July. In winter months the capacity factor remains closer to 30% and the annual capacity factor for wind is around 45%, which is promising.

The hourly analysis of the wind profile indicates that the wind generation is expected to remain above 50% of its capacity for nearly half of the time (43%) in a year. In the summer months, the generation remains more than half for a massive three-quarters of the time with this number nearing 85% in July. This value is quite high and suggests that analyzing network requirements at 50% of the wind might not be an appropriate approach. On the other hand, wind generation remains below half for about 80% of the time in winter months. The instances with more than 75% of the generation occur predominantly in May, June, and July. This value, however, remains relatively lower for other months. This suggests that the wind generation remains in a window of 50% – 75% for a considerable amount of time.

The ramp rates indicate that the maximum hourly variation in wind generally remains within the range of 15% - 30% of its capacity. It is also noticed that the variation in wind generation is larger in winter than in summer. This is also depicted in Figure 4-6 which shows probabilistic indices of P95, P90, P75, P50, P25 and P10 in the twelve months.

Figure 4-6: Probabilistic indices associated with the wind generation



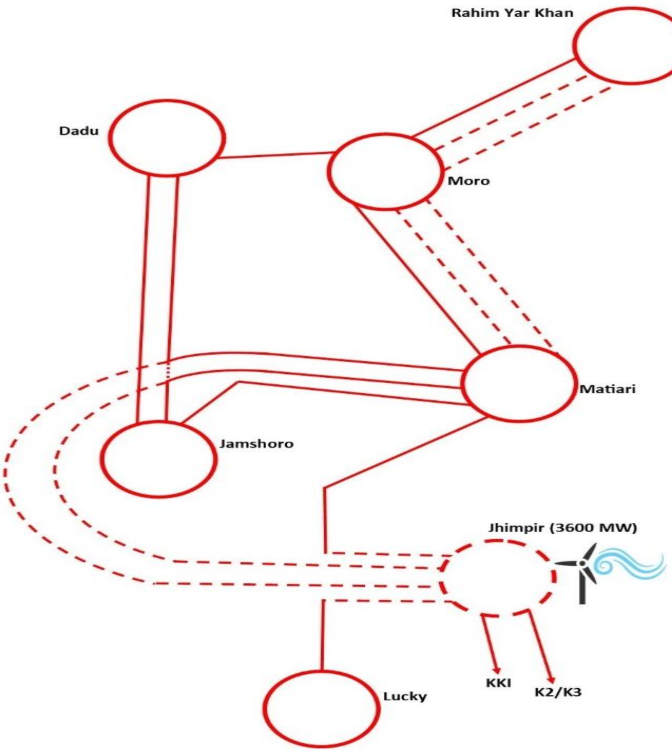
The wind generation is relatively random from October to April. However, the wind generation is quite precise and remains consistently on the higher side in the remaining months with even P10 indices approaching 40% of the generation. Importantly, in almost every month, the P95 value remains close to 70% mark. Subsequently, it can be concluded that for a coverage of 95% of the system operating conditions (P95), it is necessary to carry out analysis of wind at about 70% - 80% of its generation capacity. Accordingly, it is agreed to use 70% (instead of 51%) availability of wind capacity in summer season and 50% availability of wind capacity for winter season. This is an important finding and has been utilized in the TSEP 2024.

Huge quantum of wind generation was optimized in the generation addition sequence of IGCEP 2022. Integration of this wind generation in the system was a challenging task and has been addressed in the Wind Integration Study. As per World Bank Study "VRE Locational Study - 2021", there are three major potential wind generation sites, namely Jhimpir, Chaghi/Panjgur and Rojhan in the country. These can be utilized for future wind generation addition. Accordingly, the interconnection options for each site are conceived and studied. These solutions will form the basis for wind integration in the future.

The study results indicate that the existing power transfer interface between south to north is not capable of transmitting full generation available in the south, including the 1845 MW wind generation. Therefore, different solutions to reinforce the southern network were studied considering additional wind generation. Considering that no new wind power projects have been optimized in IGCEP 2024, the AC option, as shown in Figure 4-7, seems the most economical solution to enhance the south to north transmission interface capacity.

It is important to note that although, for NTDC system new wind generation is not optimized (except two power plants of 50 MW each) in IGCEP24, however, the requirement to reinforce the southern network still prevails for avoiding any curtailment of existing generation in the south and make power transfer capacity available for any new indigenous generation in future. Accordingly, a part of the proposed 500 kV HVAC option is selected for implementation, i.e., from D/C Matiari to Moro to RY Khan OHL.

Figure 4-7: HVAC Option for dispersal of Wind generation at Jhimpir and enhancement of south to north transmission interface capacity



4.6 DYNAMIC REACTIVE POWER SUPPORT

To improve the system performance and to eradicate dependance of north to south interface power transfer limit on the intermediate generating stations (Guddu, Muzaffargarh, KAPCO, etc.), installation of dynamic reactive support is also under consideration. In this regard the installation of STATCOMs at different locations have been studied by an international consultant CESI under the project titled "System Studies for Review of Grid System Performance" and some potential sites for installation of ±400 MVAR STATCOM each have been initially identified which are as follows:

- Dadu 500/220/132 kV grid station
- Guddu 500/220/132 kV grid station
- R. Y. Khan 500/220/132 kV grid station
- M. Garh 500/220 kV grid station
- Lahore-SKP 500/220/132 kV grid station

4.7 POWER SUPPLY OPTIONS FOR REKO-DIQ PROJECT AND GAWADAR

Reko-diq is a major development project in Baluchistan and its load demand would increase from 130 MW in the beginning to about 300 MW, when the project will be fully functional. Currently, there is no network in the area to supply power to the project. The nearest substation is about 250 km away but the network is very weak to supply highly inductive load anticipated for the project.

This study covered a broad perspective of transmission infrastructure expansion in the area. However, in order to have a dedicated supply plan solely for Reko-diq a detailed analysis is required that shall consider different technologies to have a secure and optimal solution considering the load demand, nature of load, phasing of the project, etc.

At present, the electrical consultant of the Project Consortioum is taking the lead to come up with a dedicated supply plan for the Reko-diq load considering the following composition of generation sources:

- Wind and solar farms
- RFO based thermal generation
- Connection to grid in the long term

To supply the initial load, a hybrid wind and solar solution appears to be the optimal option. For security and stability of supply, better voltage regulation, and to cater for intermittency of the renewable energy sources an RFO based thermal plant also seems necessary. Currently, NTDC is waiting for the finalization and submission of the supply plan by the project consultant. This plan will then be reviewed by NTDC and if accepted, this will be adopted in the next version of TSEP.

A 300 MW CFPP on imported coal has been committed for Gwadar area which is expected to be commissioned in 2027-28. The interconnection of this plant has also been developed and is a part of TSEP 2024 along with other three existing sources feeding Gwadar/Makran Area which are as under:

- National Grid - through 132 kV network (Nal - Basima - Nag upto Panjgoor) feeding from 220kV/132kV Khuzdar
- Import from Iran
    - 70-100 MW through existing 132 kV T/Line from Jackigoor (Iran) to Mand (Gwadar)
    - 100 MW from Polan (Iran) – Jiwani (Pakistan). The interim 132 kV supply link has been completed from Pak-Iran border (Gabd) to Gwadar-Jiwani T/Line. The permanent 220 kV supply link shall be completed in 2027-28.

4.8 HYDRO POWER INTEGRATION

Pakistan possesses a substantial estimated hydro power potential due to its abundant water resources and diverse geography. With several rivers originating from glacial meltwater in the mountainous regions, the country has an estimated hydro power capacity of over 60,000 megawatts (MW) in different hydro power corridors. An analysis of the regional topography suggests dividing the region into the following four hydro corridors:

- Chitral river corridor
- Swat river corridor
- Indus river corridor
- Kunhar and Neelum-Jhelum rivers corridor

Each corridor lies on a different river(s) channel with potential sites where hydro generating units can be set up. These corridors also form the potential routes of the transmission lines to be installed for evacuation of power from the hydro power potential sites. These transmission line corridors have been mapped on Google Earth as depicted in Figure 4-8.

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Figure 4-8: Tentative transmission line corridors in the northern region

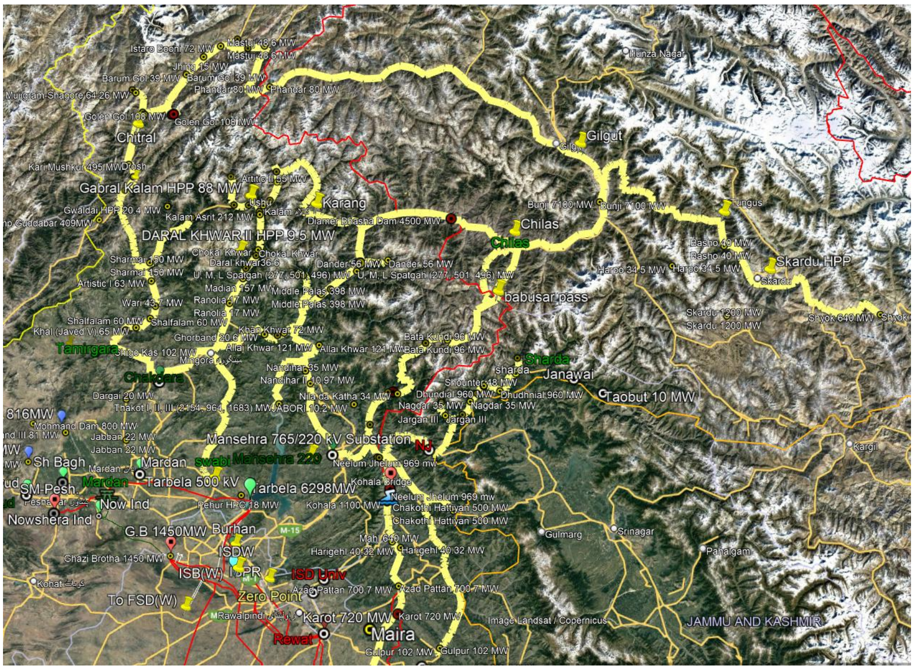


Table 4-6 summarizes the approximate hydro power potential in different corridors, this is based on the input data used in the IGCEP and PEDO reports.

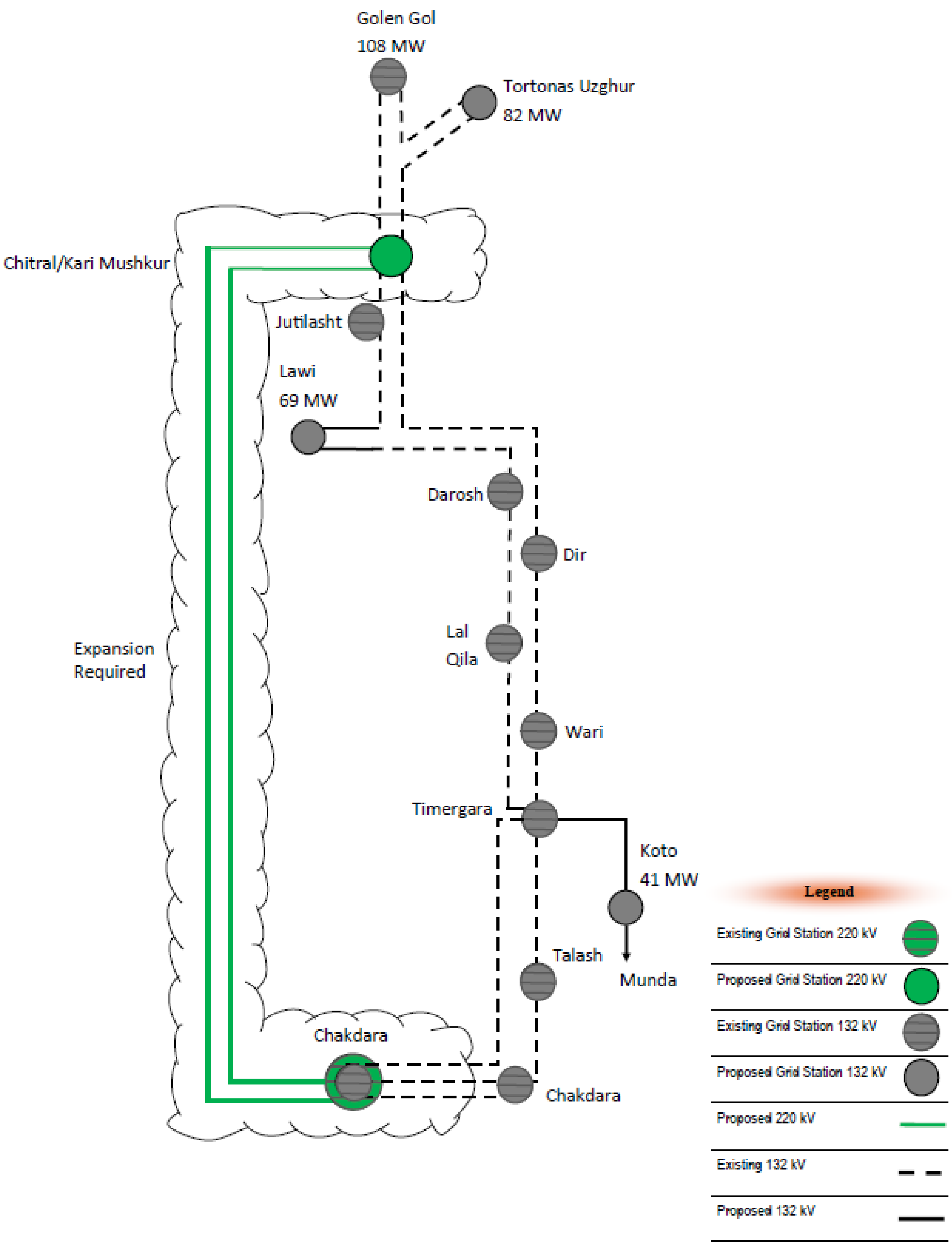
Table 4-6: Hydro power potential in different hydro power corridors

Description	Cumulative Capacity (MW)			
	River corridors			
	Chitral	Swat	Indus	Kunhar & N. Jhelum
Approximate identified potential	4374	1144	32,632	8,800
Existing Projects	108	36.6	340	1,962
IGCEP 24	192	84	6695	1245
Foreseeable Future	918	841	6268	3710
Beyond	3156	184	19,329	1,883

Tapping of this huge quantum of hydro generation and connecting it to the main grid is a complex task. Limited availability of transmission corridors, optimization, phasing, and implementation strategies of different power plants make the interconnection options quite challenging. Keeping this in view, a comprehensive Hydro Integration Study was performed for the long-term horizon to come up with optimal interconnection options. Conceptual transmission plans for evacuation of power from the power plant sites have been worked out, thoroughly studied, and the final transmission schemes for the four corridors have been developed. Since the potential hydro power development will be materialized in different time horizons, a phase-wise implementation approach is employed while developing the transmission evacuation schemes. The details are provided in the Hydro Integration Study attached as Appendix D with the report. These schemes are used as guidelines to propose the interconnections of power plants optimized in IGCEP-23-34 and are incorporated in the relevant power flow base cases. The following is the description of connection schemes proposed for each corridor for the power plants connections.

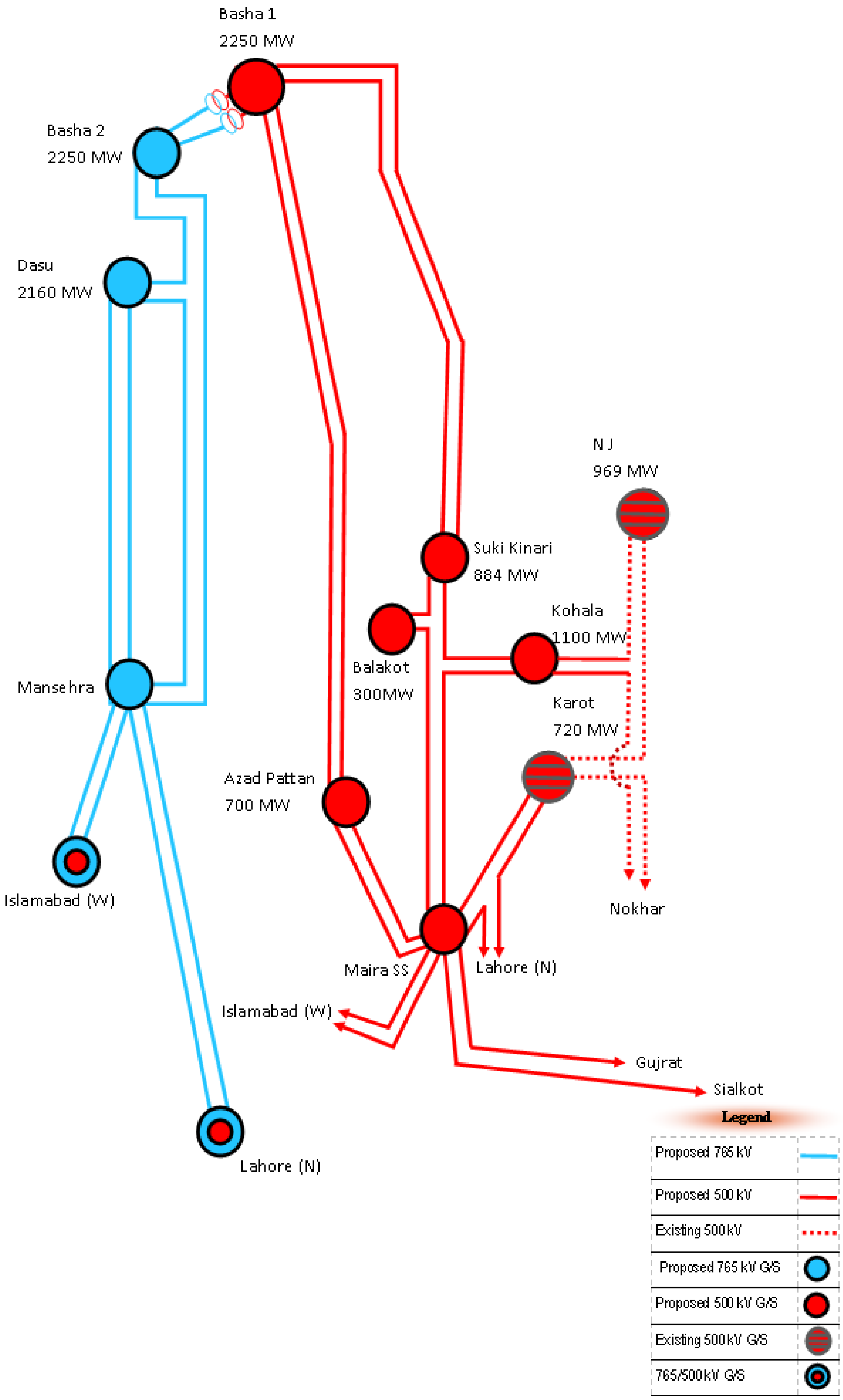
IGCEP 2024 optimized only one power plant (Tortonas Uzghur) in Chitral region. Its connectivity is a real challenge since there is no capacity available in the existing network and major transmission expansion is required for its power dispersal. Based on the comprehensive scheme proposed for the Chitral region, its probable final interconnection scheme after utilizing considerable hydro potential in this region is depicted in Figure 4-9. Clearly, the cost of this scheme would be quite high to materialize this scheme only for one power plant. Considering this high transmission interconnection cost the plant may not become economically viable and shall either be delayed or may be connected in the existing network with some operating restrictions to be agreed by the IPP. This may involve disconnecting the plant in case of congestion in the local network.

Figure 4-9: Proposed power evacuation scheme for HPPs in Chitral region as per IGCEP-24



Major hydro power projects, which are optimized in IGCEP 2024 on the Indus, Kunhar and Neelum Jhelum rivers corridors are Bhasha, Balakot, Azad Pattan and Kohala. Dasu power project is already under construction and its power will be evacuated through a double circuit 765 kV OHL. Diamer Bhasha Power Project (DBPP) is the biggest HPP (4500 MW) considered in IGCEP and is expected to significantly affect the power flows in the northern bulk transmission network. Considering the availability of 765 kV transmission line, evacuation schemes for DBPP are conceptually conceived, studied, and tested for different interconnection alternatives. Eventually, the evacuation scheme, depicted in Figure 4-100, seems an optimal solution and is recommended for the interconnection of DBPP. Accordingly, this scheme is incorporated in the base cases and expansion requirements become part of the TSEP 2024.

Figure 4-10: Proposed power evacuation scheme for HPPs in Indus, Kunhar and Neelum-Jhelum River corridors.



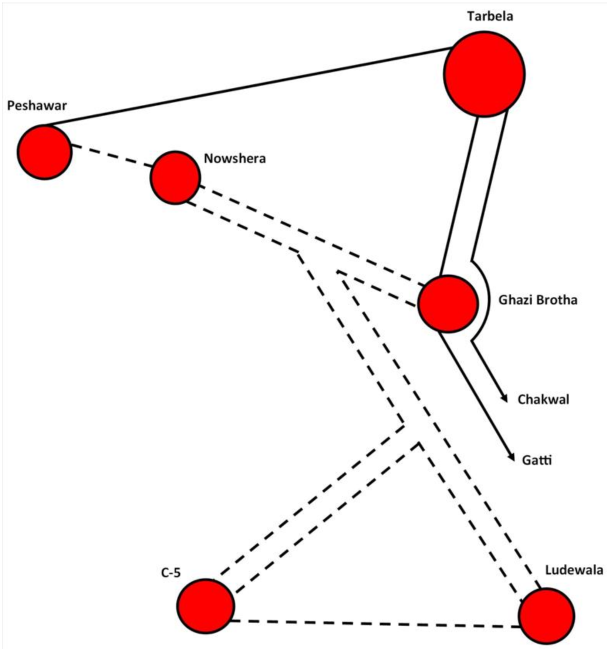
4.9 INTERCONNECTION OF C-5 NPP

Chashma-5 (C-5) Nuclear Power Plant (NPP) is a committed generation plant assumed in the IGCEP 2024 and is expected to be commissioned in 2030-31. The plant will be connected at 500 kV level. After detailed studies, the power evacuation scheme for the plant has been developed and is described below:

- 500 kV S/C OHL from C-5 to the proposed 500 kV Ludewala grid station
- Looping in/out of the proposed Nowshera – Ludewala 500 kV circuit at C-5 NPP

The proposed scheme is shown in Figure 4-111. This scheme would provide N-2 contingency provision to the plant and would help in transferring power to the northern area during winter conditions.

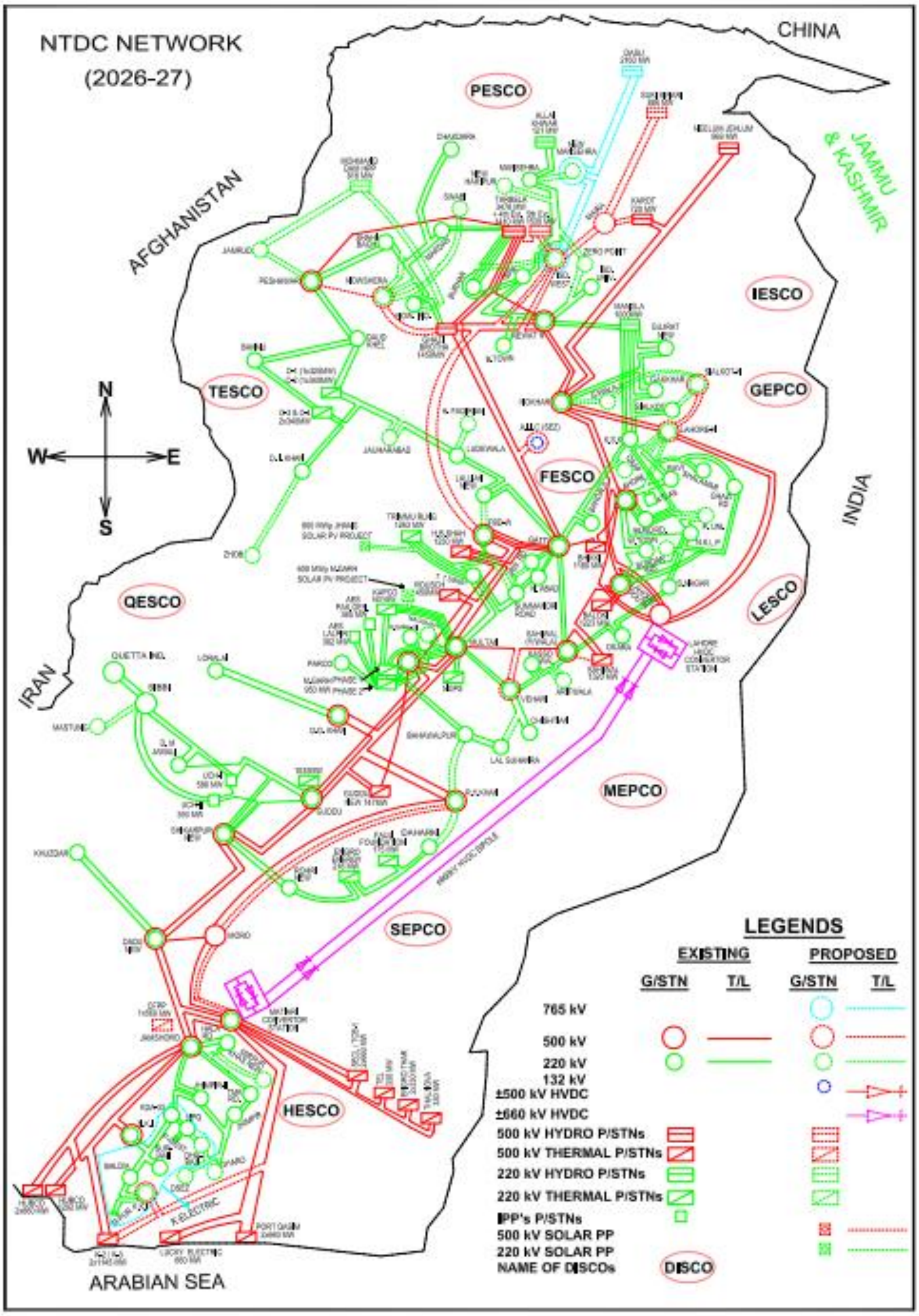
Figure 4-11: Proposed power evacuation scheme for C-5 NPP.



5. ANALYSES OF SPOT YEAR 2026-27

A comprehensive analysis for spot the year 2026-27 has been carried out considering the seasonal variation of loads and generation dispatch. All the proposed transmission solutions and remedial measures discussed in the previous section were incorporated into the 2026-27 base cases. These updated power flow cases have been used for detailed system studies and analyses. Figure 5-1 depicts the expected NTDC network by 2026-27.

Figure 5-1: Expected NTDC 500/220 kV System by 2026-27



5.1 POWER FLOW AND CONTINGENCY ANALYSIS

Load flow studies for summer peak operating scenarios, corresponding to the high hydro (July/August) and the low hydro-high thermal (June) dispatch conditions, have been performed for normal (N-0) and contingency (N-1) conditions for each scenario. For the 220 kV network, thermal operating limits are used as the permissible line loading limits for the lines less than 80 km, whereas stability limits are used for the lines longer than 80 km. For 500 kV lines, depending upon the line lengths, stability limits are used as permissible line loading. A 10% overloading margin has been considered for power transformers. The automatic contingency analysis (ACCC) activity of PSS/E® has been used for the analyses.

Similarly, two operating scenarios have been studied for winter conditions, i.e., a) winter peak and b) winter off-peak (minimum), which proved to be more stringent and have been used to determine the reactive shunt compensation requirements.

5.1.1 RESULTS AND ANALYSIS OF SUMMER PEAK – JULY/AUGUST 2026

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 5-1.

Table 5-1: System Summary – July/August 2026

Description	MW	MVAR
NTDC Generation	30180	6332
NTDC/DISCOs Load	27097	16017
Export to KE	2050	795
Shunt Reactors	-	6162
Shunts Capacitors	-	-12192*
Line Charging	-	-17517
Losses	1033	18161

* Does not Include filters at HVDC terminal stations

Salient features of this case include commissioning of new hydro generation. Hydro power plants at Suki Kinari and Tarbela 5th extension have been considered commissioned. The power flow plots of normal operating conditions, showing 500 and 220 kV networks are provided in Appendix E. The results show that the voltage profile, lines and transformers loadings, with the selected generation dispatch, are well within the normal operating limits and fulfill the grid code operating requirements.

Figure 5-2 shows the power flow plot for 500 kV network under normal operating condition. The power flows from hydro power plants in the north towards mid country and from south to mid country, which is primarily from thermal generation in the south. This case is characterized as high hydro with peak demand scenario and as expected, the 500 kV northern network is relatively highly loaded as compared to the southern network. Also, since a large amount of power from southern generation flows on the HVDC link (4,000 MW) the parallel 500 kV AC system is relatively lightly loaded in the base case.

As mentioned earlier, in this base case scenario, Islamabad-west substation is not considered. However, it is assumed that the proposed D/C 500 kV OHL to Faisalabad-west will be available. Therefore, an interim arrangement is proposed and studied in detail to come up with a configuration facilitating the dispersal of power from Tarbela 5th Extension without the commissioning of Islamabad-west substation. The power flow plot considering the proposed/selected arrangement is depicted in Figure 5-3. The analysis indicates that it would be possible to dispatch full generation of Tarbela 5th Extension with this interim arrangement.

However, a sensitivity case is also studied wherein the D/C 500 kV line to Faisalabad-west is assumed not available and a different interim arrangement is proposed and studied. It is found that this arrangement limits the dispersal of power from the Tarbela 5th extension and a cross-trip scheme needs to be employed to trip one unit of Tarbela 5th to keep N-1 provision on G. Brotha to Gatti/AIIC 500 kV circuits. This clearly shows the timely requirement of the new 500 kV OHL to Faisalabad-west.

Similarly, the 500 kV Maira switching station and the planned 500 kV double circuit from Karot to Maira are also delayed. This has severely affected the secure and timely dispersal of power from the Karot and Suki Kinari power plants. Currently the Karot power plant is already working with a cross-trip scheme to provide N-1 contingency provision. To commission the Suki-Kinari power plant, an interim arrangement is proposed which requires looping-in both the 500 kV circuits from Suki Kinari on the N. Jhelum to Karot section of the existing 500 kV OHL. In addition, a cross-trip scheme also needs to be employed at Suki Kinari's generating units to trip in order to keep N-1 provision on N. Jhelum/Suki-Kinari/Karot to Gujranwala 500 kV OHL.

It is interesting to note that with 4000 MW of power transfer on HVDC, the power flow on the AC interface from Dadu to Multan is quite low and it is pertinent that reducing flow of power on the HVDC link would reduce the overall system losses. This implies that there is operational flexibility available in loading the HVDC system viz-a-viz AC system for optimal system operation.

Figure 5-2: 500 kV Network Summer Peak July/August 2026– Normal Operating Conditions

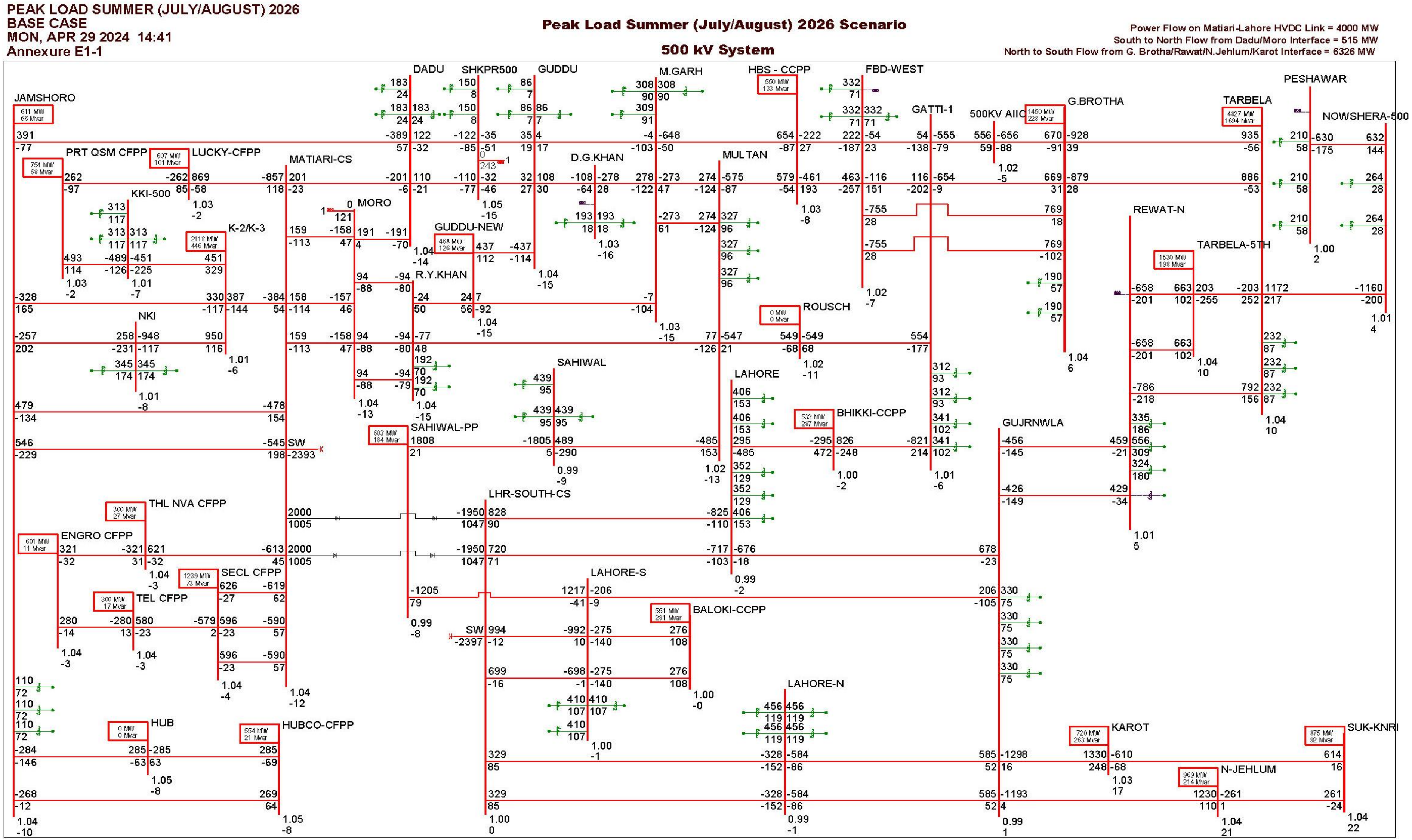
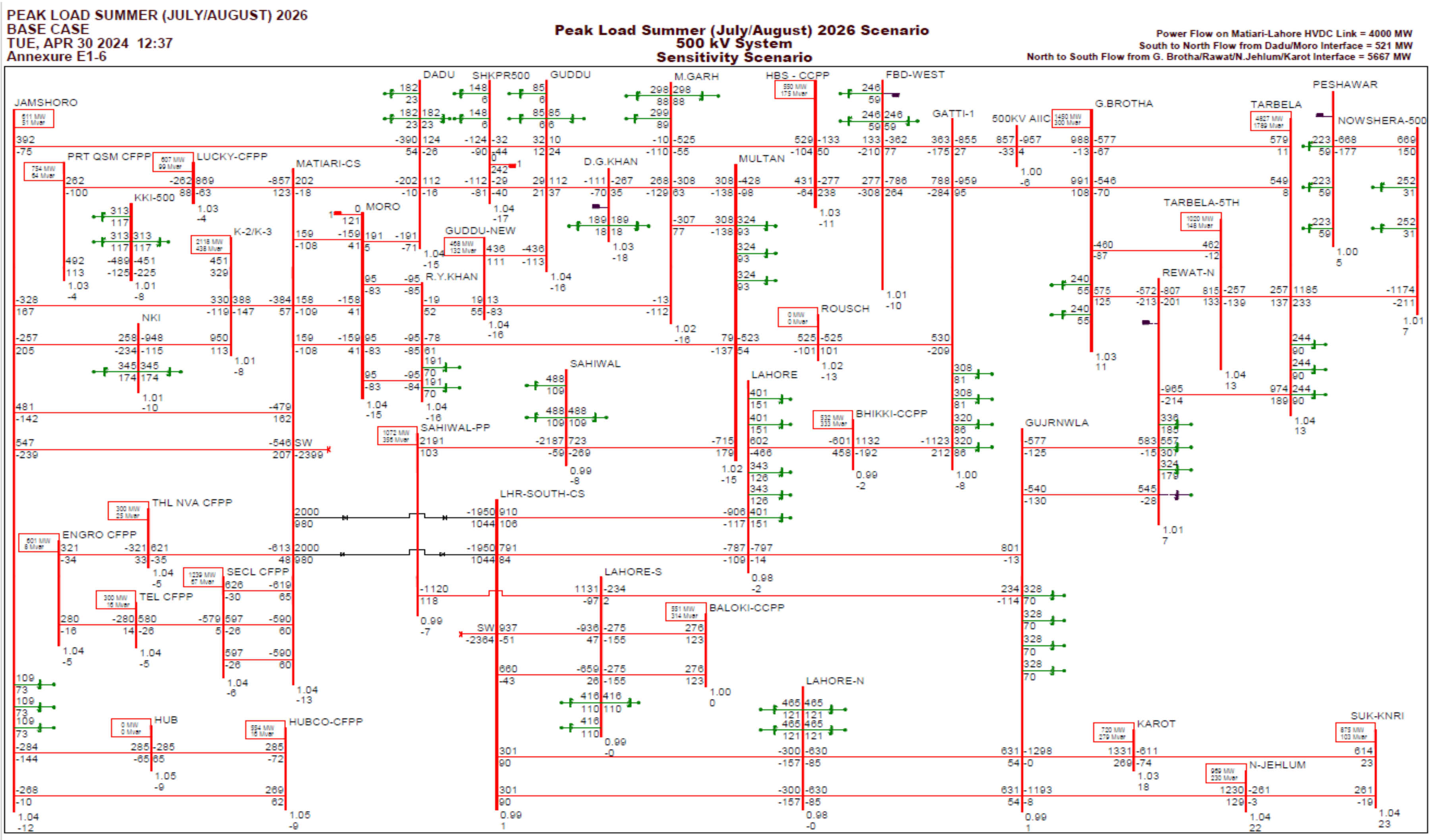


Figure 5-3: 500 kV Network Summer Peak July/August 2026– Sensitivity Case



Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) for all transmission elements (HVDC and HVAC lines, 500/220 kV and 220/132 kV transformers) has been performed. This analysis has been performed for the system (NTDC) peak as well as for the peak demand scenarios of all the ten DISCOs. The overloading violations along with their planned solutions are summarized in Table 5-2, which also includes results for DISCO networks. Although many overloading violations are observed in this case, solutions have been planned for each of these violations and the network loading position will improve considerably after commissioning of planned network reinforcement projects. All the relevant power flow plots along with the ACCC output files are provided in Appendix E.

As discussed earlier, the Suki Kinari and Karot Hydro power plants are connected in interim arrangements due to delay in commissioning of 500 kV Maira substation. This interim arrangement does not provide N-1 provision and therefore, cross-trip schemes are employed at these power plants to trip some generation units in case of contingencies. The N-1 provision will be available after commissioning of 500 kV Maira Substation in 2027.

Table 5-2: Summary of Contingency Analysis – July 2026

<---------------- MONITORED BRANCH ---------------->							CONTINGENCY LABEL	RATING	FLOW	%	Planned Solutions
From Bus			To Bus			Ckt					
No.	Name	kV	No.	Name	kV	2					
NTDC PEAK											
24	GUJRNWLA	500	213*	N-JEHLUM	500	1	SINGLE 137-211(1)	1500	1861.5	124.1	Due to interim arrangement of Suki Kinari
150	MARDAN	220	200*	TARBELA	220	1	SINGLE 11-20(1)	250	271.1	108.5	Due to absence of 2nd source of Supply to 500 kV Sheikh Muhammadi
3050*	S.P.ROAD	132	3055	LALAPUR	132	1	SINGLE 3105-3108(1)	112	171.5	153.1	Solution is 500 kV Sialkot
1150*	JEHANGRA	132	2031	GONDAL	132	1	SINGLE 2022-2030(1)	112	147.1	131.3	Solution is 500 kV Islamabad west
4116*	BUND-RD	132	4117	SAIDPUR	132	4	SINGLE 4116-4117(3)	202	257.2	127.3	Solution is 220 kV Punjab University
5475	BHALWAL	132	5476*	PIEDMC	132	1	SINGLE 3034-3037(1)	112	135.7	121.1	Solution is 220 kV Head Faqirian
3108*	GHUINKE	132	3180	PASRUR	132	1	SINGLE 3050-3055(1)	112	130.9	116.8	Solution is 500 kV Sialkot
3050*	S.P.ROAD	132	3055	LALAPUR	132	1	SINGLE 3108-3180(1)	112	130.7	116.7	
3034	KUTHIL.S	132	3037*	HELAN	132	1	SINGLE 5419-5460(1)	182	211.1	116	Solution is 220 kV Head Faqirian
1183*	TARU JABA	132	1185	PESH CTY	132	1	SINGLE 10-11(1)	112	124.3	111	Due to absence of 2nd source of Supply to 500 kV Sheikh Muhammadi
1255	JAMRUD TESCO	132	1290*	SH-MUHDI	132	1	SINGLE 1276-1290(1)	112	123.7	110.5	Solution is 220 kV Jamrud
7100*	P.GAIB-1	132	7119	PIRAN GAIB	132	1	SINGLE 6666-7285(4)	202	222.7	110.3	220 kV Nagshah
4116*	BUND-RD	132	4117	SAIDPUR	132	4	SINGLE 272-4270(1)	202	222	109.9	220 kV Punjab University
2025*	ISPR-132	132	2190	PIRWADHAI	132	1	SINGLE 2200-2220(1)	184	202.1	109.8	220 kV Zero Point
4116*	BUND-RD	132	4117	SAIDPUR	132	3	SINGLE 4116-4117(4)	202	218	107.9	220 kV Punjab University
6666*	MULTAN-N	132	7285	QASIMPUR	132	4	SINGLE 7100-7119(1)	202	217.5	107.7	220 kV Nagshah
7285*	QASIMPUR	132	7290	MESCO	132	1	SINGLE 7270-7287(3)	112	120.2	107.4	

<---------------- MONITORED BRANCH ---------------->							CONTINGENCY LABEL	RATING	FLOW	%	Planned Solutions
From Bus			To Bus			Ckt					
No.	Name	kV	No.	Name	kV	2					
3050*	S.P.ROAD	132	3055	LALAPUR	132	1	SINGLE 4027-4266(1)	112	120.2	107.3	500 kV Sialkot
3108*	GHUINKE	132	3180	PASRUR	132	1	SINGLE 4027-4266(1)	112	117.1	104.6	
FESCO PEAK											
1360*	ABBOTABD	132	1365	HAVELIAN	132	1	SINGLE 135-138(1)	112	149.8	133.8	Reconductoring assumed in June 2027
1365*	HAVELIAN	132	1410	HARIPUR	132	1	SINGLE 135-138(1)	112	126.8	113.2	
1379*	MANSHR-N	132	1415	HARIPUR-II	132	1	SINGLE 135-138(1)	112	138.4	123.5	
1410	HARIPUR	132	1415*	HARIPUR-II	132	1	SINGLE 135-138(1)	112	124.4	111	
1360*	ABBOTABD	132	1365	HAVELIAN	132	1	SINGLE 138-215(2)	112	127.3	113.6	
1379*	MANSHR-N	132	1415	HARIPUR-II	132	1	SINGLE 138-215(2)	112	117.7	105.1	
2200	IBD. I-10	132	2220*	ZEROPOINT	132	1	SINGLE 2025-2190(1)	184	189.6	103	220 kV Zero Point
2025*	ISPR-132	132	2190	PIRWADHAI	132	1	SINGLE 2200-2220(1)	184	197.8	107.5	
GEPCO PEAK											
5419*	LUDWLA-N	132	5460	S.PR.NON	132	1	SINGLE 3034-3037(1)	182	237.1	130.3	220 kV Head Faqirian
HESCO PEAK											
650*	SIBBI	220	970	QUETTA	220	2	SINGLE 650-970(1)	300	320.8	106.9	220 kV Mastung
MEPCO PEAK											
6170*	VEHARI-O	132	6175	LUDDEN	132	1	SINGLE 6169-6175(2)	112	122.1	109	Upgradation of Vehari to 500 kV level
6169*	VEHARI-N	132	6175	LUDDEN	132	2	SINGLE 6170-6175(1)	112	119.7	106.9	
7119*	PIRAN GAIB	132	7280	MN.VR.RD	132	1	SINGLE 6666-7285(4)	202	212.6	105.2	220 kV nagshah
7050	JEHANIAN	132	7100	*P.GAIB-1	132	1	SINGLE 7075-7100(1)	112	124.1	110.8	
7110	BASTIMLK	132	7125	*LAR	132	2	SINGLE 7100-7110(3)	112	125.2	111.7	
6666*	MULTAN-N	132	7285	QASIMPUR	132	4	SINGLE 7100-7119(1)	202	235.5	116.6	
6666*	MULTAN-N	132	7285	QASIMPUR	132	4	SINGLE 7119-7280(1)	202	213.5	105.7	
7285*	QASIMPUR	132	7290	MESCO	132	1	SINGLE 7270-7287(3)	112	129.2	115.4	

5.1.2 RESULTS AND ANALYSIS OF SUMMER PEAK - JUNE 2027

In June, the hydro generation is relatively lower as compared to July/August and the peak system demand is met mainly from thermal power generation in the south and mid country. This scenario stresses the south to north transmission (sending) network, which may lead to transient stability issues in the northern (receiving) network. Therefore, June peak load case is considered more stringent as compared to the July peak load case. The June 2027 base case is developed by updating the July 2026 case by incorporating all the committed projects to be commissioned from July 2026 till June 2027.

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 5-3.

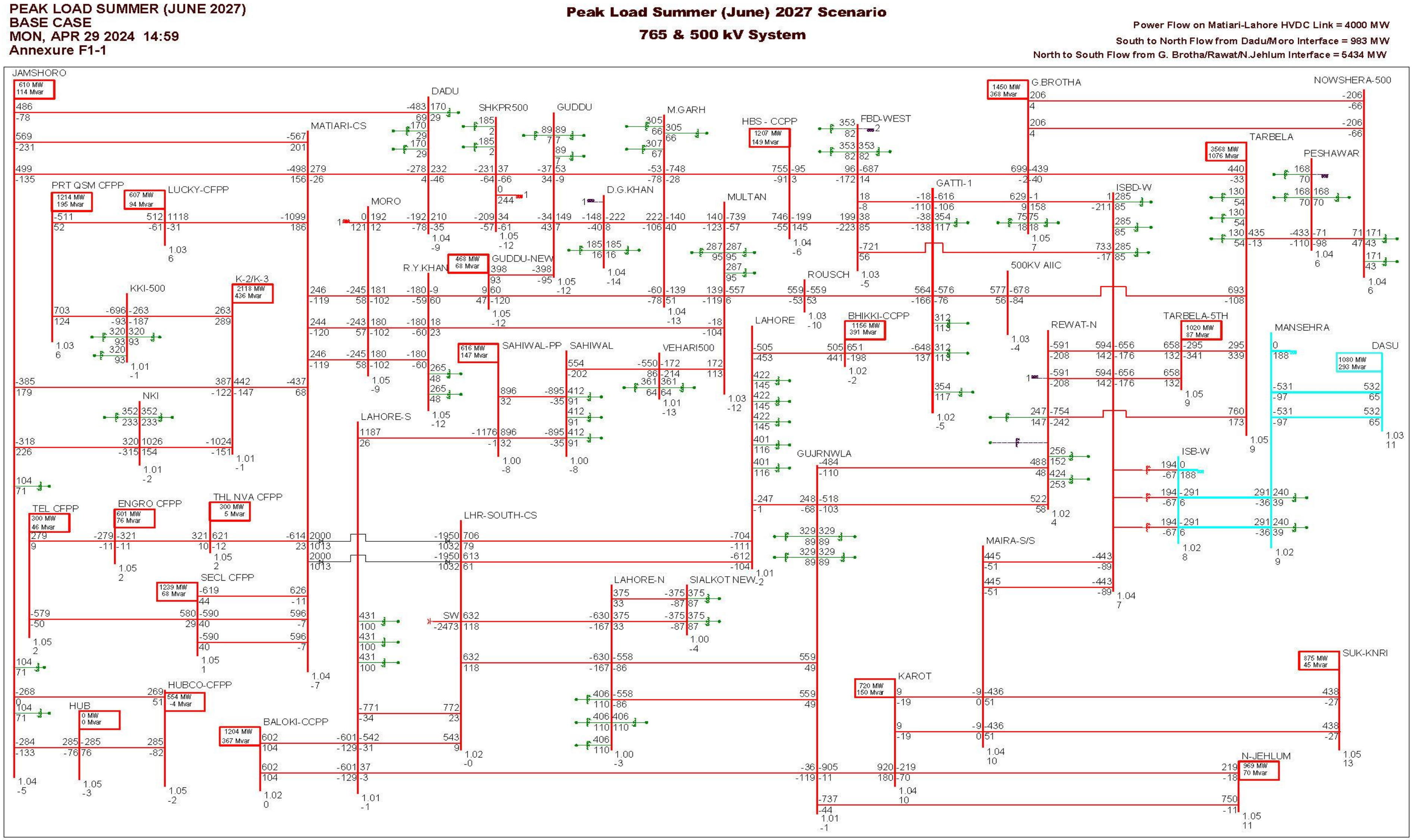
Table 5-3: System Summary – Peak June 2027

Description	MW	MVAR
NTDC Generation	30155	5510
NTDC/DISCOs Load	27181	16092
Export to KE	2050	811
Shunts Reactors	-	8422
Shunts Capacitors	-	-11639*
Line Charging	-	-20506
Losses	925	17359

* Does not Include filters at HVDC terminal stations

The power flow plots of normal operating conditions, showing 500 and 220 kV networks are provided in Appendix F. The results reveal that the voltage profile, lines and transformers loadings are well within the normal ratings complying to the Grid Code requirements. Figure 5-4 shows the power flow plot for 500 kV network under normal operating condition. The power from the hydro plants in the north flows towards mid country and power from thermal generation in the south also flows towards mid country serving the major load centers. This case is characterized as high thermal with relatively low hydro (as compared to July) with peak system demand operating scenario. As expected, the 500 kV south to north transmission network is highly loaded as compared to the northern transmission network. The proposed Matiari-Moro-R.Y. Khan 500 kV double circuit OHL has been considered in this case.

Figure 5-4: 500 kV Network Summer Peak June 2027 – Normal Operating Conditions



Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) for all transmission elements (HVDC and HVAC lines, 500/220 kV and 220/132 kV transformers) has been performed. This analysis has been performed for the system (NTDC) peak as well as for the peak demand scenarios of all the ten DISCOs. The analysis indicates that no voltage or overload violations occur on the entire network including NTDC and DISCOs. All the relevant power flow plots along with the ACCC output files are provided in Appendix F. This establishes the fact that the transmission system is adequately planed for the expected operating conditions of June 2027 and fulfills the Grid Code operating criteria.

5.1.3 SENSITIVITY ANALYSIS: MAXIMUM DISPATCHED FROM SOUTH WITH/WITHOUT MATIARI-MORO-RYK OHL

In the base case scenario, it is assumed that the proposed Matiari-Moro-RY Khan 500 kV D/C line will be available by June 2027. However, considering the long length of the line and expected construction/right of way difficulties it is likely that the proposed line might face delays in construction. Therefore, a sensitivity case is performed to ascertain the maximum generation, including wind, which can be utilized from the south maintaining a secure power transfer limit without this line. This analysis will also determine the maximum power transfer limit from south to north with the proposed line. This analysis will not only provide justification of this line but will also quantify the cushion available for any new indigenous generation in the south which can be transferred without any additional expansion. The objective of this analysis is to determine the maximum power transfer capability from South to North in the following cases.

- Case A: With the proposed D/C 500 kV Matiari – Moro – RYK OHL
- Case B: Without the proposed D/C 500 kV Matiari – Moro – RYK OHL (existing network)

The analysis is carried out by increasing generation in the south with corresponding reduction in dispatch of the RLNG plants in the mid country, till voltage or overloading violations observed under N-1 contingency conditions. The most sever contingency is the outage of one HVDC pole.

Case A: With the proposed D/C 500 kV Matiari – Moro – RYK OHL:

It is found that this line increased the steady state power transfer limit of south to north transmission interface to about 7000 MW. This increased limit not only provides provision of utilizing the maximum available generation in south but would also facilitate transfer of additional 400 MW of any new indigenous generation, if installed in the south. The limiting factor in this case is the 500 kV Jamshoro – Dadu circuit. The loading at some critical lines at the maximum flow of 7000 MW under the contingency of one HVDC pole is shown in Table 5-44. The power flow plot for normal operating condition under the maximum feasible power transfer scenario is shown in Figure 5-5.

Table 5-4: Contingency Analysis of Case A

<----------------- MONITORED BRANCH ----------------->							CONTINGENCY LABEL	%
From Bus			To Bus			Ckt		
No.	Name	kV	No.	Name	kV			
NTDC PEAK								
75	Moro	500	58	R. Y. Khan	500	1	One pole of Matiari – Lahore CS DC OHL	63
80	Jamshoro	500	70	Dadu	500	1		99
95	Matiari	500	75	Moro	500	1		68

Case B: Without the proposed D/C 500 kV Matiari – Moro – RYK OHL (existing network)

The steady-state analysis reveals that it is not feasible to transfer more than 5700 MW on the south to north existing interface. This implies that the existing network is not able to transfer the full available generation in the south and a volume of 940 MW of relatively low cost southern generation will have to be curtailed. Figure 5-6 provides power flow plot for normal operating condition under the maximum feasible power transfer scenario.

All the relevant power flow plots and the ACCC output files of the simulated contingencies are provided in Appendix F. The loading at some critical lines under the contingency of one HVDC pole is shown in Table 5-5. No overload violation was observed in DISCOs.

Table 5-5: Contingency Analysis of Case B

<---------------- MONITORED BRANCH ---------------->							***CONTINGENCY LABEL***	**%**
From Bus			***To Bus***			**Ckt**		
No.	**Name**	**kV**	**No.**	**Name**	**kV**			
NTDC PEAK								
75	Moro	500	58	R. Y. Khan	500	1	One pole of Matiari – Lahore CS DC OHL	78
80	Jamshoro	500	70	Dadu	500	1		99
95	Matiari	500	75	Moro	500	1		87

It should be noted that the above-mentioned limits are steady state limits and will be reevaluated in the stability analysis carried out in section 5.3.

Figure 5-5: 500 kV Network Summer Peak June 2027 – Case A

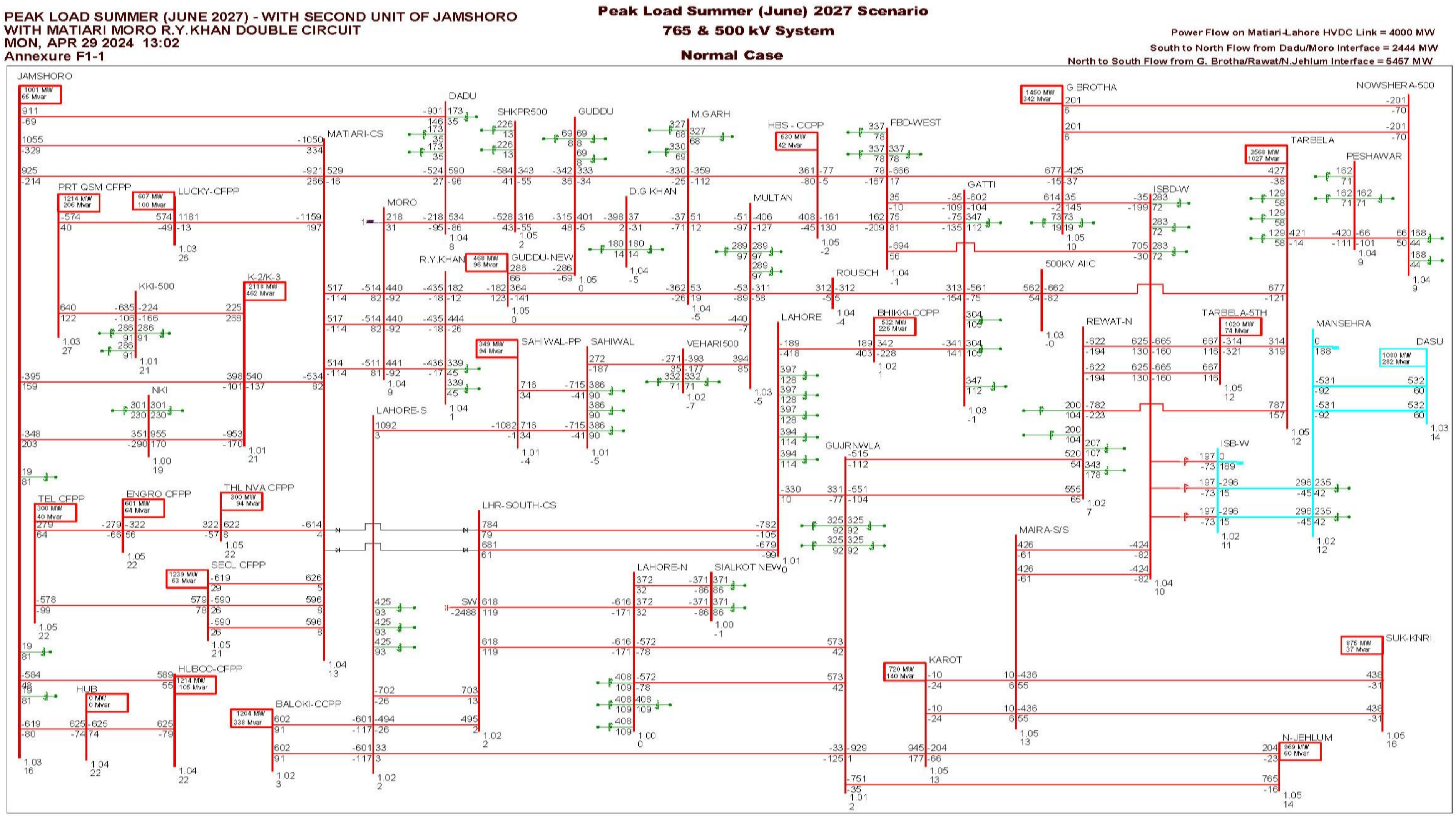
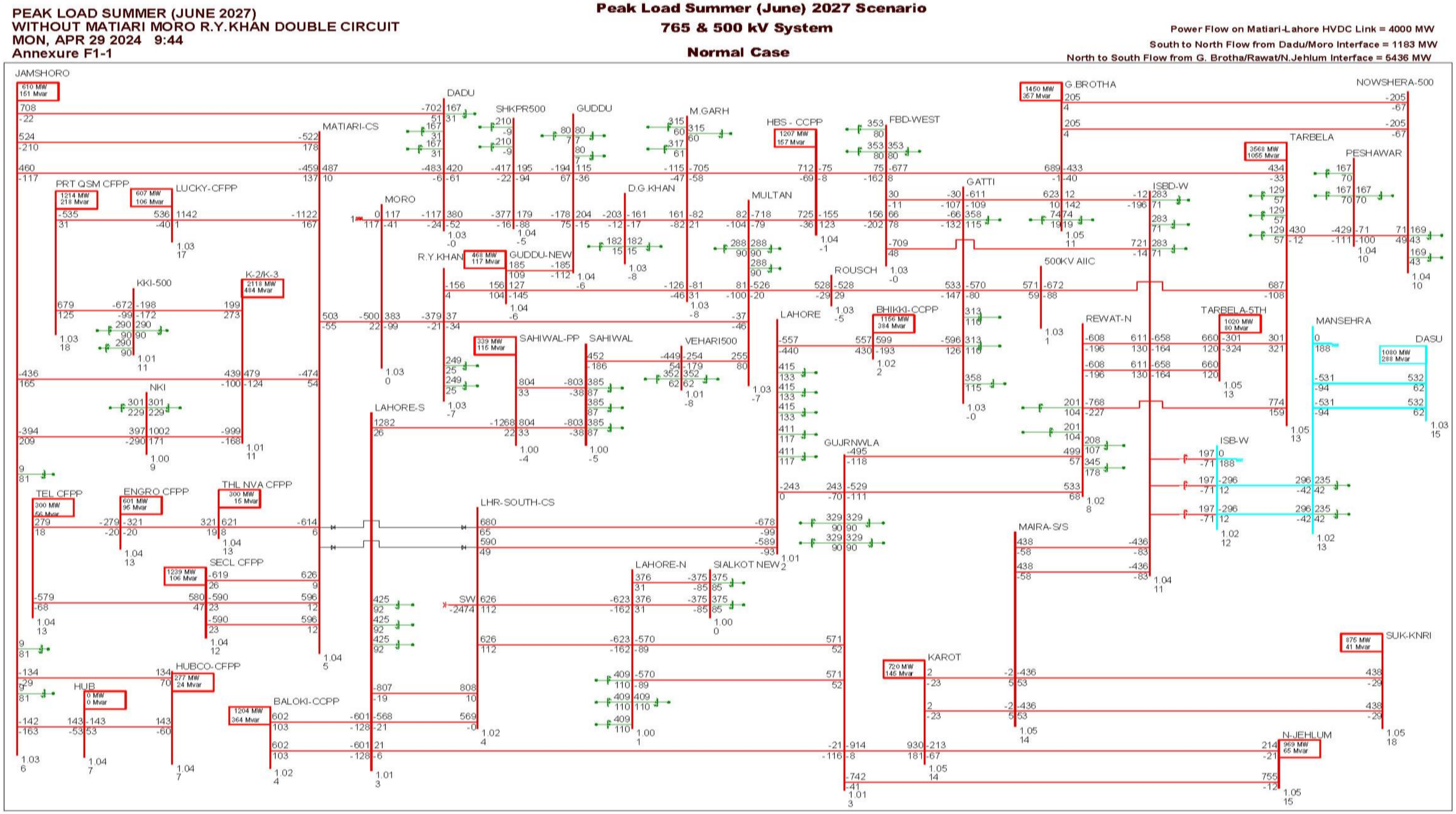


Figure 5-6: 500 kV Network Summer Peak June 2027 – Case B



5.1.4 RESULTS AND ANALYSIS OF WINTER PEAK - JANUARY 2027

In the winter peak case, the load is reduced to almost 60% of the summer peak load. The winter scenario is critical in terms of voltage control as line charging is very high due to lightly loaded longitudinal HVAC network. This excessive line charging MVARs need to be absorbed for maintaining a proper voltage profile. Normally, adequate sizes of shunt reactors shall be installed to maintain the voltages within the limits. In addition, the extra line charging is reduced by opening some of the parallel circuits, without jeopardizing the system reliability and violating the Grid Code operating criteria.

In winter, the hydro power generation in the North is minimum, especially during canal closer period in December and January. Most of the load is fed from the thermal power plants in the South and mid country, which results in maximum flow of power from South to North. This leads to relatively lightly loaded transmission lines in the North and provides an opportunity to switch off some of these lines, without violating the N-1 criteria, to reduce impact of the charging MVARs. Also, some of the line connected shunt reactors installed in the system are configured in a way which enables them to be used as bus reactors when the line is switched off and thus provides some additional compensation. Table 5-6 below lists the major lines openings recommended for the winter peak case of 2027. This significantly helps to control voltages within their normal operating range.

Table 5-6: Major line openings recommended for the peak winter case of 2027

S/N	Circuit Open	S/N	Circuit Open
1	500 kV Ghazi Brotha – Gatti S/C	9	500 kV Rawat – Islamabad West S/C
2	500 kV Gujranwala – Rawat S/C	10	500 kV Matiari – Moro D/C
3	500 kV Gujranwala – Neelum Jhelum S/C	11	500 kV Moro – R. Y. Khan D/C
4	500 kV Maira – Suki Kinari S/C	12	220 kV Kassowal – Arifwala S/C
5	500 kV Maira – Karot S/C	13	220 kV Kassowal – Vehari S/C
6	500 kV Maira – Islamabad West S/C	14	220 kV KAPCO – Multan S/C
7	500 kV Tarbela – Rawat S/C	15	220 kV KAPCO – M. Garh Solar S/C
8	500 kV Tarbela – Ghazi Brotha S/C		

A significant attention has been given to the selection of line openings in the winter scenarios. The winter peak and off-peak scenarios have been developed in parallel to ensure that same line openings suffice both the scenarios. This guarantees that no lines are switched within the day for voltage control. Hence, it is recommended to switch the above lines on a seasonal basis which shall ensure much-improved network operation.

The base case of July 2026 has been updated by scaling the loads expected in winter peak – January 2027. The Generation dispatch has been changed as per the available generation during winter and any change in the transmission network from July 2026 onward has been incorporated in the base case.

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 5-7.

Table 5-7: System Summary – Peak January 2027

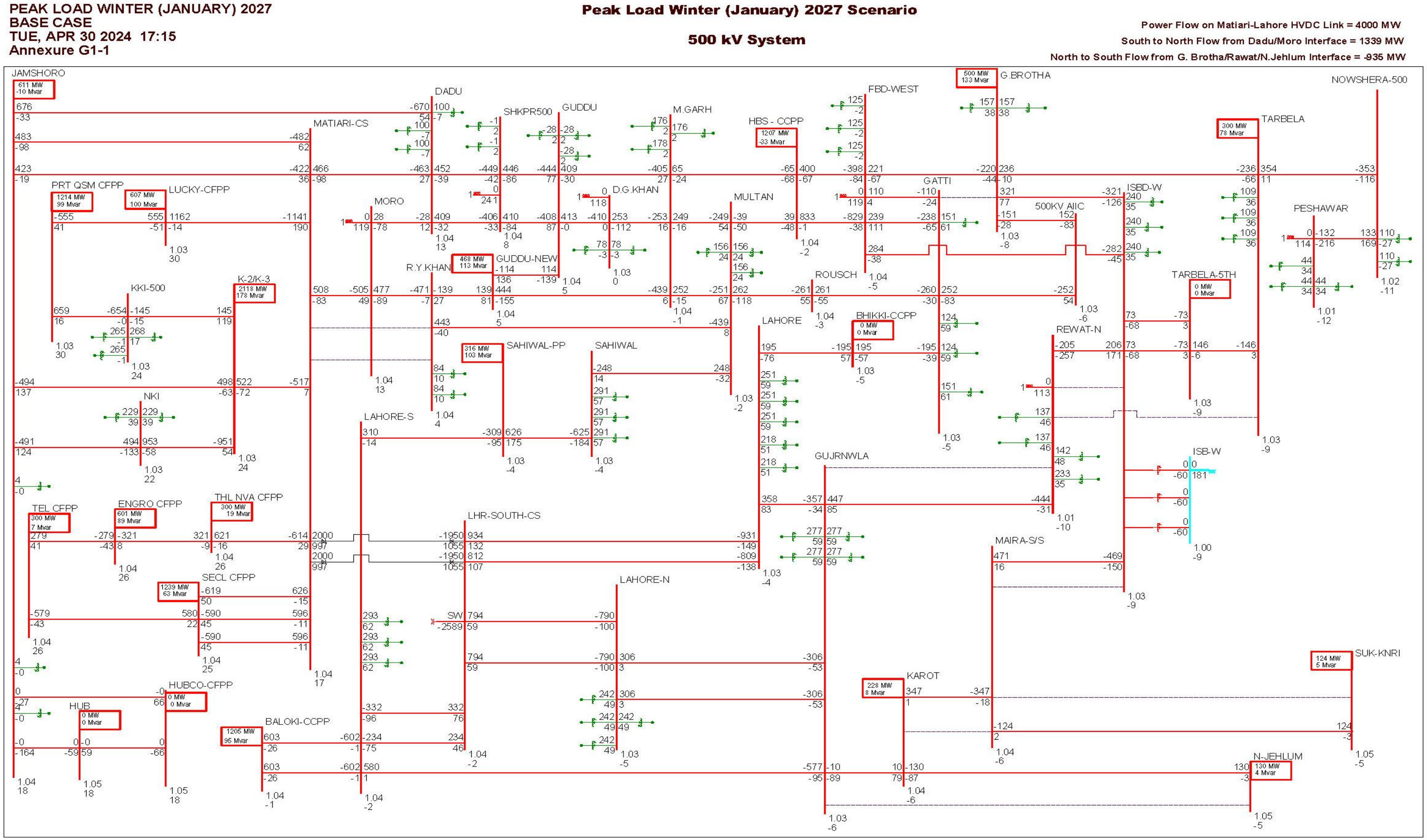
Description	MW	MVAR
NTDC Generation	17954	1461
NTDC/DISCOs Load	15927	7547
Export to KE	1500	107
Shunts Reactors	-	7608
Shunts Capacitors	-	-3748*
Line Charging	-	-15582
Losses	528	10460

* Does not include filters at HVDC terminal stations

Power flow analysis has been performed for the winter peak case and the results for normal operating conditions are provided in Appendix G.

The results show that the transmission line loadings are well within their operating limits, however, over voltages were observed at a few buses. To keep these voltages within the normal operating limits, operational measures of absorbing the VARs by generating units are followed. These measures bring the voltage profile within their normal operating limits (though at higher side) and no violation of the Grid Code is observed as can be seen from the power flow plot of 500 kV network depicted in Figure 5-7.

Figure 5-7: 500 kV Network Winter Peak January 2027 – Normal Operating Conditions



Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) has been performed for the bulk transmission system (EHV and HVDC lines and 500/220 kV and 220/132 kV transformers). The analysis indicates that no voltage or overload violations occur on the entire 500 and 220 kV network. It should be noted that in the studied scenario the full generation in the south is not utilized thus relieving the southern network.

5.1.5 RESULTS AND ANALYSIS OF WINTER OFF PEAK - JANUARY 2027

Traditionally, the winter off-peak load was normally considered as 60% of the winter peak load. However, in recent years, it has been observed that the minimum recorded demand is relatively lower than anticipated. Therefore, this factor is taken into consideration while developing the base case of winter-off peak from the winter peak case of 2027.

The winter minimum operating condition is the most challenging scenario for maintaining the voltage profile within the limits. This scenario determines the requirements of reactive power management necessary for secure system operation, requiring either to switch-off additional circuits as compared to winter peak condition or to install more shunt sinks. It is always preferrable to minimize the intra-day switching of the transmission lines. Therefore, to avoid intra-day switching of the lines, winter peak and off-peak scenarios were developed side-by-side to formulate a set of line openings which can be used for both the conditions. These lines are already listed in Table 5-6. This approach not only adds significant ease to network operation but also safeguards the network from various risks including human errors.

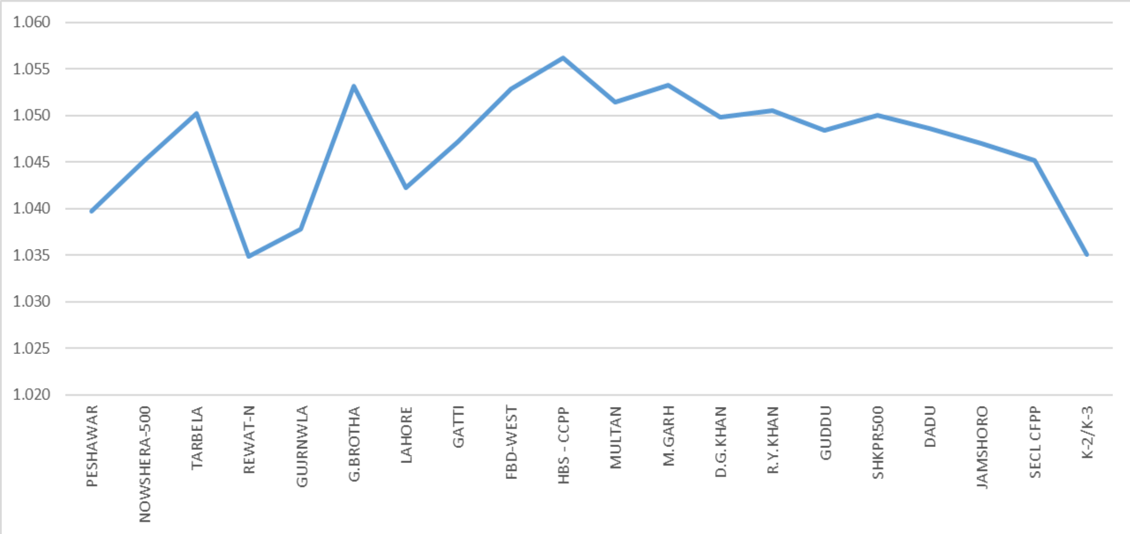
After critically analyzing the network's voltage profile, additional reactors have been proposed to bring system voltages within the allowed limits. This additional reactive power compensation is summarized in Table 5-8.

Table 5-8: Proposed New Shunt Reactors

Bus	MVAR
500 kV Sheikh Muhammadi	111
500 kV Rawat	111
500 kV Faisalabad West	111
500 kV Shikarpur	222
500 kV D.G. Khan	111
220 kV Zhob	60
220 kV D.M. Jamali	60
220 kV Loralai	60
TOTAL	**846**

Considerable improvement in the system voltage profile was seen after installation of the proposed reactors. Figure 5-8 presents the voltage profile of the key buses in the 500 kV network.

Figure 5-8 : Voltages at key 500 kV buses in the network



The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 5-4. This table shows that even after installation of reactors, a substantial volume of reactive power is absorbed by the generators to maintain the system voltages within the limits.

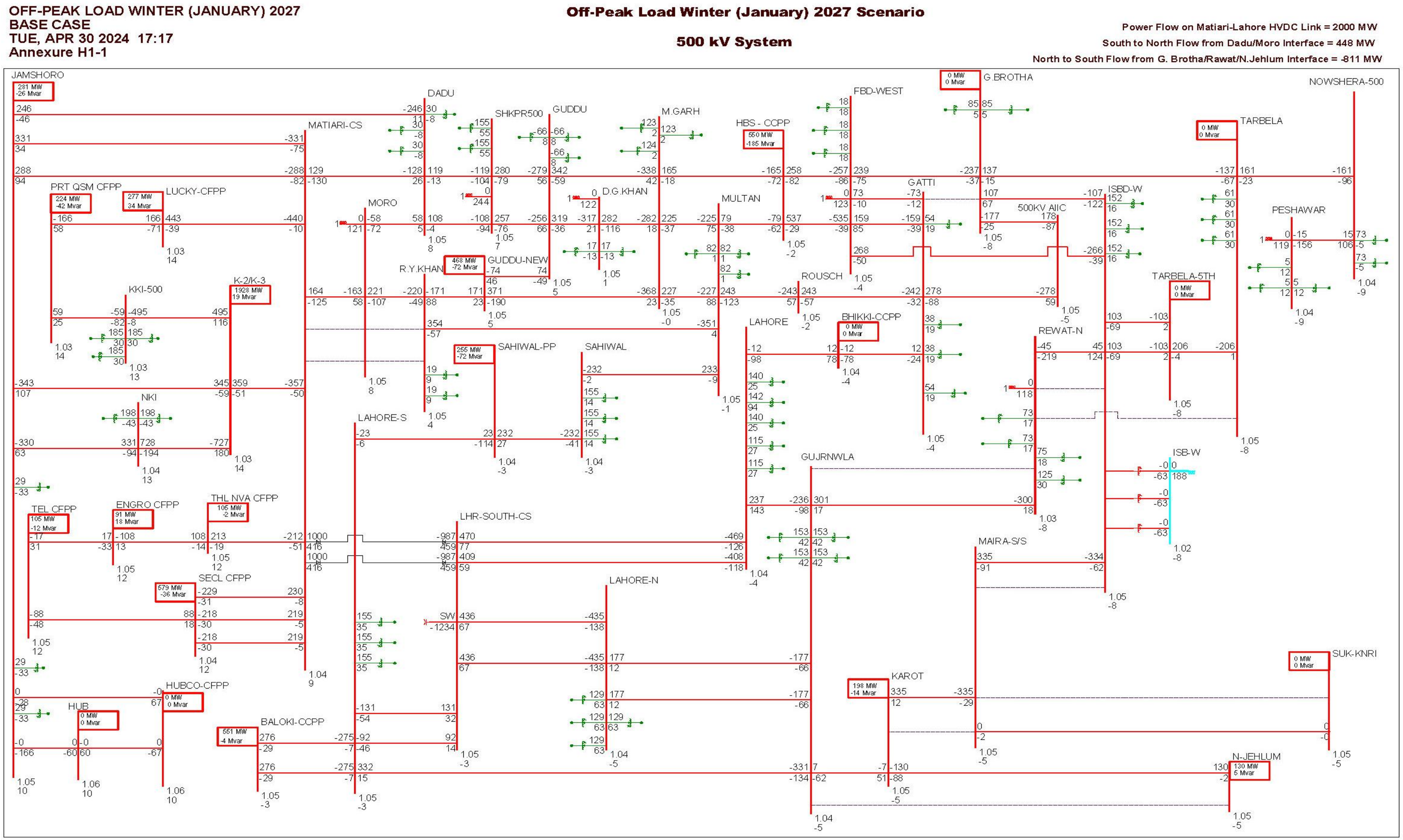
Table 5-4: System Summary – Off-peak January 2027

Description	MW	MVAR
NTDC Generation	9982	-800
NTDC/DISCOs Load	8774	4082
Export to KE	1001	68
Shunts Reactors	-	8211
Shunt Capacitors	-	-146*
Line Charging	-	-15897
Losses	207	4220

* Does not include filters at HVDC terminal stations

Power flow analysis was performed for the winter off-peak case and the results for normal operating conditions are provided in Figure 5-9 and also in Appendix H. The results show that the transmission line loadings are well within their operating limits.

Figure 5-9: 500 kV Network Winter Off-Peak January 2027 – Normal Operation



Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) was performed on the bulk transmission system (EHV transmission lines and 500/220 kV and 220/132 kV transformers) with the proposed additional shunt reactors. The analysis indicates that no voltage or overload violations occur on the entire 500 kV and 220 kV network. Also, no violations were observed in the DISCO networks.

5.1.6 HIGH SOLAR SCENARIO

The generation expansion plan (IGCEP 2024) assumes that about 2,400 MW (AC) utility scale solar PV generation will be installed during the next two to three years. Three sites have been identified for the installation of 2400 MW. These solar PV generation additions are envisaged as fuel substitution projects, i.e., expensive RLNG/RFO generation will be reduced during the daytime and maximum power will be evacuated from solar power plants using the same infrastructure with minimum reinforcement in the system.

Out of this 2400 MW, 1200 MW is expected to commission before June 2027 and is included in the base case. The remaining 1200 MW will be included in the base case for July 2028. Table 5-5 lists the interconnection schemes proposed for connecting the 2,400 MW Solar PV projects to the national grid:

Table 5-5: Proposed locations for addition of 2400 MW Solar PV

S/N	Site Location	Capacity (MW)	Connection Scheme	Expected Commissioning
1	Near HBS (will be included in Peak July 2028 base case)	1200	In/out S/C of 500 kV Muzafargarh - HBS OHL at the site	2027-28
2	Near Muzafargarh	600	In/out S/C of 220 kV Multan - KAPCO OHL at the site	2026-27
3	Near Jhang	600	In/out S/C of 220 kV Jhang to TT Singh OHL at the site	2026-27

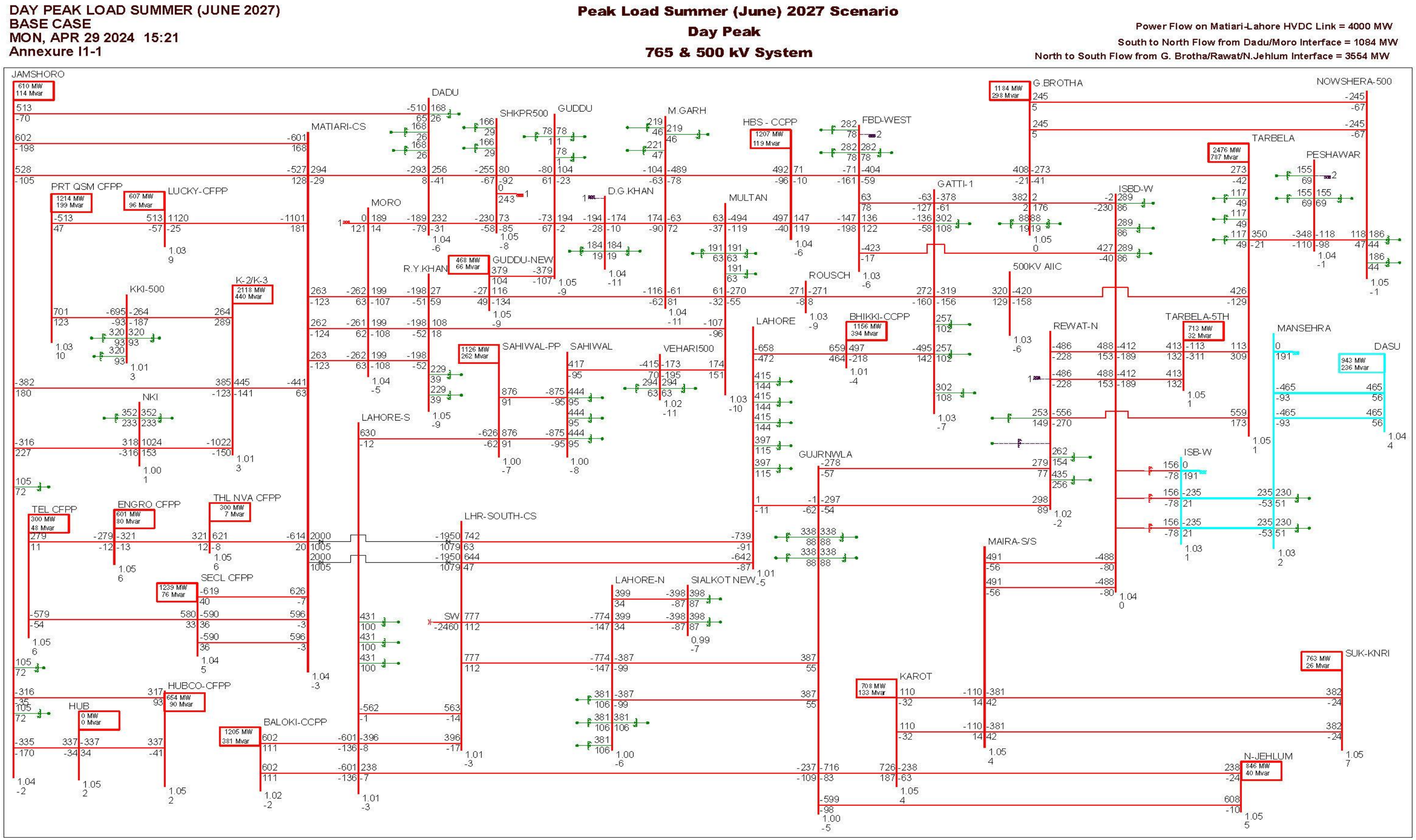
To ascertain impacts of the new solar PV additions on the interconnected power system, a day peak case for June 2027 has been simulated. The base cases already developed for the peak load conditions were used for conducting the power flow analysis. Loads are kept the same as of the respective peaks, however, the generation dispatch is modified to accommodate the solar PV generation during daytime. The objective of this analysis is to quantify any power evacuation limitation that these new solar PV plants could pose on dispatch of the existing plants and to ascertain any transmission constraints on the DISCOs networks.

Power Flow and Contingency Analysis for Summer Day Peak - June 2027

Power flow and contingency analysis have been performed using the day-peak June 2027 base case, which incorporated the new solar PV generation projects into the two connection sites mentioned above. The hydro power generation dispatch was slightly reduced as per the current practice of daytime dispatch, and the thermal power generation is adjusted to balance the dispatch of maximum solar PV generation.

Results of the analysis are provided in Appendix F. The power flow analysis indicates that no voltage or overloading violations occur under normal system operation. However, under contingency conditions, the dispatch from the Jhang 1263 MW RLNG-based power plant may need to be reduced (in case dispatching at maximum capacity) to avoid N-1 violation if the generation from the solar PV plants are kept at maximum. Figure 5-10 depicts normal system power flows for the 500 kV network.

Figure 5-10: 500 kV Network Day-Peak June 2027 – Normal Operation



5.2 SHORT CIRCUIT ANALYSIS FOR SPOT YEAR 2026-27

Short circuit analysis has been carried out to calculate maximum fault currents for balanced and unbalanced faults on the bulk power system, i.e., three phase to ground (LLLG) and single phase to ground (LG) faults, respectively. The objective of the analysis is to determine the following:

- Short circuit rating of the switchgear to be installed at new substations considering the connection of new power plants and transmission expansion in the system.
- Adequacy of the existing switchgear ratings against the increased short circuit levels prevailing in the system and to suggest remedial measures in case violations are observed.
- System short circuit strength, protection coordination, short circuit impedance to develop system equivalence for EMTP studies, etc.

The analysis has been performed using IEC 60909 Standards to determine the maximum short circuit currents considering the following assumptions:

a. Pre-fault voltage (C-factor) to be equal to 1.1 per unit (up to 500 kV level)

b. Set tap ratios to unity

c. Set line charging to zero

d. Set shunts to zero in positive sequence

e. All generating units online for ultimate fault levels

Fault currents are computed at all nodes of the NTDC transmission network. The short-circuit base cases were developed considering the expected on-line generation for the spot year. This may not provide the maximum fault currents which would occur if all the available generation is kept on-line. Since both the operating scenarios are being analyzed, i.e, low hydro high thermal and high hydro low thermal, therefore, this approach provides a reasonably good and realistic estimation of short circuit levels, which would prevail in the system corresponding to the operating conditions under study. It should be noted that in all operating scenarios, the short circuit analysis has been performed keeping all units of the four RLNG-based power plants operational, irrespective of their status in the power flow analysis.

However, an ultimate short circuit case was also studied where all the available generation, which could probably be put on-line, was switched on and the short circuit levels were computed. The results show that there is minimal impact on the short circuit levels and no major violation is observed except at 500/220 kV Lahore substation, which indicates that the 220 kV circuit breakers may need to be replaced with higher rating, if and when required.

5.2.1 SHORT CIRCUIT RESULTS 2026-27

The maximum computed short circuit levels at key buses for 2026-27 are shown in Table 5-6. The detailed results of the analysis are provided in Appendix E. The proposed remedial measures of reconfigurations reduce short circuit levels at all the buses that are now within the circuit breaker ratings. However, where the short circuit level at a node is quite close to the switchgear ratings, a replacement program for 220 kV breakers, bus splitting, and inter bus CLR at 132 kV substations shall be initiated in due course of time.

After the commissioning of Islamabad West 500/220/132 kV grid station the fault levels in the area have increased. The computed short circuit currents at 132 kV Rawat and ISPR buses marginally exceed the respective switchgear ratings. To limit the fault levels within the switchgear ratings, it is proposed to switch-off one 500/220 kV transformer at Rawat and two 220/132 kV transformers at ISPR. This is achievable since after the commissioning of Islamabad West 500/220/132 kV grid station, the transformer loadings of 220/132 kV ISPR transformers has considerably reduced. Alternatively, the 132 kV bus bars at these substations may be operated in split arrangement or the line openings may be revised for the 132 kV network linking to these substations.

It is pertinent to note that the short circuit analysis is normally performed by simulating faults at the buses. However, the probability of occurring faults on a bus is quite low and normally faults occur on the transmission lines. This means that the short circuit currents would be less than the levels computed in this analysis.

Ultimate short circuit levels, considering all the generation on bar, have also been computed and the results are provided in Appendix E. Also, the minimum short circuit levels corresponding to system conditions in winter are attached in Appendix E.

Table 5-6: Short Circuit Levels – 2026-27

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	1-Phase
13	ISB-W	765	50	13.4	12.0
64	MANSEHRA	765	50	12.0	9.9
16	DASU	765	63	9.5	8.9
20	TARBELA	500	50/63	43.5	44.8
29	TARBELA-5TH	500	63	42.7	42.6
21	ISBD-W	500	63	42.4	34.6
25	G.BROTHA	500	40/50	35.6	24.4
95	MATIARI-CS	500	50	30.9	25.2
80	JAMSHORO	500	40	30.4	26.6
24	GUJRNWLA	500	40	30.4	23.4
212	ISBD-W	220	63	44.5	38.6
260	LAHORE-N	220	63	42.9	35.6
444	FBD-W	220	63	40.4	32.4
151	NOWSHERA-220	220	50	40.2	30.6
245	NOKHAR	220	50/63	39.1	32.7
300	LAHORE	220	40/50	38.5*	33.3
200	TARBELA	220	50/63	37.4	37.2
145	NOSHRA-I	220	40	37.4	26.9
400	GATTI	220	40/50	37.2*	29.2
303	LAHORE-S	220	50	35.2	31.0
410	SUMNDIRD	220	40	35.2	25.4
500	MULTAN	220	40/50/63	34.4	27.4
910	NKI	220	40	33.8	28.2
100	PESHAWAR	220	40	33.6	25.5
440	JRN W.RD	220	31.5/40/50	33.2	24.3
220	RAWAT-N-I	220	40/50	33.0*	27.1

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	1-Phase
4012	LAHORE	132	31.5/40	37.5	32.1
4127	LAHORE-2	132	31.5/40	37.5	32.1
2300	REWAT132-1	132	40	36.9	30.2
2301	REWAT132-2	132	40	36.9	30.2
4262	LHR-N-132	132	40	36.5	30.4
2025	ISPR-132	132	40	36.3	27.5
2022	220/132 BUR2	132	25/40	35.2	26.7
1070	MARDAN	132	40	34.7	26.1
4029	ATTABAD	132	40	34.5	26.8
4330	NSHTBD-1	132	31.5/40	34.5	27.1
3000	GAKKHAR	132	31.5/40	34.0	25.6

Note: * bus split

5.3 TRANSIENT STABILITY STUDY FOR SPOT YEAR 2026-27

This section discusses the results of the transient stability analysis, which was performed to ascertain the robustness of the system and its dynamic behavior under disturbance conditions. The generation dispatch in the July 2026 power flow case is slightly adjusted, i.e., Pgen is kept slightly less than Pmax for the generating units with spinning reserve allocation. This is done to keep adequate spinning reserve, close to the largest unit in the system. It is noted that the steady state performance of the network under peak load conditions of July 2026 have already been tested through extensive power flow and contingency analyses and found satisfactory, as discussed in the previous sections.

The transient stability analysis was performed by simulating three phase fault at each 500 kV bus and all generation buses connected at 220 kV level. The following parameters were observed to assess stability of the integrated power system:

- Rotor angles of generators
- Power flow swings on the healthy circuit(s) impacted due to the trip of the faulted circuit
- Bus voltages
- Bus frequencies

As per the Grid Code guidelines, a three phase fault is applied at a bus, which is cleared normally in five (5) cycles following the outage of the heavily loaded circuit. The following were assumed while performing the studies:

- Loads connected at the 11 kV buses are represented as complex load models.
- Power System Stabilizers (PSS) exist at all the new/proposed generating units and available at some of the existing power plants.

The recently developed dynamic data file, under the CESI project, has been used in the analysis. This file has been developed, by the Consultant, after an exhaustive data collection exercise which includes site visits to many power plants. The collected data was thoroughly reviewed, verified against international standards, tested using ERUN and GRUN activities of PSSE to finally come up with a trustworthy dynamic data file which can successfully capture the system response under disturb conditions.

5.3.1 RESULTS AND ANALYSIS OF SUMMER PEAK - JULY 2026

Table 5-7 shows some of the critical contingencies and the corresponding stability plots are exhibited in Figure 5-11 through Figure 5-16, whereas, the results of all transient stability simulations are attached in Appendix E.

The transient stability simulation results reveal that, in general, the integrated power system stays stable under all the simulated faults. Generally, all the oscillations damp down within the reasonable time frames for most of the contingencies. Although no angular instability issues were noticed, oscillations were seen at some of the plants in the South, especially K2/K3. This shows that tuning of some control parameters would be required, or additional PSS may have to be installed at some of the existing power plants.

Generally, voltage recoveries at most of the nodes are quite good and are within the acceptable limits after clearing the three-phase fault. However, the voltage recovery in the Lahore region was relatively sluggish which signifies the requirement of dynamic reactive power support near this area.

Table 5-7: Summary of the Transient Stability Analysis Results - July 2026

S/N	Faulted Bus		Base Voltage (kV)	Trip Circuit		Loading (MVA)	Fault Type	Stability Status			
	Number & Name			Number & Name				VOLT	ANGL	POWR	FREQ
1	95	MATIARI	500	N/A	MATIARI CS – LAHORE CS One HVDC Pole	2000	3P	Stable*	Stable*	Stable*	Stable
2	80	JAMSHORO	500	80-95	JAMSHORO - MATIARI	582	3P	Stable	Stable*	Stable*	Stable
3	89	K2/K3 PP	500	89-91	K2/K3 - NKI	942	3P	Stable	Stable*	Stable	Stable
4	95	MATIARI CS	500	95-930	MATIARI – LUCKY CFPP	857	3P	Stable	Stable*	Stable	Stable
5	213	N. Jhelum	500	24-213	N. Jehlum - Gujranwala	1239	3P	Stable*	Stable	Stable*	Stable*
6	36	Sahiwal PP	500	35-36	Sahiwal PP - Sahiwal	1744	3P	Stable	Stable**	Stable	Stable

***Oscillatory, ** delayed recovery**

Figure 5-11, shows transient stability plots relevant to the contingency of a single pole of Matiari – Lahore HVDC line. This is the worst contingency for evaluation of stability of the South to North 500 kV HVAC interface. The graphs indicate a stable response but the system is poorly damped, resulting in an oscillatory response. Also, the angular excursion is quite large for plants in the South, especially K2/K3 nuclear power plant.

Similarly, Figure 5-12 to Figure 5-14 show stability plots for faults at key locations in the South. Once again, although response is stable, relatively large angular excursions are observed in K2/K3 power plant.

Figure 5-15, shows the stability plots when the fault is simulated at 500 kV bus bar of Neelum Jhelum and the 500 kV Neelum Jhelum – Gujranwala circuit is tripped. It is a critical contingency in July 2026 due to delay in commissioning of 500 kV Maria substation, resulting in operation of Karot and Suki Kinari on interim power evacuation schemes. Also, a cross-trip scheme is employed to trip entire complex of Suki Kinari and three units of Karot power plant in case of contingency. The plots show a stable graph. However, the response is poorly damped resulting in sustained oscillations, especially in voltage and power flow.

Figure 5-16 shows the stability plots when the fault is simulated at the 500 kV bus bar of Sahiwal Power Plant followed by tripping of 500 kV Sahiwal – Sahiwal PP circuit. The results indicate that the transient responses are stable. However, after contingency, the voltage at key buses in the load center, such as 500 kV Sahiwal and Lahore, is quite low, indicating the need for reactive power support in these areas. It should also be noted that this contingency blows up the load flow case due to inadequate reactive support.

Figure 5-11: 3-Phase Fault at 500 kV Matiari – Trip one HVDC pole

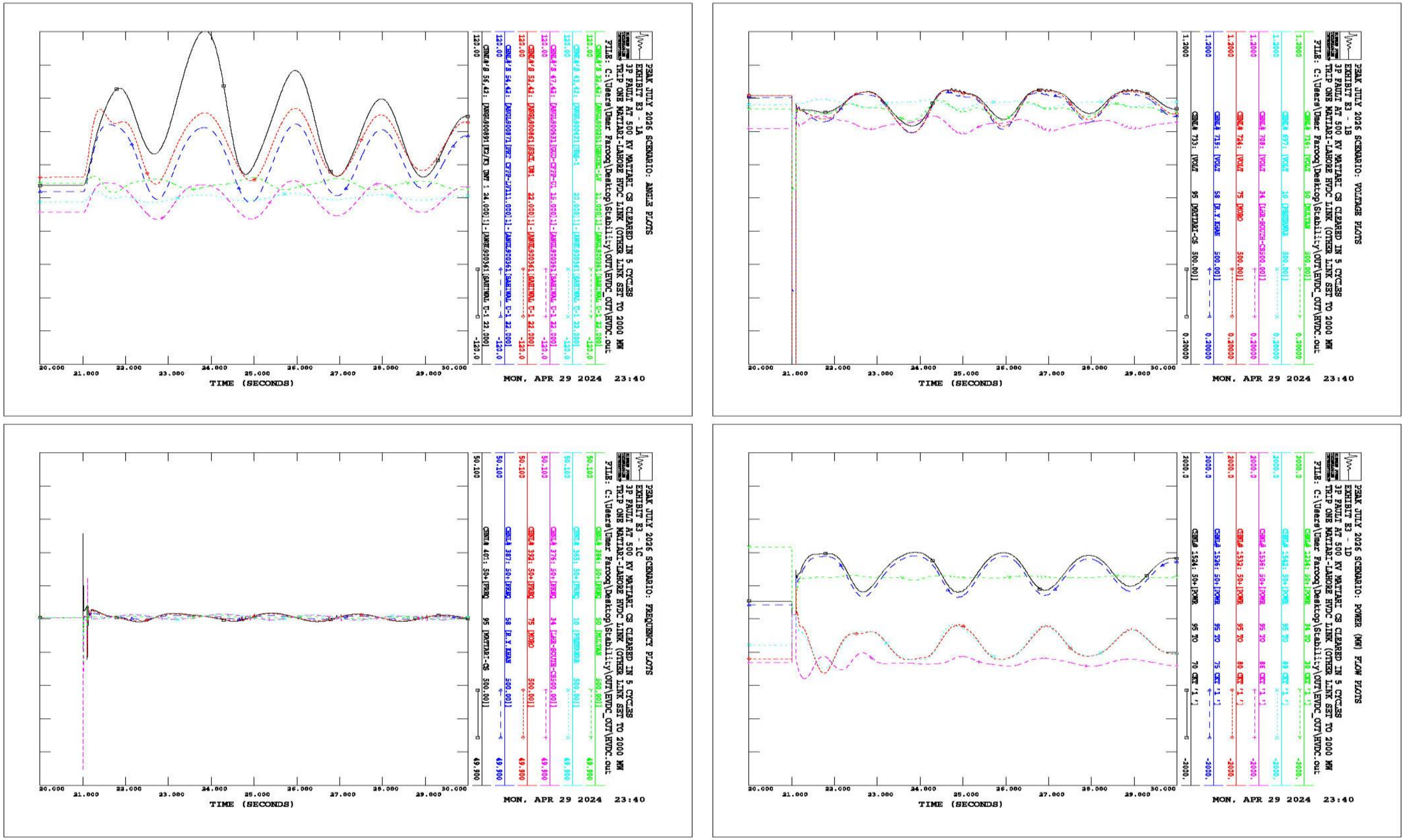


Figure 5-12: 3-Phase Fault at 500 kV Jamshoro

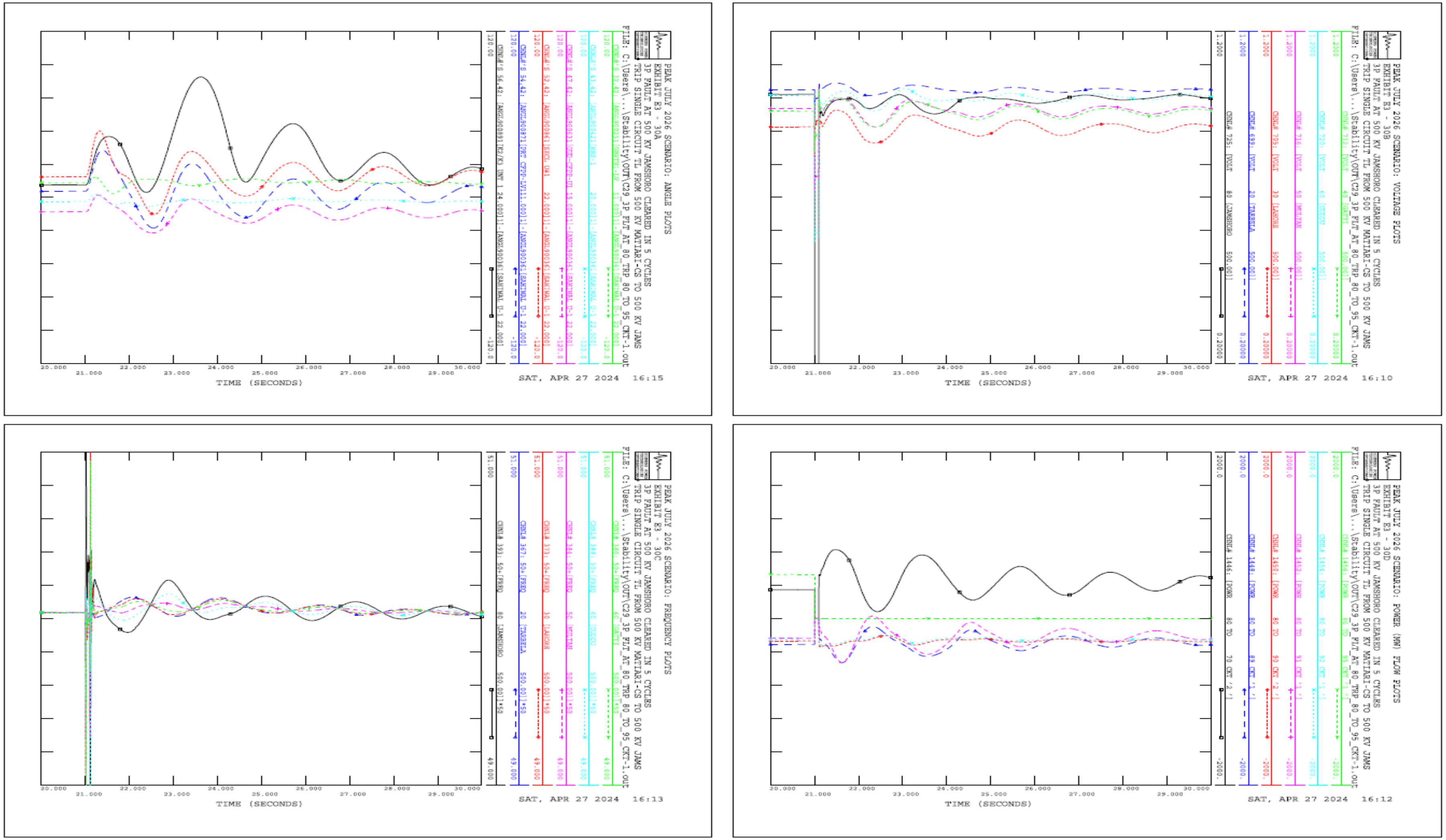


Figure 5-13: 3-Phase Fault at 500 kV K2/K3 Power Plant

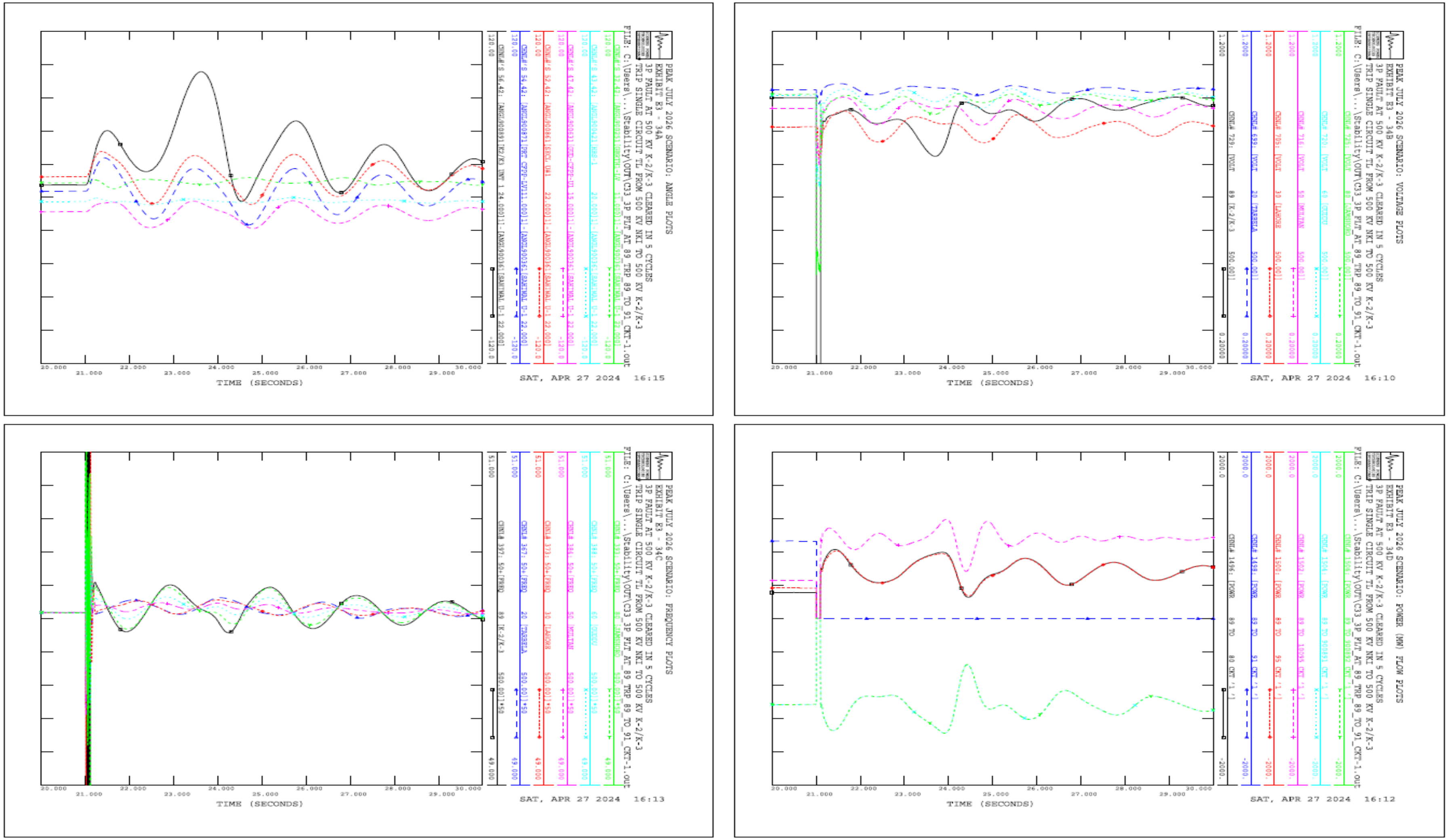


Figure 5-14: 3-Phase Fault at 500 kV Matiari CS

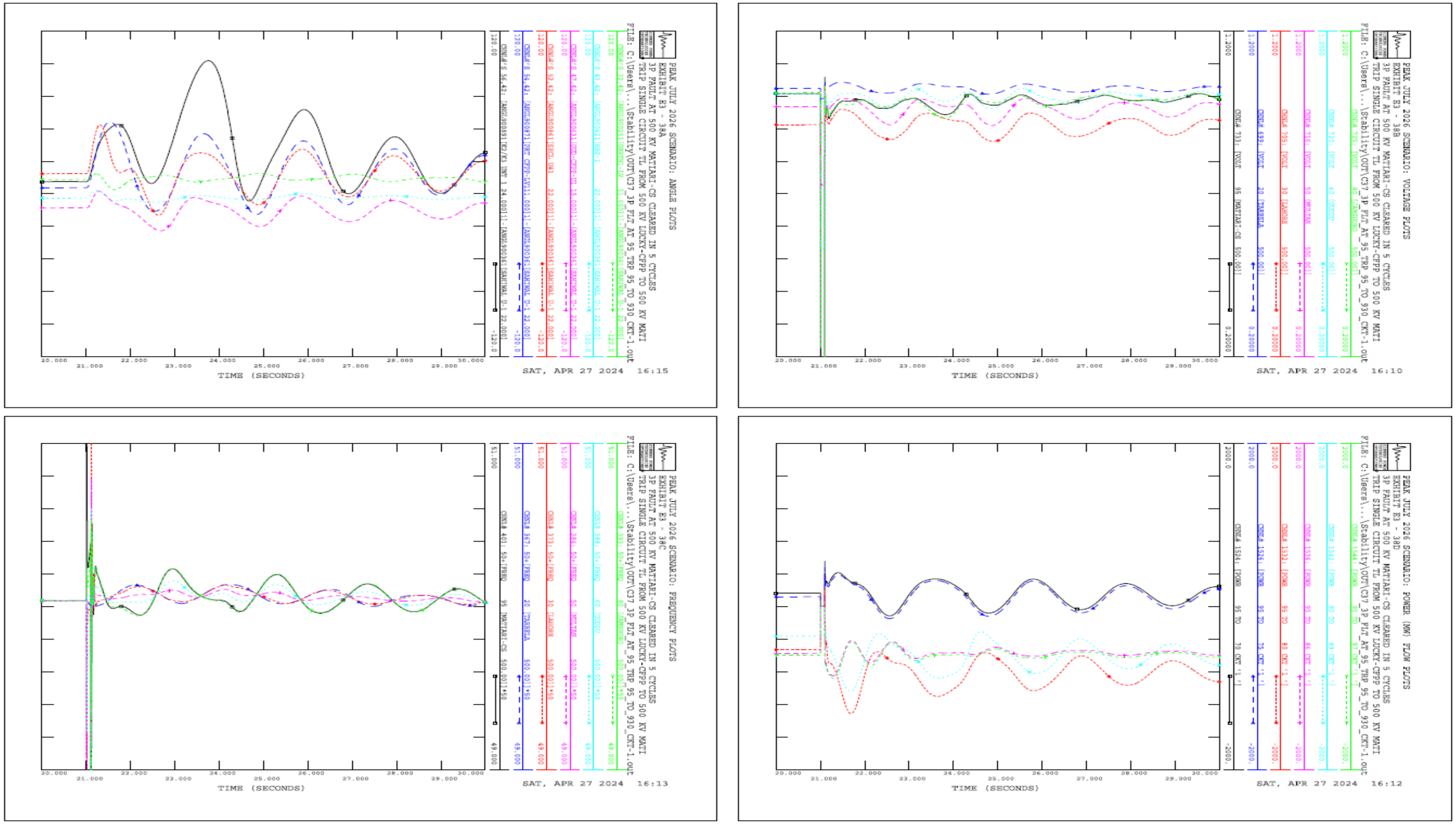


Figure 5-15: 3-Phase Fault at 500 kV Neelum Jhelum

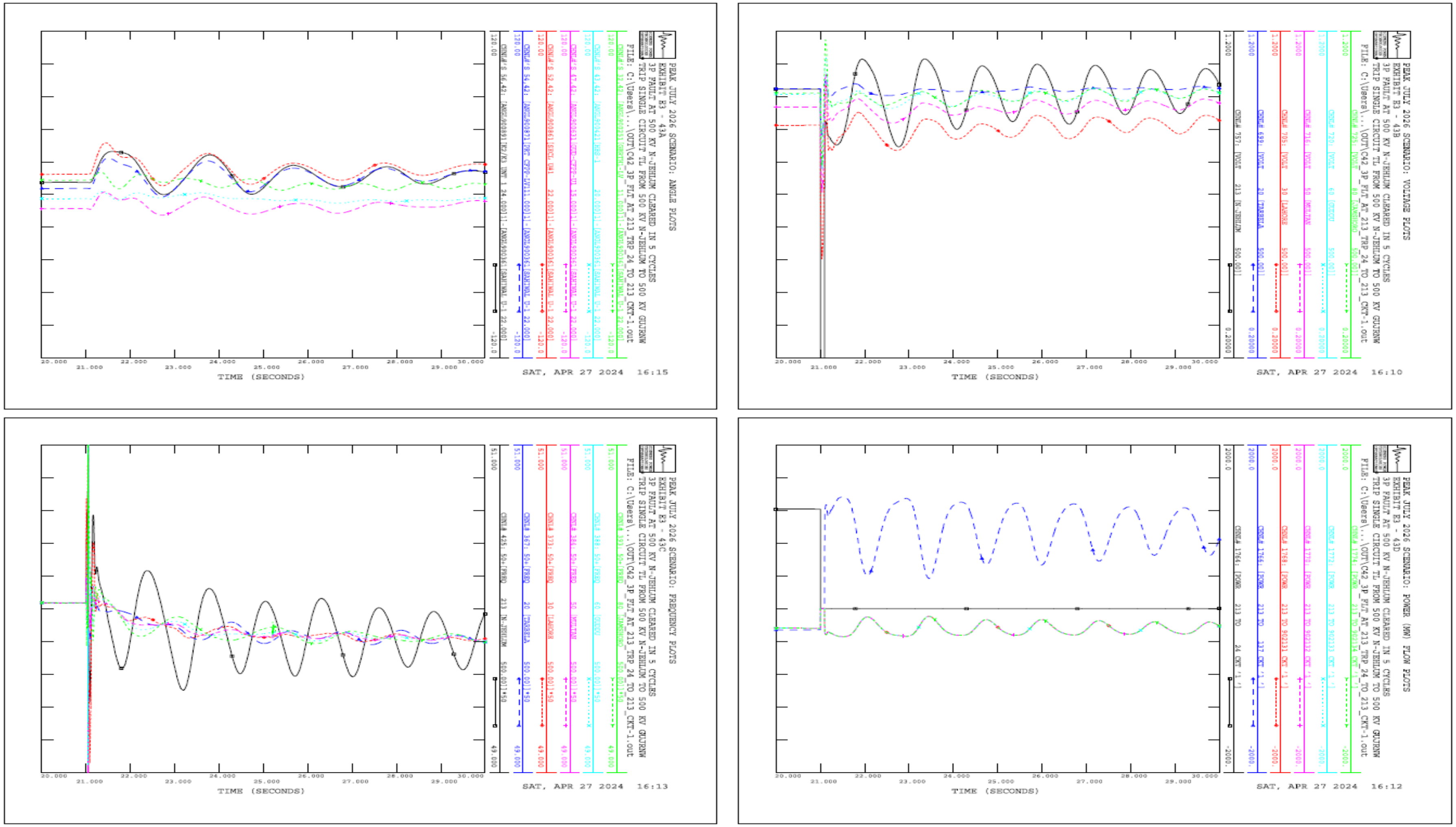
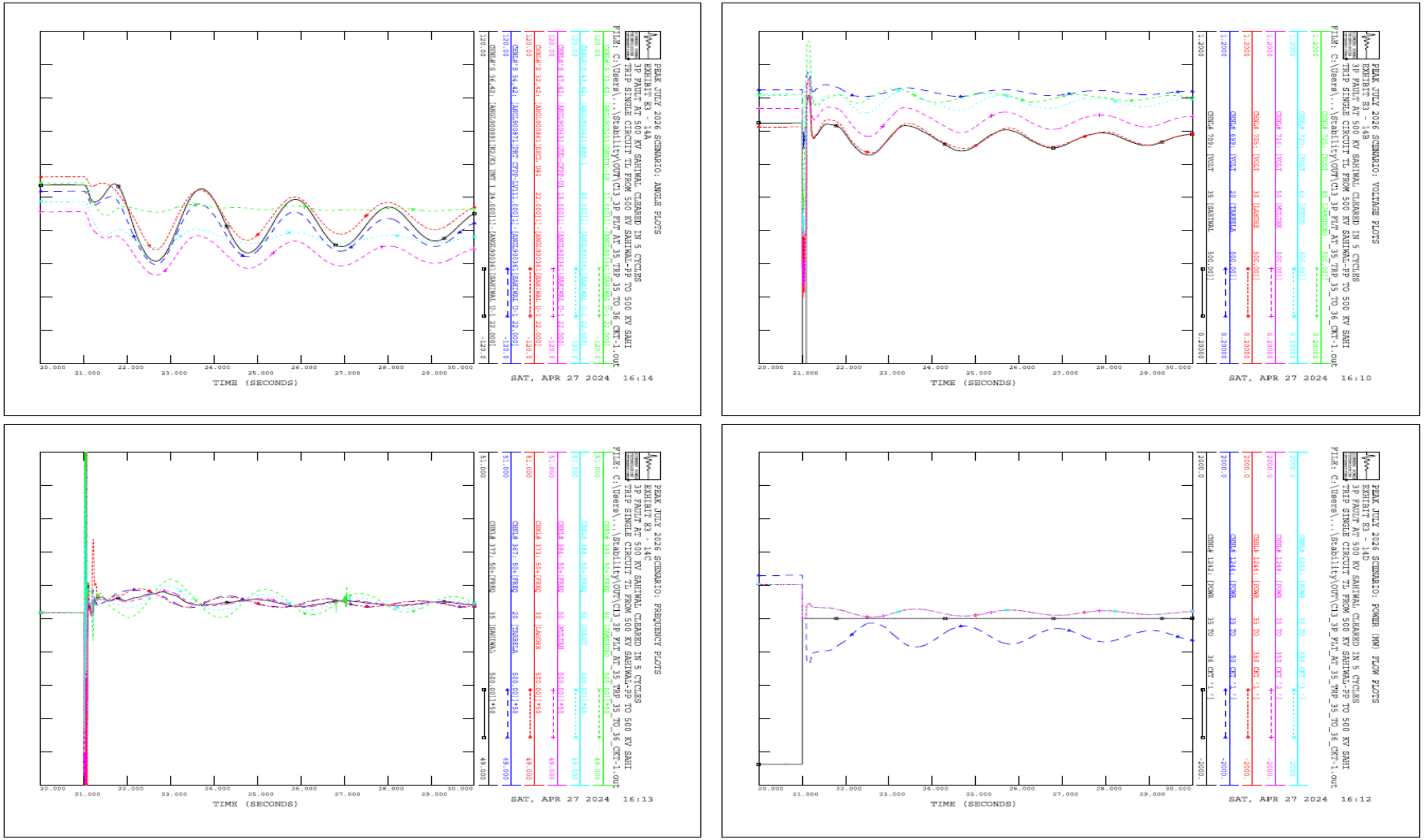


Figure 5-16: 3-Phase Fault at 500 kV Sahiwal Power Plant



5.3.2 RESULTS AND ANALYSIS OF SUMMER PEAK - JUNE 2027

Transient stability analysis has been performed for Summer Peak June 2027 operating conditions and the simulation results are attached in Appendix F. Table 5-8 shows results for some of the critical contingencies and the corresponding stability plots are exhibited in Figure 5-17 through Figure 5-19. In general, the results indicate the system remains stable for all the contingencies.

Table 5-8: Summary of the Transient Stability Analysis Results - June 2027

S/N	Faulted Bus		Base Voltage (kV)	Trip Circuit		Loading (MVA)	Fault Type	Stability Status			
	Number & Name			Number & Name				VOLT	ANGL	POWR	FREQ
1	95	MATIARI	500	N/A	MATIARI CS – LAHORE CS One HVDC Pole	2000	3P	Stable*	Stable*	Stable	Stable
2	89	K2/K3 PP	500	89-91	K2/K3 - NKI	1012	3P	Stable*	Stable	Stable	Stable
3	95	MATIARI CS	500	95-930	MATIARI – LUCKY CFPP	1190	3P	Stable*	Stable	Stable	Stable

*Oscillatory

Figure 5-17 shows the stability plots for fault at 500 kV Matiari CS followed by tripping of one HVDC pole. The stability response of the system is stable. However, the angular response of the machines in the South is relatively oscillatory.

Figure 5-18 and Figure 5-19 show the stability plots when faults are simulated at 500 kV K2/K2 and Matiari CS, respectively. Once again, the response is stable but oscillations are observed in the angular response of K2/K3 and Port Qasim power plants.

Figure 5-17: 3-Phase Fault at 500 kV Matiari – Trip one HVDC pole

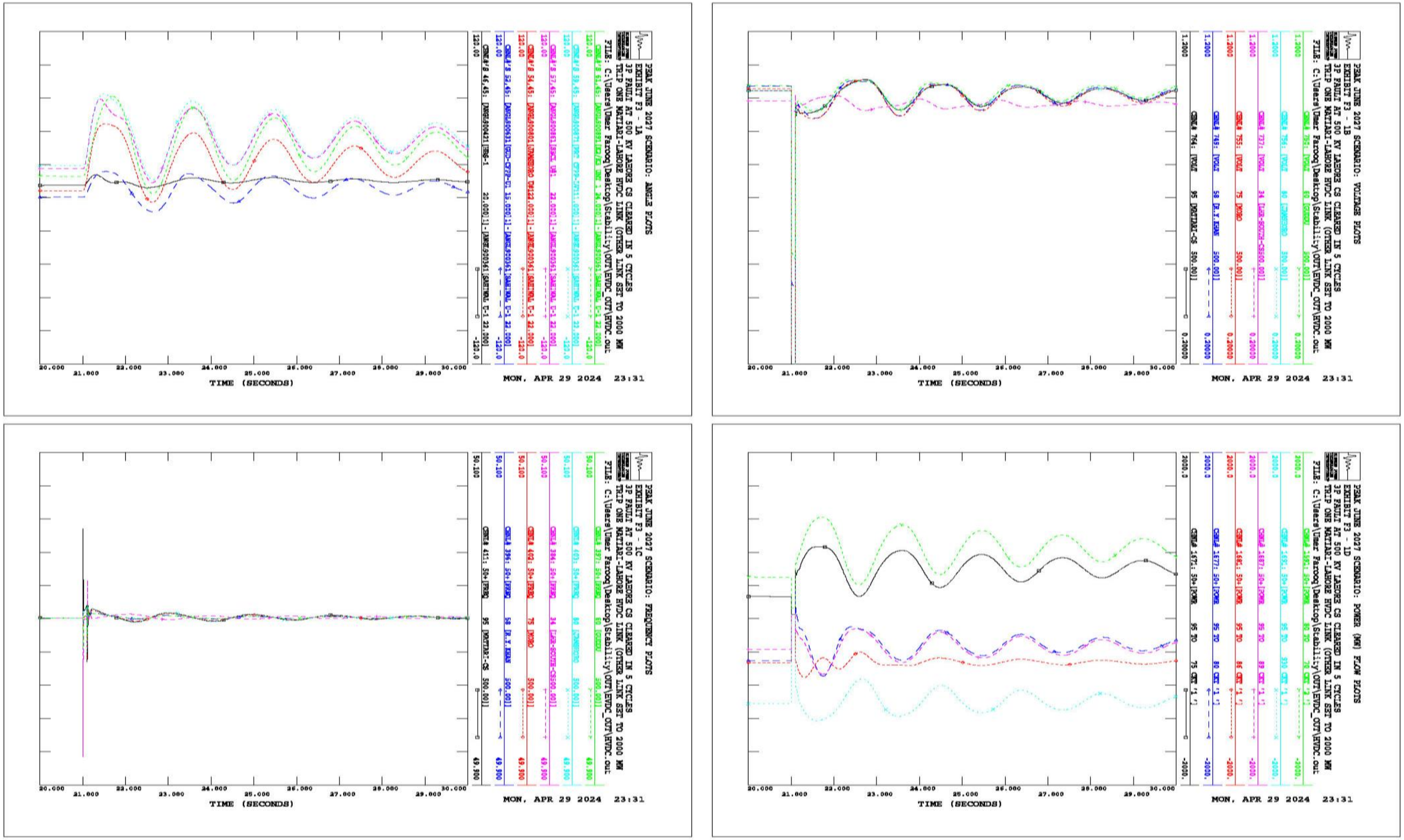


Figure 5-18: 3-Phase Fault at 500 kV K2/K3 Power Plant

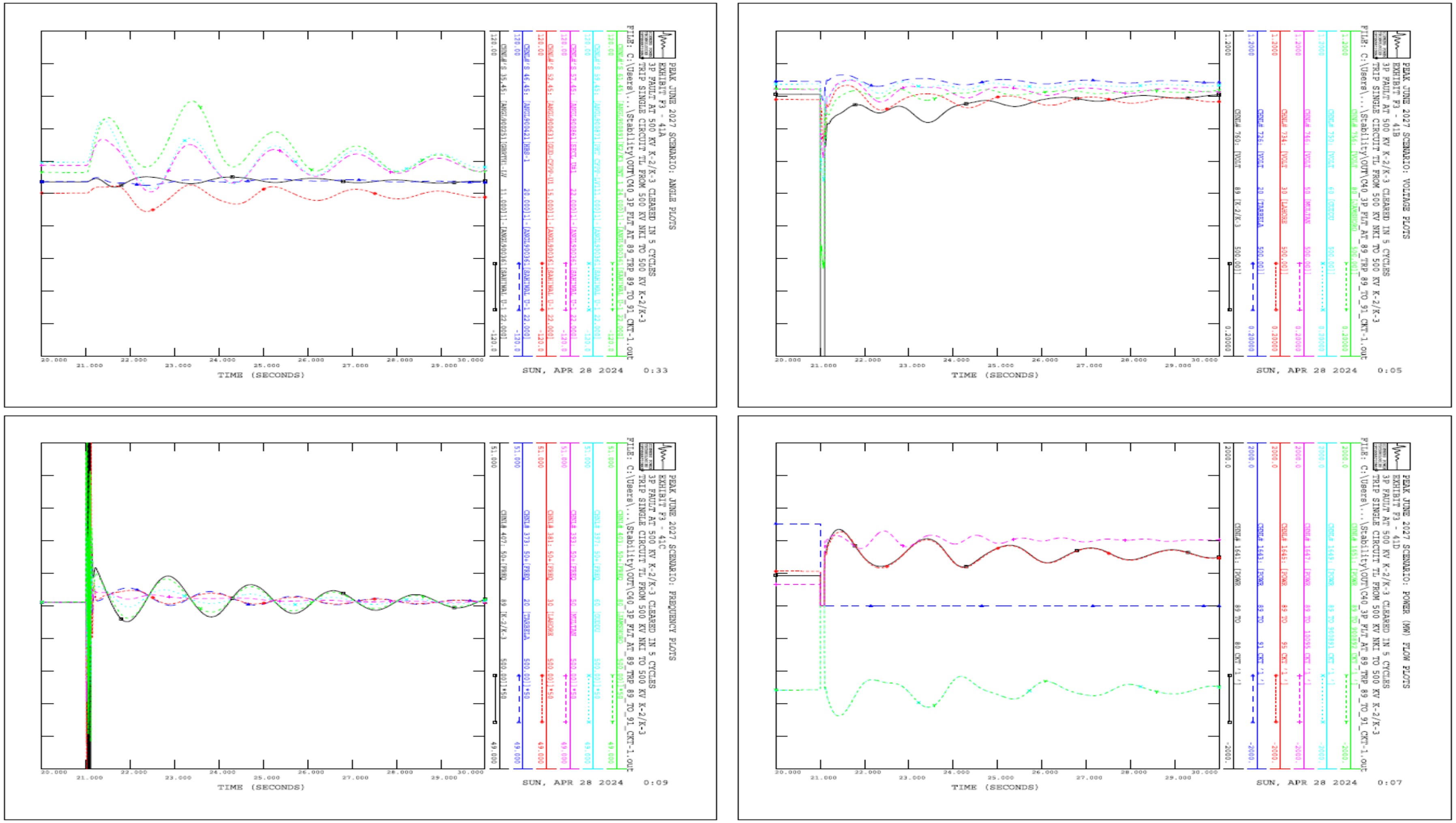
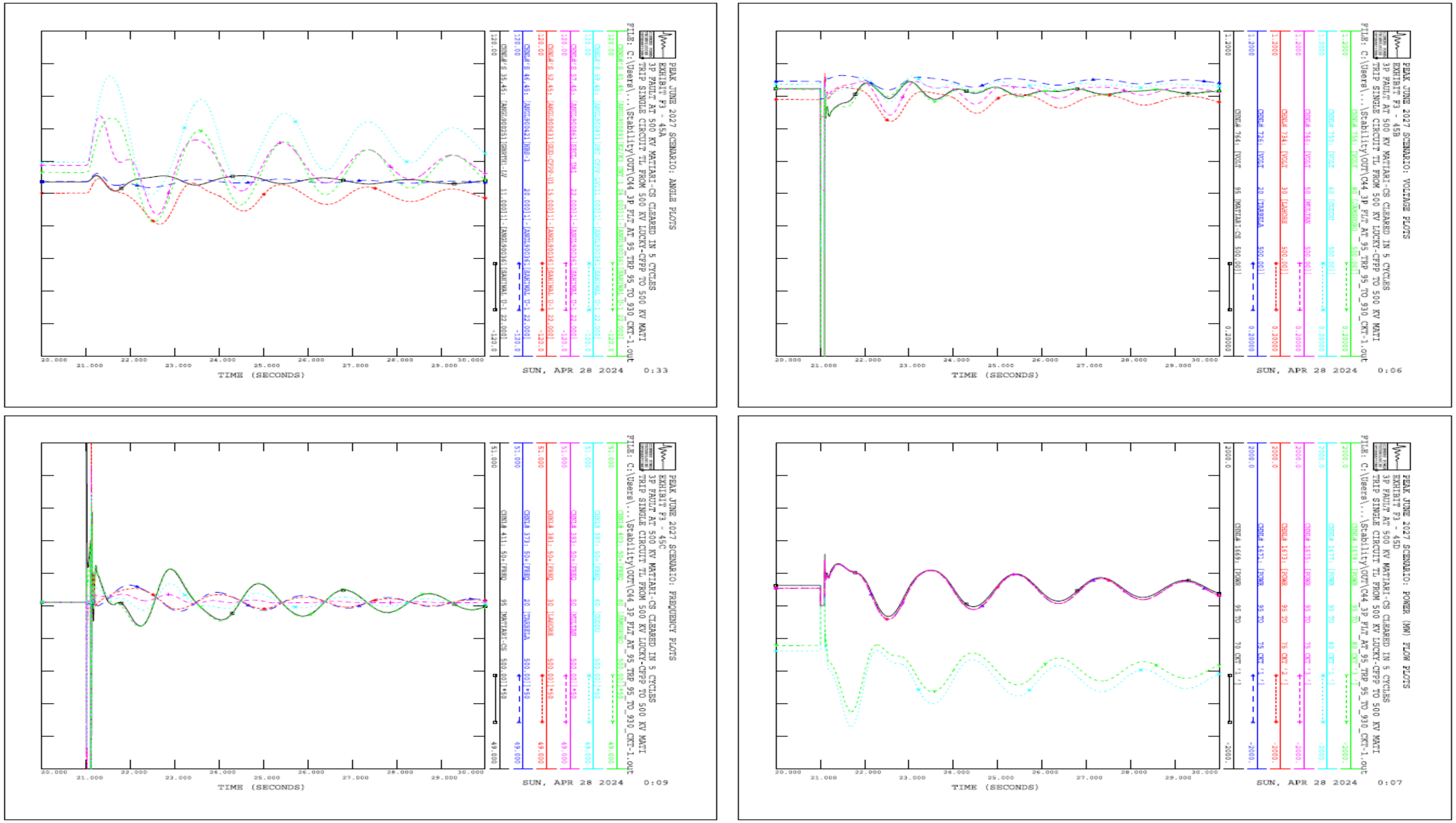


Figure 5-19: 3-Phase Fault at 500 kV Matiari CS



5.3.3 SENSITIVITY ANALYSIS: MAXIMUM DISPATCHED FROM SOUTH WITH/WITHOUT MATIARI-MORO-RYK OHL

It was discussed in section 5.1 that it is assumed that the proposed Matiari-Moro-RY Khan 500 kV D/C line will be available by June 2027. However, considering the long length of the line and expected construction/right of way difficulties it is likely that the proposed line might face delays in construction. Therefore, a sensitivity case is performed to ascertain the maximum generation, including wind, which can be utilized from the south maintaining a secure power transfer limit without this line.

Stability analysis has been performed to reevaluate the power transfer capability of the South to North Interface which was identified in the steady state analysis. As expected, the power transfer capability reduced in the stability analysis. At the power flow levels identified in the steady state, large and sustained oscillations were seen in the stability results and therefore, the generation in the South was reduced to reach to an optimal level where a reasonable stable response of the system was observed. The results of this analysis are summarized in Table 5-9.

Table 5-9: Results of Sensitivity Analysis of Matiari-Moro-RYK D/C

Case	Steady State Power Transfer Capability	Power Transfer Capability evaluated from stability analysis
Case A - with Matiari-Moro-RYK OHL	7000	5500
Case B - without Matiari-Moro-RYK OHL	5700	4600

The stability plots for Case A and Case B are presented in Figure 5-20 and Figure 5-21, respectively. The results indicate that the power transfer capability is limited by system's stability and is considerably reduced in comparison to those identified in the steady state analysis. Even at these levels, relatively large oscillations are seen, especially for the network in the South.

Figure 5-20: 3-Phase Fault at 500 kV Matiari – Trip one HVDC pole – Case A

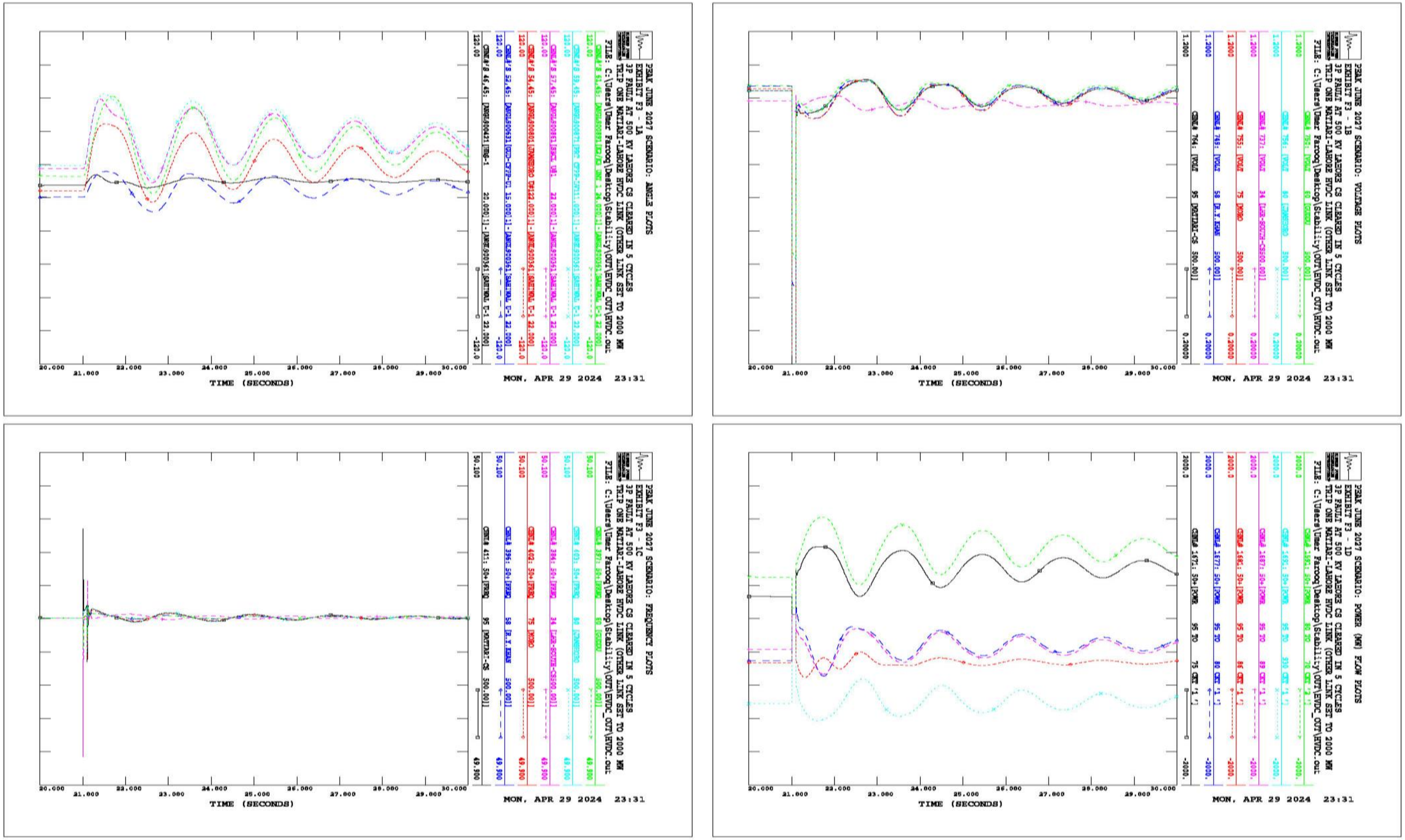
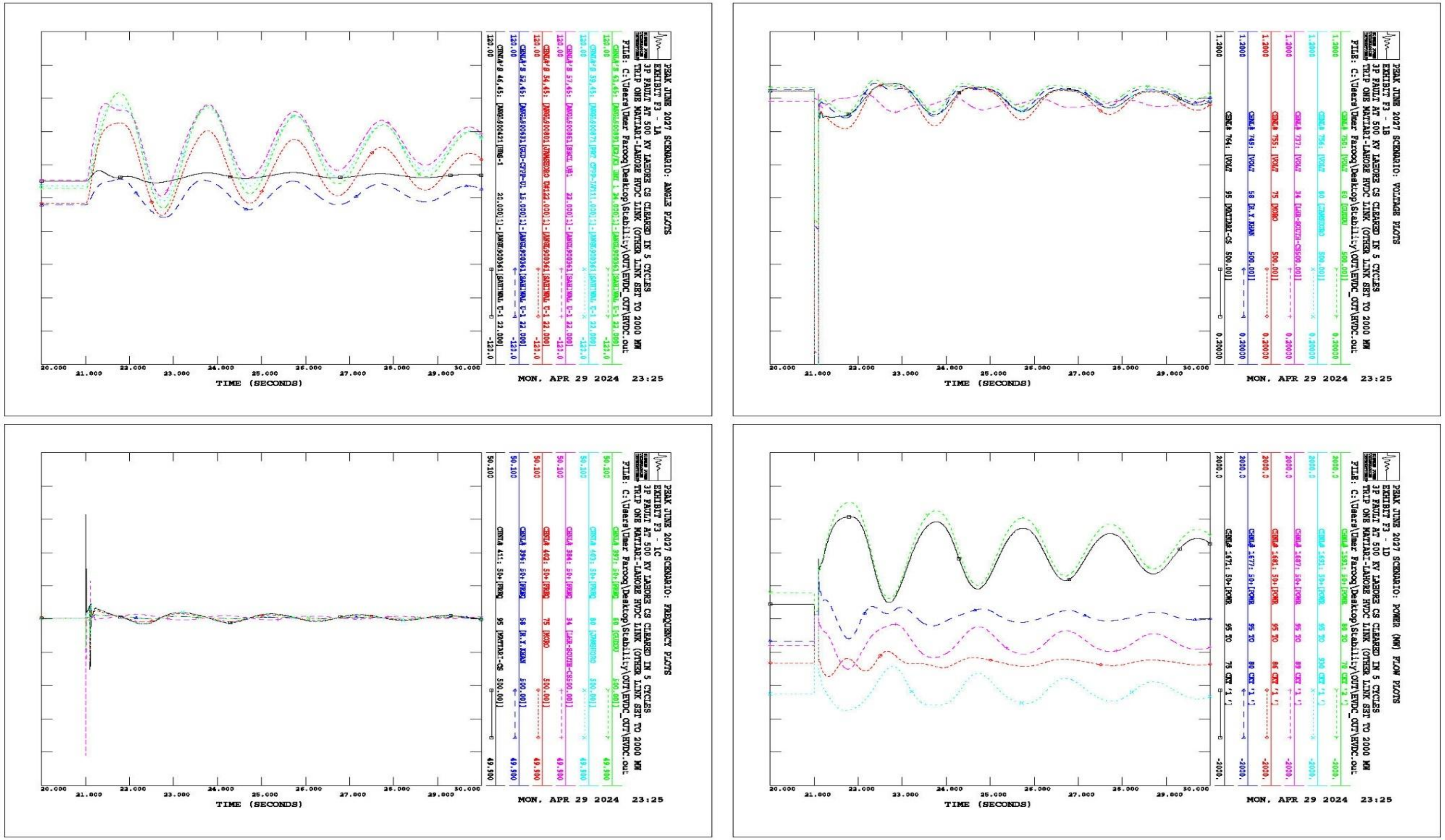


Figure 5-21: 3-Phase Fault at 500 kV Matiari – Trip one HVDC pole – Case B



5.3.4 RESULTS AND ANALYSIS OF WINTER OFF-PEAK - JANUARY 2027

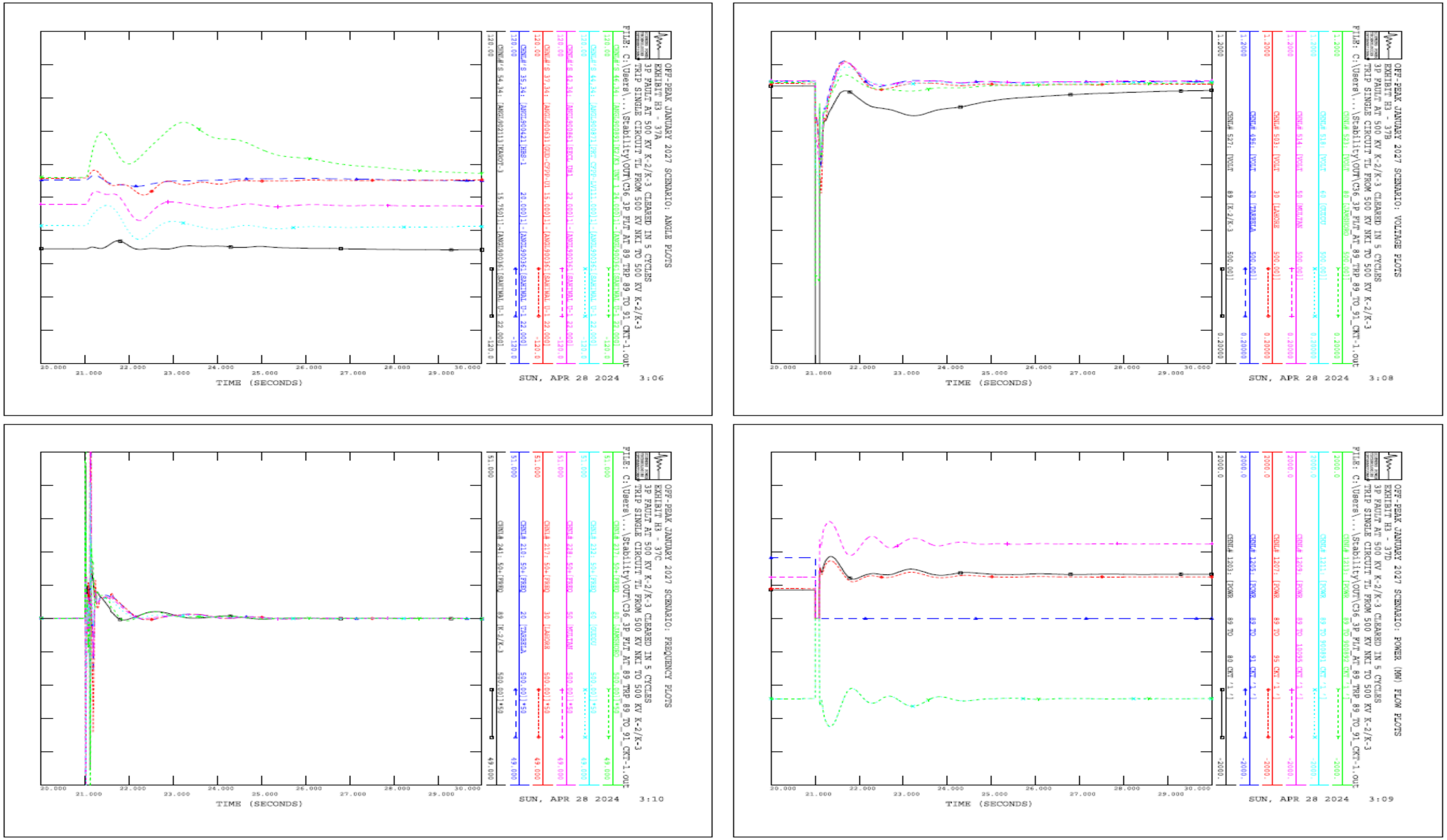
To analyze the system under minimum load conditions, transient stability analysis was performed for Winter Off-Peak January 2027 conditions and the simulation results are attached in Appendix H. The transient response of the system for all the contingencies were quite stable. Table 5-10 shows the only critical contingency in this case and corresponding stability plot is shown in Figure 5-22. This figure shows that the angular excursion of machines at K2/K3 power plant is relatively large as compared to rest of the contingencies within this scenario.

Table 5-10: Summary of the Transient Stability Analysis Results – Off-Peak January 2027

S/N	Faulted Bus		Base Voltage (kV)	Trip Circuit		Loading (MVA)	Fault Type	Stability Status			
	Number & Name			Number & Name				VOLT	ANGL	POWR	FREQ
1	89	K2/K3 PP	500	89-91	K2/K3 - NK1	729	3P	Stable*	Stable	Stable	Stable

*Oscillatory

Figure 5-22: 3-Phase fault at 500 kV K2/K3 Power Plant



5.4 EXPANSION REQUIREMENTS UP TO 2027

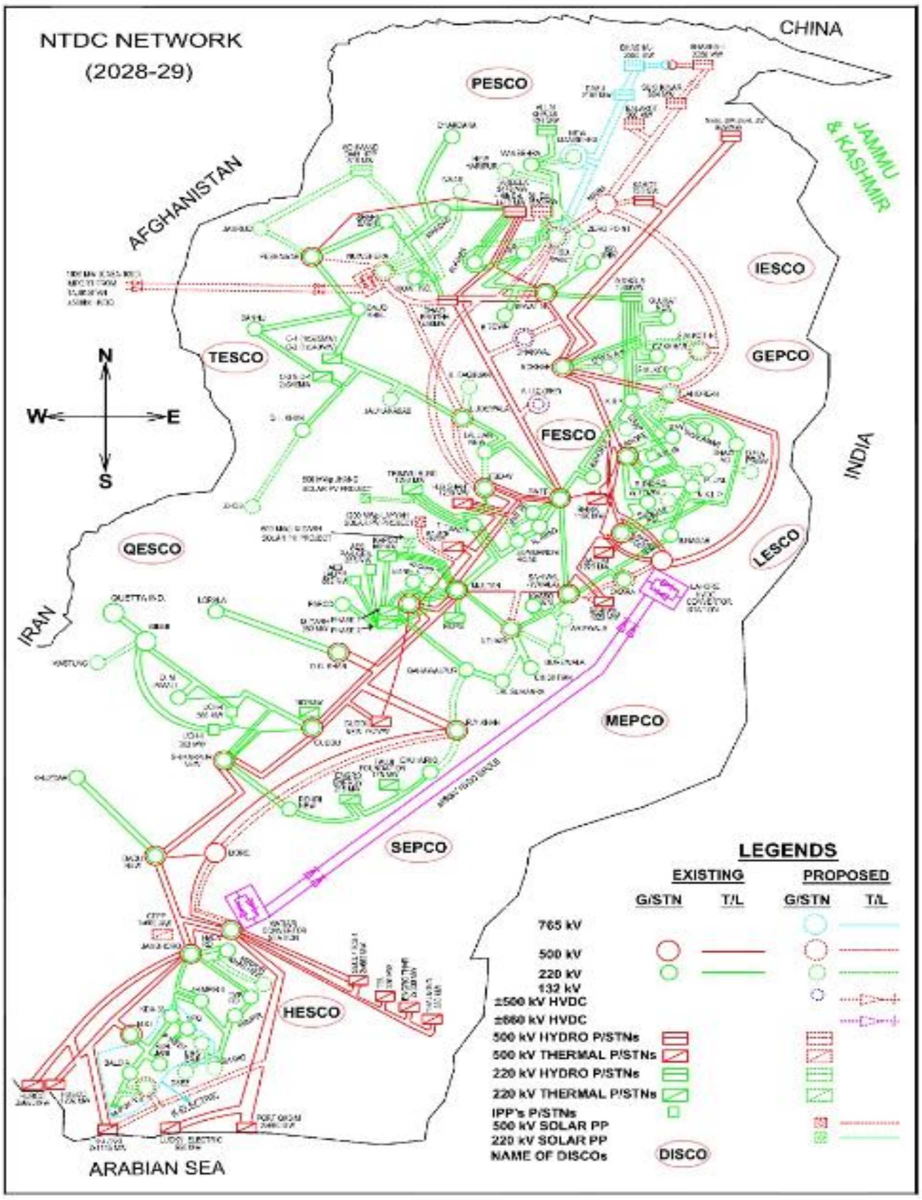
Analysis of these consolidated base cases shows that additional transmission reinforcements and expansion projects are required for reliable and secure operation of the primary network. Section 8 lists these newly proposed projects, which have been identified after conducting rigorous analyses considering the system peak as well as the individual peak demands of DISCOs.

6. ANALYSES OF SPOT YEAR 2028-29

A comprehensive analysis for spot year 2028-29 has been carried out considering the load forecast, seasonal variation of loads, and generation dispatch. All the proposed solutions and remedial measures identified in the previous section are incorporated in the base cases of 2028-29. Additionally, interconnections of new generating plants, as per IGCEP 2024, are also included in the base case. An initial assessment of short circuit currents identified some additional measures to be taken to keep the short circuit currents within limits. These are explained in Section 6.2 and are incorporated in the base cases of 2028-29.

Figure 6-1 depicts the expected transmission network by 2029. Some major expansion, both in generation and transmission, are expected by 2028-29. Dasu hydro power plant is considered fully commissioned along with the 765 kV network. CASA (1000 MW) and five units of Basha HPP (1875 MW) have been assumed available. Also, new 500 kV substations proposed at Okara and Ludewala are considered commissioned by 2027-28.

Figure 6-1: Expected NTDC Transmission Network by 2029



6.1 POWER FLOW AND CONTINGENCY ANALYSIS

Load flow studies for summer peak operating scenarios, corresponding to the high hydro (July/August) and the low hydro-high thermal (June) dispatch conditions, have been performed for normal (N-0) and contingency (N-1) conditions. Additionally, two operating scenarios have been studied for winter conditions, i.e., winter peak case and winter off-peak (minimum) case.

6.1.1 RESULTS AND ANALYSIS OF SUMMER PEAK – JULY/AUGUST 2028

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 6-1.

Table 6-1: System Summary – Peak July/August 2028

Description	MW	MVAR
NTDC Generation	31908	4861
NTDC/DISCOs Load	28812	17015
Export to KE	2050	687
Shunts Reactors	-	9288
Shunts Capacitors	-	-12756*
Line Charging	-	-22512
Losses	1046	17691

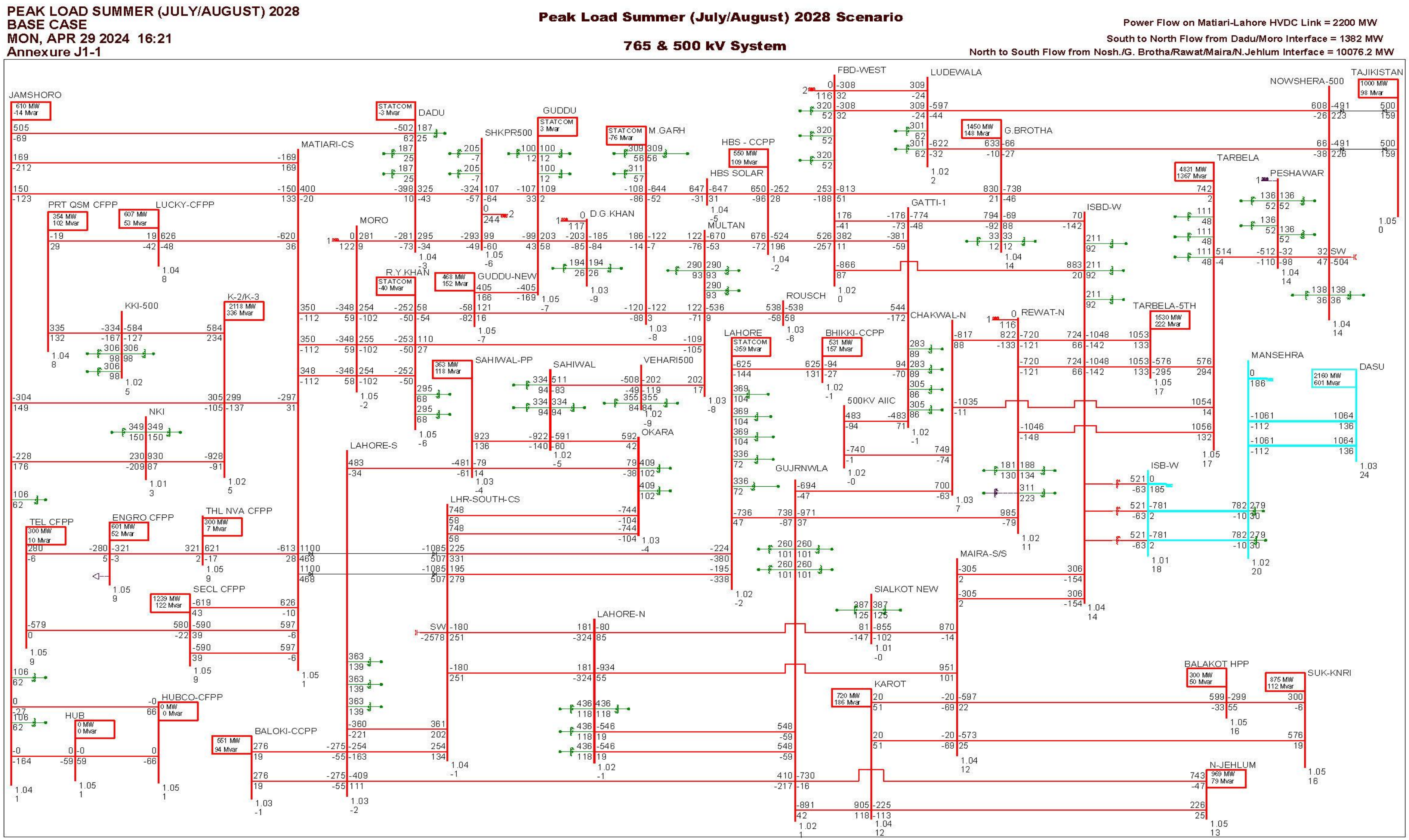
* Does not include filters at HVDC terminal stations

The power flow plots of normal operating conditions, showing 500 and 220 kV networks are provided in Appendix J. Figure 6-2 shows the power flow plot for 500 kV network under normal operating condition. The results show that the voltage profile, lines and transformers loadings, with the selected generation dispatch, are well within the normal operating limits and fulfill the grid code operating requirements.

<u>Contingency (N-1) Analysis</u>

The automatic contingency analysis (ACCC) has been performed for the bulk transmission system (EHV and HVDC lines, 765/500 kV, 500/220 kV and 220/132 kV transformers). The analysis indicates that no voltage or overload violations occur on the entire 500 and 220 kV network. This establishes the fact that the transmission system is adequately planned for the expected operating conditions of summer 2028 and fulfills the Grid Code operating criteria.

Figure 6-2: 500 kV Network Summer Peak July/August 2028– Normal Operating Conditions



6.1.2 HIGH SOLAR SCENARIO

It was discussed in Section 5 that 2400 MW utility scale solar has been selected in the IGCEP 2024 and 1200 MW was included in the base case for 2027. The additional solar generation of 1200 MW near Haveli Bahadur Shah has been assumed in July/August 2028. The connection arrangement will be In/Out of S/C 500 kV Muzaffargarh – HBS OHL at Solar Power Plant.

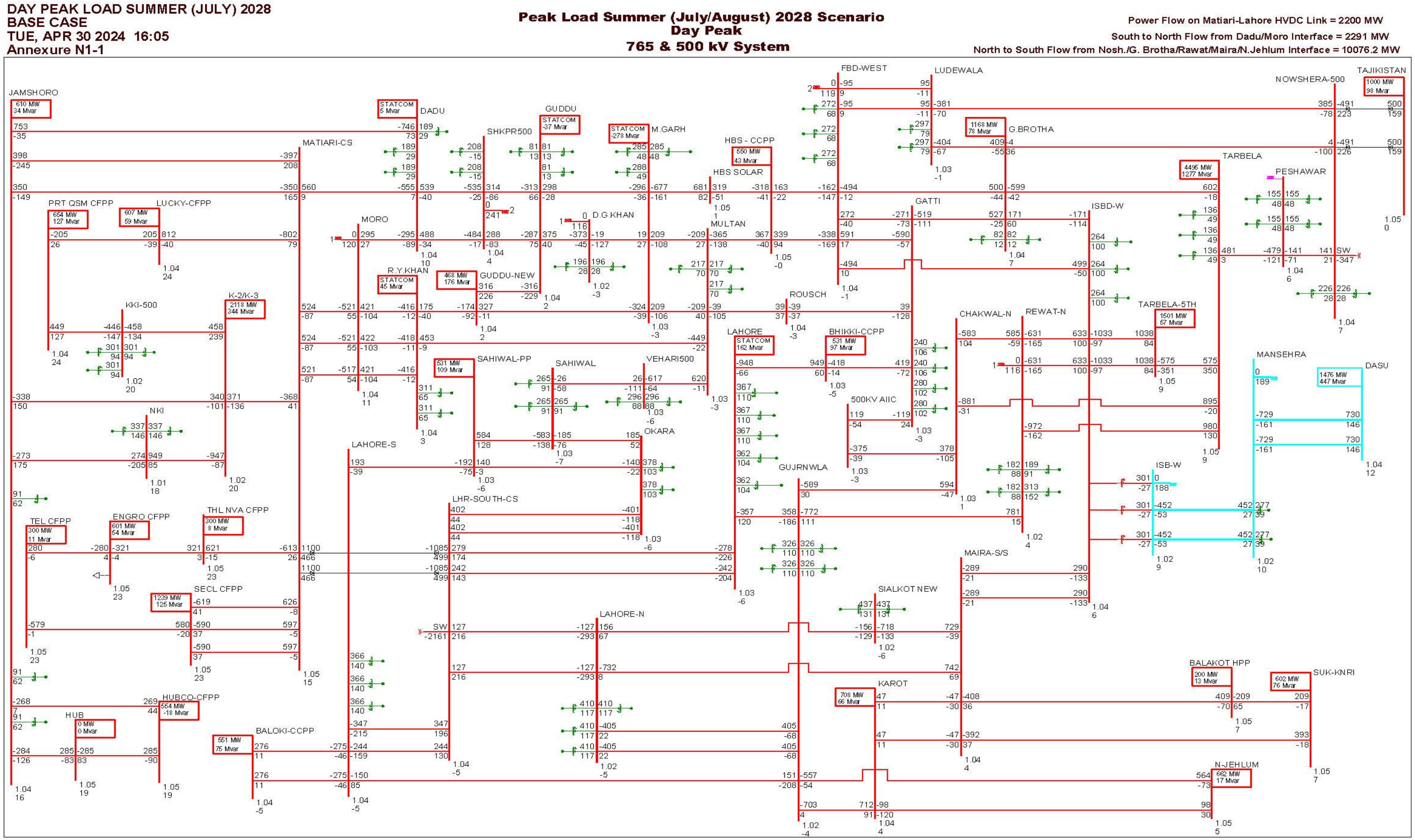
To ascertain impacts of the new solar PV additions on the interconnected power system, a day peak case for July 2028 has been simulated. The objective of this analysis is to quantify any power evacuation limitation that these new solar PV plants could pose on dispatch of the existing plants and to ascertain any transmission constraints on the DISCOs networks.

Power Flow and Contingency Analysis for Summer Day Peak – July/August 2028

Power flow and contingency analysis have been performed using the day-peak July/August 2028 base case, which incorporated all solar PV generation projects into the three connection sites. The hydro power generation dispatch was slightly reduced as per the current practice of daytime dispatch, and the thermal power generation is adjusted to balance the dispatch of maximum solar PV generation.

Results of the analysis are provided in Appendix J. The power flow analysis indicates that no voltage or overloading violations occur under normal system operation. However, as indicated in earlier sections, the dispatch from the Jhang 1263 MW RLNG-based power plant may need to be reduced under contingency conditions to avoid N-1 violation if the generation from the solar PV plants are kept at maximum. Figure 6-3 depicts normal system power flows for the 500 kV network.

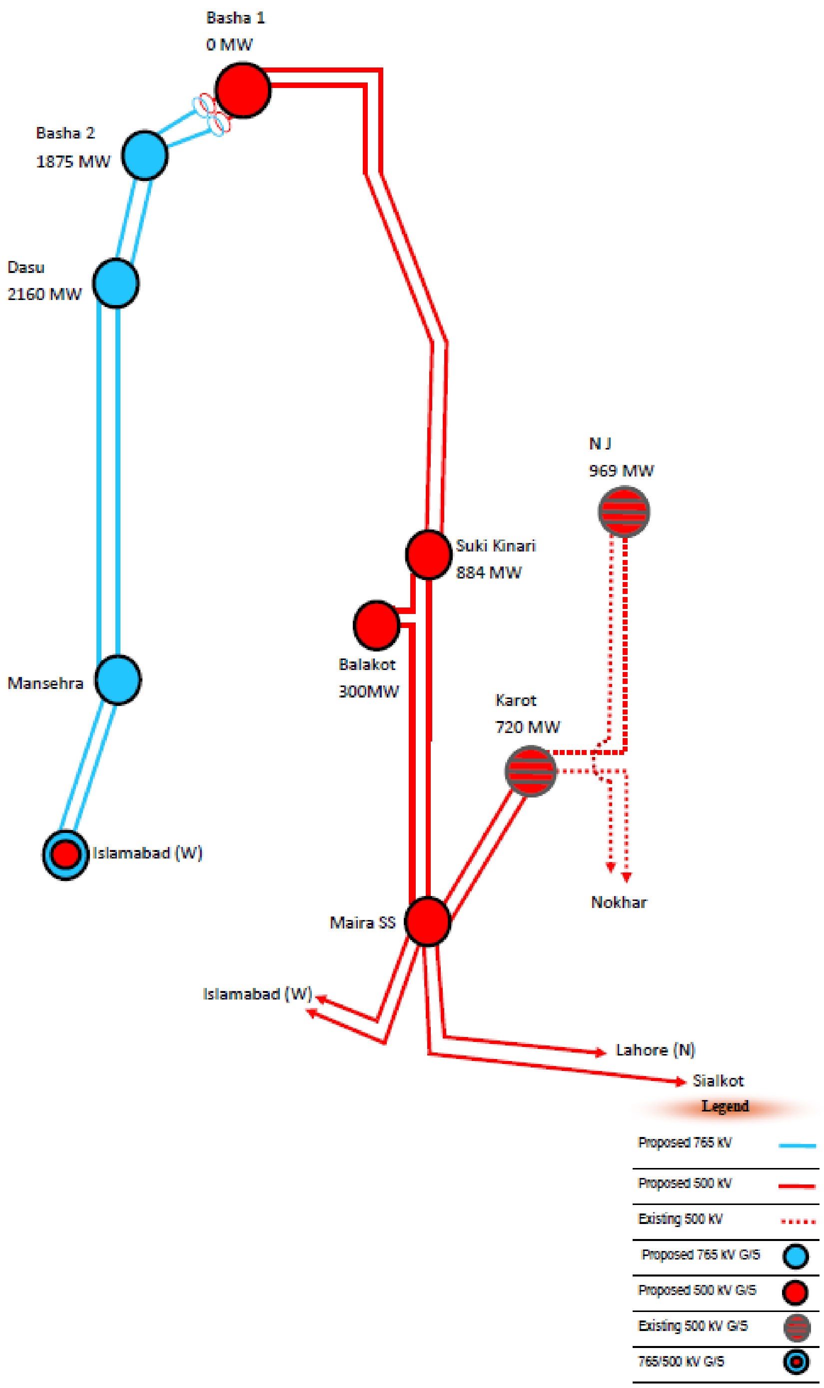
Figure 6-3: 500 kV Network Summer Peak July 2028 – Day Peak



6.1.3 RESULTS AND ANALYSIS OF SUMMER PEAK - JUNE 2029

The June 2029 base case is developed by updating the July 2028 case and incorporating all the projects to be commissioned from January 2029 till June 2029. Salient features of this case include commissioning of some units at Basha HPP and to evacuate this power, an intermediate stage of the power evacuation scheme of Basha HPP is assumed implemented as shown in Figure 6-4.

Figure 6-4: Intermediate evacuation scheme for Basha HPP



The commissioning of some units at Basha by June 2029 implies that available hydro generation will increase in the June scenario as compared to previous spot year. Traditionally, peak June scenario is considered more stringent as compared to the July scenario due to the reason that the peak system demand is mainly met from thermal power generation in the south and mid country. However, due to commissioning of some units at Basha, the June 2029 scenario has become almost like the July/August 2028 scenario.

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Figure 6-4.

Table 6-2: System Summary – Peak June 2029

Description	MW	MVAR
NTDC Generation (Including Tajikistan)	31986	5438
NTDC/DISCOs Load	28870	17013
Export to KE	2050	669
Shunts Reactors	-	9960
Shunts Capacitors	-	-12870*
Line Charging	-	-23361
Losses	1047	18267

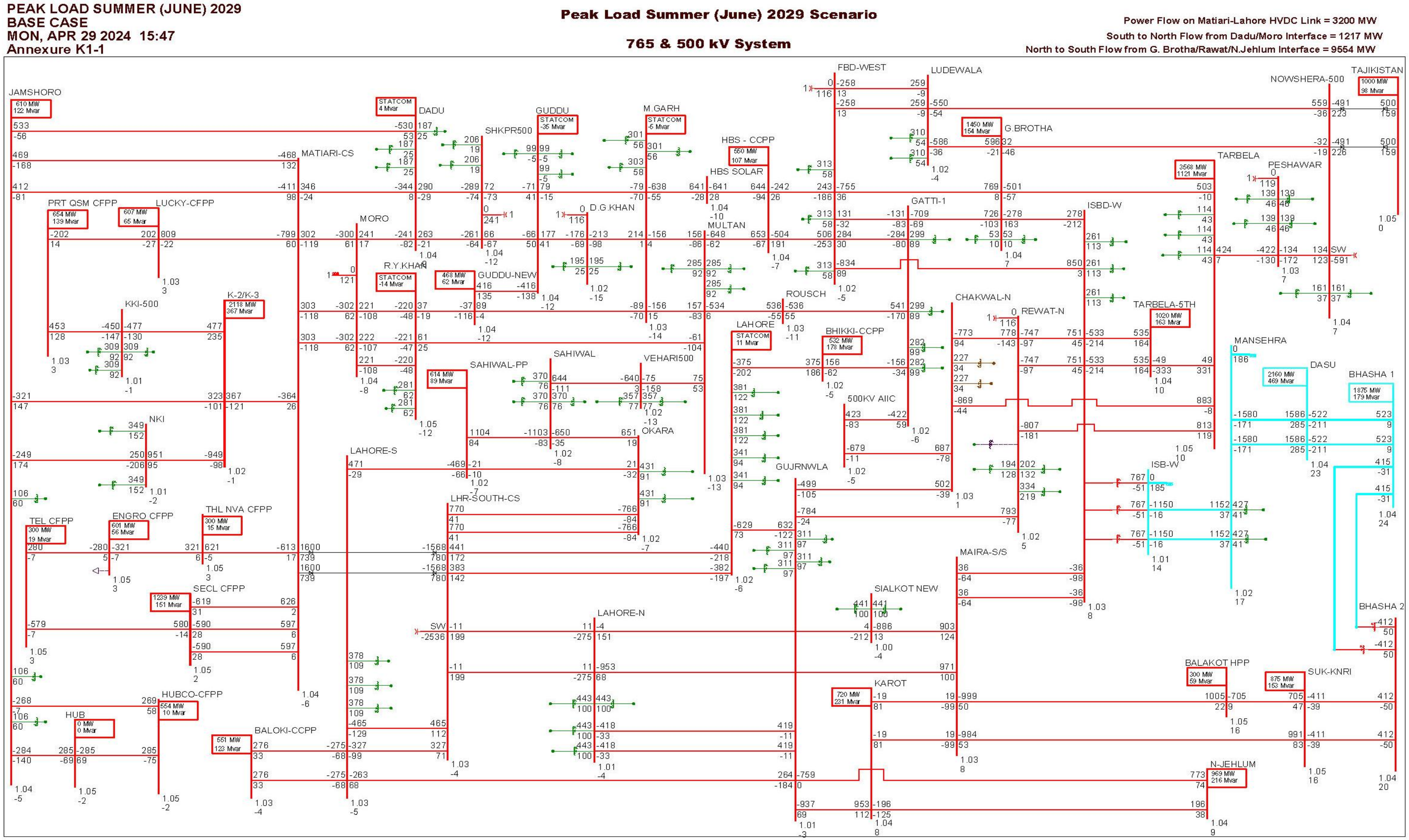
* Does not include filters at HVDC terminal stations

The power flow plots of normal operating conditions, showing 500 and 220 kV networks are provided in Appendix K. The results reveal that the voltage profile, lines and transformers loadings are well within the normal ratings complying to the Grid Code requirements. Figure 6-5 shows the power flow plot for 500 kV network under normal operating condition. The power from the hydro plants in the north flows towards mid country and power from thermal generation in the south also flows towards mid country serving the major load centers.

Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) has been performed for the bulk transmission system (EHV and HVDC lines and 500/220 kV and 220/132 kV transformers). The analysis indicates that no voltage or overload violations occur on the entire 500 and 220 kV network. This establishes the fact that the transmission system is adequately planned for the expected operating conditions and fulfills the Grid Code operating criteria.

Figure 6-5: 500 kV Network Summer Peak June 2029– Normal Operating Conditions

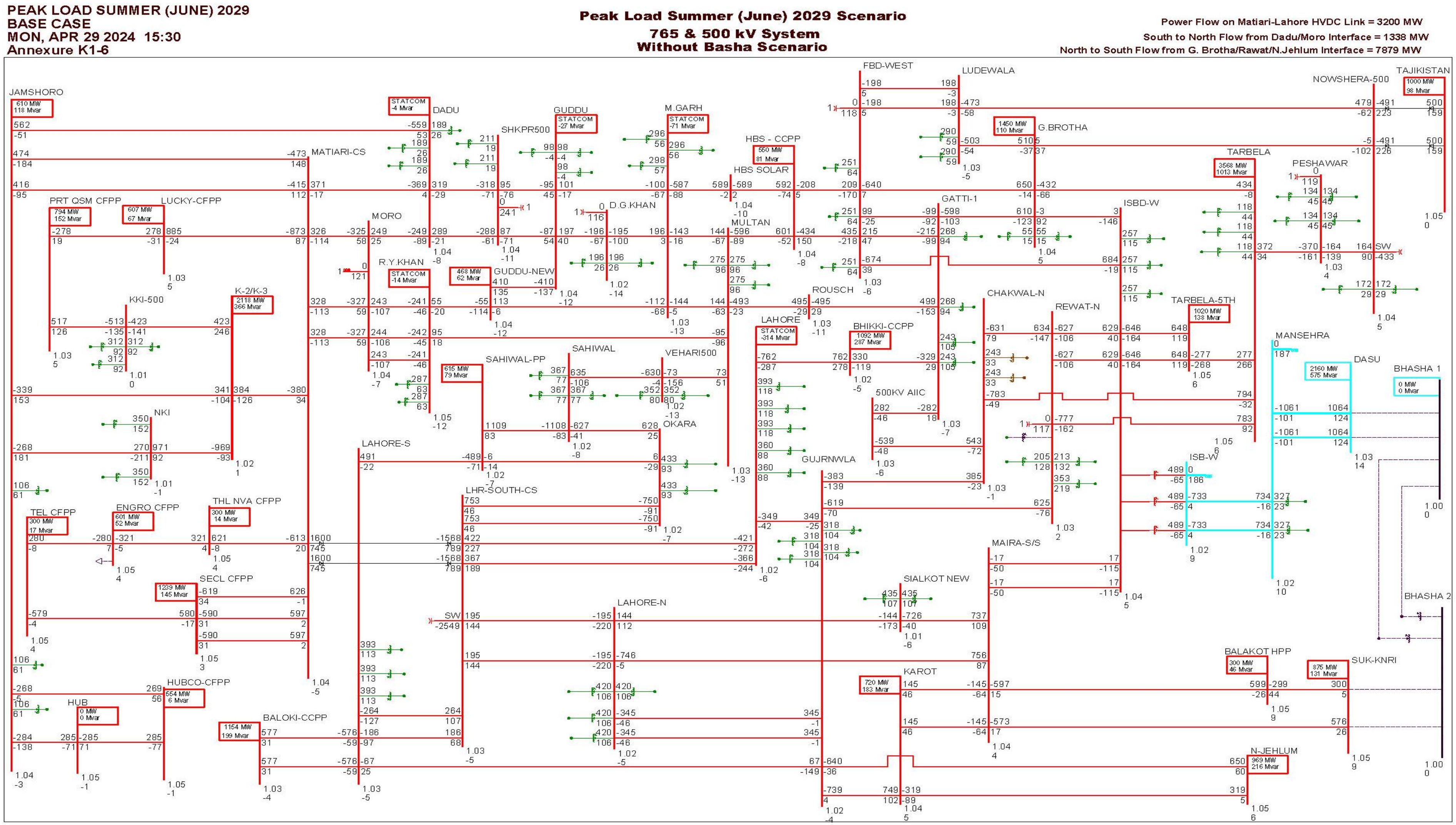


6.1.4 SENSITIVITY ANALYSIS: DELAYED COMISSIONING OF BASHA HPP

In IGCEP 2024, the Basha HPP is committed for commissioning from January 2029 as per the confirmation from the WAPDA. However, considering the present ground realities it seems not likely that such a mega project will be constructed within the next five years. Therefore, to minimize the impact of such uncertainties on the transmission plan and network operation requirements a sensitivity case is studied wherein Basha is assumed not available by June 2029.

The power flow analysis is performed after adjusting the generation dispatch and updating the transmission network connectivity in the base case of June 2029. The power flow plots of normal operating conditions, showing 500 kV and 220 kV networks are provided in Appendix K. The results reveal that the voltage profile, lines and transformers loadings are well within the normal ratings complying to the Grid Code requirements. Figure 6-6 shows the power flow plot for 500 kV network under normal operating condition. Due to the unavailability of Basha HPP, this sensitivity case becomes a typical June scenario where most of the country demand is met from thermal generation in south and mid country.

Figure 6-6: 765 & 500 kV Network Summer Peak June 2029– Without Basha HPP



6.1.5 RESULTS AND ANALYSIS OF WINTER PEAK - JANUARY 2029

A similar approach is used in developing the base case for winter peak 2029 as was used for winter peak 2027. The base case of July/August 2028 has been updated by scaling the loads expected in winter peak – January 2029. The Generation dispatch has been changed as per the available generation during winter and any change in the transmission network from July/August 2028 onward has been incorporated in the base case.

As mentioned earlier, in winter, the maximum flow of power is from South to North. This leads to relatively lightly loaded transmission lines in North and provides an opportunity to switch off some of them, without violating the N-1 criteria, to reduce impact of the charging MVARs. This line opening is carefully done to avoid inter-day switching of circuits due to load variation during the day. Also, some of the line connected shunt reactors installed on the system are configured in a way which enables them to be used as bus reactors when the line is switched off and thus provides some additional compensation. Table 6-3 below lists the major lines openings recommended for the winter case of 2029. This operational measure significantly helps to control voltages within their normal operating range.

Table 6-3: Major line openings recommended for the winter case of Jan 2029

S/N	Circuit Open
1	500 kV Maira – Balakot S/C
2	500 kV Maira – Islamabad West S/C
3	500 kV Rawat – Islamabad West S/C
4	500 kV Ghazi Brotha – Gatti S/C
5	500 kV Tarbela – Ghazi Brotha S/C
6	500 kV Tarbela – Chakwal S/C
7	500 kV Ghazi Brotha – Ludewala S/C
8	500 kV Gujranwala – Neelum Jhelum S/C

It is important to note that the number of lines opening, as mentioned in Table 6-4, has been considerably reduced as compared to January 2027 case. This is due to the reason that the STATCOMS proposed at five key locations within the network, to provide dynamic reactive support during the summer as well as winter seasons, have been utilized for voltage control in the winter cases. These are listed in Table 6-4.

Table 6-4: Proposed STATCOMS for the 2028-29 network

Bus	MVAR
500 kV Lahore	±400
500 kV Muzaffargarh	±400
500 kV Rahim Yar Khan	±400
500 kV Guddu	±400
500 kV Dadu	±400
TOTAL	**±2000**

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 6-5.

Table 6-5: System Summary – Peak January 2029

Description	MW	MVAR
NTDC Generation	20369	923
NTDC/DISCOs Load	18350	8656
Export to KE	1500	328
Shunts Reactors	-	11396
Shunts Capacitors	-	-4006*
Line Charging	-	-21191
Losses	518	10948

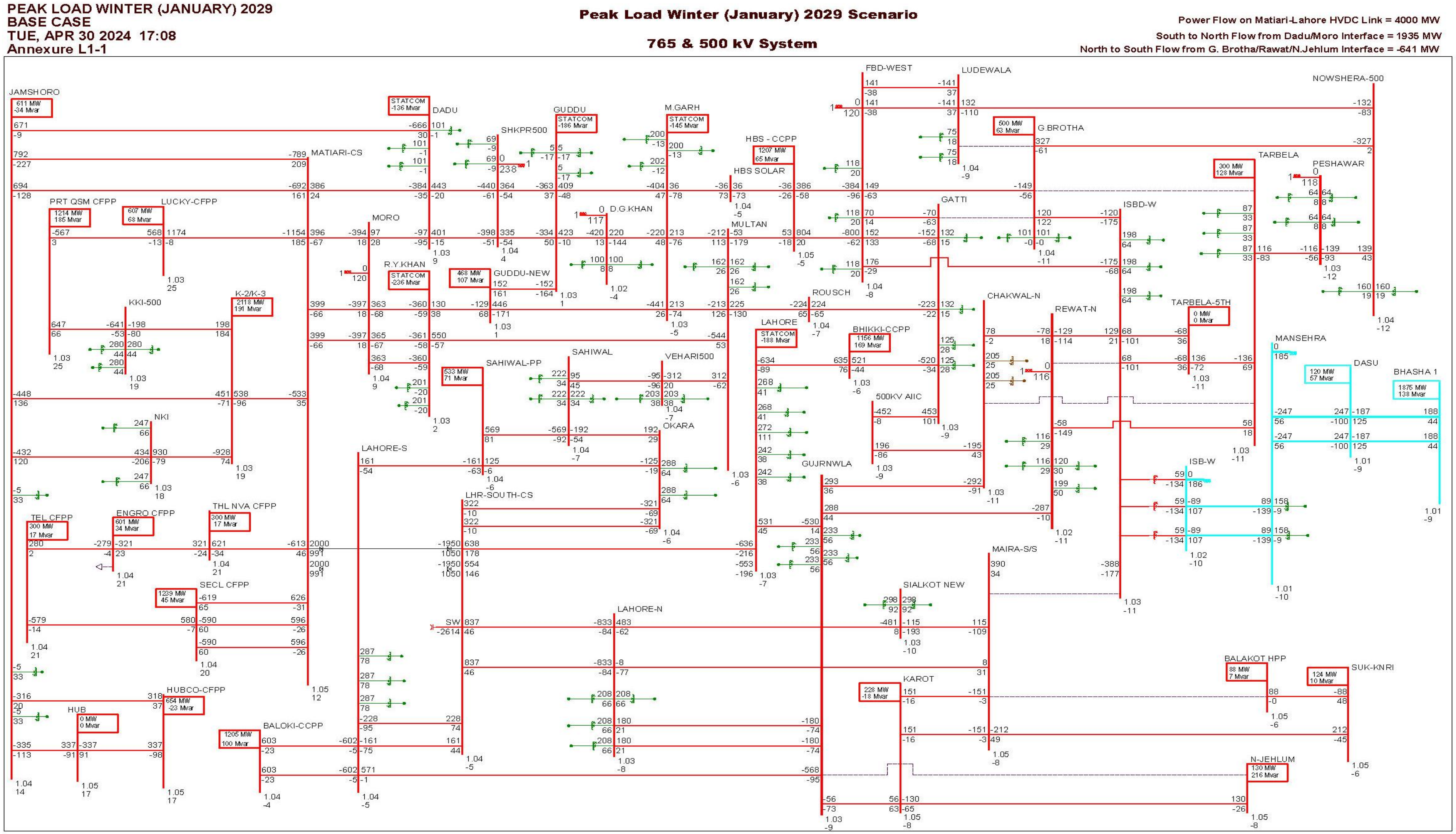
* Does not include filters at HVDC terminal stations

Power flow analysis was performed for winter peak 2029 case and the results for normal operating conditions are provided in Appendix L. The results show that the transmission line loadings are well within their operating limits. The power flow plot of 500 kV network in this scenario is depicted in Figure 6-7.

Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) has been performed for the bulk transmission system (EHV and HVDC lines and 500/220 kV and 220/132 kV transformers). The analysis indicates that no voltage or overload violations occur on the entire 500 and 220 kV network.

Figure 6-7: 500 kV Network Winter Peak January 2029– Normal Operating Conditions



6.1.6 RESULTS AND ANALYSIS OF WINTER OFF PEAK - JANUARY 2029

A similar approach is used in developing the base case for winter off-peak 2029 as was used for winter off-peak 2027. The winter peak case 2029 has been revised to develop winter off-peak (minimum) case 2029. Same line openings have been assumed in both peak and off-peak winter base cases to avoid intra-day line switching.

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 6-6.

Table 6-6: System Summary – Off-peak January 2029

Description	MW	MVAR
NTDC Generation	11394	-1670
NTDC/DISCOs Load	10191	4706
Export to KE	1000	279
Shunts Reactors	-	11916
Shunts Capacitors	-	-710
Line Charging	-	-21386
Losses	203	4830

* Does not include filters at HVDC terminal stations

Power flow analysis was performed for the winter off-peak case and the results for normal operating conditions are provided in Appendix M. Figure 6-9 presents the power flow plot of the 500 kV network under normal operating conditions whereas Figure 6-8 presents the voltage profile of the key buses in the 500 kV network. It is seen that the voltage profile is quite reasonable and is within the limits prescribed by the GC.

Figure 6-8: Voltage Profile of the 500 kV Network in Off-Peak January 2029

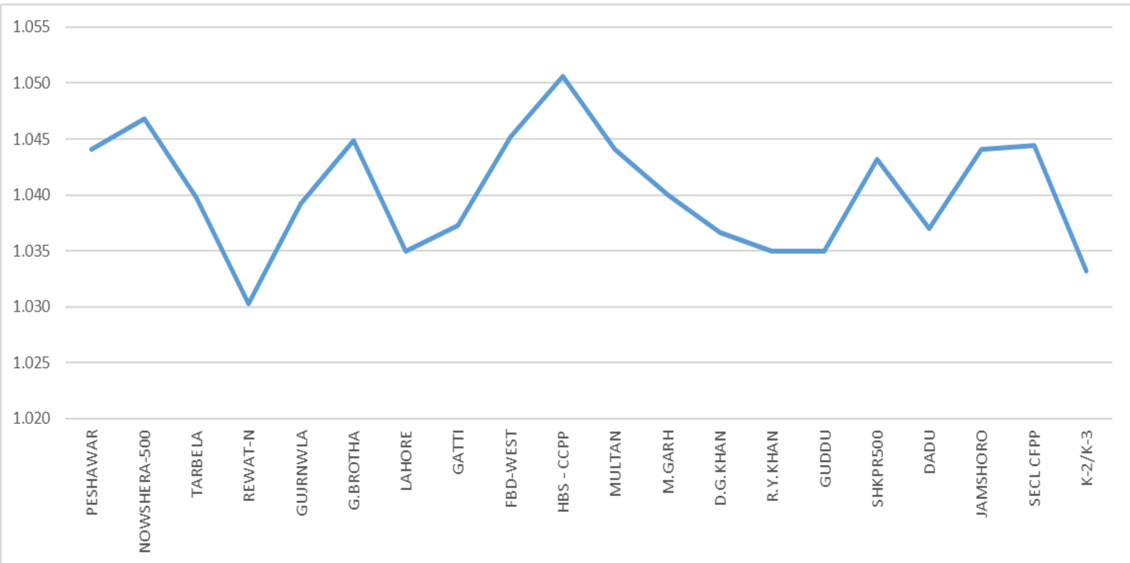
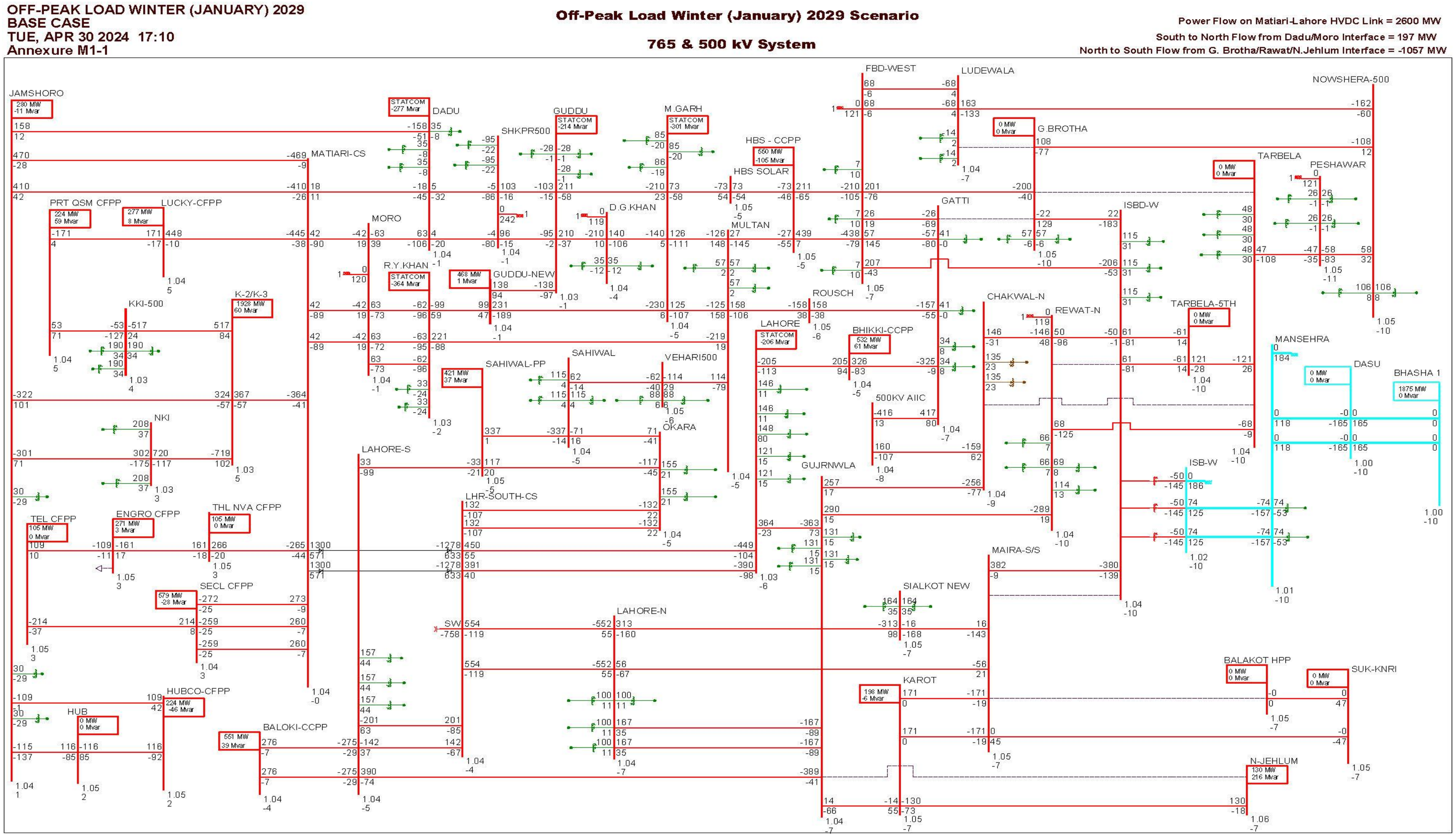


Figure 6-9: 500 kV Network Winter off-Peak January 2029– Normal Operating Conditions



6.2 SHORT CIRCUIT ANALYSIS FOR SPOT YEAR 2028-29

Short circuit analysis has been carried out to calculate maximum fault currents for balanced and unbalanced faults on the bulk power system, i.e., three phase to ground (LLLG) and single phase to ground (LG) faults, respectively.

The analysis has been performed using IEC 60909 Standards to determine the maximum short circuit currents considering the assumptions as listed in Section 5.2.

Fault currents has been computed at all nodes of the NTDC transmission network. The short-circuit base cases were developed considering the expected on-line generation for the spot year. This may not result in a set of maximum fault currents which would occur if all the available generation is kept on-line. Since both the operating scenarios are being analyzed, i.e., low hydro high thermal and high hydro low thermal, therefore, this approach provides a reasonably good and realistic estimation of short circuit levels, which would prevail in the system corresponding to the operating conditions under study. It is noted that in all these operating scenarios, the short circuit analysis is performed with all units of the four RLNG-based power plants on bar, irrespective of their status in the power flow analysis.

6.2.1 SHORT CIRCUIT RESULTS 2028-29

The maximum computed short circuit levels at key buses, with the proposed remedial measures mentioned earlier, are shown in Table 6-7, whereas the detailed results of the analysis are provided in Appendix J. Also, the minimum short circuit levels corresponding to system conditions in winter are attached in Appendix J.

Commissioning of Okara 500 kV increased the fault levels in the area. Fault level at Yousafwala exceeds the switchgear rating and to limit it one circuit of 220 kV Yousafwala-Okara is kept open.

Table 6-7: Short Circuit Levels – 2028-29

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	1-Phase
16	DASU	765	63	18.6	18.5
17	BHASHA 1	765	63	17.4	17.1
64	MANSEHRA	765	50	17.4	12.9
13	ISB-W	765	50	17.3	14.2
21	ISBD-W	500	63	47.2	37.3
20	TARBELA	500	50/63	46.4	47.0
29	TARBELA-5TH	500	63	45.5	44.5
25	G. BROTHA	500	40/50	38.1	25.4
24	GUJRNWLA	500	40	34.2	26.1
34	LHR-SOUTH-CS	500	50	33.6	28.3
30	LAHORE	500	40	32.5	27.9
22	REWAT-N	500	40	32.2	22.6
41	FBD-WEST	500	63	32.2	23.9

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	1-Phase
28	LAHORE-N	500	63	31.9	24.6
40	GATTI-1	500	40	31.7	23.2
212	ISBD-W	220	563	47.3	40.4
260	LAHORE-N	220	63	46.6	38.8
444	FBD-W	220	63	42.6	34.3
245	NOKHAR	220	50/63	41.7	35.0
151	NOWSHERA-220	220	50	40.2	30.1
200	TARBELA	220	50/63	39.2	38.5
400	GATTI	220	40/50	38.9*	30.4
350	YOSAFWAL	220	40/50	38.8	31.6
145	NOSHRA-I	220	40	38.0	27.2
300	LAHORE	220	40/50	37.4*	31.4
303	LAHORE-S	220	50	37.1	32.5
410	SUMNDIRD	220	40	36.6	26.5
500	MULTAN	220	40/50/63	36.5	28.4
270	BUNDRD-1	220	40/50	36.3	27.9
272	BUNDRD-2	220	40/50	36.3	27.9
215	ISPR-220	220	40	35.1	24.6
300000	LAHORE2	220	40/50	35.0*	30.5
440	JRN W.RD	220	40/50	34.5	25.1
220	RAWAT-N-1	220	40/50	34.5*	28.1
2300	REWAT132-1	132	40	39.5	32.0
2301	REWAT132-2	132	40	39.5	32.0
4012	LAHORE	132	31.5/40	38.0	31.7
2025	ISPR-132	132	40	37.9	28.4
4262	LHR-N-132	132	40	37.6	31.2
2022	BURHAN	132	25/40	37.2*	28.3
6070	YOUSFWLA	132	31.5/40	36.2	30.1
4330	NSHTBD-1	132	40	35.7*	28.1
4029	ATTABAD	132	40	35.1	26.7
4510	J.W-RD	132	25/40	35.0	27.6
3000	GAKKHAR	132	31.5/40	35.0	26.3
3003	NOKHAR	132	40	33.8	29.3

Note: * bus split

6.3 TRANSIENT STABILITY STUDY FOR SPOT YEAR 2028-29

The transient stability analysis has been performed for the Peak June 2029 case to test the system's response under faults and disturbances. The methodology and assumptions utilized in this analysis remain consistent with those applied in 2028-29.

6.3.1 RESULTS AND ANALYSIS OF SUMMER PEAK – JUNE 2029

Table 6-8shows some of the critical contingencies and the corresponding stability plots are exhibited in Figure 6-10 through Figure 6-12, whereas, the results of all transient stability simulations are attached in Appendix K.

The transient stability simulation results reveal that, in general, the integrated power system stays stable under all the simulated faults. No angular stability issue has been observed and the post-disturbance response is adequately damped since all the oscillations damp down within the reasonable time frames for most of the contingencies. However, oscillations at some of the plants, although damped but take more time to settle, which shows that tuning of some control parameters would be required or additional PSS may have to be installed at some of the existing power plants. Specifically, relatively large angular excursions are seen at the generators in the South, especially K2/K3 power plant. This can be seen in Figure 6-10, Figure 6-11, and Figure 6-12.

Table 6-8: Summary of the Transient Stability Analysis Results – June 2029

S/N	Faulted Bus		Base Voltage (kV)	Trip Circuit		Loading (MVA)	Fault Type	Stability Status			
	Number & Name			Number & Name				VOLT	ANGL	POWR	FREQ
1	95	MATIARI	500	95-34	MATIARI CS – LAHORE CS One HVDC Pole	1600	3P	Stable*	Stable*	Stable*	Stable
2	89	K2/K3 PP	500	89-91	K2/K3 - NKI	942	3P	Stable	Stable*	Stable	Stable
3	95	MATIARI CS	500	95-930	MATIARI – LUCKY CFPP	857	3P	Stable	Stable*	Stable	Stable

***Oscillatory, ** delay recovery**

Figure 6-10: 3-Phase Fault at 500 kV Matiari – Trip one HVDC pole

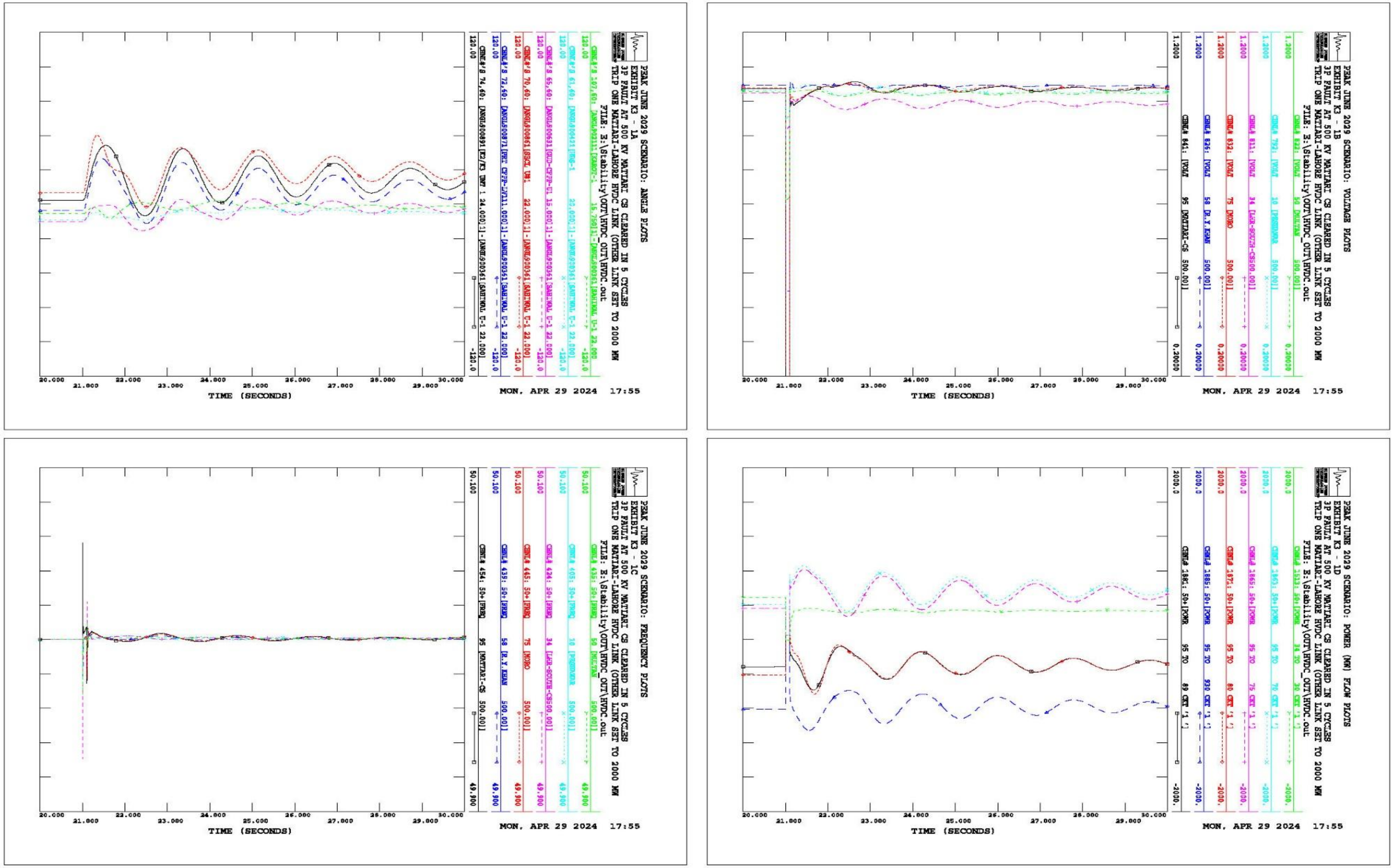


Figure 6-11: 3-Phase Fault at 500 kV K2/K3 Power Plant

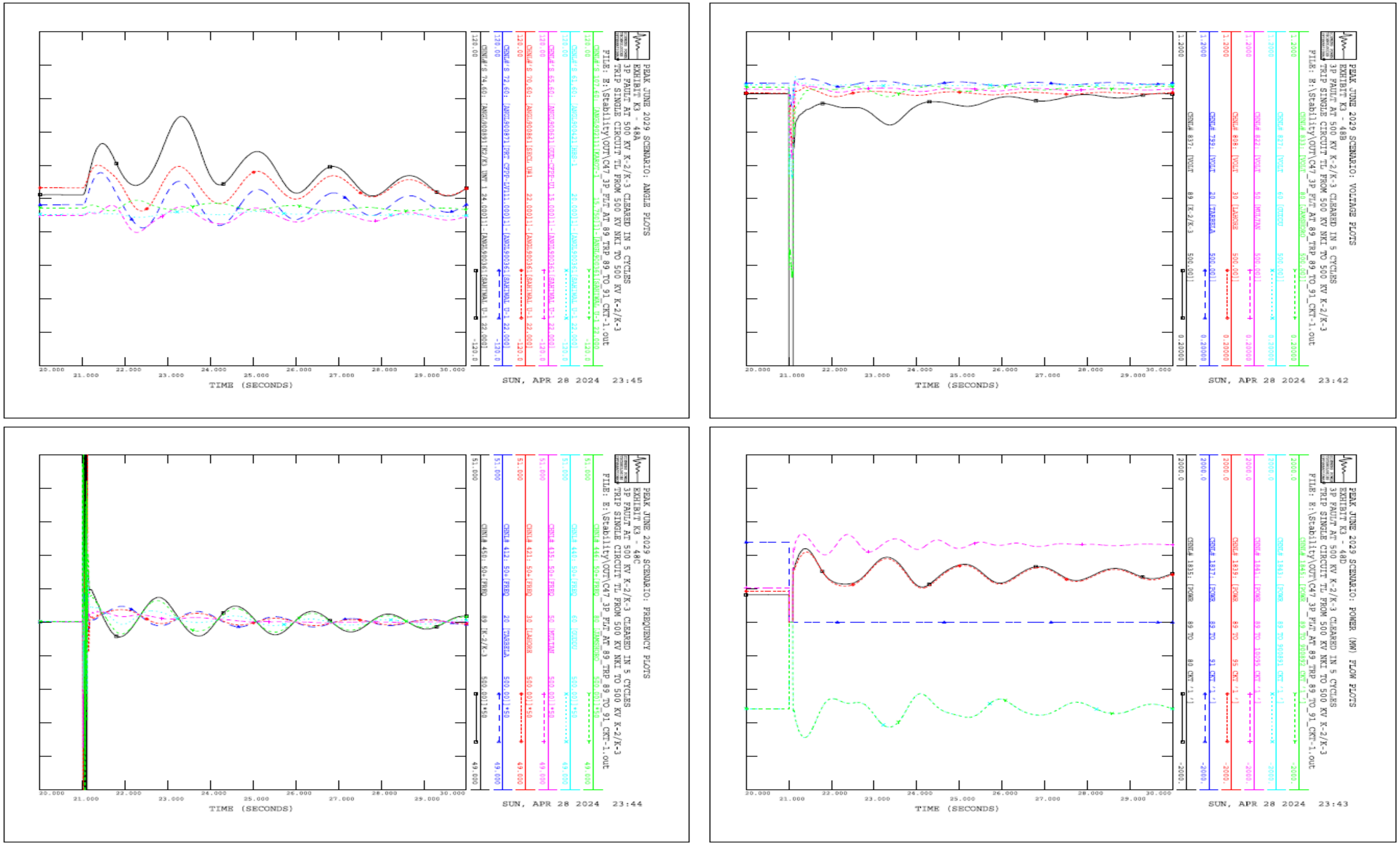
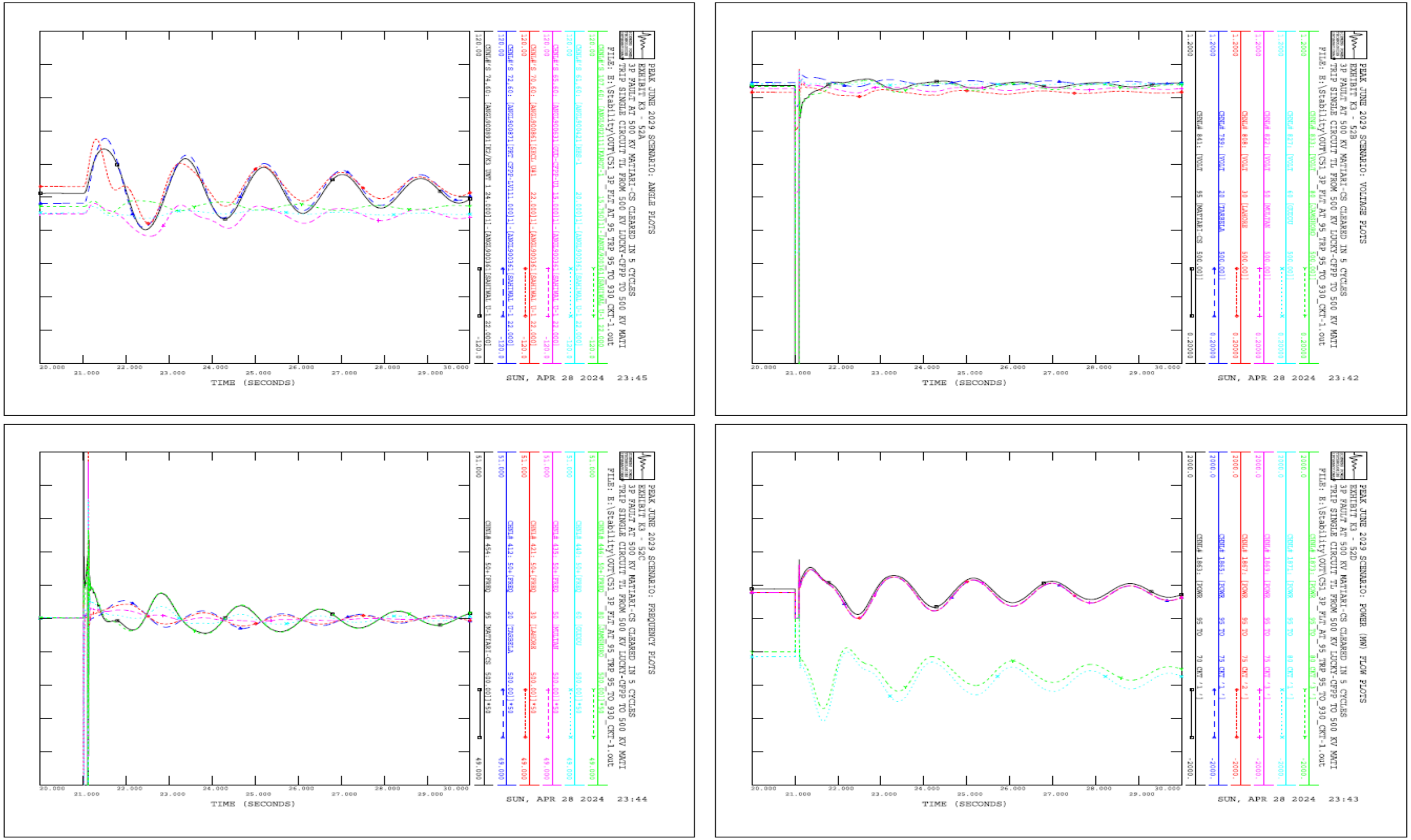


Figure 6-12: 3-Phase Fault at 500 kV Matiari CS



6.4 EXPANSION REQUIREMENTS UP TO 2029

Analysis of these consolidated base cases shows that additional transmission reinforcements and expansion projects are required for reliable and secure operation of the primary network. Section 8 lists these newly proposed projects, which have been identified after conducting rigorous analyses considering the system peak as well as the individual peak demands of DISCOs.

7. ANALYSES OF SPOT YEAR 2033-34

A comprehensive analysis for spot year 2033-34 has been carried out considering the load forecast, seasonal variation of load and generation dispatch. All the proposed solutions and remedial measures identified in the previous sections are incorporated in the Base Cases of 2028-29 to come up with updated power flow cases for 2033-34 which will be used for the detailed analysis. As mentioned earlier, the DISCOS networks are frozen at the stage of June 2029. Loads of DISCOS are increased uniformly to their demand expected at the time of system peaks of 2033-34. An initial assessment is performed for loading at each 220/132 kV substation. In case any substation exceeds its firm capacity a new 220/132 kV substation or augmentation/extension of existing substation, if feasible, is proposed in that DISCO.

This spot year is critical as a lot of new hydro generation, identified in IGCEP24, has been assumed commissioned by 2033-34 and its connectivity is part of the transmission expansion. As mentioned earlier, a comprehensive Hydro Integration Study was performed covering the medium and long terms scenarios of potential hydro power addition in different parts of the northern region. The results and recommendations of this study have been used as an input in developing the schemes of new hydro generation interconnections, aimed at optimizing the limited transmission line corridors available in the North.

The hydro power projects optimized in IGCEP 2024 lie on the Indus, Kunhar and Neelum Jhelum rivers corridors. The main projects are Bhasha, Balakot, Azad Pattan and Kohala. Dasu power project is already under construction and its power will be evacuated through a double circuit 765 kV OHL. Diamer Bhasha Power Project (DBPP) is the biggest HPP (4500 MW) considered in IGCEP and is expected to significantly affect the power flows in the northern bulk transmission network.

Considering the availability of Dasu-Mansehra-Islamabad West 765 kV transmission line, use of this line in the evacuation plan of DBPP is a must. Also, the Indus corridor is the most secure transmission corridor for power evacuation due to its availability throughout the year. Accordingly, evacuation schemes for DBPP are conceptually conceived, studied and tested for different interconnection alternatives. Considering the criticality and quantum of the generation from DBPP and Dasu power projects, N-2 contingency provision is ensured at least up to Mansehra to cover possibility of tower collapse in the hilly and land sliding areas. After detailed evaluation an optimal power evacuation scheme is finalized and recommended which is shown in Figure 7-1. Accordingly, this scheme is incorporated in the base cases and expansion requirements become part of the TSEP. Also, anticipating the high quantum of power flow on the 500 kV lines emanating from Basha HPP, up to 50% series compensation is proposed on these circuits. Resultantly, the expected NTDC network by 2033-34 is depicted in Figure 7-2.

Although Kohala and Azad Patten power projects are committed projects. However, their timeline is not fixed in IGCEP 24 (Reference Scenario) and it is very likely that these power plants would be deferred if DBPP is smoothly constructed and commissioned as per a realistic schedule. Accordingly, the following two scenarios are studied for July 2033 case.

- without the Kohala and Azad Pattan power plants as base case scenario
- with Kohala and Azad Pattan as a sensitivity scenario

Figure 7-1: Base case evacuation scheme for Basha HPP

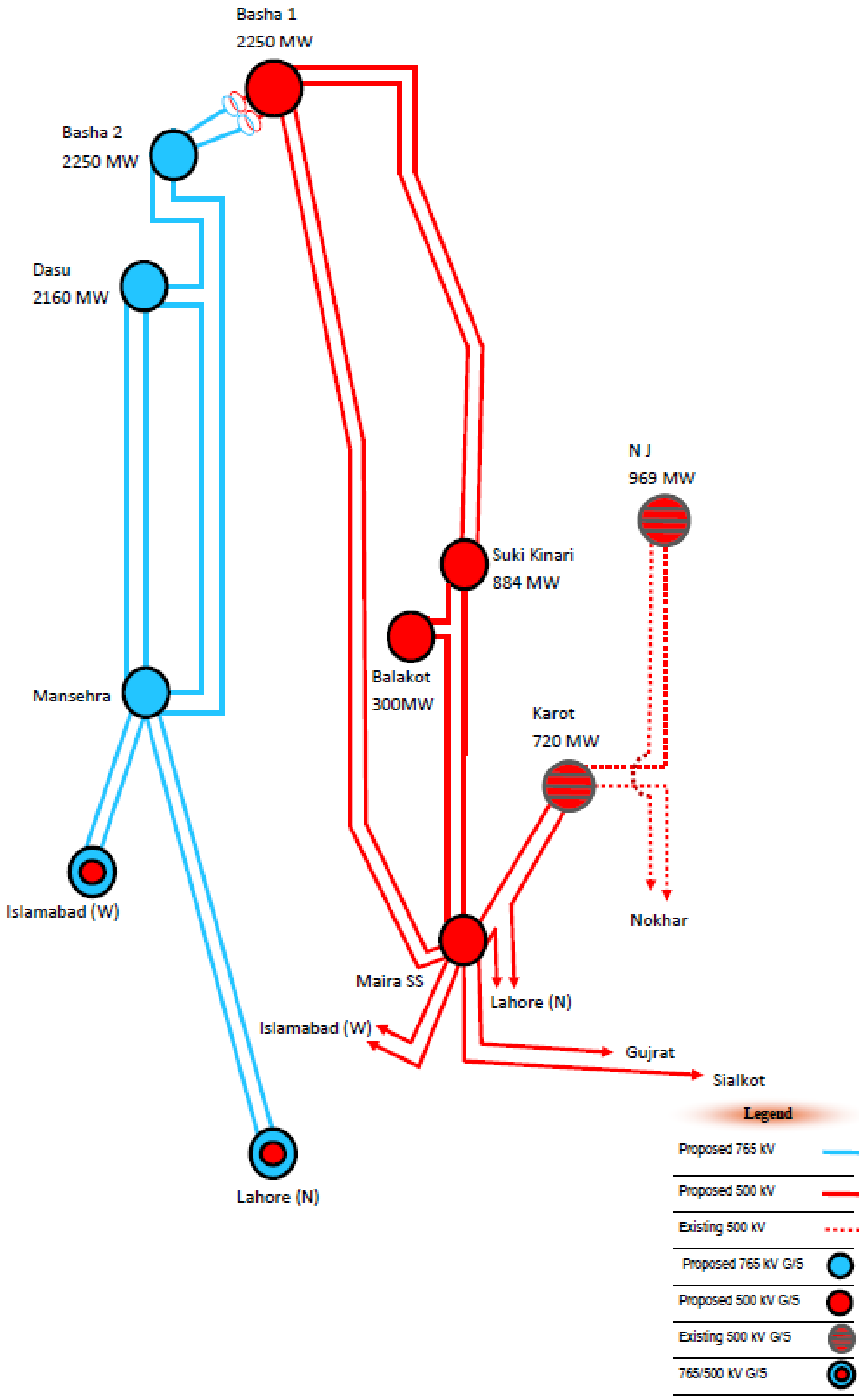
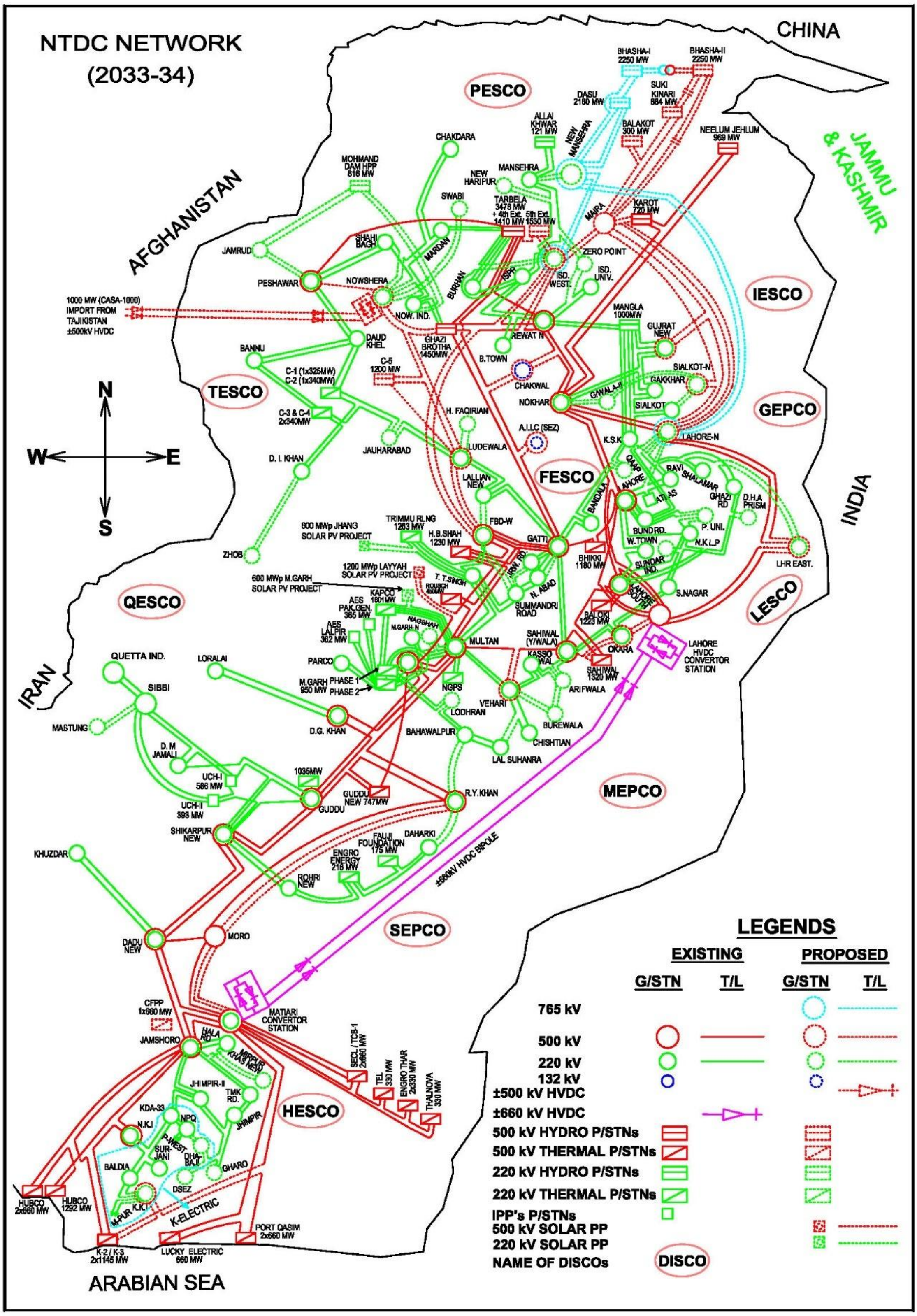


Figure 7-2: Expected 500/220 kV NTDC System by 2033-34



7.1 POWER FLOW AND CONTINGENCY ANALYSIS

Load flow studies for summer base case operating scenarios, corresponding to the high hydro (low thermal) and the low hydro (high thermal) dispatch conditions, have been performed for normal (N-0) and contingency (N-1) conditions for each scenario. The reliability criteria, as defined earlier, have been used in performing the analyses. The automatic contingency analysis (ACCC) activity of PSS/E® was used for the analyses.

Similar to previous sections, the peak and off-peak load conditions have also been studied for winter scenario.

7.1.1 RESULTS AND ANALYSIS OF SUMMER PEAK – JULY/AUGUST 2033

The reactive compensation devices identified in the previous cases are made part of peak July/August 2033 case. Additionally, some more reactive compensation devices are proposed and included in the base case. These are listed in Table 7-1.

Table 7-1: Proposed Reactive Compensation Devices for 2033-34

Bus	Technology	MVAR
500 kV Faisalabad West	STATCOM	±400
220 kV Chishtian	STATCOM	±400
132 kV Sialkot New	Switched Shunt	96
132 kV Lodhran	Switched Shunt	96
132 kV Islamabad University	Switched Shunt	96

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 7-2.

Table 7-2: System Summary – July/August 2033

Description	MW	MVAR
NTDC Generation (including Tajikistan)	35767	6305
NTDC/DISCOs Load	32381	19107
Export to KE	2050	608
Shunts (Reactors)	-	11477
Shunt Capacitors	-	-14568
Line Charging	-	-27839
Losses	1335	22011

* Does not include filters at HVDC terminal stations

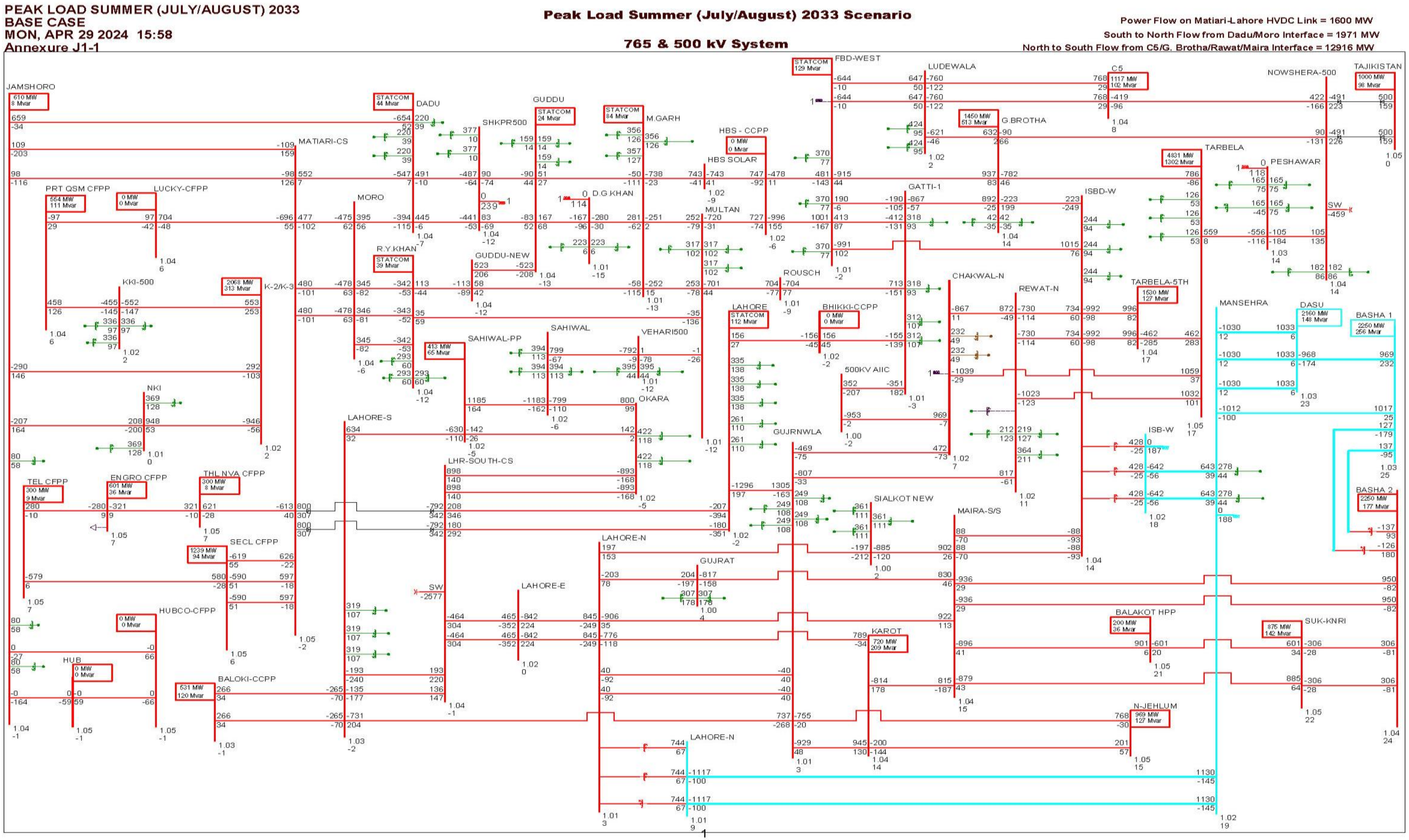
The power flow plots of normal operating conditions, showing 765, 500 and 220 kV networks are provided in Appendix N. The results show that the voltage profile and lines and transformers loadings are well within the normal operating limits and fulfill the grid code operating requirements.

Figure 7-3 shows the power flow plot for 765 kV and 500 kV network under normal operating condition. The power flows from hydro power plants in the north towards mid country and from south to mid country, which is primarily from thermal generation in the south.

Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) for all transmission elements (HVDC and HVAC lines, 765/500 kV, 500/220 kV and 220/132 kV transformers) has been performed. The results indicate that there is no voltage or loading violations for the entire 765 kV, 500 kV and 220 kV network indicating that the transmission system is adequately planned for the expected operating conditions of July 2033 and fulfills the Grid Code operating criteria. All the relevant power flow plots along with the ACCC output files are provided in Appendix N.

Figure 7-3: 765 & 500 kV Network Summer Peak July/August 2033– Normal Operating Conditions



7.1.2 RESULTS AND ANALYSIS OF SENSITIVITY CASES - SUMMER PEAK – JULY/AUGUST 2033

Different sensitivity scenarios have been studied for the secure dispersal of power from the northern generation. As pointed out in the previous section, under the base case scenario, the proposed transmission expansion is adequate. However, two sensitivities are made part of this report to identify any additional requirements to reinforce the dispersal plan. The following two sensitivity cases have been studied.

Case X: Increase of DBPP generation from 4500 MW to 5400 MW

Case Y: DBPP generation at 5400 MW along with Azad Pattan and Kohala power plants

Results and Analysis of Sensitivity Case X

Figure 7-5 depicts the power flow plots with increased generation at DBPP. The power flow results indicate that there is no overloading or voltage violation in the system under normal and contingency conditions. It implies that the proposed evacuation scheme is adequate to accommodate this generation increase at DBPP.

Results and Analysis of Sensitivity Case Y

This sensitivity analysis is performed to ascertain the adequacy of the evacuation plan in case the generation of Basha HPP is increased from 4500 MW to 5400 MW and at the same time the Aazad Pattan and Kohala power plants are also available for production. The power flow analysis is performed for both normal and N-1 contingency conditions. Also, some critical N-2 contingencies in the North are also simulated. The final network configuration after commissioning of Azad Pattan and Kohala HPPs is shown in Figure 7-4 and is used for this analysis.

Figure 7-4: Final Network Configuration after commissioning of Azad Pattan and Kohala

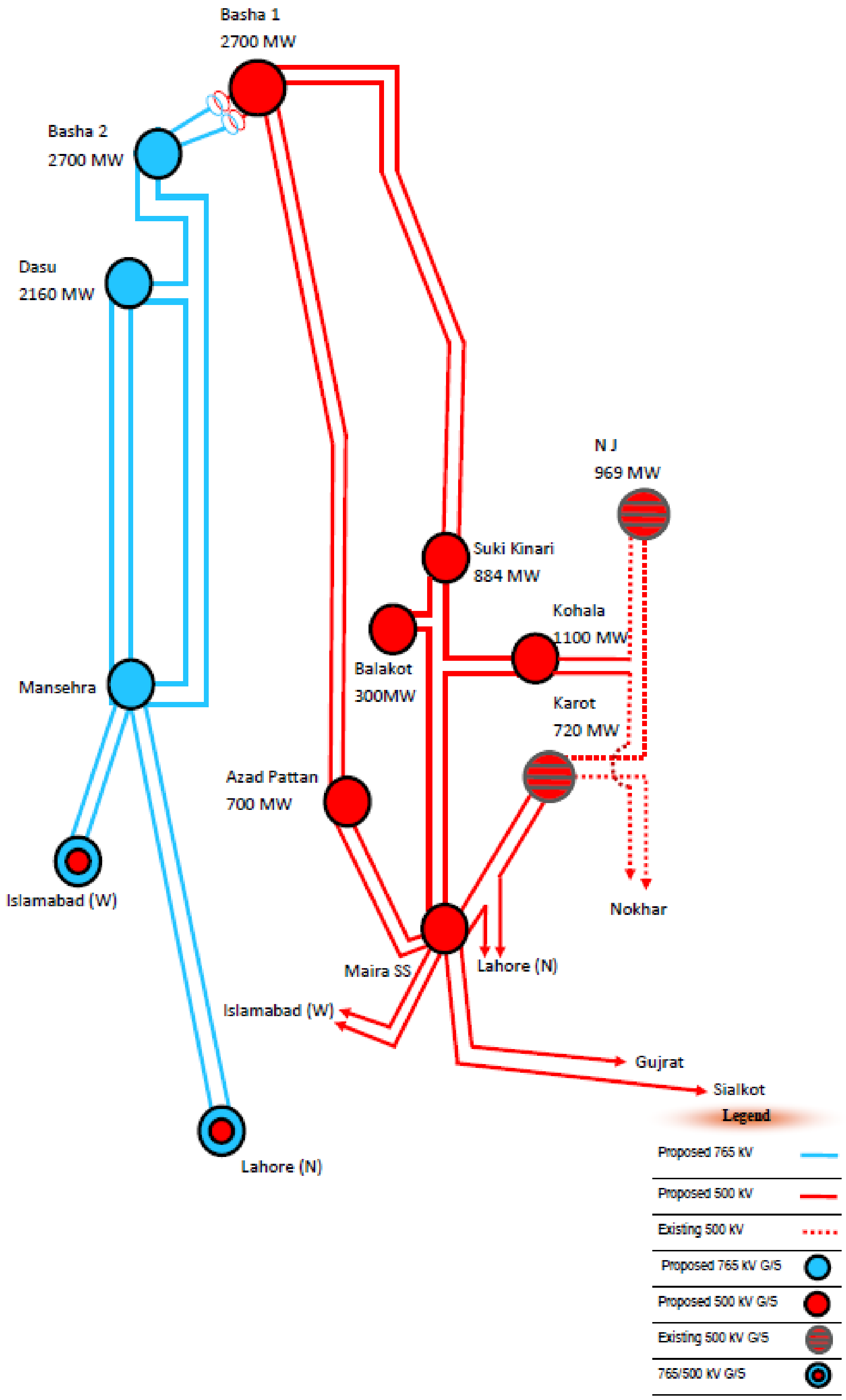


Figure 7-6 and Figure 7-7 depict the power flow plots under normal operating conditions and under N-2 contingency, respectively. The results show that with increased generation at Basha and additional generation at Azad Pattan and Kohala power plants, the evacuation plan is robust enough to accommodate this additional generation without any grid code violation.

However, it is important to note that the power generated from the hydro power plants in the North reaches almost up to Shikarpur and it would be required to close all the RLNG units and imported coal power plants in the south as well as a bare minimum flow of power on HVDC (200 MW on each pole). This clearly indicates that any new plan for hydro generation addition shall be carefully reviewed before making any commitment and shall not lead to underutilization of the existing resources with additional financial burden due to pre-mature transmission expansion.

An important inference can easily be made from the above discussion that commissioning schedule of Azad Pattan and Kohala power plants shall have a reasonable time interval with DBPP and these three power projects shall not be constructed in parallel.

Figure 7-5: 765 & 500 kV Network Summer Peak July 2033 – CASE X

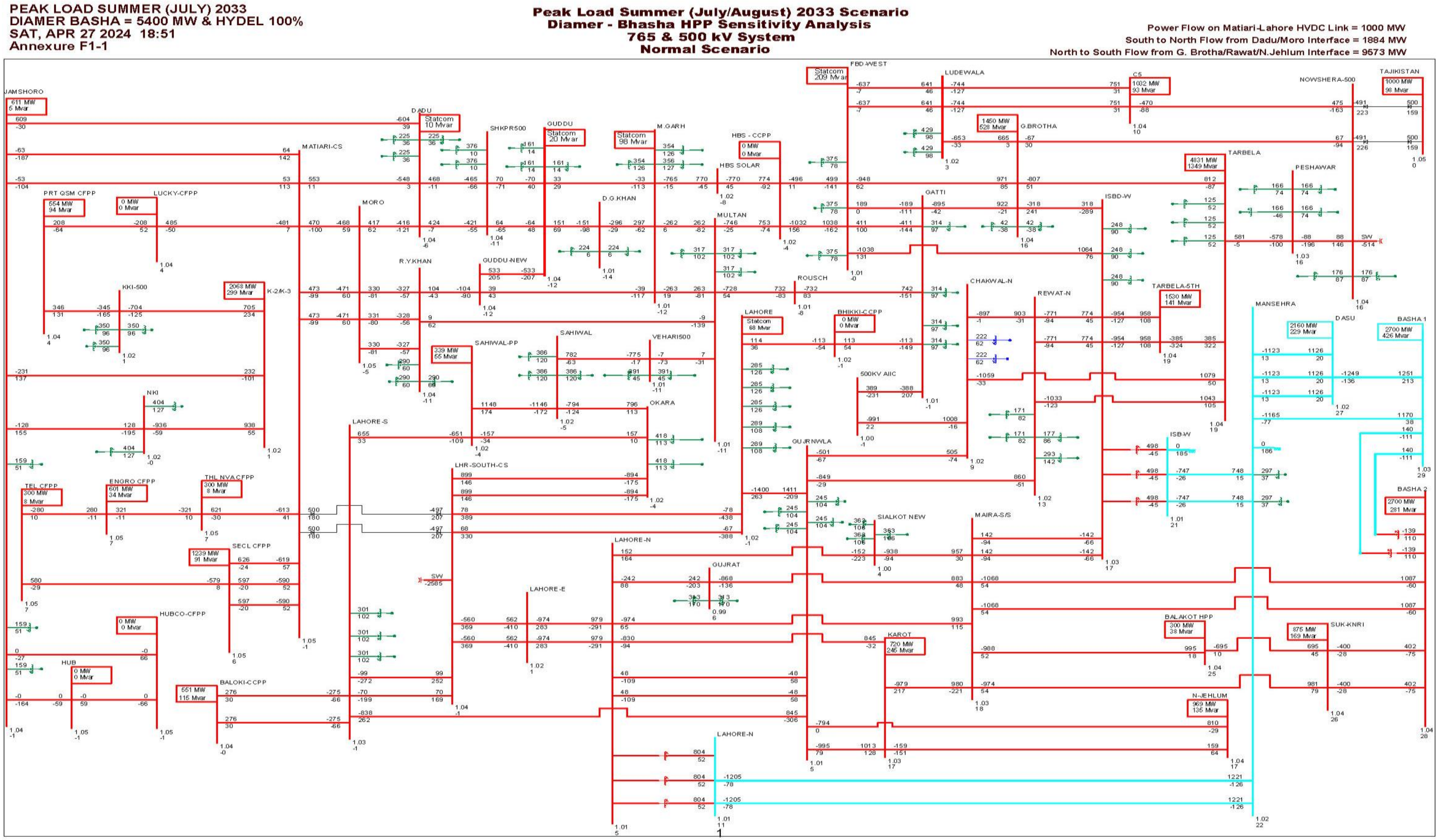


Figure 7-6: 765 & 500 kV Network Summer Peak July/August 2033 – CASE Y

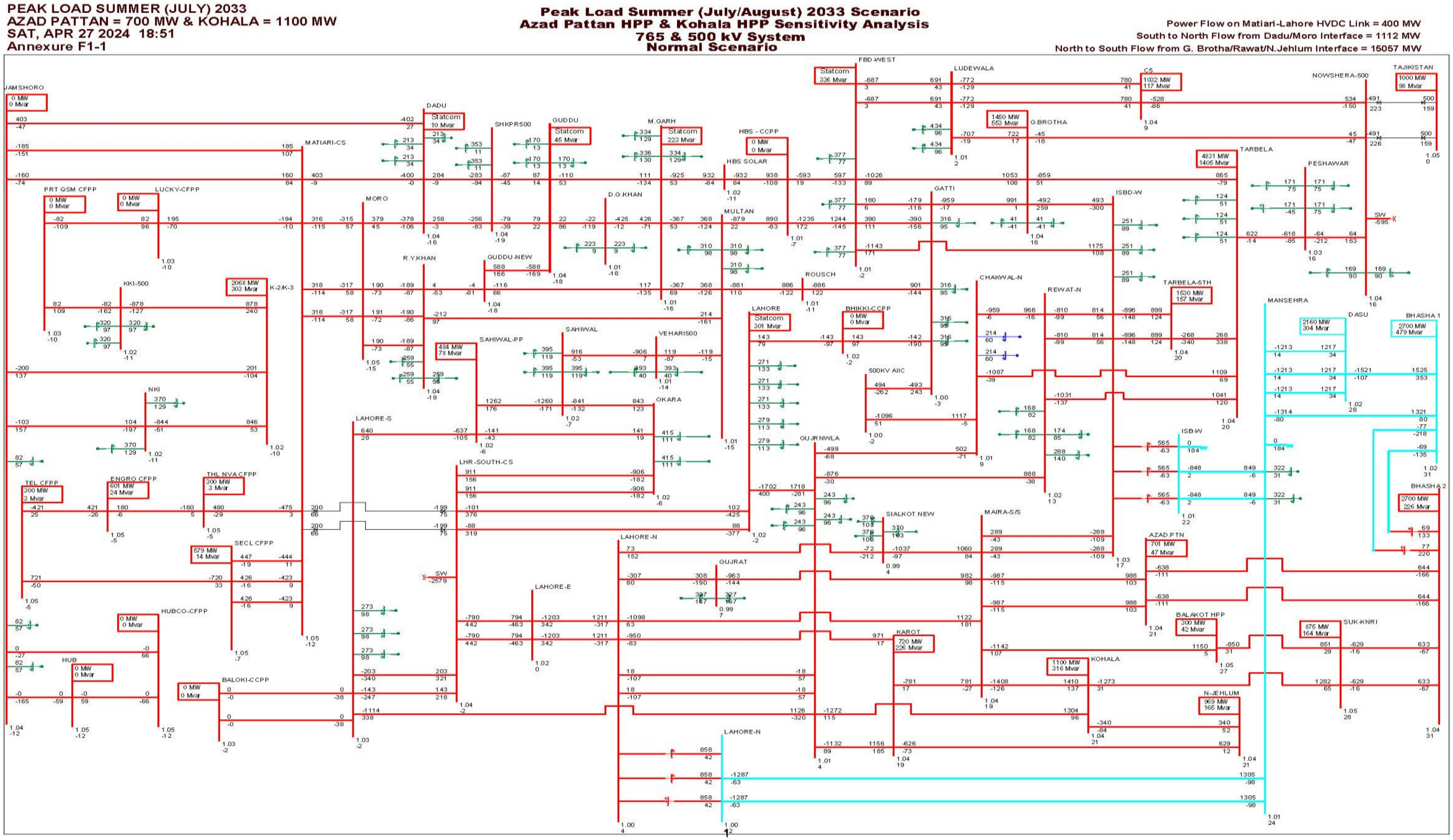
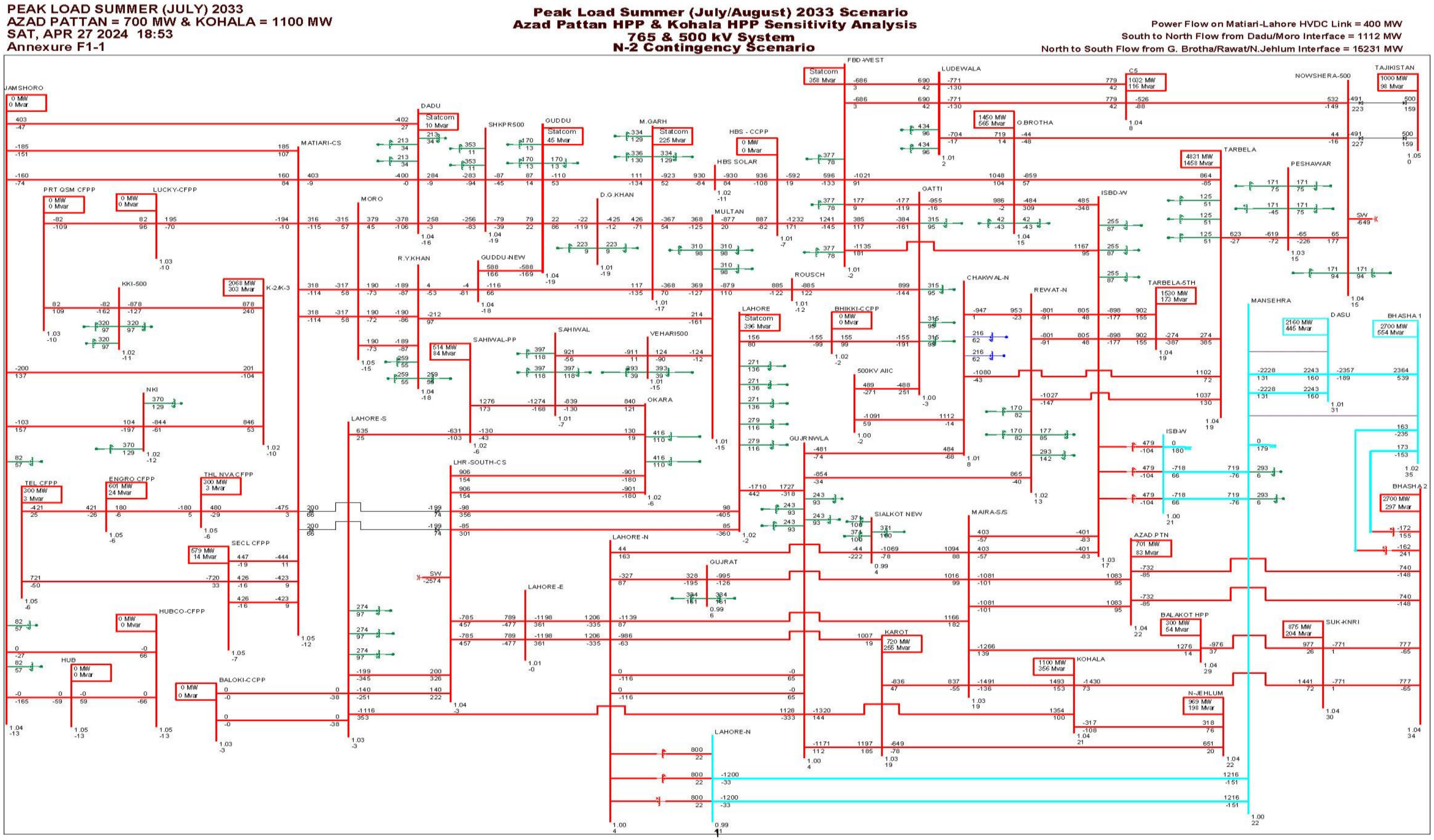


Figure 7-7: 765 & 500 kV Network Summer Peak Summer 2033 – CASE Y (N-2 Contingency)



7.1.3 RESULTS AND ANALYSIS OF SUMMER PEAK – JUNE 2034

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 7-3.

Table 7-3: System Summary – Peak June 2024

Description	MW	MVAR
NTDC Generation (Including Tajikistan)	35881	6652
NTDC/DISCOs Load	32516	19144
Export to KE	2050	609
Shunts Reactors	-	11385
Shunts Capacitors	-	-14955*
Line Charging	-	-27712
Losses	1314	24005

* Does not include filters at HVDC terminal stations

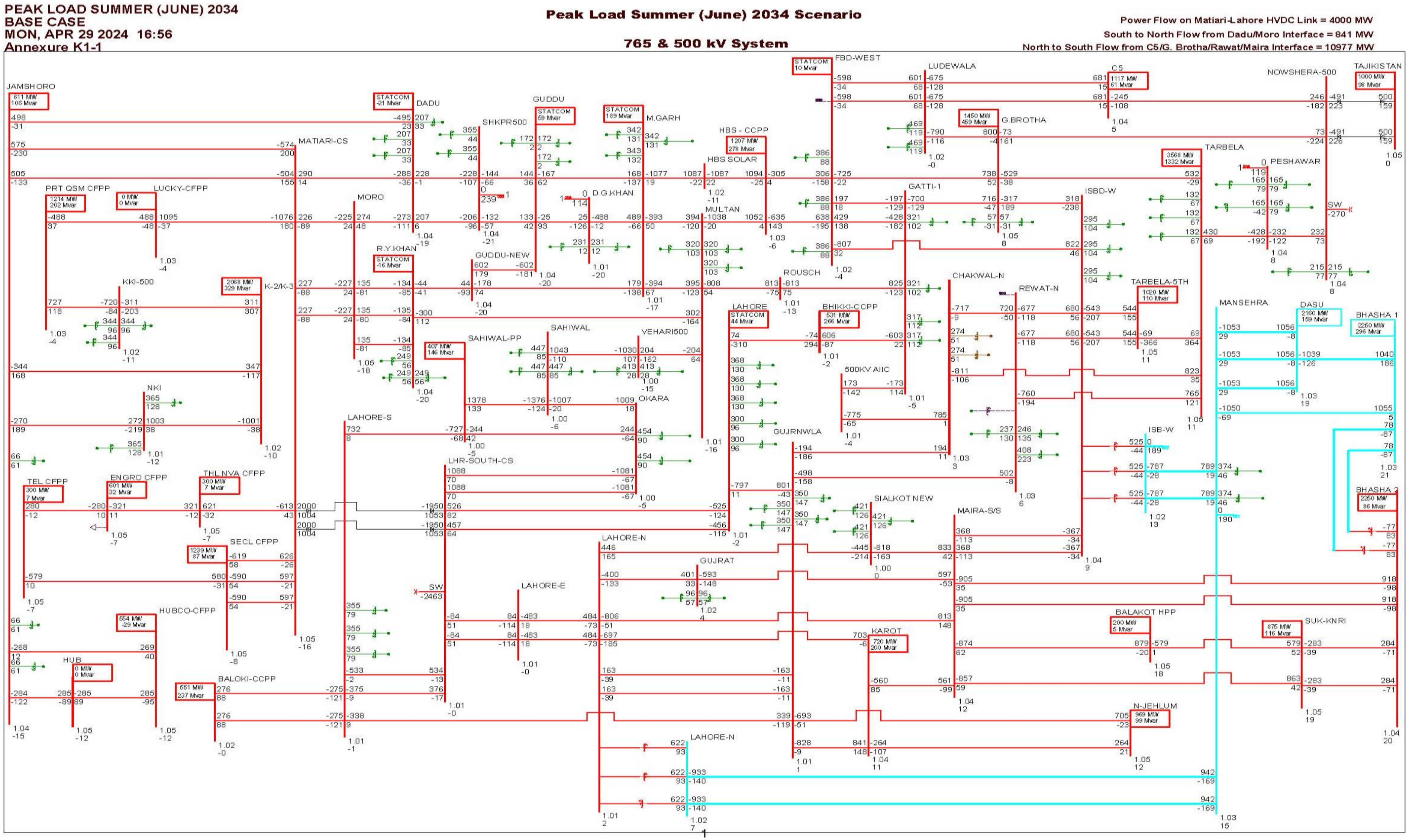
The power flow plots of normal operating conditions, showing 765, 500 and 220 kV networks are provided in Appendix O. The results show that the voltage profile and lines and transformers loadings are well within the normal operating limits and fulfill the grid code operating requirements.

Figure 7-8 shows the power flow plot for 765 & 500 kV network under normal operating condition. The 500 kV northern network is relatively highly loaded as compared to the southern network, since a large amount of southern power flows on HVDC link (4,000 MW) the parallel 500 kV AC system is relatively lightly loaded in the base case.

<u>Contingency (N-1) Analysis</u>

The automatic contingency analysis (ACCC) for all transmission elements (HVDC and HVAC lines, 765/500 kV, 500/220 kV and 220/132 kV transformers) has been performed. The results indicate that there is no voltage or loading violations for the entire 765 kV, 500 kV and 220 kV network.

Figure 7-8: 765 & 500 kV Network Summer Peak June 2034– Normal Operating Conditions



7.1.4 RESULTS AND ANALYSIS OF WINTER PEAK - JANUARY 2034

This scenario is relatively different from the previous winter scenarios. Unlike previous scenarios where the hydro generation was extremely low in winter, DBPP will produce reasonable generation even during winter months in addition to the generation available from Dasu PP. Therefore, hydro generation during winter will be substantial as compared to the previous spot years. The same approach, as used earlier, is adopted to develop the base case for winter peak 2034 conditions. Table 7-4 lists the major lines openings recommended for the winter case of 2034. This operational measure significantly helps to control voltages within their normal operating range.

Table 7-4: Major line openings recommended for the winter case of Jan 2034

S/N	Circuit Open	S/N	Circuit Open
1	500 kV Balakot - Maira S/C	6	500 kV Ghazi Brotha – Ludewala S/C
2	500 kV Basha 2 -Maira S/C	7	500 kV Islamabad West – Rawat S/C
3	500 kV Tarbela – Chakwal S/C	8	500 kV Gujranwala – N. Jhelum
4	500 kV Tarbela – Ghazi Brotha S/C	9	500 kV Karot – Lahore North S/C
5	500 kV Ghazi Brotha – Gatti S/C		

The July 2033 base case was updated by modifying the loads expected in winter peak – January 2034. Generation dispatch was changed as per the available generation during winter, incorporated any change in the transmission network from July 2033 onward and the transmission lines listed above are kept open.

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 7-5.

Table 7-5: System Summary – Peak January 2034

Description	MW	MVAR
NTDC Generation	23356	783
NTDC/DISCOs Load	21305	10032
Export to KE	1500	238
Shunts Reactors	-	13390
Shunts Capacitors	-	-4467*
Line Charging	-	-25798
Losses	551	12536

* Does not include filters at HVDC terminal stations

Power flow analysis was performed for this winter peak case and the results for normal operating conditions are provided in Appendix P.

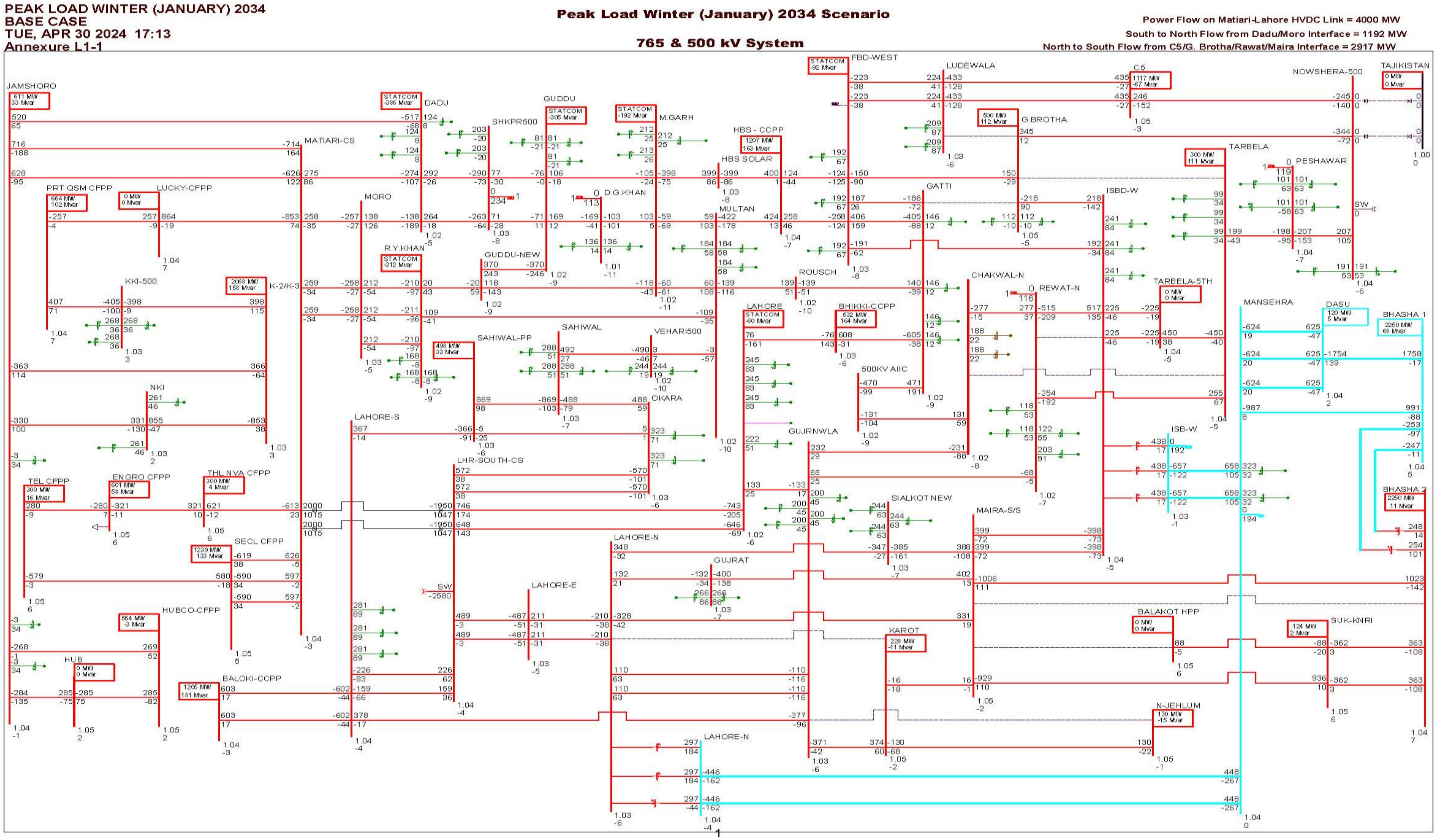
The results show that the transmission line loadings are well within their operating limits as can be seen from the power flow plot of 500 kV network depicted in Figure 7-9.

Contingency (N-1) Analysis

The automatic contingency analysis (ACCC) has been performed for the bulk transmission system (EHV and HVDC lines and 765/500 kV,500/220 kV and 220/132 kV transformers). The analysis indicates that no voltage or overload violations occur on the entire 500 and 220 kV network.

All the relevant power flow plots and the ACCC output files of the simulated contingencies are provided in Appendix P.

Figure 7-9: 765 & 500 kV Network Winter Peak January 2034– Normal Operating Conditions



7.1.5 RESULTS AND ANALYSIS OF WINTER OFF PEAK - JANUARY 2034

A similar approach is used in developing the base case for winter off-peak 2034 as was used for winter off-peak 2029. Winter peak case 2034 has been revised to develop winter off-peak (minimum) case 2034.

The requirements of shunt reactors are determined to maintain a reasonable voltage profile in the system. The additional reactive power compensation proposed under this scenario is summarized in Table 7-6. It shall be noted that the proposed compensation is in addition to the already recommended for previous spot years.

Table 7-6: Reactors proposed for the 2033-34 network configuration

Bus	MVAR
220 kV Mirpur Khas	60

The system generation and load summary for the NTDC/DISCOs systems under this scenario is provided in Table 7-7.

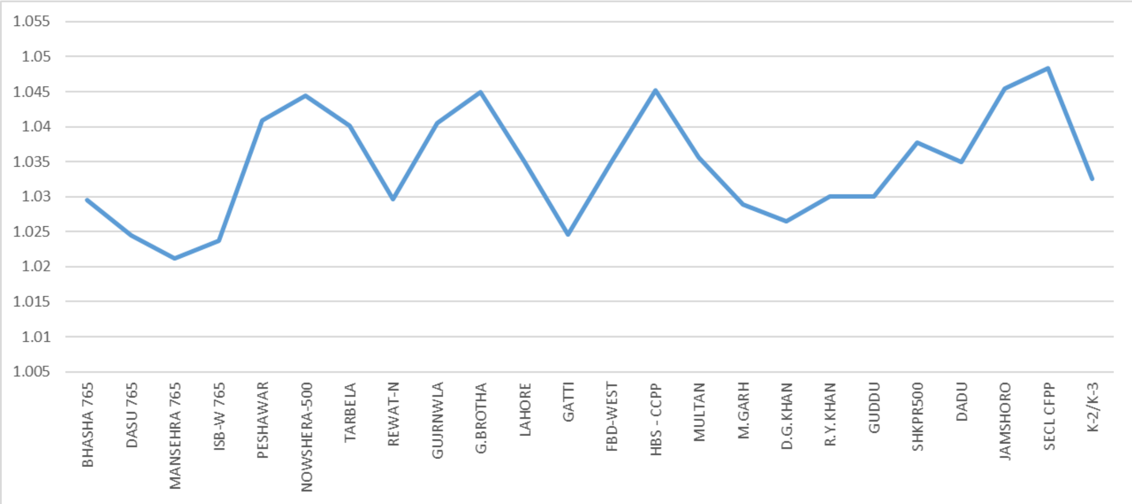
Table 7-7: System Summary – Off-peak January 2034

Description	MW	MVAR
NTDC Generation	14417	-1815
NTDC/DISCOs Load	13185	6100
Export to KE	1000	123
Shunts Reactors	-	13903
Shunts Capacitors	-	-1505*
Line Charging	-	-24347
Losses	232	5526

* Does not include filters at HVDC terminal stations

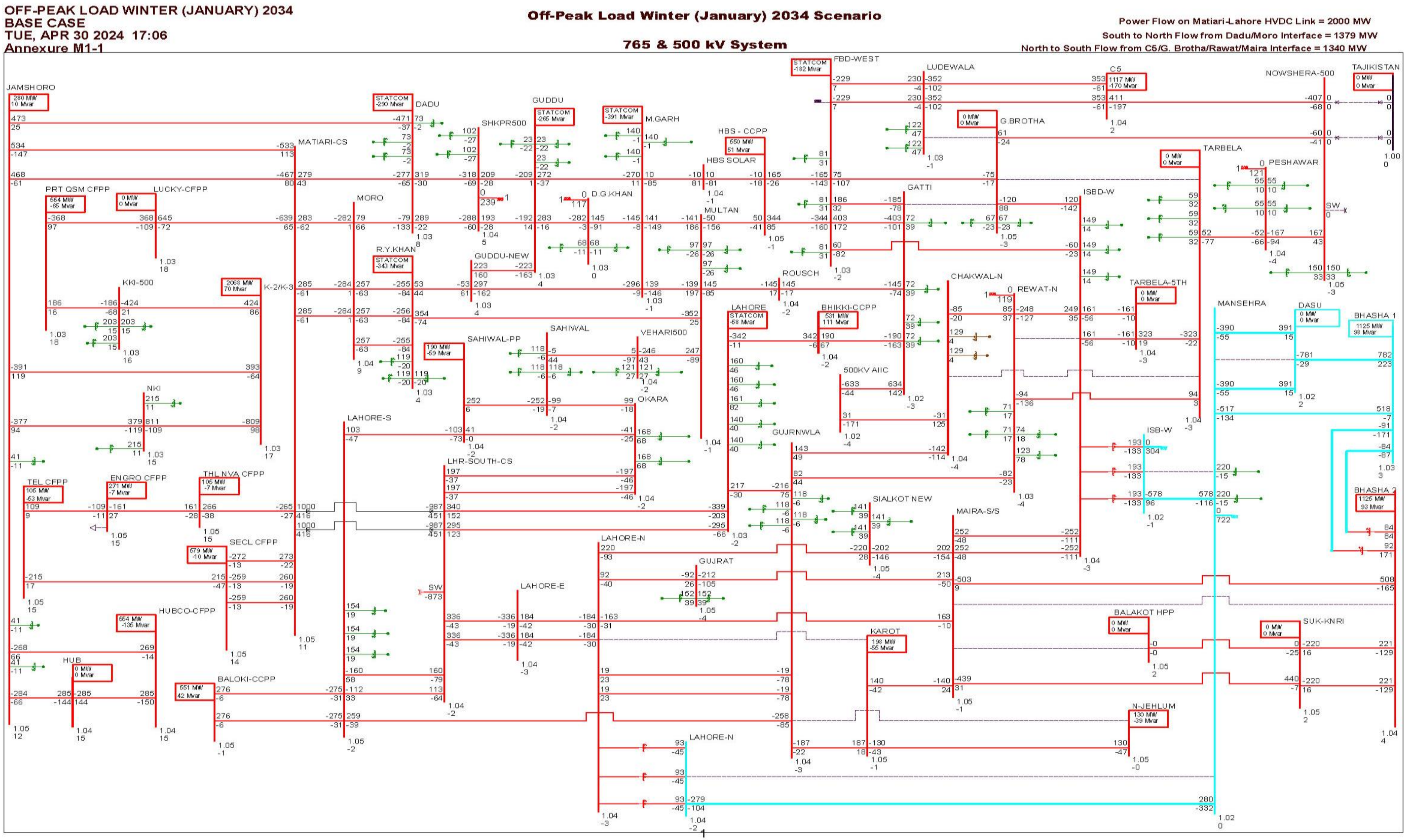
Figure 7-10 presents the voltage profile of the key buses in the 765 and 500 kV network and as can be seen the voltage profile is quite reasonable and is within the limits prescribed by GC.

Figure 7-10: Voltage Profile of 500 kV Network - Winter Off- Peak January 2034



The power flow plots of the 765 kV and 500 kV network under normal operating conditions is presented in Figure 7-11.

Figure 7-11: 765 & 500 kV Network Winter Off- Peak January 2034– Normal Operating Conditions



7.2 SHORT CIRCUIT ANALYSIS FOR SPOT YEAR 2033-34

Short circuit analysis has been carried out to calculate maximum fault currents for balanced and unbalanced faults on the bulk power system, i.e., three phase to ground (LLLG) and single phase to ground (LG) faults, respectively. The same assumptions as described in Section 5.2 have been used in performing the analysis.

Fault currents are computed at all nodes of the NTDC transmission network. The short-circuit base cases were developed considering the expected on-line generation for the spot year. This may not result in a set of maximum fault currents which would occur if all the available generation is kept on-line. However, it would be a realistic estimation of short circuit levels, which would prevail in the system corresponding to the operating conditions under study.

7.2.1 SHORT CIRCUIT RESULTS 2033-34

The maximum computed short circuit levels at key buses are shown in Table 7-8, whereas the detailed results of the analysis are provided in Appendix N.

Ultimate short circuit levels, considering all the available generation on bar, have also been computed and the results are provided in Appendix N.

Table 7-8: Short Circuit Levels – 2033-34

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	1-Phase
64	MANSEHRA	765	50	23.8	20.2
17	BHASHA 1	765	63	22.4	23.1
16	DASU	765	63	22.3	20.9
13	ISB-W	765	50	20.7	16.8
9	LAHORE-N	765	50	15.3	12.7
21	ISBD-W	500	63	50.7	40.0
20	TARBELA	500	50/63	48.4	48.6
29	TARBELA-5TH	500	63	47.5	46.1
25	G. BROTHA	500	40/50	40.6	26.6
28	LAHORE-N	500	63	39.3	30.5
6	MAIRA-S/S	500	63	38.9	29.3
24	GUJRNWLA	500	40	38.8	29.0
34	LHR-SOUTH-CS	500	50	36.3	30.0
30	LAHORE	500	40	35.6	30.0
41	FBD-WEST	500	63	34.9	26.2
32	LAHORE-S	500	50	33.8	28.6
22	REWAT-N	500	40	33.5	23.2
40	GATTI-1	500	40	33.5	24.4
211	KAROT	500	50	33.0	27.7
19	BHASHA 2	500	63	32.1	33.1

Bus No.	Bus Name	Bus Voltage (kV)	Switchgear Rating (kA)	Short Circuit Current (kA)	
				3-Phase	I-Phase
260	LAHORE-N	220	63	52.6	44.1
212	ISBD-W	220	63	48.3	41.4
245	NOKHAR	220	50/63	44.6	37.3
444	FBD-W	220	50	44.3	36.1
151	NOWSHERA-220	220	50	41.2	30.6
300	LAHORE	220	40/50	39.7*	34.1
350	YOSAFWAL	220	40/50	39.9	32.1
200	TARBELA	220	50/63	39.4	38.6
303	LAHORE-S	220	50	39.2	33.9
270	BUNDRD-1	220	40/50	39.1	29.2
145	NOSHRA-I	220	40	38.7	27.5
400	GATTI	220	40/50	38.5	30.2
300000	LAHORE2	220	40/50	37.5*	31.1
410	SUMNDIRD	220	40	37.5	27.2
100	PESHAWAR	220	40	36.4	26.6
500	MULTAN	220	40/50/63	36.4	28.9
280	K.L.PAT	220	40/50	35.8	25.6
273	PUNJAB UNI	220	50	35.7	25.5
215	ISPR-220	220	40	35.6	24.9
134	NEW MANSEHRA	220	50	35.5	31.4
220	RAWAT-N-1	220	40/50	35.0	28.5
4262	LHR-N-132	132	40	39.8	32.9
2025	ISPR-132	132	40	38.3	28.7
2022	BURHAN	132	25/40	37.6	28.5
4443	FSD-W	132	40	37.4	31.7
3000	GAKKHAR	132	31.5/40	36.6	27.9
4330	NSHTBD-1	132	40	36.4	28.7
4029	ATTABAD	132	40	36.2	27.3
4510	J.W-RD	132	40	35.7	28.1
4144	NKLP-1	132	40	35.3	29.1
3003	NOKHAR	132	40	35.1	30.3
1070	MARDAN	132	40	34.9	26.0
2336	CHAKWAL-NEW	132	50	34.5	27.9
4076	RAVI-I	132	40/44.9	34.1	26.1
6070	YOUSFWLA	132	31.5/40	34.0	27.9

Note: * bus split

7.3 TRANSIENT STABILITY STUDY FOR SPOT YEAR 2033-34

This section discusses the results of the transient stability analysis, which was performed to ascertain the robustness of the system and its dynamic behavior under disturbance conditions. Normally, stability analysis is not performed for long-term scenarios. However, considering the importance of Basha HPP, stability analysis has been carried out for the network in the North to ascertain the performance of newly proposed scheme under disturbed conditions. This analysis, however, is limited to the July 2033 operating condition.

It is noted that the steady state performance of the network under peak load conditions of July 2033 has already been tested through extensive power flow and contingency analyses and found satisfactory, as discussed in the previous sections.

The transient stability analysis has been performed by simulating three phase faults at critical 765 kV and 500 kV buses in the vicinity of Basha, Dasu and Mansehra grid stations. The stability models and parameters for Basha HPP units are assumed to be the same as some of the existing similar units.

7.3.1 RESULTS AND ANALYSIS OF SUMMER PEAK - JULY 2033

The results of transient stability simulations are attached in Appendix N. Although all the simulated results in this case were very stable, the stability result for faults at 765 kV DBPP, Dasu and Islamabad have been summarized in Table 7-9 for completeness. The corresponding stability plots are exhibited in Figure 7-12 to Figure 7-14 for ready reference.

Table 7-9: Summary of the Transient Stability Analysis Results - July 2033

S/N	Faulted Bus		Base Voltage (kV)	Trip Circuit		Loading (MVA)	Fault Type	Stability Status			
	Number & Name			Number & Name				VOLT	ANGL	POWR	FREQ
1	17	DBPP	765	17-64	DBPP – Mansehra	1017	3P	Stable	Stable	Stable	Stable
2	16	Dasu PP	765	16-64	Dasu - Mansehra	1033	3P	Stable	Stable	Stable	Stable
3	13	Islamabad West	765	64-13	Mansehra – Islamabad West	643	3P	Stable	Stable	Stable	Stable

Figure 7-12: 3-Phase Fault at 765 kV DBPP

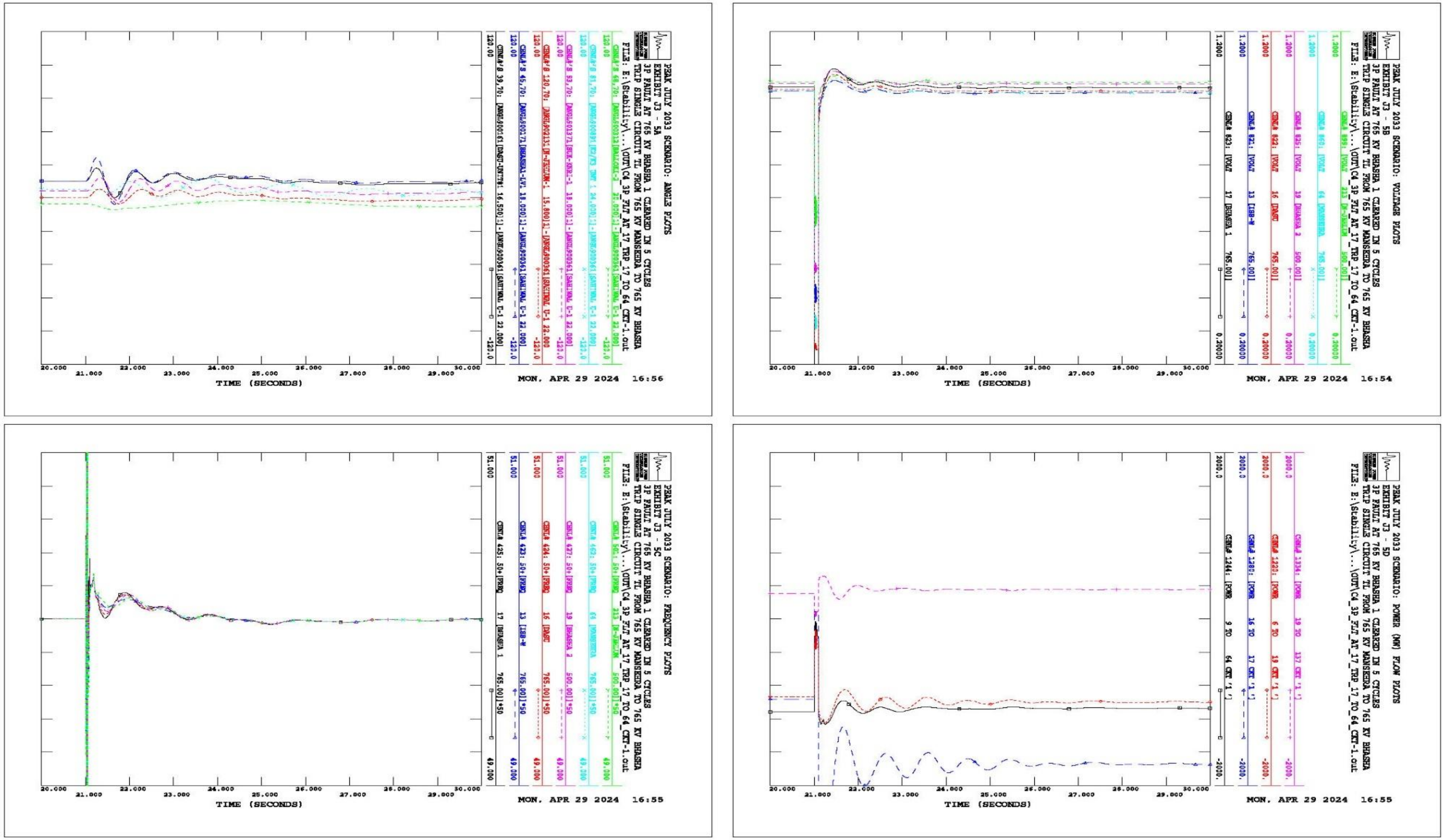


Figure 7-13: 3-Phase Fault at 765 kV Dasu

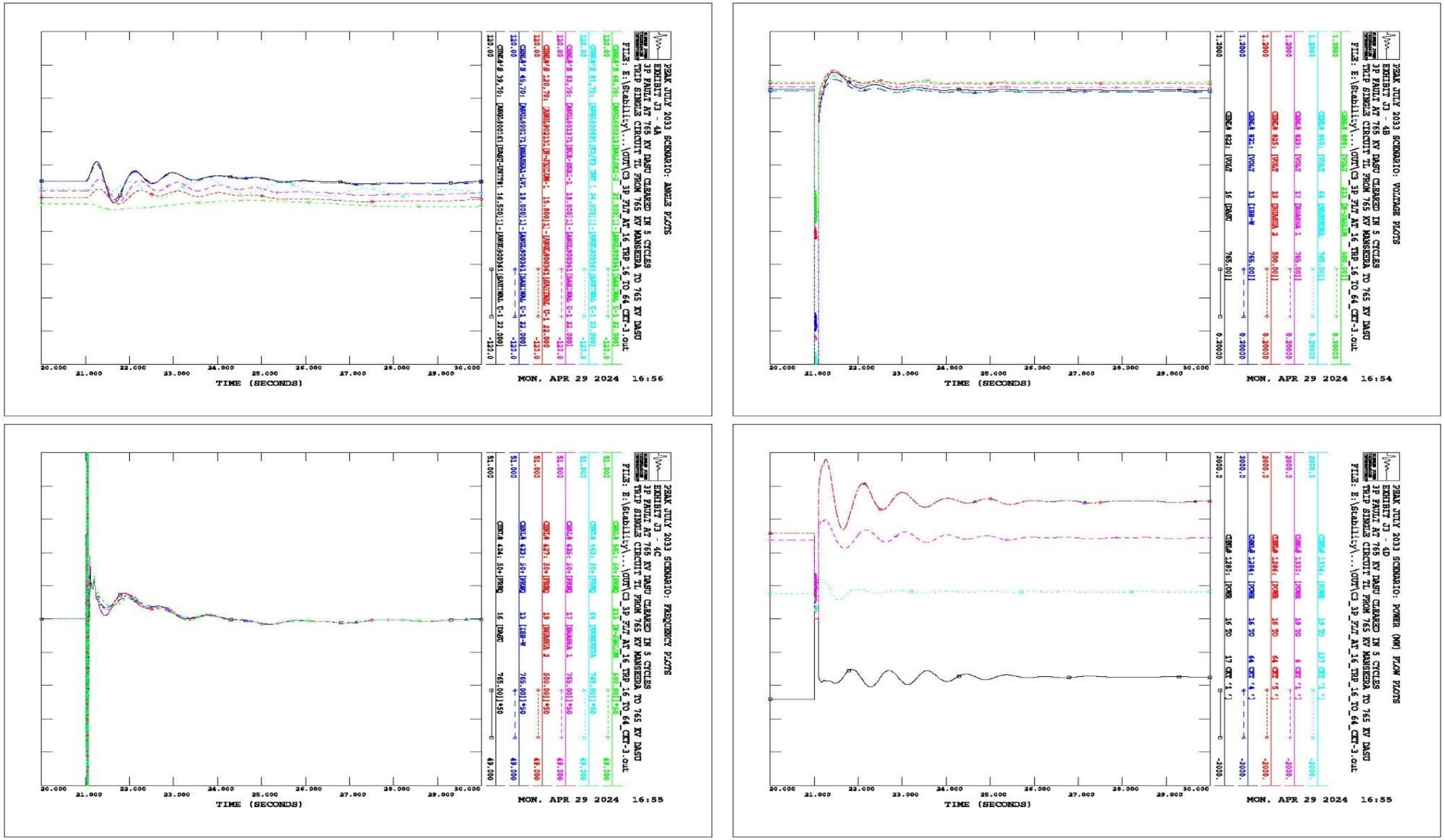
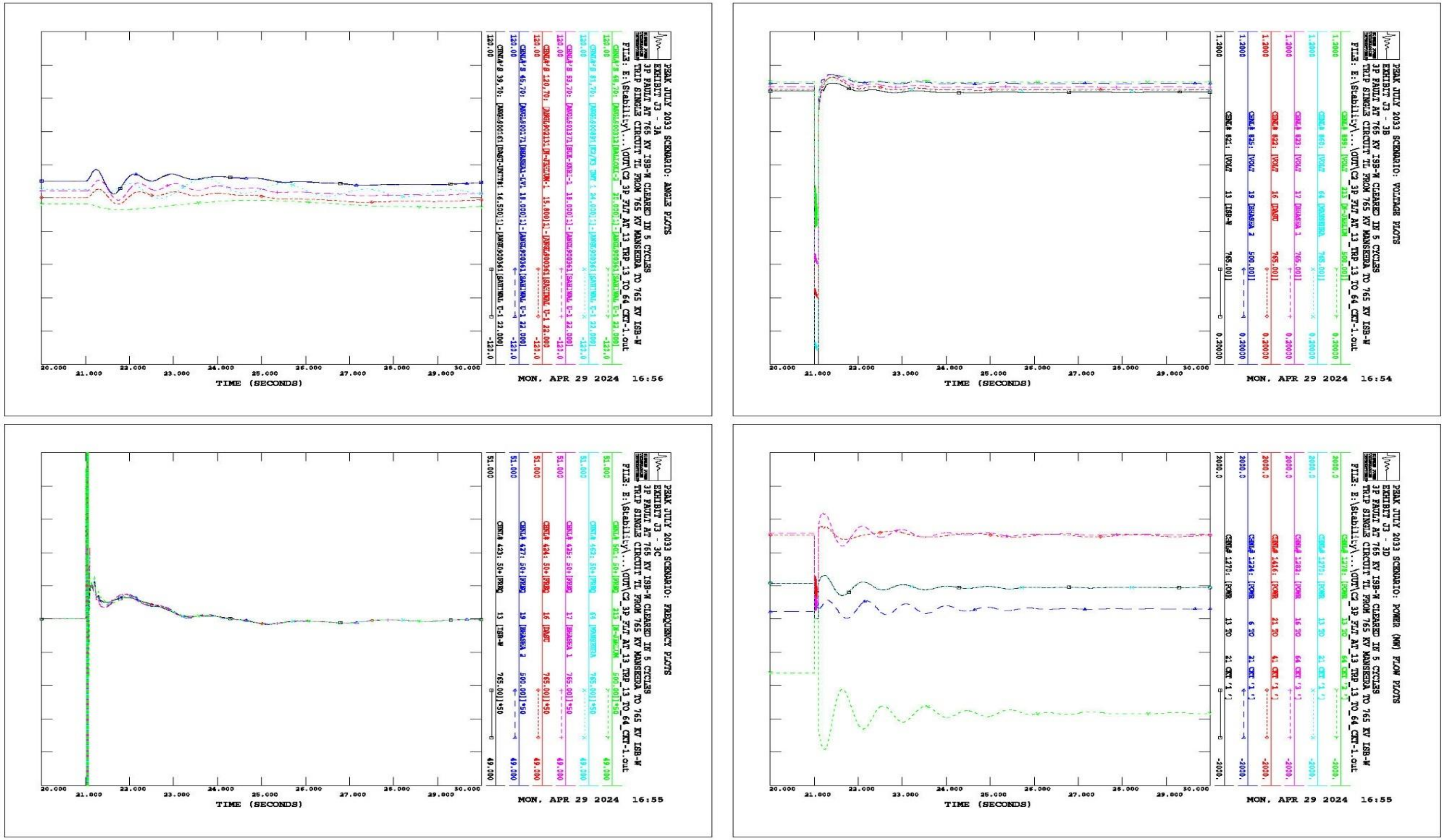


Figure 7-14: 3-Phase Fault at 765 kV Islamabad West



7.4 EXPANSION REQUIREMENTS UP TO 2034

Analysis of these consolidated base cases shows that additional transmission reinforcements and expansion projects are required for reliable and secure operation of the primary network. Section 8 lists these newly proposed projects, which have been identified after conducting rigorous analyses.

8. TRANSMISSION DEVELOPMENT/EXPANSION PLAN

The projects conceived in the previous sections together with all the ongoing projects form the TSEP 2024. These projects are listed in the relevant tables within this section with their high-level scope and tentative commissioning schedule. The timelines mentioned in these tables for each project are based on the system operation requirements. However, considering the uncertainties associated with the procurement process, availability of funds, execution plans and implementation, it is likely that these timelines may slip by some months. In addition, the high-level cost estimates have also been provided in this section.

The following table illustrates the existing and planned NTDC transformation and transmission system capacity.

Table 8-1: Existing and Planned Transformation and Transmission System Capacity of NTDC

Year	765 kV			500 kV			220 kV			±660 kV	±500 kV
	No. of G/S	T/F Cap. (MVA)	T/L Length (km)	No. of G/S	T/F Cap. (MVA)	km (T/L)	No. of G/S	T/F Cap. (MVA)	T/L Length (km)	T/L Length (km)	T/L Length (km)
2023-24	-	-	-	18	25,950	9,275	51	39,840	12,416	2x886	-
2033-34	3	9,600	2,152	28	48,550	14,683	67	56,470	15,088	2x886	2x113

There are additional 500 kV and 220 kV grid stations owned and operated by other entities but are part of NTDC integrated system:

- 500 kV Tarbela and Ghazi Brotha having 500/220 kV transformation capacities of 1350 MVA and 1200 MVA respectively.
- 220 kV Mangla, KAPCO and Bahria town having transformation capacities of 414 MVA, 500 MVA and 63 MVA respectively.

The NTDC network expansion is continuous process for meeting future load demand and evacuation of power from upcoming power plants.

Table 8-2: Power Dispersal & Import/Export projects

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Dasu HPP	Dasu HPP (Phase-1: 2160 MW) – Mansehra	765	D/C	157	June 2026
2	Suki Kinari HPP	In/Out of Neelum Jhelum HPP – Karot HPP S/C at Suki Kinari HPP	500	D/C	75	May 2024
3	K-2/K-3 NPP	In/Out of Port Qasim CFPP – Matiari S/C at K-2/K-3 NPP	500	D/C	102	August 2024
4	Tarbela 5th Ext. HPP	Tarbela 5th Ext. HPP – Islamabad West	500	D/C	55	November 2024
		Tarbela 5th Ext. HPP – Tarbela		S/C	2	
5	HVDC Convertor Station at Nowshera (Azakhel)	HVDC Bi-pole Line from Tajikistan to Nowshera Azakhel (CASA-1000)	±500 kV DC		113	February-2025
6	1200 MW Solar Power Plant near Haveli Bahadur Shah	In/Out of H.B. Shah PP – Muzaffargarh S/C at 1200 MW Solar Power Plant	500	D/C	4.5	2027-28
7	Mohmand HPP	Mohmand HPP – Jamrud	220	D/C	65	2026-27
		Mohmand HPP – Nowshera Industrial			70	
8	600 MW Solar Power Plant near Trimmu Jhang	In/Out of Trimmu – T.T. Singh S/C at 600 MW Solar Power Plant	220	D/C	23	2026-27
9	600 MW Solar Power Plant near Muzaffargarh	In/Out of KAPCO – Multan S/C at 600 MW Solar Power Plant	220	D/C	4	2026-27
10	Gwadar	Gwadar – Pak Iran Border	220	D/C	75	2027-28

Note: 500 kV KKI Grid Station is being constructed by K-Electric and its expected commissioning is in June 2024.

Table 8-3: 765 kV Grid Stations/Switching Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
1	Mansehra	Mansehra – Islamabad West	D/C	97	2x1200	G/S: December-2025 T/L: June-2026
2	Upgradation of Islamabad West from 500 kV to 765 kV				3 x 1200	December-2026

Table 8-4: 500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines

<table>
<tr><th>Sr. No.</th><th>Name of Project</th><th>Transmission Line Description</th><th>Circuit Config.</th><th>Length of Each Circuit (km)</th><th>Transformer Capacity (MVA)</th><th>Expected Completion Date</th></tr>
<tr><td>1</td><td>Nowshera (Azakhel)</td><td>In/Out of Tarbela – Peshawar S/C at Nowshera Azakhel</td><td>D/C</td><td>12</td><td>2 x 750</td><td>August-2024</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Lahore North</td><td>Lahore North – Lahore South CS</td><td>D/C</td><td>68</td><td rowspan="2">3 x 750</td><td rowspan="2">T/F #1: August 2024
T/F #2: October 2024
T/F #3: December-2024
T/L: Already Completed</td></tr>
<tr><td>Lahore North – Nokhar</td><td>D/C</td><td>45</td></tr>
<tr><td rowspan="3">3</td><td rowspan="3">Maira Switching Station(S/S)</td><td>Maira – Suki Kinari HPP</td><td>D/C</td><td>156 (75 + Remaining 81 km)</td><td></td><td rowspan="3">S/S: August-2024
T/L: 2026-27</td></tr>
<tr><td>Maira – Islamabad West</td><td>D/C</td><td>135</td><td></td></tr>
<tr><td>Karot HPP – Maira</td><td>D/C</td><td>15</td><td></td></tr>
<tr><td>4</td><td>Allama Iqbal Industrial City (AIIC)-FIEDMC</td><td>In/Out of Gatti - Ghazi Brotha S/C at AIIC</td><td>D/C</td><td>2</td><td>2 x 750
(500/132 kV)</td><td>November-2024</td></tr>
</table>

<table>
<tr><th>Sr. No.</th><th>Name of Project</th><th>Transmission Line Description</th><th>Circuit Config.</th><th>Length of Each Circuit (km)</th><th>Transformer Capacity (MVA)</th><th>Expected Completion Date</th></tr>
<tr><td>5</td><td>Islamabad West</td><td>In/Out of Ghazi Brotha HPP – Rewat D/C at Islamabad West</td><td>2 x D/C</td><td>5.9</td><td>3 x 750</td><td>December-2026</td></tr>
<tr><td>6</td><td>Sialkot New</td><td>Sialkot New – Lahore North</td><td>D/C</td><td>55</td><td>2 x 750</td><td>2026-27</td></tr>
<tr><td>7</td><td>Upgradation of Vehari from 220 kV to 500 kV Voltage Level</td><td>In/Out of Multan – Sahiwal S/C at Vehari</td><td>D/C</td><td>35</td><td>2 x 750</td><td>2026-27</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">Chakwal New</td><td>In/Out of AIIC – Ghazi Brotha/Tarbela S/C at Chakwal New</td><td>D/C</td><td>3</td><td rowspan="2">2 x 500 (500/132 kV)</td><td rowspan="2">2027-28</td></tr>
<tr><td>In/Out of Gujranwala – Rewat S/C at Chakwal New</td><td>D/C</td><td>30</td></tr>
</table>

Table 8-5: 220/132 kV Grid Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
1	Quaid-e-Azam Business Park (QABP)	In/Out of Bandala – KSK D/C at QABP	2 x D/C	3	2 x 250	G/S: June-2024 T/L: Already Completed
2	Lahore North	In/Out of Ghazi Road/Ravi – K.S.K D/C at Lahore North	2 x D/C	15	3 x 250	G/S: August-2024 T/L: Already Completed
		In/Out of Lahore Old – Ravi S/C at Lahore North	D/C	14		
3	Zhob	Zhob – D.I Khan	D/C	220	2 x 160	G/S: August-2024 T/L: Already Completed
4	Swabi	Swabi – Nowshera	D/C	55	3 x 250	G/S: December-2024 T/L: July-2024
5	Haripur New	In/Out of Mansehra – ISPR S/C at Haripur New	D/C	2	3 x 250	G/S: December-2024 T/L: June-2024
6	Pilot Battery Energy Storage System (BESS) at Jhimpir-I					December-2024
7	Dhabeji SEZ	In/Out of Gharo – Jhimpir S/C at Dhabeji SEZ	D/C	10	2 x 160	G/S: December-2024 T/L: July-2024
8	Mirpur Khas New	In/Out of the Hala Road – Jamshoro S/C at Mirpur Khas New	D/C	67	2 x 250	G/S: December-2024 T/L: December-2025
9	Jauharabad	In/Out of C-1/C-2/C-3/C-4 – Ludewala D/C at Jauharabad	2 x D/C	6	2 x 250	June-2025
10	Arifwala	In/Out of Yousafwala – Kassowal D/C at Arifwala	2 x D/C	25	2 x 250	2026-27
11	Nowshera (Azakhel)	In/out of Shahibagh – Chakdara S/C at Nowshera	D/C	2		2026-27
		In/out of Shahibagh – Nowshera Industrial S/C at Nowshera	D/C	12		
12	Sunder Industrial	In/Out of Kot Lakhpat – Sarfraz Nagar S/C at Sunder Industrial	D/C	2	2 x 250	2026-27

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
13	Gharo				2 x 250	2026-27
14	Islamabad West	In/Out of Tarbela – ISPR S/C at Islamabad West	D/C	12.5	3 x 250	December-2026
		In/Out of Haripur – ISPR S/C at Islamabad West	D/C	21		
15	Head Faqirian	H. Faqirian – Ludewala	D/C	88	2 x 250	2026-27
16	Mastung	Mastung – Sibbi	D/C	147	3 x 160	2026-27
17	Jamrud	Jamrud – Peshawar	D/C	45	2 x 250	2026-27
18	Punjab University	In/Out of Bund Road – New Kot Lakhpat D/C at Punjab University	2 x D/C	1	3 x 250	2026-27
19	Gujranwala-II	Gujranwala-II – Nokhar	D/C	80	2 x 250	2026-27
20	Sialkot New	Sialkot New – Sialkot (Sahuwala)	D/C	12	3 x 250	2026-27
		Sialkot New – Gujranwala-II	D/C	36		
21	Nagshah	In/Out of 220 kV Multan – M. Garh New S/C at Nagshah	D/C	5	3 x 250	2026-27
		In/Out of 220 kV Multan – M. Garh-II at S/C Nagshah	D/C	5		
22	Zero Point	In/Out of 220 kV I.S.P.R – Mansehra S/C at Zero Point	D/C	22.5	2 x 250	2026-27
		In/Out of 220 kV Islamabad University – Rawat S/C at Zero Point	D/C	4		

Table 8-6: Transmission Lines for System Reinforcement

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1		In/Out of one circuit of the proposed Islamabad West -Ghazi Brotha D/C T/L at Faisalabad West	500	D/C	270	2026-27
2	Reinforcement of Sahiwal Area	Sahiwal – Sahiwal PP	500	S/C	11.6	2026-27
		2x500 kV line bays				
3	Second Source of Supply to 500 kV Sheikh Muhammadi	OHL line from Peshawar to In/Out point of Nowshera using the same right of way	500	D/C	29	2026-27
		500 kV line bay at Sheikh Muhammadi				
		Nowshera - Ghazi Brotha (By-passing of 500 kV Tarbela – Ghazi Brotha – Chakwal S/C from Ghazi Brotha)	500	D/C	52	
4	Second Source of Supply to Jaranwala Road	In/Out of Trimmu RLNG - FBD West S/C at Sammundri Road	220	D/C	35	May-2024
		Sammundri Road to Jaranwala Road (Including 2 km U/G cable)		D/C	23	2026-27
5		Faisalabad West – Lalian New	220	D/C	56	October-2024
6		Reconductoring of Tarbela – Burhan D/C on twin bundled Rail conductor	220	D/C	35	2025-26
7		Reconductoring of Bund Road – Kot Lakhpat D/C T/L (Partially on U/G cable)	220	D/C	17	2026-27
8	Second Source of Supply to Hala Road	In/Out of Jamshoro – T.M. Khan S/C at Hala Road	220	D/C	21	2026-27
		In/Out of Jamshoro – T.M. Khan S/C at Hala Road Part-II on Composite Tower			3	
9	Interlinking of Dharki, Rahim Yar Khan, Bahawalpur and Chishtian Grid Stations	Dharki – Rahim Yar Khan	220	D/C	105	2026-27
		Rahim Yar Khan – Bahawalpur		D/C	150	
		In/Out of Chishtian – Vehari S/C at Lal Sohanra		D/C	80	
10		Reconductoring of Burhan – ISPR D/C on twin bundled Rail conductor	220	D/C	27.5	2026-2027

Table 8-7: Extension/Augmentation of 500/220 kV and 220/132 kV Transformers

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
1	Nokhar	Extension of 4th Transformer	500/220	1 x 600	November-2024
2	Lahore (Sheikhupura)	Replacement of 1x450 MVA Transformer with1x600 MVA	500/220	1 x 600	2026-27
3	Faisalabad West	Extension of 3rd Transformer	500/220	1 x 750	
4	Multan	Replacement of old 1x450 MVA Transformer with new one	500/220	1 x 450	
5	Dadu	Extension of 3rd Transformer	500/220	1 x 450	
6	Lahore North	Extension of 4th Transformer	500/220	1 x 750	
7	Sheikh Muhammadi (Peshawar)	Extension of 4th Transformer	500/220	1 x 450	2028-29
8	Khuzdar	Extension of 3rd Transformer	220/132	1 x 160	May-2024
9	Rohri	Extension of 3rd Transformer	220/132	1 x 250	May-2024
10	Bahawalpur	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1 x 250	June-2024
11	Quetta Industrial	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1 x 250	June-2024
12	Sibbi	Extension of 3rd Transformer	220/132	1 x 160	
13	Loralai	Extension of 3rd Transformer	220/132	1 x 250	
14	Wapda Town	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	June-2024
15	Sheikhupura	Augmentation of 4x160 MVA Transformers with 4x250 MVA	220/132	4 x 250	
16	Ludewala	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1 x 250	
17	New Kot Lakhpat	Extension of 4th Transformer	220/132	1 x 250	June-2024
18	T.M. Khan	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	August-2024
19	Hala Road	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	
20	Jamshoro	Extension of 3rd Transformer	220/132	1 x 160	
21	Guddu	Extension of 2nd Transformer	220/132	1 x 160	

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
22	Nokhar	Augmentation of 3x160 MVA Transformers with 3x250 MVA	220/132	3 x 250	November-2024
23	Islamabad University	Extension of 3rd Transformer	220/132	1 x 250	December-2024
24	Yousafwala	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1 x 250	December-2024
25	Guddu	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2026-27
26	R.Y. Khan	Extension of 3rd Transformer	220/132	1 x 250	2026-27
27	Allai Khwar	Extension of 3rd Transformer	220/132	1 x 160	2026-27
28	Yousafwala	Augmentation of 3x160 MVA Transformers with 3x250 MVA	220/132	3 x 250	2026-27
29	Guddu	Extension of 3rd Transformer	220/132	1 x 250	2027-28

Table 8-8: Projects for Voltage Control and Reliability Improvement

Sr. No.	Name of Project	Project Description	Expected Completion Date
1	246 MVAR SVS at 132 kV Quetta Industrial	96 MVAR Switched Shunt ±150 MVAR STATCOM	2026-27
2	196 MVAR SVS at 132 kV Khuzdar	96 MVAR Switched Shunt ±100 MVAR STATCOM	2026-27
3	Reactive Power Compensation at 220 kV and 132 kV Grid Stations	96 MVAR Switched Shunt each at 132 kV Ravi, Ghazi Road, Wapda Town, Punjab University, Lahore North, Lalian New, Nishatabad, Nokhar, KAPCO, Piranghaib, Bahawalpur, Sahuwala, Jaranwala Road, Yousafwala, Vehari, Mastung and 220 kV Kala Shah Kaku	2026-27
4	Mitigation of high fault level at 132 kV Burhan	16 Ohm inter bus Current Limiting Reactor (CLR) between 132 kV bus bars of Burhan 220/132 kV Grid station	2026-27

Table 8-9: Newly Proposed Power Dispersal & Import/Export projects

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Basha HPP	Basha HPP – Dasu HPP with 111 MVAR Line Reactors at both ends	765	D/C	75	2027-28
		Mansehra – Lahore North with 222 MVAR Line Reactors at both ends	765	D/C	350	2028-29
		In/Out of one circuit of Basha HPP – Dasu HPP D/C at Mansehra with 222 MVAR Line Reactors at Basha and Mansehra ends	765	D/C	157	
		Basha HPP – Suki Kinari HPP with 111MVAR Line Reactors at Basha HPP end	500	D/C	190	2027-28
		50% Series Compensation of D/C T/Line from Basha HPP to Suki Kinari HPP	500	D/C		
		Basha HPP – Maira Switching Station with 111MVAR Line Reactors at both ends	500	D/C	350	2028-29
		50% Series Compensation of D/C T/Line from Basha HPP to Maira Switching Station	500	D/C		
		In/Out of one circuit of the proposed Maira – Karot HPP D/C T/L at Lahore North with 111MVAR Line Reactors at Maira, Karot and Lahore North ends	500	D/C	240	
2	Balakot HPP	In/Out of Maira – Suki Kinari HPP S/C at Balakot HPP	500	D/C	2	2027-28
3	C-5 NPP	In/Out of Ludewala – Nowshera S/C at C-5 NPP with 111MVAR Line Reactors at C-5 NPP end	500	D/C	19.25	2029-30
		C-5 NPP – Ludewala with 111MVAR Line Reactors at both ends		S/C	150	
4	Line Reactors	Basha HPP – Maira Switching Station	500			2028-29

Table 8-10: Newly Proposed 765, 500 & 220 kV Grid Stations and Associated Transmission Lines

Sr. No.	Name of Project	Transmission Line Description	Circuit Config.	Length of Each Circuit (km)	Transformer Capacity (MVA)	Expected Completion Date
765 kV						
1	Upgradation of Lahore North from 500 kV to 765 kV (Part of scope of work of Basha HPP)				3x1200	2028-29
500 kV						
1	Upgradation of Okara from 220 kV to 500 kV	In/Out of one circuit of Yousafwala – Sahiwal CFPP D/C at Okara	D/C	15	2x750	2027-28
		Okara – Lahore South CS	D/C	70		
2	Upgradation of Ludewala from 220 kV to 500 kV	In/Out of proposed Nowshera – Ghazi Brotha S/C at Ludewala with 111MVAR Line Reactors at Nowshera, Ludewala and Ghazi Brotha ends	D/C	325	2x750	2027-28
		Ludewala – Faisalabad West with 111 MVAR Line Reactors at Ludewala end	D/C	100		
3	Upgradation of Gujrat from 220 kV to 500 kV	In/Out of Maira – Lahore North S/C at Gujrat	D/C	52.5	2x750	2029-30
4	Lahore East	In/Out of Lahore South CS – Lahore North D/C at Lahore East	2 x D/C	60	2x750	2032-33
220 kV						
1	DHA Prism	In/Out of Ghazi Road – Lahore South S/C at DHA Prism	D/C	1	2x250	2027-28
2	Burewala	Burewala – Vehari	D/C	30	2x250	2027-28
		Burewala – Arifwala	D/C	40		
3	Lodhran	In/Out of M. Garh – Bahawalpur D/C at Lodhran	2 x D/C	20.5	3 x 250	2032-33
4	Lahore East	In/Out of Ghazi Road – Shalimar S/C at Lahore East	D/C	22.7	3 x 250	2032-33

Table 8-11: Newly Proposed Transmission Lines for System Reinforcement

Sr. No.	Name of Project	Transmission Line Description	Voltage (kV)	Circuit Config.	Length of Each Circuit (km)	Expected Completion Date
1	Reinforcement of South to North transmission interface	Matiari – Moro with 111MVAR Line Reactors at Moro end	500	D/C	155	2026-27
		Moro – R.Y. Khan with 111MVAR Line Reactors at both ends	500	D/C	335	
2		In/Out of one circuit of the proposed Sialkot New – Lahore North D/C T/L at Maira	500	D/C	235	2027-28
3		Reconductoring of 220 kV D/C T/Line from KSK to Bund Road Grid Station	220	D/C	27	2028-29
4		Nishatabad – Gatti 3rd circuit (cable)	220	S/C	2.2	2032-33

Table 8-12: Newly Proposed Extension/Augmentation of 500/220 kV and 220/132 kV Transformers

Sr. No.	Name of Grid Station	Transformer Description	Voltage Ratio (kV)	Transformer Capacity (MVA)	Expected Completion Date
1	Muzaffargarh	Extension of 3rd Transformer	500/220	1 x 600	2025-26
3	R. Y. Khan	Extension of 3rd Transformer	500/220	1 x 600	2032-33
4	Sialkot New	Extension of 3rd Transformer	500/220	1 x 750	2032-33
4	Sarfraz Nagar	Augmentation of 1x160 MVA Transformers with 1x250 MVA	220/132	1x250	June-2024
5	D. I. Khan	Extension of 3rd Transformer	220/132	1 x 250	2027-28
6	Faisalabad West	Extension of 4th Transformer	220/132	1 x 250	2032-33
7	Zhob	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2032-33
8	Dadu	Augmentation of 2x160 MVA Transformers with 2x250 MVA	220/132	2 x 250	2032-33

Table 8-13: Newly Proposed Projects for Voltage Control and Reliability Improvement

Sr. No.	Name of Project	Project Description	Expected Completion Date
1	Reactive Power Compensation at 220 & 132 kV Grid Stations	96 MVAR Switched Shunt each at 220 kV Lahore South and 132 kV Sarfraz Nagar	2025-26
2	Bus Reactors at 500 & 220 kV Grid Stations	• 2x111 MVAR at 500 kV Shikarpur • 111 MVAR each at 500 kV Sheikh Muhammadi, Rewat, Faisalabad West and D.G. Khan • 60 MVAR each at 220 kV Zhob, D.M. Jamali and Loralai	2026-27
3	STATCOM at 500 kV Grid Stations	±400 MVAR each at 500 kV Dadu, Guddu, M. Garh, R.Y. Khan and Sheikhupura	2027-28
4	Reactive Power Compensation	96 MVAR Switched Shunt at 132 kV switchyard of proposed 220/132 kV Burewala	2027-28
5	STATCOM at 500 & 220 kV Grid Stations	±400 MVAR each at 500 kV Faisalabad West and 220 kV Chishtian	2032-33
6	Reactive Power Compensation at 132 kV Grid Stations	96 MVAR Switched Shunt each at 132 Sialkot New, Lodhran and Islamabad University	2032-33
7	Bus Reactor	60 MVAR Bus at 220 kV Mirpur Khas	2032-33
8	Switchgear replacement	Replacement of switchgear equipment at 500 kV Gatti	2032-33
9	Switchgear replacement	Replacement of switchgear equipment at 500 kV Lahore	2032-33

9. COST ESTIMATES OF THE TRANSMISSION PLAN

The transmission planning process focuses on identifying transmission projects that could connect generation sources to load centers to meet future load demand with adequate reliability and at the lowest total electricity cost. For quantifying transmission investment requirements, high-level unit cost estimates have been developed for the bulk transmission facilities at the 765 kV, 500 kV and 220 kV level, including 132 kV part of 220/132 kV substations. These unit cost estimates have been used to estimate cost of each identified project in the plan.

While preparing the unit cost estimates, due care is given to professional judgment to achieve the intended level of accuracy. Following methodology is adopted for cost calculations of transmission lines and substations.

9.1 AC TRANSMISSION LINE

Historically, cost estimates for transmission facilities have been developed taking references of similar projects costs in the recent past and adjusting the costs according to the new scopes of work and considering inflation and other related factors. Also, the quantity of transmission structures per km of a transmission line is considered to determine total cost estimate for a potential transmission line project.

New right of way requirement is considered for new transmission projects and the existing right-of-way is assumed adequate for the reconductoring projects. The cost estimating team utilizes Google Earth to assess route length, land types, and terrain types for constructing new EHV transmission lines, which are assumed to be built on steel structures.

In summary, cost estimate of a transmission line is sub-divided into four categories: land and right-of-way; structures and foundations; conductor, OPGW and shield wire; professional services and overhead. The per km cost of 765 kV, 500 kV and 220 kV transmission lines, considering three (3) different terrain types, are calculated and are used in the cost estimates.

9.2 SUBSTATIONS

Substation cost estimates are sub-divided into four categories: land and site work; equipment and foundations; protection and control; professional services and overhead. The planning stage cost estimate assumes land size requirements and equipment quantities based on the prevailing practices and assumptions for the project area. The size of a substation and equipment quantities depend upon the voltage class of the proposed facility owing to clearance requirements and the quantities of new transmission line interconnections and transformers. The cost of the 765 kV, 500kV, 220kV and 132kV switchyards are calculated and used in the cost estimates.

Costs used for other network equipment are shown in Table 9-1.

Table 9-1: Cost of other network equipment

Item	Unit	Cost
		USD
Auxiliary Supply System	Lot	357,367
Shunt Reactor	per MVAr	30,000
STATCOM	per MVAr	100,000
Switched Capacitor Banks	per MVAr	15,000

The transmission planning studies have identified the need for transmission connection, reinforcement, and expansion facilities corresponding to the 10-year generation expansion plan (Indicative Generation Capacity Expansion Plan 2024-2034) and spatial demand forecast. The identified transmission projects include connection facilities for the proposed generation plants that connect to the existing transmission network, the associated transmission reinforcement infrastructure that facilitate power transfer to different load centers, upgraded and expanded transformation capacities at numerous substations to meet the forecasted demand with adequate reliability and least cost investment. This constitutes a 10-year Transmission System Expansion Plan (TSEP 2024-2034). The estimated costs for the proposed transmission facilities are given in US Dollars and are inclusive of all applicable taxes, security, health, and safety fees.

The spot year-wise cost estimates for the ongoing transmission line and substation facilities, which had already been identified in the previous system studies, as well as the cost estimates for the newly proposed transmission facilities identified through extensive system studies for the TSEP 2024-2034 are given in the tables below:

Table 9-2: Cost Estimates for Spot Year 2026-27

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	698.54
2	765 kV Grid Stations/Switching Stations and Associated Transmission Lines	185.1
3	500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines	312.32
4	220/132 kV Grid Stations and Associated Transmission Lines	780.93
5	Transmission Lines for System Reinforcement	654.24
6	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	56.24
7	Projects for Voltage Control and Reliability Improvement	390.01
8	Newly Proposed 765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	132.35
9	Newly Proposed Transmission Lines for System Reinforcement	633
10	Newly Proposed Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	12.07
11	Newly Proposed Projects for Voltage Control and Reliability Improvement	67.91
12	Newly Proposed Line Reactors	23.0
Total		**3,945.71**

Note: *The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

Table 9-3: Cost Estimates for Spot Year 2028-29

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	42.92
2	500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines	85.51
3	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	6.25
4	Newly Proposed Power Dispersal & Import/Export projects	2,376.13
5	Newly Proposed 765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	598.68
6	Newly Proposed Transmission Lines for System Reinforcement	542.5
7	Newly Proposed Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	4.3
8	Newly Proposed Projects for Voltage Control and Reliability Improvement	403.84
9	Newly Proposed Line Reactors	103.0
Total		**4,163.13**

Note: *The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

Table 9-4: Cost Estimates for Spot Year 2033-34

Sr. No.	Projects	Estimated Cost (MUSD)
1	Newly Proposed Power Dispersal & Import/Export projects	94
2	Newly proposed 765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	343.65
3	Newly Proposed Transmission Lines for System Reinforcement	0.4
4	Newly Proposed Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	38.57
5	Newly Proposed Projects for Voltage Control and Reliability Improvement	193.7
6	Newly Proposed Line Reactors	9.0
Total		**679.32**

Note: *The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

It shall be noted that the cost of equipment and civil works heavily depends on the market dynamics, international supply/demand trends, dollar price, etc. Therefore, the estimated costs are likely to vary and expecting a variation of ±25% to ±40% is a normal utility practice.

10. CONCLUSIONS & RECOMMENDATIONS

Transmission System Expansion Plan (TSEP) for the bulk transmission network (765 kV, 500 kV and 220 kV voltage levels) has been developed based on the Indicative Generation Capacity Expansion Plan 2024 (IGCEP 2024) and substation-wise demand forecasts at the system and each DISCO level. The following three spot years have been selected to develop load flow base cases considering different operating conditions (high hydro, low hydro, high solar PV, summer, winter, peak, off-peak, etc.).

- Year 2026-27
- Year 2028-29
- Year 2033-34

Extensive power flow, short-circuit and stability analyses have been performed to identify the transmission development/expansion and investment requirements in the next 10 years.

Many new projects for network expansion and reinforcement have been identified based on a detailed analysis of all the above-mentioned system operating conditions. A summary of category wise aggregated scope of work of the new transmission expansion and reinforcement projects, identified in addition to the already planned/ongoing projects, and the corresponding cost estimates are presented in Table 10-1 and Table 10-2.

Table 10-1: Ongoing/Already Planned Transmission Facilities

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	741.46
2	765 kV Grid Stations/Switching Stations and Associated Transmission Lines	185.10
3	500/220 kV Grid Stations/Switching Stations and Associated Transmission Lines	397.83
4	220/132 kV Grid Stations and Associated Transmission Lines	780.93
5	Transmission Lines for System Reinforcement	654.24
6	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	62.49
7	Projects for Voltage Control and Reliability Improvement	390.01
Total		**3,212.06**

Note: *For ongoing projects, Cost to be incurred in future is used in the above table. The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

Table 10-2: Newly Proposed Transmission Facilities

Sr. No.	Projects	Estimated Cost (MUSD)
1	Power Dispersal & Import/Export projects	2,551.13
2	765 kV, 500 kV and 220 kV Grid Stations and Associated Transmission Lines	1,086.68
3	Transmission Lines for System Reinforcement	1,217.90
4	Extension/Augmentation of 500/220 kV and 220/132 kV Transformers	54.94
5	Projects for Voltage Control and Reliability Improvement	665.45
Total		**5,441.1**

Note: *The prevalent exchange rate of 1US$ = 278.70 PKR has been assumed for cost calculations.*

The general conclusions and recommendations from the system studies performed are given as follows:

1. Installation of 2x48 MVAR switched shunt capacitors at132 kV bus bars of 220/132 kV substations where needed. The proposed solution will not only improve the voltage profile and reduce loading on transformers but also help in minimizing the use of expensive/out of merit generation. A list of substations that urgently need steady state reactive support is provided in this report, which may be considered as a pilot project. NTDC shall expedite this project on urgent basis for economical and secure operation of the system.

   In addition, timely completion of Vehari 500 kV and Nagshah 220/132 kV grid stations is instrumental in eradicating dependance of secure system operation on KAPCO or other generation in the vicinity. Therefore, these projects should be expedited on a priority basis.

2. To improve the system performance and to eradicate dependance of north to south interface power transfer limit on the intermediate generating stations (Guddu, Muzaffargarh, KAPCO, etc.), installation of dynamic reactive support has been studied in parallel with an international consultant CESI under the project titled "System Studies for Review of Grid System Performance" and some potential sites for installation of ±400 MVAR STATCOM each, have been initially identified and included in the TSEP.

3. Expedite implementation of 500/132 kV Chakwal and 765/500/220/132 kV Islamabad West substations and reinforce supply network to Faisalabad West substation by connecting it to Ghazi Brotha/Islamabad West through new 2x500 kV circuits in line with upcoming generation in the north. These developments are very crucial and any delay in these projects would stress the system making it vulnerable to voltage instability and causing severe overloading on multiple circuits/transformers. Therefore, it is strongly recommended that these projects should be completed on a fast-track basis.

4. The existing south to north power transfer interface is not capable of transmitting full generation available in the south, including the 1845 MW wind generation. Reinforcement of south to north transmission interface is inevitable to avoid any curtailment of power in the south. Accordingly, 500 kV D/C Matiari-Moro-R. Y. Khan OHL is included in the plan and shall be built on priority basis.

5. Although, a comprehensive interconnection scheme for Diamer Basha HPP has been proposed, however, there might be slight changes in this scheme since another consultancy project is being initiated to review and finalize the power evacuation plan for Basha HPP based on detail routes survey, soil investigation, high altitude, engineering considerations, tower spotting, etc.

6. The following switchgear ratings have been proposed for the existing (as per requirements) and future substations after carrying out extensive short circuit analysis and by suggesting operational measures/network re-configuration:

   - 40 kA short circuit ratings for 132 kV voltage level.
   - 50 kA short circuit rating for 220 kV and 500 kV voltage levels.
   - 50-63 kA short circuit rating for 765 kV voltage level.
   - 63 kA short circuit rating shall be used for grid stations or power plants connected at 220 kV or 500 kV level where the use of 63 kA rating is unavoidable due to network requirements.

7. The results of transient stability studies reveal that the system is transiently stable for all the credible contingencies analyzed, however, a few contingencies, under certain operating conditions, cause post-disturbance oscillations on the system, which need to be further investigated. The under-execution study project "System Studies for the Grid System Performance and Proposals for System Stability Improvement" has also made some recommendations in this regard. In addition, the following remedial measures are recommended:

   - Validation of dynamic models and control parameters of generators, exciters, governors, and Power System Stabilizers through measurements and where possible, check response of these validated models against actual events. Also, develop appropriate dynamic load models since contribution of the air-conditioning load on the system has increased significantly and voltage recovery has become challenging under certain contingencies.
   - Installation/commissioning of Power System Stabilizers (PSS) at some of the existing power plants and all new power plants. System Operator should carry out the required system studies to identify appropriate locations for PSS installations and supervise tuning of these PSSs to avoid any inter-area or local area oscillations on the integrated power system.
   - Installation of Dynamic System Monitors (DSM) at all 500/220 kV substations for real time recording. Also, install PMUs at key substations to improve observability of the system for better control. Installation of these devices would help in performing diagnostic/post-mortem analysis and for improving the dynamic system model.

8. Installation of dynamic reactive power compensation devices, such as STATCOM, in the QESCO area to address its voltage stability issues. Phase-wise additions are recommended and to start with, it is proposed to install 150 MVAR STATCOM and 96 MVAR Switched Shunt at Quetta and 100 MVAR STATCOM and 96 MVAR Switched Shunt at Khuzdar by 2026-27.

9. Evaluate and initiate a process of converting the old power plants, which are close to the load centers, into synchronous condenser instead of decommissioning them. In this regard, the key stakeholders including CCPA, IPPs and GENCOs shall be consulted to

come up with a way forward enabling NTDC to use this potential of ancillary service with possible amendments in the tariff structure and contracts.

10. Adopt higher equipment ratings and standardize development plans, as recommended below.

    - 500/220 kV transformers shall be 750 MVA and 220/132 kV transformers shall be 250 MVA.
    - The 500/220 kV, 500/132 kV and 220/132 kV substations should be standardized to have three transformers each feeding main load centers. In remote areas where load demand is relatively low, a two-transformers configuration can be used initially but the layout of the substations should have provision to install up to 4th transformer in the future, as and when required.
    - Reconductoring or replacement of existing 220 kV lines of single conductor to twin-bundled conductors or HTLS in order to increase the line capacity. This shall be decided on case-to-case basis. Quad bundled 220 kV lines for specific use may also be considered.
    - 220/132 kV grid stations in thickly populated areas can be of GIS type connected with the main grid through XLPE cables of standard sizes.

11. The connection of line reactors shall be standardized with provision to use the line reactors as bus reactors when the respective line is switched-off.

12. Enhancement in knowledge base of planning and operation teams through structured capacity building training programs. These teams need to prepare themselves to meet challenges related to excessive penetration of VRE resources, appropriate application of FACTS devices, use of new software tools, such as PSCAD for transient studies, etc.

11. WAY FORWARD

Transmission expansion requirements have been conceived which are thoroughly studied to develop an optimal transmission system expansion plan TSEP24 for the next ten years (2023-34). The main challenges are the interconnections of hydro projects as identified in the IGCEP 24. Existing technologies are considered in developing the plan. The TSEP24, after completing the due internal approval process, may be submitted to the Regulator to fulfill NTDC/SO obligation.

Power System Planning Department
NTDC