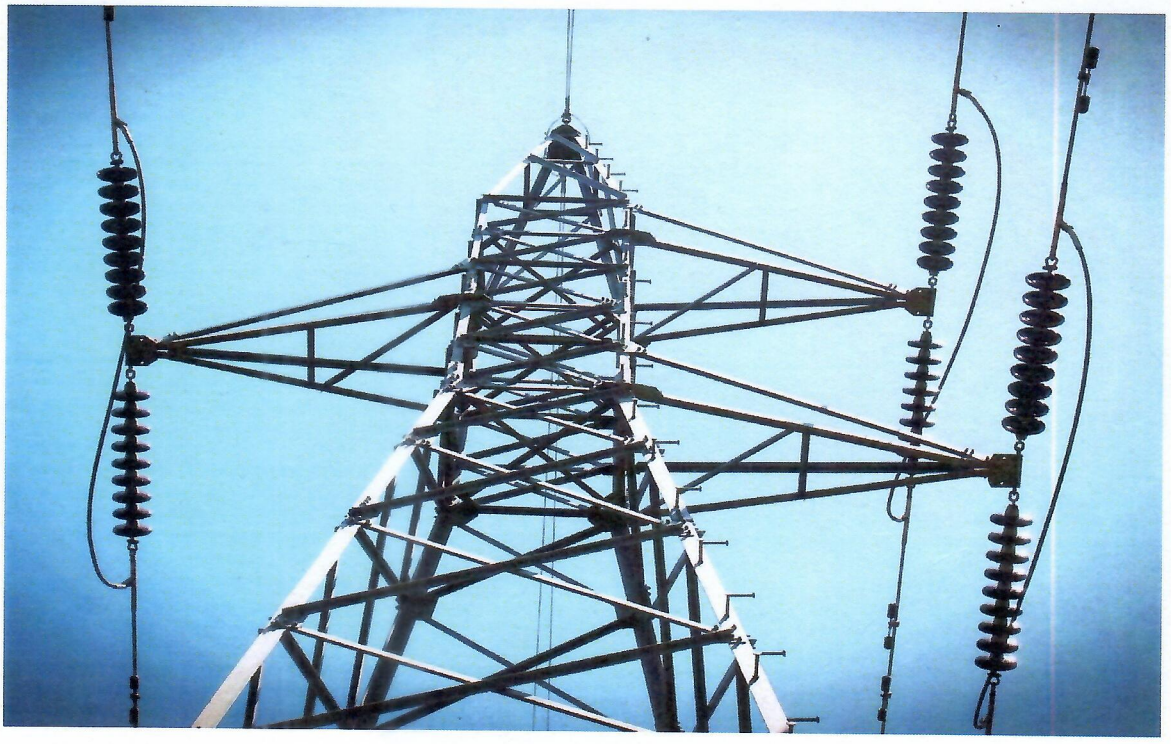
NATIONAL ELECTRIC POWER REGULATORY AUTHORITY (NEPRA)

INQUIRY REPORT

TOTAL POWER BLACKOUT IN THE COUNTRY ON

January 23, 2023



INQUIRY INTO THE MATTER OF TOTAL POWER BLACKOUT IN THE COUNTRY OCCURRED ON JANUARY 23, 2023 DUE TO SYSTEM DISTURBANCE IN NTDC & K-ELECTRIC TRANSMISSION NETWORK

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Part 1

Background

1. BACKGROUND:

Total power collapse/blackout in the country occurred on 23rd January 2023 at 07:34:43:800 Hrs. National Electric Power Regulatory Authority (NEPRA), being an exclusive Regulator of electric power sector in Pakistan, took serious notice of the referred blackout and decided to probe into the matter through an Inquiry Committee (IC) comprising the NEPRA as well as the market experts.

1.1 Constitution of Committee:

NEPRA vide office Orders No. MON-1/2023/110 dated 10th February 2023 and No. MON-01/202/153 dated 23rd February 2023 constituted an Inquiry Committee (IC) to probe in the matter of total power collapse/blackout in the country on 23rd January 2023. **Annex. 1 & 2**

1.	Mr. Imran Kazi	Senior Advisor, M&E, NEPRA	Convener
2.	Mr. Nadir Ali Khoso	Market Expert	Member
3.	Mr. Ghulam Abbas Memon	Market Expert	Member
4.	Syed Safeer Hussain	Market Expert	Member
5.	Mr. Manu Ram	Market Expert	Co-Opt Member
6.	Syed Aqib Ali Shah	Dy. Director, M&E, NEPRA	Secretary

1.2 Terms of Reference (TORs)

i) To determine, the causes and the faults which resulted in the cascade trippings and system collapse;
ii) To fix the responsibility for the country wide blackout occurred on 23.01.2023;
iii) To review, whether the restoration efforts were adequate and the power supply was restored within the reasonable time;
iv) To check/update the implementation status of the findings/recommendations of inquiry reports furnished thereof for such break downs in the past;
v) To recommend, the remedial measures to be taken in order to avoid recurrence of such events in future;

2. BRIEF INTRODUCTION OF THE POWER SYSTEM OF PAKISTAN:

2.1 The main segments of electric power sector are Generation, Transmission and Distribution. In Karachi and its suburb the Generation, Transmission and Distribution of electric power are being maintained and operated by a privatized vertically integrated utility namely the K-Electric (KE). KE, besides having its own power generation plants, is importing power from NTDC through Central Power Purchasing Agency Guarantee Limited (CPPAG) and other private power generation companies.

2.2 The details of KE's generation plants and transmission network along with other power plants supplying electric power to KE is attached as **Annex. 3 & Annex. 4**. The distribution and supply of electric power in its area is being done by KE itself.

2.3 In the larger area of the country, the generation, transmission, distribution and supply of the electric power is being done by different companies. The electric power generation, is being done through different private (Independent Power Producers-IPPs) as well as public sector entities like WAPDA, PEDO, GENCOs etc. Transmission of electric power is being done by National Transmission and Despatch Company (NTDC), a company wholly owned by the Government of Pakistan. The recently developed, ± 660kV High Voltage Direct Current (HVDC) transmission

system is operated by Pak Matiari Lahore Transmission Company (PMLTC). The Central Power Purchasing Agency (CPPA-G) works as power agency on behalf of Ex-WAPDA DISCOs.

2.4 Generally, the high voltage transmission system to transfer bulk electric power generation consists of two regions i.e. North and South; At 500 KV voltage level these two regions are connected through five HVAC circuits while a ± 660kV HVDC transmission system is also transmitting electric power from Matiari in South to Lahore in North. A map showing the NTDC network is attached as **Annex 5**. The Distribution and Supply of electric power in this area is being done through ten (10) Ex-WAPDA distribution companies (XWDISCOs), wholly owned by the Government of Pakistan. A map showing the territories of the distribution companies is attached as **Annex 6**.

3. NATIONAL POWER CONTROL CENTRE (NPCC) – SYSTEM OPERATOR (SO):

NPCC/NTDC is discharging the duties under the Grid Code approved by the NEPRA. The NPCC/System Operator (SO) is responsible to operate the system in an economic manner without compromising the system stability, reliability and safety.

4. GENERATION:

The brief regarding electric power generation capacity (dependable) as on 30.06.2022 and generation there from during fiscal year 2021-22 as provided in NEPRA's State of Industry Report 2022 is reproduce here below:

		Dependable Capacity (MW)
1	WAPDA Hydel	9443
2	IPPs Hydel	1009
3	Total Hydel	10452
4	GENCOs	3900
5	IPPs	17258
6	SPPs/CPPS	257
7	Nuclear	3345
8	Total Thermal	24760
9	Wind	1838
10	Solar	530
11	Bagasse/Biomass	278
	Total CPPA G System	37858
12	KW Own	2135
13	IPPs	354
14	SPPs/CPPs	106
15	KANUPP	0
16	Solar	79
17	Total KE System	2674
18	**Grand Total**	**40532**

4.1 The share of public sector power plants in power sector of Pakistan is around 21521 MW; out of which 11893 MW from thermal, 9524 MW from Hydel and 104 MW is procured from Iran. A list of power plants in NTDC as well as in KE system is attached as **Annex – 7** and **Annex-8**.

5. TRANSMISSION SYSTEM:

5.1 NTDC is the only National Grid Company (NGC) in Pakistan and its transmission network is spread all over the country except the area served by K-Electric. NTDC is responsible to maintain and operate long transmission network of 500KV and 220KV; details of NTDC system is given here below:

- 17 x Grid Station of 500 kV with capacity of 32700 MVA;
- 67 circuits of 500 kV lines with total length of 8388 km;
- 50 x Grid stations of 220 kV with capacity of 28160 MVA;
- 163 circuits of 220 kV lines with total length of 11611 km.

5.2 Diagram of NTDC system is attached as **Annex-9**. ± 660kV HVDC Transmission Line (T/Line) is maintained by NTDC, while ± 660 kV Converter Stations at Matiari and Lahore are maintained by Pak Matiari Lahore Transmission Company (PMLTC). HVDC T/Line is capable to carry 4000 MW. Due to non-availability of the adequate AC network at Lahore side, the HVDC system is underutilized.

5.3 Detail of South and North regions of NTDC is as under:

Northern Region:

Region	500kV Grid Stations		220kV Grid Stations	
		No.		No.
Islamabad	Rawat, Sheikh Munda	02	Sangjani, University, Shahi Bagh, Mardan, Daud Khail, Burhan, Mansehara, Bannu, Chakdara, Nowshera and D I Khan	11
Lahore	Gatti, Sheikhupura, New Lahore, Nokhar, Yousufwala and Faisalabad West	06	NKLP Lahore, Ravi Lahore, Kala Shah Kaku, Sarfaraz Nagar, Bund Road, Ghakkar, Gujjrat, Sialkot, Wapda Town, Nishatabad, Sammandri Road, Ludewala, Jaranwala, Shalamar, Ghazi road, Bandala, Toba Tek Singh, Okara, Kasowal and Lalian	20
Multan	Multan, Muzaffar garh, DG Khan and Rahim Yar Khan	04	Lal Sohanra, Bahawalpur, Vehari, Muzaffargarh, Chishtian, NGPS Piran Ghaib and TPS Muzaffargarh	07

Southern Region:

Region	500kV Grid Stations	No.	220kV Grid Stations	No.
Hyderabad	NKI, Jamshoro, Shikarpur, Dadu, Guddu, Guddu 747	06	Hala Road Hyderabad, TM Khan, Jhimpir-I, Jhimpir-II, Daharki, Rohri, 220/132 kV switchyard Guddu	07
Quetta	-	00	Quetta, Loralai, Sibbi, Khuzdar, DM Jamali	05

5.4 Transmission System of K-Electric:

KE is operating and maintaining transmission network of 220kV and 132kV; brief regarding KE transmission system is given here below:

- 11 x Grid Station of 220 kV with capacity of 4580 MVA;
- Total length of 220 kV transmission line is 364 km;
- 69 x Grid stations of 132 kV with capacity of 7465 MVA;
- Total length of 132 kV transmission line is 838 km;

Besides its own transmission system, KE has following four interconnections with the NTDC's 220 kV grid system:

i. 220 KV NKI-KDA;
ii. 220 KV NKI-Baldia;
iii. 220 KV Jhimpir II – KDA 1;
iv. 220 KV Jhimpir II – KDA 2.

Diagram of KE Transmission System is attached as **Annex- 10**.

6. Distribution of Electricity:

Following companies, under the licenses granted by NEPRA, are engaged in distributing and supplying of electric power in their designated areas:

i. Peshawar Electric Supply Company Limited (PESCO)
ii. Tribal Area Electricity Supply Company (TESCO)
iii. Islamabad Electric Supply Company Limited (IESCO)
iv. Lahore Electric Supply Company Limited (LESCO)
v. Faisalabad Electric Supply Company Limited (FESCO)
vi. Gujranwala Electric Power Company Limited (GEPCO)
vii. Multan Electric Power Company Limited (MEPCO)
viii. Sukkur Electric Power Company Limited (SEPCO)
ix. Hyderabad Electric Supply Company Limited (HESCO)
x. Quetta Electric Supply Company Limited (QESCO)

Maps showing the territories of above distribution and supply companies are at **Annex - 11**.

Part 2

Proceedings

7. PROCEEDINGS:

7.1 To probe in the matter it was decided to approach the relevant entities through field visits and/or by requiring relevant information and documents. IC visited the following entities to discuss the issues and obtained the information/ documents and briefs relating to total power blackout in the country on 23rd January 2023 and restoration of the system thereafter:

- National Power Control Centre (NPCC), Islamabad;
- K-Electric, Karachi;
- NTDC 500 / 220 kV NKI grid station;
- Port Qasim Power Plant, Karachi;
- Lucky Power Plant, Karachi;
- K-2 & K-3 Nuclear power plants, Karachi;
- ± 660kV HVDC Converter Station, Matiari;
- 220/132 kV Jhimpir-I and Jhimpir-II Grid Stations;
- Tarbela Power Station;
- NTDC Head Office, Lahore;
- ± 660kV HVDC Converter Station, Lahore;

7.2 The summary of those presentations/briefings is given below;

7.3 National Power Control Centre (NPCC), Islamabad (Annex-12)

- System was operating normally and within permissible limits, no intimation was given by any entity i.e. NTDC Grid Stations, K-Electric, Power Plants and DISCOs. At 07:34 Hrs., the system collapsed with following sequence of events;

  - 07:33:36 Oscillations noticed
  - 07:34:02 to 07:34:14 Frequency hunting
  - 07:34:14 System collapsed
  - 500kV Guddu 747-RY Khan circuit tripped on Power Swing and 500kV supply failed
  - 07:34:14:895 Commutation Failure occurred at HVDC
  - 07:34:14:908 Sudden power loss (2306 MW to 2154 MW)
  - 07:34:14:908 following 500kV Cct. tripped;

Time	Names of 500kV Cct.	Indication
07:34:14:908	Guddu-DG Khan Cct tripped from both ends	DG Khan End: Power Swing Block Guddu End: Over Voltage
07:34:14:908	Guddu-Muzafargarh Cct tripped from Muzaffargarh end	Muzafargarh End: Power Swing Block
07:34:14:908	Guddu 747-RY Khan Cct tripped from Guddu 747 ends	Guddu 747 End: Power Swing Block

  - 07:34:14:908 System split into Northern & Southern regions
  - 07:34:15:417 following 500kV Cct. tripped;

Time	Names of 500kV Cct.	Indication
07:34:15:417	K2-K3 - NKI Cct. tripped from both ends	K2-K3 End: DTT received from NKI NKI End: Over Voltage (640kV)
07:34:15:417	NKI - Jamshoro Cct tripped from both ends	NKI End: Over Voltage (640kV) Jamshoro End: DTT Received from NKI
07:34:15:417	Guddu 747-RY Khan Cct tripped from Guddu 747 end	Guddu 747 End: Power Swing Block

- 07:34:15:568 Frequency Limit Controller (FLC) at HVDC automatically activated due to difference in frequencies of North and South zones.

- 07:34:29:987 HVDC blocked **Annex-13:**

  - 500kV Guddu – Muzafargarh Cct. was opened at 11:56 Hrs on 18/01/23 due to foggy weather.
  - 500kV Moro – RYK Cct was opened at 23:22 Hrs on 21/01/23 for voltage control

7.3.1 Power Plants Trippings

Time	Names of Power Plant	Indication
07:34:15:900 (K2) 07:34:15:935 (K3)	K2-K3 P/H (900+1040 MW)	Over Speed
07:34:16	Port Qasim P/H (620 MW)	Run-back
07:34:23	Lucky P/H (606 MW)	Under Frequency
07:34:25	Engro Thar (150 MW)	Under Frequency
07:34:25	Thar Energy Ltd (151 MW)	Under Frequency
07:34:25	Shanghai Electric (1230 MW)	Under Frequency

- **Low Frequency Oscillations** are evident from all the power plants which may be attributed to complexities of the power system, weak transmission network, weak damping system and harmonics induced due to inverter based generation.

- **Commutation Failure** resulted in sudden power loss in HVDC link. 350 commutation failure in HVDC have been witnessed. Commutation failure is frequent in winters.

- **The Failure of Over-Frequency Tripping at Port Qasim**: After the splitting event, frequency of southern region went beyond 51.5 Hz. Port Qasim did not trip at it's designed over frequency trip setting i.e. 51.4 Hz [Inst. trip], instead it run backed slowly. This failure of 620 MW tripping of Port Qasim, resulted in sustained over-frequency in south region [max recorded =51.568 Hz], which consequently tripped K-2 and K-3 power plants (1940 MW) [Trip setting=51.5 Hz for 250msec]. Tripping of

1940 MW in southern island, acted as a major disturbance leading to cascaded tripping of other generators in south.

7.3.2 Restoration

Sr. No.	Restoration Attempt	Power House			
		Warsak	Tarbela	Mangla	Uch-I
1	First	0813Hrs-1024Hrs	0810Hrs-0910Hrs	1010Hrs-1140Hrs	1010Hrs-Onwards
2	Second	1035-1252	0916-1024	1210-1245	-
3	Third	1302-1502	1036-1138	1258-1624	-
4	Fourth	1533-Onwards	1148-1234	1629-Onwards	-
5	Fifth	-	1259-2426	-	-
6	Sixth	-	1438-1521	-	-
7	Seventh	-	1522-1845	-	-
8	Eighth	-	1858-Onwards	-	-
9	Ninth	-			

- With the help of Black Start Facility at UCH-1 Power Plant, the power supply of some Grid Stations in SEPCO, QESCO and HESCO was restored including main cities i.e. Sukkur, Jacobabad, Quetta and Khuzdar.

7.4 K-Electric (Annex 14)

7.4.1 Briefing/Presentation of K-Electric is summarized below;

- On January 23, 2023 prior to power breakdown, KE and NTDC networks were running synchronized. KE network was being operated in split mode i.e., major portion of KE network including generation was connected at 500kV NKI and another island was connected to 220kV Jhimpir for the purpose of network load flow conditions.
- Plant wise generation and demand position @0730 hrs in KE network **(Annex 15)**
- Sequence of Tripping Events;

Time	Sequence of Event	Source
07:34:14:906	Disturbance in 500kV network & Over-frequency in the system	DFR
07:34:15:205	Load variation on BQPS3 units from 239 to 79 MW	BQ3 DFR
07:34:15:350	NKI-Jamshoro and NKI-K2K3 tripped on over-voltage	Calculated

07:34:15:457	CTS Operation in the system initiated – (Baldia)	SCADA
7:34:15:588	CTS Operation in the system (KDA)	SCADA
7:34:16:149	CTS Operation in the system (Mauripur)	SCADA
7:34:16:224	UFR initiated in the system	SCADA / DFR
07:34:16:860	UVLS initiated in the system	SCADA / DFR
07:34:17:706	BQPS-3, Unit-10 tripped on thermal load variation	BQ3
07:34:18:323	BQPS-3, Unit-20 tripped on under frequency protection	BQ3
07:34:18:323	Breakdown in KE island connected with 500kV NKI	DFR
07:34:43:800	Breakdown in KE island connected with 220kV Jhimpir	DFR

- 624 MW load was rejected through cross trip scheme and under frequency/voltage protection
- System Restoration through Tapal & Gul Ahmad (08:32 Hrs – 16:22 Hrs)
- System Restoration through BQPS-2 and CCPP (16:25 Hrs – 1900 Hrs)

24/01/2023

- 03:22 Hrs , KE received power from National Grid Jhimpir
- 05:28 Hrs, BQ2 – CCPP island synchronized with NTDC.
- 05:34 & 05:35 Hrs, 220kV NKI - KDA & 220 kV NKI - Baldia circuits also normalized respectively.
- Compliance of Recommendation of Breakdown dated January 09, 2021

S.No	Recommendations by NEPRA	Actions by KE
1	The islanding facility available at KCCPP and BQPS-II could not be utilized as KCCPP was off due to low gas pressure whereas only one machine out of the two machines of BQPS-II came on island for short interval but could not survive.	With the commissioning of HSD at CCPP, black start facility is also available at KCCP. Also, with integration of PLL gas, BQ2 complex now also possess Black start facility. Also, BQPS III will have black start option post commissioning on secondary fuel (HSD).
2	The quantum of load to be rejected through under frequency relays along with time and setting coordination between those of transmission lines and machines needs to be	Detailed study was conducted by consultant and under frequency and under voltage schemes were revised which responded accurately in the

	reviewed for making those efficient and effective. The feeders which were supposed to but did not trip on under frequency shall be checked and kept healthy.	recent breakdown. Details of UFLS and UVLS are annexed.

7.5 NTDC 500/220kV NKI Grid Station, Karachi

The information by the NKI G/Station is placed at **Annex 16**

7.6 Port Qasim Power Plant, Karachi (Annex-17)

Essence of the Port Qasim Power Plant presentation is given below;

- 660 MW Unit 1 was under shutdown. Unit 2 was operating at 656 MW load.
- 07:34:16 Hrs, the system voltage increased from 501kV to 546kV and dropped to 463kV after 1 second.
- 07:34:16 Hrs, frequency increased from 50.5hz to 51.458Hz of Unit 2 and the speed of Unit 2 steam turbine increased to 3084 rpm. Unit 2 ST tripped resulting in decrease in frequency and speed.
- 07:34:16 Hrs, Unit 2 boiler tripped but due to grid failure, reverse power protection was not activated.
- 07:34:30 Unit 2 tripped. Unit 2 restored on 04:44 Hrs. dated January 24, 2023.
- Connected to National Grid at 12:53 Hrs. January 25, 2023 after 50.32 Hrs.
- As per PPA agreement, the maximum restoration time is 72 hours after restoration of 500kV Grid System **(Annex-18).** However, the generator was synchronized with busbar after 50.32 hours.

7.7 Lucky Power Plant, Karachi (Annex-19)

From the data provided by Lucky Power Plant, following has been observed;

- Generation before the breakdown was 606 MW
- 07:34:24:12 the power plant tripped
- Generator tripped immediately after tripping of Lucky-Matiari Cct. due to disturbance in Grid frequency and Lucky – Port Qasim Cct. voltage became zero resulting in power loss at the complex
- Frequency at the time of tripping was 47.0 Hz

7.8 K2, K3 Karachi

Brief of the K2, K3 presentation is given below (**Annex-20**);

- Capacity of K2 Power Plant is 1100 MW and K3 Power Plant is 1100 MW
- Before the power breakdown, K2 was generating 1040 MW and K3 was generating 900 MW
- At 07:34:15:216 DTT trip signal received from NKI Grid at K2/K3 Grid
- NKI Line Breakers Opening Time: 9ETT120JA (07:34:15:248) & 9ETT130JA (07:34:15:250)
- 07:34:15.719, K3 tripped on Over Frequency Split Tripping setting. The K2 trip command issue time was 07:34:15:670, whereas breakers opening time was 07:34:15.719 & 07:34:15.721 and the Grid Freq. @ Breaker opening was 51.642 Hz, V= 25.73kV

- 07:34:15.722, K2 Power Plant tripped on Over Frequency Split Tripping setting. The K2 trip command issue time was 07:34:15:669, whereas breaker opening time was 07:34:15.722 (another breaker earlier opened at DTT) and the Grid Freq. @ Breaker opening was 51.642 Hz, V= 25.73kV

7.9 ± 660kV HVDC Converter Station, Matiari (Annex-21)

Summary of the briefing given by HVDC, Matiari Converter Station is as under;

- ± 660kV HVDC Project from Matiari to Lahore starts from Matiari Converter Station in Sindh and ends at Lahore Converter Station in Punjab. The project includes two ±660kV DC converter stations, 886km HVDC Bi-pole transmission lines.
- The rated capacity is 4000MW. The rated voltage is ± 660kV, whereas the rated maximum current of each pole 3030A.
- 07:34:13:222, AC voltage started decreasing i.e. 478kV
- 07:34:15:568, FLC activation
- 07:34:16:130 first instant when FLC achieve 1000MW
- 07:34:29:987, Pole 1 block
- 07:34:30:001, Pole II block
- Power before Tripping was 2400MW
- AC voltage at the time of tripping was 46.6KV
- DC voltage at the time of tripping was ±43KV

7.10 ± 660kV HVDC Converter Station, Lahore (Annex-22)

Summary of the presentation given by HVDC, Lahore Converter Station is as under;

- 07:34:30:258, Pole 1 block
- 07:34:30:270, Pole II block
- 07:34:14:895, Pole I Commutation Failure
- 07:34:14:895, Pole II Commutation Failure
- 07:34:30:241, AC voltage at Y Block = 213kV (L-N) RMS
- 07:34:30:241, DC voltage at Y Block = 226kV
- Commutation Failure occurred at low voltage indication
- Power before Tripping was 2400MW

7.10.1 Out of Step Splitting Devices: Out of step protection devices have been installed at the different locations to solve the problem of system out of step between North and South power grid under extremely serious fault (**Annex-23**);

7.11 220/132kV Jhimpir - II Grid Stations (Annex-24)

Brief of RE Jhimpir-II submissions is as under;

- Capacity = 3 x 250 MVA
- 07:00:00 Load = 3 MW
- 07:00:00 Voltage = 234kV
- 07:00:00 Frequency = 49.8 Hz
- 07:35 Hrs Main Supply Fail

7.12 220/132kV Jhimpir - I Grid Station

Briefing given by the 220kV/132kV RE Jhimpir-I is as under (**Annex-25**);

- Capacity = 4x250 MVA
- 07:00 Hrs. Load = 7 MW on each transformer
- 07:00 Hrs. Voltage = 230V
- 07:00 Hrs. Frequency = 49.7 Hz
- 7:35 Hrs. Main Supply Fail.

7.13 Tarbela Power Station (Annex-26)

Brief of the Tarbela Power Station is as under;

- Total installed capacity = 4888 MW.

Pre Fault Conditions:

- Loading of Tarbela + 4th Extension = 686 MW
- All 220kV/500kV T/Lines were energized except 500kV Ghazi Barotha T/Line 2

Bus Bar Voltage:

- 220kV Bus Bar No 1 & 2 = 232/235kV
- 500kV Bus Bar No 1 & 2 = 529/539 kV
- 07:34:30 sudden dip in the system frequency from (50Hz to 0 Hz) caused the **tripping** of generating units & transmission lines of Tarbela Power Station.

7.13.1 Restoration events submitted by Tarbela Power Station

23/01/2023

- 07:35 Hrs. DG Set – 2 started on Auto
- 07:38 Hrs. DG Set – 1 started on Manual
- 07:56 Hrs. Unit No. 2 started and Busbar 2 energized
- 08:07 Hrs. Unit No. 1 taken off the Busbar
- 08:52 Hrs. Unit No. 2 started and synchronized with the system
- 08:55 Hrs. 220kV Burhan 3 energized
- 09:00 Hrs. 220kV Cct. Burhan 2 energized
- 09:10 Hrs. severe frequency swing (45Hz – 55 Hz) observed in the system and the energized circuits i.e. Burhan 2-3, ISPR tripped on loss of voltage
- 09:16 Hrs. Unit No 3 started and 220kV busbar 1 & 2 energized
- 09:40 Hrs. 220/500kV Auto T/F 2 energized
- 09:55 Hrs. 220/500kV Auto T/F 1 energized
- 10:24 Hrs. serious frequency swing observed (48Hz – 55 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 10:36 Hrs. Busbar 1 & 2 energized by Unit No. 3
- 11:38 Hrs. frequency swing observed (45Hz – 51 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 11:49 Hrs. 220kV Busbar 1 energized and later 220kV Ccts. & auto T/Fs energized
- 12:54 Hrs. frequency swing observed (46Hz – 54 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 12:59 Hrs. Unit No. 6 started and auto T/Fs and 220kV/500kV Busbar energized. Later-on, other Units and 220kV T/lines energized

- 14:26 Hrs. frequency swing observed (47Hz – 54 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 14:38 Hrs. Busbar 2 energized and subsequently 220kV Ccts also energized
- 15:22 Hrs. frequency swing observed (45Hz – 55 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 15:31 Hrs. Busbar energized and subsequently 220kV Ccts also energized
- 15:45 Hrs. frequency swing observed (45Hz – 55 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage
- 15:50 Hrs. Busbar energized and subsequently 220kV Ccts also energized
- 18:46 Hrs. frequency swing observed (48Hz – 55 Hz) in the system and resultantly tripping of units occurred, whereas the tripping of 220kV Ccts. occurred on loss of voltage.
- Note: All the above trippings occurred due to Tarbela Units being operated in island mode as instructed by NPCC
- 18:54 Hrs. Busbar 1 was energized after receiving voltage from far end via 220kV ISPR T/Line. Subsequently, other units of Tarbela, 220/500kV Auto T/Fs, and 220/500kV T/Line were energized.
- 22:33 Hrs. Busbar 2 was also energized forward by energization of remaining 2 units

24/01/2023:

- 00:05 Hrs. Unit No. 14 started & synchronized with system
- 00:16 Hrs. 220/500kV Auto T/F 3 energized
- 00:23 Hrs. remaining T/Lines energized

7.14 Mangla Power Station (Annex-27)

Brief of the Mangla Power Station data is as under;

- Installed capacity = 1100 MW.
- Pre Fault Conditions: Zero Irrigation Indent, No power generation as units were standby/shutdown and on maintenance etc. 220kV Busbar 1 was under shutdown for shifting of its protections

23/01/2023:

- 07:35 system blackout occurred
- 10:10 Hrs. Unit No. 1 started and switched over to 132kV Busbar 1
- 10:30 Hrs. Unit No. 2 started and kept running on SNL/FSNL. Unit stopped due to oil leakage in inlet valve pressure system
- 11:27 Hrs. after receiving voltages from far end 220kV Mangla New Rawat 2 energized
- 11:55 Unit 2 started on FSNL
- 12:45 Unit No. 2 switched on SNL mode
- 12:56 220kV Cct. Mangla, New Rawat 1 & 2 tripped due to hunting in voltages and frequency
- 12:58 Hrs. Unit No. 2 connected to Busbar 2
- 13:17 Hrs. severe hunting/fluctuation observed in voltages (160kV to 250kV) and frequency (47hz to 53hz) causing abnormal sound from the P.T of Unit No. 2
- 13:51 Hrs. severe hunting/fluctuation observed in frequency (46hz to 54 hz)
- 14:25 Hrs. severe hunting/fluctuation observed in frequency (47hz to 55hz) causing abnormal sound from the P.T of Unit No. 10

- 15:47 Hrs. due to severe fluctuation in frequency (45.5hz to 62hz) causing abnormal sound from the P.T of Unit No. 9&10 and both units tripped along with tripping of 220kV Cct Mangla New Rawat – 2
- 16:24 Hrs. due to severe hunting/fluctuation in frequency (46hz to 58hz) causing abnormal sound from the P.T of Unit No. 2 and Unit tripped along with tripping of 132kV Cct Rajjar and 220kV Cct Mangla Gujrat 1
- 17:30 Hrs. Severe hunting / fluctuation observed in frequency (49.04Hz to 53.37Hz) causing abnormal sound from the P.T of Unit No. 2,9 & 10.
- 22:47 Hrs. Unit No. 1 taken off the bar from Island Mode. Afterwards, 132kV CB closed and resultantly station supply shifted to the National Grid from radial mode

7.15 Ghazi Barotha Power Station

Brief of the Ghazi Barotha Power Station data is as under (**Annex-28**);

- Installed capacity = 1400 MW.
- Pre Fault Conditions at 07:33 Hrs: Generation (Unit 2) = 250 MW. All 500/220kV energized except 500kV Barotha – Tarbela 2. Voltage Busbar 1 & 2 = 526kV

23/01/2023

- 07:34 Hrs. Fault Occurrence power system collapse / de-energization of HV & MV system at Ghazi Barotha Power stations and tripping of the Unit 2
- Note: An abrupt system frequency dip and failure of system voltages caused tripping and no fault at Ghazi Barotha

7.15.1 Restoration by Ghazi Barotha Power Station

- 07:44 Hrs. January 23, 2023 Restoration Started
- 06:14 Hrs. January 24, 2023 : Complete Restoration

7.16 NTDC Head Office, Lahore (Annex-29)

Event description provided by NTDC Head Office, Lahore is reproduced below;

Sr. No.	Time	Event Description
1.	Prior to 07:30 Hrs.,	HVDC Flow = 2400 MW HVAC Flow = 1730 MW
2.	07:30 Hrs.,	Curtailment of wind generation lifted. Congestion on HVAC network. HVDC Flow = 2400 MW HVAC Flow = 2252 MW → To be confirmed from NPCC
3.	07:32 Hrs.,	System Frequency ≈ 50.75 Hz. Generator at Ghazi Barotha Power Plant ordered to shutdown to bring the system frequency within nominal range.
4.	07:32:20 Hrs.,	Oscillations started in the network parameters.
5.	07:34:06 Hrs.,	Oscillation recorded in the vicinity of 500 kV Guddu G/S. Voltage on 500 kV system swinging between 276 kV (Ph-Ph) to 510 kV (Ph-Ph) Current on 500 kV T/Line swinging between 495 A to 1594 A.
6.	07:34:14.895 Hrs.,	Commutation failure at Lahore Converter Station. Voltages on 500 kV AC Bus ≈ 410 kV (value provided by M/s. PMLTC).
7.	07:34:14.908 Hrs.,	a. 500 kV Guddu 747 – Rahim Yar Khan tripped. (53.5 kV / 1.75 kA) b. 500 kV DG Khan – Guddu tripped. (99.6 kV / 1.74 kA) c. 500 kV Guddu – Muzaffargarh tripped. (62 kV / 2.02 kA)
8.	07:34:15 Hrs.,	a. Voltage and Frequency overshoot in southern system. b. 07:34:15.417 Hrs., 500 kV NKI – K2/K3 & NKI – Jamshoro T/Lines tripped on over voltage (V > 600 kV). c. ≈ 07:34:15.500 Hrs., Frequency controller of HVDC activated. Power flow on HVDC T/Line momentarily increased to 3400 MW d. 07:34:15.722 Hrs., K2/K3 tripped on over frequency (f > 51.5 Hz) e. Rest of operating power plants in southern region tripped on under frequency.
9.	07:34:29.987 Hrs.,	Loss of AC voltage at Matiari AC busbar causing HVDC bi-pole block leading to system collapse.

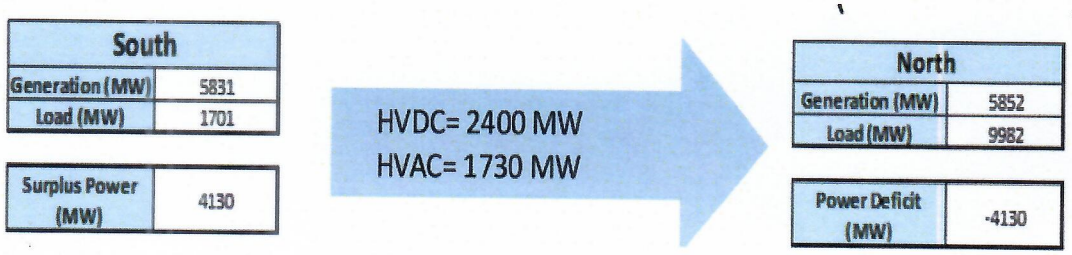
Sr. No.	Name of Ckt. / Power Plant	Grid Station/End	Type of Relay	Relay Indications	Remarks
1.	500 kV Guddu 747 – Rahim Yar Khan	Guddu 747	GE D60 Distance Relay	Zone 1 Trip, Phase A, B, C Power Swing detected	Voltage recorded at time of Tripping: ≈ 53.5 kV Current recorded at time of Tripping: ≈ 1.75 kA
2.	500 kV DG Khan – Guddu Old	DG Khan	Schneider Electric P443 Distance Relay	Zone 1 Trip, Phase A, B, C Power Swing detected	Voltage recorded at time of Tripping: ≈ 99.6 kV Current recorded at time of Tripping: ≈ 1.74 kA
3.	500 kV Muzaffargarh – Guddu Old	Muzaffargarh	Areva P443 Distance Relay	Zone 1 Trip Phase A, B, C	Voltage recorded at time of Tripping: ≈ 62 kV Current recorded at time of Tripping: ≈ 2.02 kA
4.	500 kV Guddu 747 – Guddu Old	No Trip			
5.	500 kV Muzaffargarh – DG Khan	No Trip			

7.17 Pre-Event Power System Conditions

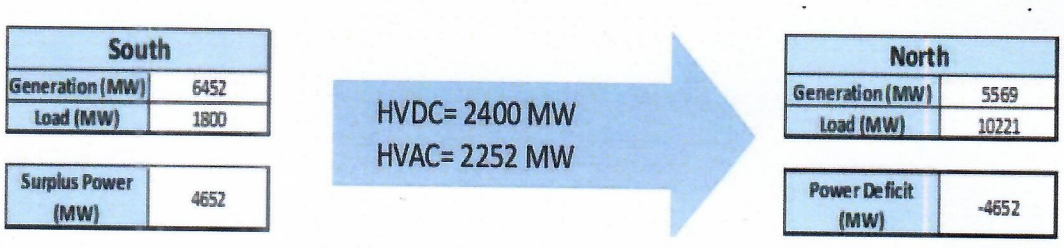
7.17.1 During the morning time, power system demand starts increasing owing to offices, school and other business activities as per usual trend. DISCOs started load management from 07:00 Hrs in groups with difference of 15 minutes. In this way, load management in FESCO and MEPCO was started at 07:30 hours. Usually, the wind generation remains restricted during the night due to less downwards regulation margin on thermal plants because of minimum system demand during night hours, which is witnessed since many years back. Resulting in higher 500kV system voltage at various locations within the transmission network due to which some T/lines are switched off/opened to manage the system stability and equipment safety.

7.17.2 Before four minutes of the collapse, the system generation was approximately 11,683 MW at 07:30 hours. As the cheaper generation resources of indigenous coal and nuclear are located in the most Southern part of the country therefore as per the Economic Merit Order (EMO) the generation in Southern region was evacuated to Northern region through HVAC and HVDC parallel T/Line corridors. The status of power generation and its flow on 23rd January 2023 @ 0725 Hrs., & 07:34 Hrs. region wise, before event, as provided by System Operator (NPCC) is given here below:

- Generation Status at 23rd January 2023 @ **0725 Hrs.** is as under;



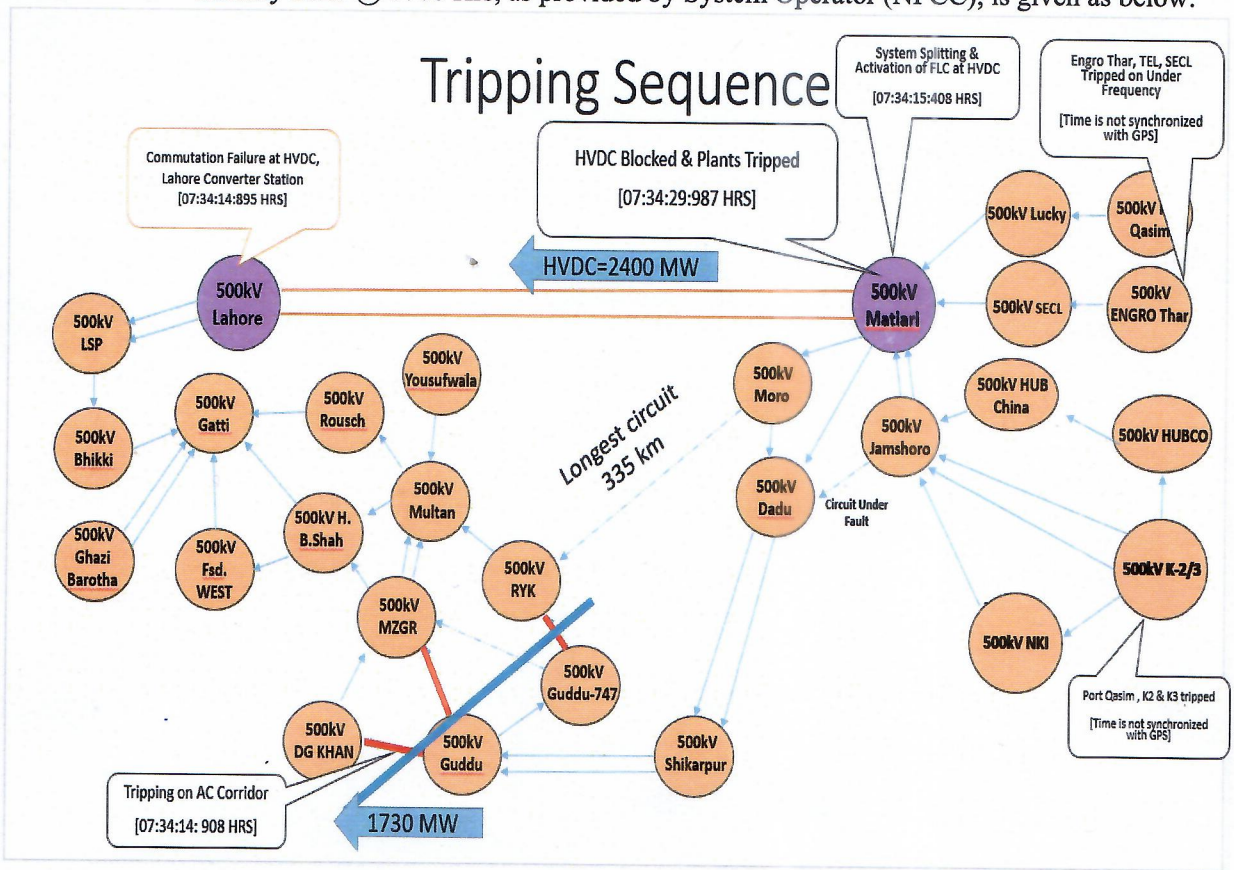
- Generation Status at 23rd January 2023 @ **0734 Hrs.** is as under;



7.17.3 The consolidated status of region wise generation along with plants names on 23rd January 2023 is as under:

South Region (MW)			North Region (MW)		
	@ 0730Hrs	@ 0734 Hrs		@ 0730Hrs	@ 0734 Hrs
Guddu 5-13	145	145	Tarbela	754	745
UCH-I	372	372	Ghazi Barotha	**580**	**250**
Engro	145	145	Karot	95	95
Foundation	178	178	Neelum Jhelum	0	0
UCH-II	188	188	Other Hydel PP	231	231
Port Qasim	621	621	AGL	94	114
Engro Thar	150	150	Atlas	0	19
Lucky	606	606	Liberty Tech	160	177
Thar Energy	150	150	Sahiwal Coal	621	621
Shangai	1230	1230	H BS	1190	1190
KANUPP-II	1040	1040	Balloki	1183	1183
KANUPP-III	**870**	**900**	Chashnupp-I	310	310
Total Bagasse	136	136	Chashnupp-II	316	316
Total Renewable	**0**	**591**	Chashnupp-III	318	318
			Chashnupp-IV	0	0
Total	**5831**	**6452**		**5852**	**5569**
Total (North + South) @ 07:30		**11,683**	**Total (North + South) @ 07:34**		**12,021**

7.17.4 The status of 500KV transmission circuits, connecting South and North zones, on 23rd January 2023 @ 0700 Hrs, as provided by System Operator (NPCC), is given as below:



Part 3

Event Occurrence

Findings

Conclusion

8. Event Occurrence:

8.1 Wind generation curtailment lifted at 07:30 Hrs. and as a result about 500 MW generation injected in the system, which caused the overloading of Transmission Lines as well as low voltage under steady state conditions in view of long AC Corridor of about 1100 KM, from Thar in South to Haveli Bahadur Shah in North with insufficient VAR generation, as the Guddu 747 Plant was under forced shutdown. This reduced the T/Line capacity in light of Surge Impedance Level (SIL).

8.2 Consequently, apart from rising trend in system frequency due to increase in wind generation, the oscillations on the system also started. At the same time the Generation in Northern region was reduced by shutdown of the one unit and ramp down the generation of other unit of Ghazi Brotha at about 07:32:22.187 Hrs. This action aggravated the situation as system was already weak and under stress due to high AC flow and low voltage/less VAR compensation in middle.

8.3 Thus, the initiation of the event started with the depression of voltages as shown in graph of **Annex-30**. This increased the oscillations which can also been seen from the graphs of Multan, Lahore & Muzaffargarh attached as **Annex-31.** Due to these oscillations in voltage and current, the Commutation Failures occurred at 07:34:14:895 Hrs. at voltage 391 kV recorded at Lahore Converter Station, graph attached as **Annex-32**.

8.4 After 13 mili-seconds of activation of the Commutation Failure, the DC power of about 304 MW, was also shifted on AC corridor. Consequently the power swing was generated on the system. However ***out of step protection scheme*** as per attached **Annex-33** for splitting the system in different Islands, did not operate. Resultantly all three HVAC circuits as mentioned in **Annex 33 (i)** tripped on Power Swing (unstable) and HVAC system split into two regions at 07:34:14:908 Hrs. but both regions still remained connected through HVDC system.

8.5 In view of the load flow, where about 4130-4652 MW was being exported from South to North, the splitting of the HVAC network into North and South sub-systems caused frequency rise in the Southern region up-to 51.525 Hz having excess generation and depressed frequency/voltage in Northern region having excess load.

8.6 Meanwhile the Frequency Limit Controller (FLC) at Converter Grid Station initiated but before completion of its cycle, Over Voltage protection at NKI operated and tripped 500KV NKI-Jamshoro and NKI-K2/K3 circuits from both ends at 07:34:15:250 hours The tripping of above-mentioned circuits isolated NKI from 500 KV National Grid. Thus the export of 521 MW to K. Electric became zero and K.E went into the Island status.

8.7 Although the consequences would not have been avoided, the rejection of load of 521 MW pushed the frequency rise trend in the South region. Looking into further, it was noted that the time delay setting of over voltage low set element at NKI end for Jamshoro and NKI-K2/k3 circuits was very low i.e.; 100 mili-second. **After pointing out the same by committee, the above setting was revised to 8 seconds and 11 seconds on Jamshoro and K2/K3 circuits respectively and for High set elements of both the circuits from 0.00 to 0.10 sec on 24-02-2023 (Annex-34).**

8.8 At 07:34:15:408, FLC of HVDC activated and provided a support of additional 1000 MW to North to balance the frequency in both regions. Prior to that, another catastrophic factor was that Port Qasim **Generating Unit #2, in operation, started Run Back instead of tripping/isolation from National grid at over frequency setting, implemented as 51.4 Hz (instantaneous) as per the agreed setting,** attached as **Annex-35, provided by the plant** Management,. This resulted in sustained over frequency which caused tripping of K-2 (1040 MW) and K-3 (900 MW) at 07:34:15:935 at agreed Trip setting of 50.5Hz with time delay of 0.25 sec. With the tripping of 1940 MW of K2, K3 plants, system experienced severe dip in frequency.

8.9 Although about 426MW was rejected through Under Frequency Load Shedding scheme in South region, but being insufficient, caused HVDC system to block at 07:34:29:987 Hrs. Resultantly cascaded outages of power plants started in south i.e.; Lucky Power (606 MW), Engro Thar (150 MW), Shanghai Electric (1230 MW), and Thar Energy Limited (151 MW) on under-frequency protection, and thus the collapse of NTDC Southern Island. With this the export to KE from NTDC 220KV network (Jhampir Grid) became zero at 07:34:43:800 Hrs.

8.10 In mean time the North region also collapsed inspite of load rejection of 3834 MW through Automatic Load Shedding Schemes i.e. Under Frequency, Under Voltage and Rate of Change of Frequency (ROCOF).

8.11 With regards to KE, prior to the event, it was running synchronized with NTDC. Major portion of its network, including all its generation, was connected with NKI and the other portion with 220KV NTDC Jhampir-II grid station. KE total load was 1246MW, out of which 708 MW import from NTDC (NKI-521MW and Jhimpir II-187MW), and the remaining 538 MW from its own generation (BQPS III-498MW and SNPC-40MW).

8.12 Upon isolation from NKI at 07:34:15:250, it faced deficiency of 521MW, however, the NKI-KE Cross Trip Scheme operated which rejected the load of 283MW from KE network. Since the Power deficit was still there, the under frequency scheme operated through which 341MW was rejected. Thus a total of 624 MW was rejected against short fall of 521MW so KE system should have sustained but Unit #10 (249MW) of BQPS-III tripped on 'Combustion Chamber Acceleration', which does not seem to be justified'. This caused the other Unit #20 (239MW) of BQPS III and SNPC (40MW) to trip on over loading.

8.13 At 07:34:43:800, upon collapse of NTDC network, export from 220KV Jhimpir-II became zero. Thus KE system completely collapsed.

9. Restoration of Power System

9.1 Timely and reliable Restoration of Power is an essential task after the blackout. The prompt initiation of the restoration process was critical to minimize the impact of the power outage. In this regard availability of Black Start facility at multiple geographical locations (load centers) of the network is essential for speedy restoration of the power system. As per the details provided by the System Operator NPCC, first unit at Tarbela was synchronized at 08:10 Hrs. on 23.01.2023. However, record from NPCC and WAPDA shows that restoration attempts failed multiple times from Tarbela & Mangla Power houses contributing towards delay in system restoration of North Region, whereas Uch-I Power Plant, being with Black Start facility, was started at 09:39 Hrs. on 23.01.2023 through which partial areas of QESCO, SEPCO, HESCO and MEPCO were restored. Moreover, auxiliary supply to most of the power plants in southern region was also provided.

9.1.1 In the aftermath of the event, restoration activities were started. Power Plants having black start facility were instructed for starting of generating units for restoration of system.

9.1.2 The Black-Start initiated at the following power houses:

- Tarbela Power Station
- Mangla Power Station
- Warsak Power Station
- UCH-1 Power Plant

9.1.3 KAPCO was also instructed to initiate Black Start Process on direction of Honorable Minister of Power (MoE), despite expiry of its PPA, since 24-10-2022, but it was not successful due to technical fault.

9.2 Restoration in Northern Region:

9.2.1 Black Start from Tarbela:

9.2.1.1 Black start facility from Tarbela power station was availed and generating unit # 3 synchronized at 08:10 Hrs. and power supply to some of the grid stations in the jurisdiction of IESCO i.e., Islamabad and Rawalpindi was restored and generation was increased gradually. However, Tarbela generating units remained unstable as reported by NPCC, resulting in large frequency swings ranging from 45-55 Hz leading to tripping of generators at 0910 Hrs.

9.2.1.2 After that, nine (09) similar startups were initiated from Tarbela with different combinations of transmission lines and different area loads, but all attempts failed and the island could not expand and could not synch with Mangla. As per NPCC the DG sets of AGL could not synch due to unstable behavior of high fluctuating Tarbela generating units.

9.2.1.3 Tarbela power house stance however was that the variation in load causes much stress and variation/fluctuation in frequency and eventually caused tripping of machines.

9.2.2 Black Start from WARSAK Power Station:

Black start facility was initiated from **Warsak Power Station** as well and supply was restored to some of the grid stations in the PESCO area.

9.2.3 Black Start from Mangla Power Station:

Mangla power station was also instructed for the black start, however, the power station could not start the units due to unavailability of IRSA indent (Indent = 0 cusecs) as per the report of Mangla power station. After getting clearance from IRSA for water discharge, the power station initiated the black start activities and synchronized Generating Unit # 1 on 132 kV Bus Bar and restored its auxiliary supply with 132 KV Mirpur circuit at 10:10 Hrs.

9.2.4 Mangla-Tarbela Coupling attempts:

9.2.4.1 Supply extended from Tarbela to Mangla power stations at 1123 Hrs. and instructed to close interconnector Transformer breaker and synch generating units to couple it with Tarbela. Mangla Unit #2 was on FSNL (Full Speed No Load), however, Mangla was unable to synchronize with the system. Meanwhile Tarbela again tripped at 1138 Hrs.

9.2.4.2 Mangla synchronized its unit #2 with 132kV Busbar at 1210 Hrs. The 220/132kV Interconnector Transformer was energized by Mangla at 1219 Hrs. Thereon, Black Start facility was again availed from Tarbela power station and supply was extended to 220kV Sangjani (ISPR). Supply from Mangla also extended to 220kV Snagjani (ISPR) and attempted to couple both power houses at 220kV ISPR. 220kV breaker controlling 220kV Rawat-Mangla circuit tripped from Mangla end at 1340 Hrs.

9.2.4.3 Supply extended from Tarbela to Mangla power station. However, while attempting to cover Mangla, Unit # 9, 10 along with 220kV, Mangla-Rawat circuit-II tripped at 1547 Hrs.

9.2.4.4 Supply extended from Mangla to Tarbela, Tarbela units got synch one by one and after the successful coupling at 1852 Hrs. on 23.01.2023 the restoration was expanded to the rest of network.

9.3 Restoration in Southern Region:

9.3.1 Black Start from UCH-I Power Plant:

In southern region, Black start capability of UCH-I power complex was availed after the system collapse. The power plant started its first generating unit at 0939 Hrs. and supply to 220 kV Sibbi Grid station was restored through 220 kV UCH – Sibbi circuit. The generation gradually increased in the island by extending its supply to nearby power plants i.e., UCH-II, Foundation, Engro Power and TPS Guddu. As the generation increased, supply was extended to a number of grid stations in the jurisdiction of SEPCO, QESCO, HESCO and MEPCO.

SUMMARY OF RESTORATION FROM DIFFERENT SOURCES					
Sr No.	Restoration Attempt	Power House			
		Warsak (HRs)	Tarbela (HRs)	Mangla (HRs)	UCH-1 (HRs)
1	First	0813Hrs-1024Hrs	0910Hrs	1010Hrs-1140Hrs	0939Hrs-Onwards
2	Second	1035-1252	1024	1210-1245	-
3	Third	1302-1502	1138	1258-1624	-
4	Fourth	1533-Onwards	1254	1629-Onwards	-
5	ifth	-	1426	-	-
6	Sixth	-	1519	-	-
7	Seventh	-	1529	-	-
8	Eighth	-	1545	-	-
9	Ninth	-	1846	-	-

9.4 Delay in Restoration – Challenges and Deficiencies

9.4.1 The restoration process took almost 20 hours which is more than expected. This was due to different factors which are discussed below:

9.4.1.1 One of the major causes of delay in restoration process was the unavailability of black start facility in the central region of the network which is crucial for restoration. However, in the northern region of the country, the black start facility was available with Tarbela, Mangla, and Warsak Power Stations. In the southern region, the only black start facility at UCH-I power plant, was utilized.

9.4.1.2 The restoration process of the power system was also impacted by the lack of mock testing of the black start facility, where ever available. The mock testing is a crucial step for the preparation of NPCC and all relevant stakeholders to handle a blackout scenario, as it ensure the healthiness of Black Start facility.

9.4.1.3 As obvious from the summary, UCH-I power plant remained stable in island mode after its starting but Tarbela did not, although hydel power stations have much higher technical capability to absorb jerks than a thermal power plant. Further

going into details it has been learnt that UCH-I power plant operated on speed control mode while running in island mode whereas Mangla and Tarbela were operating in power control mode.

9.4.1.4 The lack of SCADA and remote operations has significant impact on the restoration process of the power system. SCADA is an essential tool that allows the system operator to monitor all system parameter which helps system operator in expediting the action. Equally important is the sequence of events, specially related to equipment, of complete network, which presently are not available, and can be recorded at NPCC only through SCADA.

9.5 Restoration in K Electric:

9.5.1 K-Electric started its restoration at 0832 Hrs through Tapal, BQPS II and KCCP simultaneously through Black Start in island on 23.01.2023. At 1000 Hrs restoration from Gul Ahmed Power Plant was also started. However, all Power Plants with Black Start facility could not sustain in island modes and tripped multiple times.

9.5.2 Last successful restoration was started at 2107 Hrs from Tapal and BQPS II GT-4 at 2153 Hrs in island modes. K Electric received power from NTDC at 0322 Hrs dated 24.01.2013 through Jhimpir Grid. Restoration completed at 05:08 Hrs. on 24.01.2023 Hrs. after synchronization of all Power sources.

10. Analysis:

10.1 In light of the events narrated above, Inquiry Committee is of the opinion that following factors contributed towards black out. While issuing the operational instructions by NPCC to Generating plants due consideration should have been paid to system parameters, such as Out of Service and length of 500KV lines, required VARs and locations of Generating Plants vs. Load, elaborated as under.

10.2 Although the addition of Wind generation was not required, however, if added then prior to it firing angle at HVDC should have been adjusted for additional transmission to avoid any effect on HVAC transmission lines.

10.3 De-synchronization of Ghazi Barotha Unit # 5, which is not only located in load area, supports the system VARs requirement also, should have been avoided as the water reservoir level, being 334.2 meters at that time, was very much appropriate to keep the plant running.

10.4 Guddu 747 power plant, contribution of which towards balancing the system parameters plays an important role in view of its geographical location, was under forced outage on account of non-insurance despite its availability.

10.5 Ramping down of the only running Unit #2 of Port Qasim instead of tripping on Over Frequency.

10.6 Out of Step Devices installed in the system did not operate, which could have split the network in different stable Islands.

10.7 Although not so much contributing, the operation of Over Voltage Protection at NKI, due to which 521MW load of KE was cut-off, pushed up the over frequency trend.

10.8 KE should have survived after isolation from NKI, as proportionate load was rejected through Cross Trip and Under Frequency schemes but due to inappropriate behavior and tripping of one of the two running machines at BQPS-III, KE system also collapsed.

10.9 Delay in restoration of the NTDC system was mainly due to failed attempts of black start facilities at WAPDA hydel stations and KAPCO. Other factors include delay in synchronization of various power plants and non-availability of SCADA system in NPCC. Whereas KE system was also delayed due to repeated failed attempts on black start.

10.10 The only successful restoration on first attempt was through UCH I Power Plant black start facility.

11. Implementation status of the findings/recommendations of inquiry reports furnished thereof for such break downs in the past.

11.1 Implementation status of Recommendation of Inquiry Committee of NTDC i.r.o Partial Blackout of October 13, 2022

Sr. #	Actions proposed	Implementation Status
8.1	During planning and design phases, condition on aged transmission lines shall be assessed while interconnecting with new power plants	Under implementation
8.2	During execution stage, quality of the material/workmanship shall be ensured as per International Standards	Under implementation
8.3	O&M activities of transmission lines including thermography needs to be carried out as per SOP with availble resources	Implemented
8.4	Ongoing projects of permanent netowrk for evacuation of power in general and in particular from K2/K3 shall be	Under implementation
8.5	Implementaion of SCADA-III shall be ensured as per timelines to enhance the live visibility of system parameters to System Operator	Under implemented
8.6	Phasor Measurement Units is required to be installed to timely indicate the oscillations in the system	Under implemented
8.7	Stability Control System shall be activated at the earliest to enhanvce the system stablility	Partially Implemented
8.8	For more effective maintenance of T/Line, a yardstick for creation of new T/Line Divisions/ Sub-Divisions be developed so that with the addition of new T/Line, the requisite posts be fot sanctioned accordinlgy	Partially Implemented

8.9	T/Line maintenan staff shall be equipped with proper PPEs, T&P, spare material/hardware and vehicles to ensure healthiness of NTDC's T/Lines as per NTDC mainteancne SOPs	Partially Implemented
8.10	Condition assessment of the section of old 500 kV T/Lines near coastal/polluted areas should be carried out on war footing basis and remedial measures may be taken accordinlgy	Under implemented
8.11	Based on the visial inspection and documentary evidences, the Enquiry Committee is of the opinion that if deemed necessary, disciplinary action under the relevant rules may be intiated against the technical teams from project dielivery south involded in execution of interim arrnagment and asst management south for lack of O&M activities as per SOP keeing in view the crticitcality of said arrangment.	Partially Implemented

11.2 Implementation status of Recommendation of Inquiry Committee of NEPRA i.r.o Total Power System Collapse dated January 09, 2021 (Pertaining to NTDC/NPCC)

Sr. #	Actions proposed	Implementation Status
6.4.1	As regard to Power Swing phenomenon, a comprehensive study should be arranged from a reputed international firm to suggest Out Of Step (OOS) protection (Power Swing Blocking (PSB) and Out of Step Tripping (OST)) in order to avoid major power breakdowns and blackouts	Partially Implemented
6.4.2	NTDC, KE and Power Plants shall prepare contingency plans and establish procedures for restoration of supply in case of emergency, partial and complete power failure	Implemented
6.4.3	A Centralized Event Recorder having resolution of milli seconds (ms), is essentially required for proper analysis of events and suggestion of remedial measures	Not Implemented
6.4.4	No operation of Power Houses and Grid stations be carried out without the knowledge and directions of NPCC	Implemented
6.4.5	A function should be developed at the power houses with capacity of 200 MW and above so that instead of tripping of all machines, at least one of that shall remain available in Island Mode during under frequency and shall be in a position to energize the bus	Not Implemented

	bar to facilitate the startup of other machines and speedy restoration of the network	
6.4.6	The black start facility shall be made available at the power plants suggested/selected by NPCC especially for those located in South and Central zones	Partially Implemented
6.4.7	In case of under frequency situation, at least one machine in power plants shall be made available in island mode in order to facilitate for early restoration of supply. In this regard, necessary amendments in any applicable document i.e. PPA, Tariff Determination, License or Grid Code etc. be made if required	Not Implemented
6.4.8	Tripping of generating machine on over frequency/over voltage/over speed shall be managed through settings for their sequential tripping instead of their simultaneous outage	Implemented
6.4.9	The quantum of load to be rejected through under frequency relays along with time and setting coordination between those of transmission lines and machines needs to be reviewed for making those efficient and effective. The feeders which were supposed to but did not trip on under frequency shall be checked and kept healthy	Partially Implemented
6.4.10	The power plants which were not available for synchronization despite the notice of NPCC shall be dealt with under PPA	Implemented

11.3 Implementation status of Recommendation of Inquiry Committee of NEPRA i.r.o Total Power System Collapse dated January 09, 2021 (Pertaining to Guddu)

Sr. #	Actions proposed	Implementation Status
6.4.11	Grid Station Equipment and Protection/Control System of 220kV Switchyard Guddu shall be maintained in accordance with SOPs issued by TSG NIDC/manufacture of the equipment	Partially Implemented
6.4.12	Single Line Diagram of 220kV switchyard Guddu and Mimic diagram of its 220kV control room be updated and made available at site as well as with NTDC	Implemented
6.4.13	Interlocking scheme of equipment installed at 220kV switchyard Guddu shall be checked and ensured for proper working	Partially Implemented
6.4.14	Indiscriminate tripping GT 14 at Guddu on Unit Differential Relay checked and set night	Implemented
6.4.15	Routine testing of HV equipment at Guddu switchyard including protective relays shall be carried out regularly	Implemented
6.4.16	Technical trainings be arranged for staff and engineers at TPS Guddu for their skill improvement and capacity building	Implemented
6.4.17	The departmental enquiry initiated by Guddu Power Plant management against the delinquent staff regarding the instant breakdown be concluded	Implemented
6.4.18	Management reforms are required at TPS Guddu for systematic working	Implemented

11.4 Implementation status of Recommendation of Previous Inquiry Committees of NTDC/NPCC/Ministry etc i.r.o Partial / Full Blackouts

Sr. #	Title & Brief of Inquiry Report along with date and year	Actions proposed	Implementation Status
1	System Disturbance in North Region A hearvy jerk was observed on the system duye to damage of isolator controlling 220kV Muzaffargarh – Multan Circuit 09:21 Hrs on 15.01.2016	During canal closure and foggy seasons i.e. December 15th to February 15th, Hydel Generation is recommended to be maintained at 1500 MW (minimum) at all times and at 2000MW during peak hours	Not Implemented
2	System Disturbance in North Region System disturbance occurred due to tripping of auto transformer T3 along with 500kV Guddu Old – Guddu 747 circuit. 09:21 Hrs on 21.01.2016 Report by NTDC	Achieving of load shedding through under frequency relays at 132kV level can be better managed and controlled in NTDC grid station on radial feeders	Not Implemented
	2016	Certain number of 220kV CBs installed at Guddu Power House was reported last year by NTDC as very old which have completed their life time and need to be replaced	Not Implemented
	2018	The power plant management shall ensure enough supply of MVARs to the network. Adequate supply of MVARs maintains the system voltage and hence decreases the possibilities of voltage collapse / breakdowns. The power plants operator must follow the NPCC instructions regarding voltage regulation and incase of failure to follow the same, penalty be imposed on the power plant	Not Implemented
		i. Delay in system restoration has also been caused due to non-availability of	

	2018		black Start Facility in Power Plants located in central region. The Power Purchase Agreement for the future plants needs to include the black start facility for quick restoration of power supply to load centers.	Not Implemented
		ii.	Fully functional SCADA system helps in better monitoring & control of power system and analyzing of real time disturbances. Unavailability of SCADA system at major stations and power plants has also caused delay in system operation / restoration	
		iii.	High voltages in 500kV network is a major problem in system restoration and the same can be mitigated by installation of Shunt Reactors on appropriate stations.	
		iv.	Study of islanding schemes needs to be carried out by International Consultants to avoid the system going towards Out of Step / Out of Synchronism	

12. FINDINGS:

Based on the site visits, examination of the documents and discussion with the concerned, following are the findings of the Inquiry Committee.

12.1 Complete power blackout occurred at 07:34:43:800 Hrs. on 23.01.2023 and full restoration of NTDC system was achieved at 0322 Hrs. on 24.01.2023.

12.2 Failure of supply in the KE system happened at 07:34:43:800 Hrs. on 23.01.2023 and complete restoration was done at 0508 Hrs. on 24.01.2023.

12.3 The sequence of events which took place on during the occurrence of blackout are described below:

i. Generation of power from Wind Power Plants in South was increased whereas hydel generation was decreased in the North.

ii. Power supply in HVAC was above the capacity of lines which resulted in Oscillations.

iii. Reduced line voltage at North caused Commutation Failure which temporarily decreased power flow from HVDC Lahore converter station.

iv. Some power of HVDC was diverted to HVAC which generated Power Swing.

v. Out of step protection schemes did not operate, hence North and South zones split on HVAC system. However, both zones remained connected through HVDC.

vi. In South zone, over frequency was observed while in North zone, under frequency was experienced.

vii. Due to difference in frequencies of the HVAC at Matiari and Lahore Converter Stations Frequency Limitation Controller (FLC) was activated.

viii. Prior to completion of FLC process, 500kV NKI- Jamshoro and 500kV NKI-K2/K3 tripped on over voltage which ceased export of 521 MW from National Grid to KE Grid. This resulted under frequency in KE Grid and over frequency in the National Grid.

ix. Instead of tripping, Port Qasim Power Plant went into Run Back mode at the set over frequency settings which maintained the system over frequency and resultantly K2/K3 Power Plants generating 1940 MW tripped.

x. Abrupt loss of power caused severe dip in frequency which caused the blocking of both HVDC poles. Resultantly cascaded outages of other Power Plants in Southern region i.e. Lucky, Engro Shanghai & Thar on under frequency occurred.

xi. Power Supply to South zone including KE was suspended from Grid Network resulting in complete blackout in the South Region.

xii. In the meanwhile the North region also collapsed inspite of load rejection of 3834 MW through Automatic Load Shedding Schemes i.e. Under Frequency, Under Voltage and Rate of Change of Frequency (ROCOF).

xiii. Power Supply from NTDC network Grid Stations to Karachi network was completely suspended due to tripping of Jhimpir II - KDA circuits.

xiv. Despite suspension of Power Supply from National Grid, KE could have avoided blackout, had BQPS Power Station survived as sufficient load was rejected via Cross Trip and under frequency schemes.

xv. Due to non-availability of central event recorder great difficulty was faced in assessment of accurate sequence of events.

12.4 Following are contributing factors for cascaded tripping:

i. Injection of wind power generation in South and curtailment of hydel power generation in Ghazi Barotha Power Station at North by NPCC.

ii. Running back of Port Qasim Power Plant instead of shutdown at set over-frequency setting.

12.5 Restoration:

12.5.1 National Grid system was completely restored at 0322 Hrs. on 24.01.2023

12.5.2 KE Grid was restored on at 0508 Hrs. on 24.01.2023.

12.5.3 Factors for delayed restoration are enumerated below:

i. Frequent tripping of Tarbela units while energization/loading of circuits.

ii. Delayed synchronization of Mangla Power Station with bus bar due to internal fault.

iii. Late synchronization of Tarbela and Mangla Power Stations by System Operator.

iv. Delayed availability of following Power Plants despite Notice to Sync (NTS) by System Operator: Nandipur, Sahiwal Coal, Guddu, China Hub, HUBCO, Halmore, Rousch Power Plants took long time to sync inspite of NTS by NPCC. Details are attached as **Annex 36.**

13. Conclusion:

13.1 Causes and Faults which resulted in cascade tripping and system collapse

Induction of power generation at South and reduction of generation at North caused oscillations in the system which gave rise to power swing. Power swing could not be controlled due to non-operation of out of step protection devices. Hence in the South initially over frequency and later under frequency, whereas only under frequency occurrence in the North caused in the cascaded trippings of lines and power houses which resulted in total power blackout/breakdown in the country.

13.2 Responsibility for the country wide blackout

Following entities are jointly responsible for the event:

13.2.1 NTDC:

13.2.1.1 For issuing dispatch instructions without due consideration of prevailing network conditions.

13.2.1.2 For inconsistent protection settings at NKI Grid.

13.2.1.3 For non-activation of Out of Step Splitting System

13.2.2 Central Power Generation Limited Company (CPGCL) GENCO-II, TPS Guddu for non-availability of its 747 Guddu in the system on account of non-insurance.

13.2.3 Port-Qasim Electric Power Company Pvt. Ltd. Power plant for failure to trip at the set over-frequency values.

13.2.4 K-Electric for failure to remain in island mode due to tripping of Bin Qasim Power Station – III (BQPS-III)

13.3 Restoration of Power Supply within reasonable time

Delay in restoration of the NTDC system was mainly due to failed attempts of black start facilities at WAPDA Hydel Power Stations and KAPCO. Other factors include delay in synchronization of various power plants and non-availability of SCADA system in NPCC. Whereas, KE system was also delayed due to repeated failed attempts on their black start facilities.

13.4 Status of previous inquiry report findings/recommendations

Recommendation given in the Inquiry Report of NEPRA regarding Total Power Collapse occurred on January 09, 2021 & NTDC Inquiry Report dated October 13, 2022 regarding Partial Shutdown have been partially implemented.

13.5 Remedial measures/recommendations:

13.5.1 VAR compensations study shall be carried out and required measures in light of study shall be taken to avoid Power Swing.

13.5.2 The stability of HVDC system needs to be ensured through proper study to avoid frequent signals of 'Commutation Failure'.

13.5.3 NTDC staff needs to be trained for thorough understanding of HVDC transmission system.

13.5.4 Fully functional SCADA facility for complete system related to NTDC, GENCOS, IPPs and DISCOs is essentially required for system operator in order to ensure the on line monitoring of system parameters in all respect for sake of system security, stability and analysis of events through GPS synched time event recorder.

13.5.5 Implementation of protection settings issued by NTDC for power plants, mutually agreed, shall be ensured under witness of NTDC through CPPA-G.

13.5.6 NTDC shall ensure the healthiness and operation of recently installed Out Of Step devices, as the same did not operate during the event.

13.5.7 Quantum of load to be rejected through under frequency schemes need to be increased, especially in South region, where it is considerably less.

13.5.8 Simultaneous tripping of K2/K3 Units on Over Frequency shall be made stage wise.

13.5.9 SECL, Thal Nova and Thar Energy Power Plants are not included in the Over Frequency tripping scheme, hence shall be considered.

13.5.10 SOP to be developed between all stake holders to maintain required water indent for relevant Hydel Power Station under acute emergency situations.

13.5.11 KE shall set right the cause of undesired tripping of Unit # 10 at BQPS-III.

13.5.12 KE shall also set right their Black Start facilities as multiple attempts were made during restoration and as such not satisfactory.

13.5.13 Periodical testing of Black Start facilities shall be carried out to ensure their satisfactory performance at the time of need.

13.5.14 Black start facilities are required at some additional locations, better study based near Lahore and Hyderabad to help early restoration during Black Out.

13.5.15 Repeated tripping of Machines at Tarbela and Mangla during Black Start need to be checked and set right, as successful restorations have been carried out through these stations in the past.

13.5.16 To ensure the availability of synchronic relay at major 500kV & 220kV Grid Stations to couple/synchronize the islands

13.5.17 To ensure the healthiness of Power System Stabilizers (PSS) at power plants to damp intra-area oscillations

13.5.18 To ensure the installation of modern technologies device such as Wide Area Management (WAM) including Phasor Management Units (PMU) to detect oscillations instability which can be mitigated by Remedial Action Scheme (RAS)

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