NATIONAL ELECTRIC POWER REGULATORY AUTHORITY (NEPRA)

INQUIRY REPORT

Regarding

TOTAL POWER SYSTEM COLLAPSE

On

09th January, 2021

February 08, 2021

EXECUTIVE SUMMARY:

On 09th January, 2021 at 23:40 hours, the whole country suddenly plunged into darkness. From the initial reports appearing in media and the information obtained from NTDC, it was revealed that some severe fault in the system had caused the collapse of the entire power system of the country.

National Electric Power Regulatory Authority, being the Regulator of the power sector, took serious notice of above incident and constituted an Inquiry Committee (IC) to probe into the matter. As per Terms of Reference (TORs), the IC was required to determine the fault, causes and recommend way forward for avoidance of such break down in future.

The IC in the process of its proceedings visited a number of power houses, grid stations, offices of NTDC, Member (Power) and K-Electric. IC was briefed by the concerned offices. Some relevant record was provided by them and the incident was also discussed in detail.

Following is the summary of IC findings and recommendations based on its inquiry which are further illustrated in the Inquiry Report:

i) On 09th January, 2021 at 23:40 hours, on closing of a 220kV Circuit Breaker at Guddu switchyard, bolted fault occurred as the earth switch of related Isolator was left closed. This bolted fault was not cleared due to malfunctioning of the relevant Circuit Breaker and the subsequent breaker failure scheme. The above persistent fault reflected on 220kV and 500kV transmission lines which tripped on Distance Relays in zone 2 and Unstable Power Swing respectively.

ii) In winter season, the power flows from the power plants located in South towards North to meet the load requirement of that zone. The separation of North and South zones created an unbalance of generation v/s connected load in both the zones. In south, the generation was higher as compared to the connected load whereas, in North, the power plants experienced excessive connected load. This unbalancing of generation and connected load contributed towards complete breakdown.

iii) The restoration process was initiated quickly by the power plants and NTDC, the System Operator. Some of the power plants did not respond to the notice to synchronize (NTS) by the system operator and took more time than the specified. Similarly, KE also acted quickly by getting supply from Tapal and Gul Ahmed power plants as its own machines of BQPS-II were not available in island mode. Since KCCPP was under shutdown due to low geas pressures, therefore, its island facility could not be utilized.

iv) Most of the thermal power plants were synchronized with NTDC within 27 hours. The WAPDA Hydel power plants were synchronized with the National Grid within 20 hours. In case of K-Electric, the power plants were synchronized with its system in 17 hours. Overall, NTDC's power supply was restored in 20 hours, whereas KE took about 22 hours for the restoration. NTDC, KE and concerned power plants do not have contingency plans and SOPs for system recovery under total and/or partial shutdown of power supply.

v) The causes of black out are the persistent bolted fault at Guddu switchyard and resultant Unstable Power Swing in the power system. In order to address Unstable Power Swing Phenomenon, a comprehensive study should be arrange from a reputable international firm to avoid such incidents in future;

vi) The black start facility shall be made available at power plants to be identified by NTDC. Moreover, a function should be developed at the Power House of 200MW and above that at least one machine shall remain available in island mode during under frequency situation to facilitate early restoration.

vii) For sequential tripping instead of simultaneous outage of machines on over frequency, settings shall be managed accordingly.

viii) 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.

ix) A number of deficiencies were noted in 220kV switchyard and control room at TPS Guddu which need to be addressed on top priority. The bolted fault which consequently resulted in the black out was created due to the negligence of the staff of Guddu Power Plant. The departmental inquiry against the delinquents initiated by management of Guddu Power Plant need to be concluded. Technical trainings be arranged for skills improvement and capacity building for staff and engineers at Guddu Power Plant. Grid Station Equipment and Protection/Control System of 220kV Switchyard Guddu shall be maintained in accordance with SOPs issued by TSG NTDC/manufacturer of the equipment;

1. INTRODUCTION:

1.1 NEPRA:

NEPRA was established in 1997, through an Act of Parliament, as result of Government's Strategic Reforms for the Privatization of the Pakistan's Power Sector in order to make it reliable, efficient, stable, affordable and progressive in addition to safeguarding the interests of both investors and consumers.

1.2 POWER GENRATION:

The installed power generation capacity of Pakistan as on 30th June, 2020 stands at 38,719 MW. The total installed capacity of public sector power plants in the country as on 30th June, 2020 was 19,621 MW while the installed capacity of private sector power plants, including KE, was 19,098 MW. Out of 38,719 MW, 24,817 MW is thermal, 9,861 MW hydroelectric, 1,248 MW wind, 530 MW solar, 369 MW bagasse, 1,467 MW is nuclear and 427 MW is SPPs/CPPs.

Generation Source	Capacity (MW)
CPPA-G System	
WAPDA Hydel	9,389
IPPs Hydel	472
Total Hydel	**9,861**
GENCOs	4,881
IPPs	17,276
SPPs/CPPs	340
Nuclear	1,330
Total: Thermal including Nuclear	**23,827**
Wind	1,248
Solar	430
Baggas/Biomass	369
Total Renewable	**2,047**
Total CPPA-G System	**35,735**
K-Electric System	
KE Own	2,294
IPPs	366
SPPs/CPPs	87
KANUPP	137
Solar	100
Total KE System	**2,984**
Grand Total: Installed Capacity of Country	**38,719**

Power Plant wise detail is attached at **Annex 1**

1.3 Power Transmission:

1.3.1 NTDC's Transmission System:

NTDC is the National Grid Company in Pakistan and its transmission network is spread all over the country except the area served by KE. As of 30th June, 2020, NTDC is maintaining 16 (sixteen) Nos. of 500 kV grid stations with a transformation capacity of 23,400 MVA. There are 43 (forty-three) Nos. of 500/220 kV transformers and 33 (thirty-three) Nos. of 220/132 kV transformers installed at these grid stations. NTDC also maintains 45 (forty five) Nos. of 220 kV grid stations with transformation capacity of 31,900 MVA. There are 127 (one hundred and twenty-seven) Nos. of 220/132 kV transformers installed at 220 kV grid stations. The length of transmission lines of NTDC at 500 kV is 7,238 km while the length of transmission line at 220 kV is 11,281 km. NTDC's power network diagram is attached at **Annex 2**

1.3.2 K-Electric's Transmission System:

KE is a privatized vertically integrated utility possessing three separate licenses of Generation, Transmission and Distribution businesses. The license issued to KE allows it to generate, transmit and distribute the electricity to its consumers within its service area.

KE is operating under the license issued by NEPRA to carry out electricity transmission business within its service area. KE owns, operates and maintains transmission network of 220 kV and 132 kV. The details of existing transmission network of KE at 220 kV and 132 kV level is as under:

(a) 365 km of 220 kV Transmission Lines,
(b) 11 Nos. of 220 kV Grid Stations with transformation capacity of 4,580 MVA
(c) 801 km of 132 kV Transmission Lines.
(d) 68 Nos. of 132 kV Grid Stations having transformation capacity of 6,951 MVA

K-Electric's network diagram is attached at **Annex 3**

1.4 Power Distribution:

Distribution of electricity is an important function for provision of electricity to the end-consumers. As on 30th June, 2020, there were ten state owned DISCOs (PESCO, TESCO, IESCO, GEPCO, FESCO, LESCO, MEPCO, QESCO, HESCO, SEPCO) exclusively responsible for supply of electricity in their respective areas. These DISCOs are performing distribution function under licenses granted by NEPRA. In addition KE also possesses the Distribution License to supply electricity in its designated area.

DISCOs are responsible for the operation and maintenance of the transmission and distribution system at 132 kV and below. These include the following:

(a) 28,621 km of 132 kV Transmission Lines,
(b) 860 Nos. of 132 kV G/S with 1,923 PTs having transformation capacity of 52,640 MVA,
(c) 9,706 Nos. of 11 kV Feeders, 343,215 km long,
(d) 765,115 Nos. of Distribution Transformers having transformation capacity of 46,921 MVA and
(e) 238,551 km of LT Lines.

In addition to above, KE maintains and operates the following:

(a) 801 km of 132 kV Transmission Lines,
(b) 68 Nos. of 132 kV Grid Stations having transformation capacity of 6,951 MVA,
(c) 1,890 Nos. of 11 kV Feeders, 10,204 km long,
(d) 28,842 No. of Distribution Transformers having transformation capacity of 7,916 MVA and 18,367 km of LT Lines.

Map showing the boundaries of distribution companies is attached at **Annex 4**

1.5 Central Power Generation Company (CPGCL) – Guddu:

Central Power Generation Company Limited (CPGCL) Guddu is a public limited company owned by the Government of Pakistan ("GoP") incorporated on 26th October 1998. CPGCL consists of 05 power blocks having total capacity of 2,402 MW.

1.5.1 Units/Machines:

1) Block I: 415 MW (02GTs + 01ST) CCPP
2) Block II: 600 MW ((02GTs + 01ST)x2)CCPP
3) Block III: 420 MW (02) Conventional Steam Plant (De-Licensed)
4) Block IV: 220 MW (02) Conventional Steam Plant (De-Licensed)
5) Block V: 747 MW (02GTs + 01ST) CCPP

Unit #	Capacity (MW)	Type	Make	Date of Commissioning
Block – IV				
1.	110	Steam	Czechoslovakia	30.03.1974
2.	110	Steam	Czechoslovakia	06.10.1974
Block – III				
3.	210	Steam	Russia	07.11.1980
4.	210	Steam	China	29.12.1985
Block-II				
5.	100	CC (Steam)	G.E, USA	27.12.1987
6.	100	CC (Steam)	G.E, USA	23.03.1988
7.	100	G.T	G.E, USA	20.12.1985
8.	100	G.T	G.E, USA	01.04.1986
9.	100	G.T	G.E, USA	06.03.1986
10.	100	G.T	G.E, USA	12.04.1986

Block – I				
11.	136	G.T	Siemens	27.09.1992
12.	136	G.T	Siemens	07.12.1992
13.	143	CC (Steam)	Siemens	17.03.1994
Block – V				
14.	243	G.T	G.E, USA	17.12.2014
15.	243	G.T	G.E, USA	17.12.2014
16.	261	CC (Steam)	Harbin, China	17.12.2014
Total	**2,402**			

- GT – Gas Turbine
- ST – Steam Turbine
- CCPP – Combined Cycle Power Plant

1.5.2 Transmission Lines:

Sr. No.	Voltage (kV)	Circuit	Controlling Breaker	Capacity
1.	500	DG Khan	B3Q2 & B3Q3	1250MW/1500A
2.	500	Muzaffargarh	B4Q2 & B4Q3	1250MW/1500A
3.	500	New Guddu	B1Q2 & B1Q3	1250MW/1500A
4.	500	Shikarpur I	B3Q1 & B3Q3	2550MW/3000A
5.	500	Shikarpur II	B2Q1 & B2Q3	2550MW/3000A
6.	500	Rahim Yar Khan – 747 MW	B2Q1 & B2Q3	1250MW/1500A
7.	500	Muzaffargarh II – 747 MW	B3Q2 & B3Q3	1250MW/1500A
8.	500	Old Guddu	B1Q1 & B1Q3	1250MW/1500A
9.	220	Sibbi	D13Q2 & D13Q3	1000MW/1200A
10.	220	Shikarpur I	D14Q2 & D14Q3	300MW/750A
11.	220	Shikarpur II	D15Q2 & D15Q3	300MW/750A
12.	132	Multan L-1	E1Q1 & E1Q3	300MW/750A
13.	132	Multan L-2	E2Q1 & E2Q3	100MW/600A
14.	132	Hyderabad – Daharki	E3Q1 & E3Q3	100MW/600A
15.	132	Hyderabad – Kashmore	E4Q1 & E4Q3	100MW/600A
16.	132	Larkana – Kashmore	E5Q1 & E5Q3	100MW/600A
17.	132	Rojhan/DG Khan	E7Q2 & E7Q3	100MW/600A

1.5.3 Single Line Diagram

Single Line Diagram of Thermal Power Station Guddu Power Plant is attached at **Annex 5**

1.6 NTDC Northern and Southern Regions

1.6.1 Northern Network:

Region	500kV Grid Stations	220kV Grid Stations
Islamabad	i) Rawat ii) Peshawar	i) Bannu ii) Burhan iii) Daudkhel iv) Mardan v) Sangjani vi) Shahibagh vii) University iii) Mansehra ix) Nowshera x) D. I. Khan xi) Chakdara
Lahore	i) Gatti ii) Nokhar iii) Sheikhupura iv) New Lahore	i) Bandala ii) Bund Road iii) Gakkhar iv) Ghazi Road v) Jaranwala vi) Kala Shah Kaku vii) Ludewala viii) New Kot Lakhpat ix) New Shalimar x) Nishatabad xi) Ravi xii) Samundri xiii) Sarfaraznagar xiv) Sialkot xv) Toba Tekh Singh xvi) WAPDA Town xvii) Gujrat
Multan	i) D. G. Khan ii) Multan iii) Muzaffargarh iv) Yousafwala v) Rahim Yar Khan	i) Bahawalpur ii) Kassowal iii) Muzaffargarh iv) Okara v) Vehari vi) Chishtian vii) Lal Sohanra

1.6.2 Southern Network:

Region	500kV Grid Stations	220kV Grid Stations
Hyderabad	i) Guddu ii) Shikarpur iii) Dadu iv) Jamshoro v) NKI Karachi	i) Dharki ii) Hala Road iii) Khuzdar iv) Loralai v) Quetta vi) Rohri

		vii)	Sibbi
		iii)	T. M. Khan Road
		ix)	Jhimpir
		x)	D. M. Jamali

1.7 K-Electric Limited:

KE's Own Power Plants			
Sr. #	Name of Power Plant	Installed Capacity (MW)	Present Capacity (MW)
1.	Bin Qasim Power Station – I	840	740
2.	Bin Qasim Power Station – II	560	529
3.	Korangi Combined Cycle Power Plant (KCCPP)	246	229
4.	Korangi Gas Turbine Power Station	97.5	97
5.	SITE Gas Turbine Power Station	97.5	97
	Sub-Total – I	**1841**	**1692**
Power Purchased by KE From External Sources			
1.	Tapal	124	124
2.	Gul Ahmed	128	125
3.	KANNUP	137	75
4.	FPCL	52	52
5.	SNPC	102	102
6.	Others (APGL+IIL+ISL)	50	47
7.	NTDC	650	650
8.	OURSUN	39	39
9.	WPPS	150	150
10.	GHARO SOLAR	40	40
	Sub-Total – I	**1472**	**1404**
	Grand Total	**3313**	**3096**

1.7.1 KE's Transmission System

Sr. #	Name of 220kV Grid Stations	Capacity (MVA)
1.	Pipri West	750
2.	KDA Scheme 33	750
3.	Baldia	750
4.	ICI	0
5.	Korangi Creek Road	500
6.	Lalzar	500
7.	Mauripur	500
8.	Surjani	250
9.	Gulshan (New)	500
10.	New Port Qasim	0
	Total	**4500**

2. BACKGROUND:

On 09th January, 2021 at 23:40 hours, the power supply collapsed and the whole country suddenly plunged into darkness. From the reports appearing in the media and initial information given by NTDC, it became obvious that due to some severe fault the power system collapsed which resulted into complete blackout. The NEPRA being the Regulator of the power sector took serious notice of this incident and decided to probe into the matter.

2.1 Constitution of Committee:

A committee was constituted to inquire into the matter of the power system breakdown of 09-10 January, 2021 vide the office order dated 14.01.2021 **Annex 6**. The Inquiry Committee (IC) comprises of the following:

i)	Mr. Nadir Ali Khoso	Director General, NEPRA (Convener)
ii)	Mr. Manu Ram	Manager (Retd.) 500/220kV GSO, NTDC Private Sector (Member)
iii)	Mr. Khalid Mehmood	Chief Engineer (Retd.) System Protection, NTDC Private Sector (Member)

2.2 Terms of Reference (TORs):

i) To determine, the causes and the fault which resulted in the cascade tripping and system collapse;
ii) To fix the responsibility for the major power breakdown;
iii) To review, whether the restoration efforts were adequate and the power supply was restored within the reasonable time;
iv) To go through the findings of inquiry reports furnished thereof, for such breakdowns in the past;
v) To recommend the remedial measures, to be taken in order to avoid recurrence of such events in future.

3. PROCEEDINGS:

The IC started its inquiry proceedings from Central Power Generation Company Limited (CPGCL) Guddu where a severe fault was reported resulting into the failure of entire power system in the country. The IC made visits to following entities/offices during the inquiry proceedings from 18.01.2021 to 29.01.2021.

i) Thermal Power Station Guddu;
ii) 500kV SE (GSO) Guddu;
iii) GM (GSO) South NTDC, Jamshoro;
iv) K-Electric, Karachi;
v) China Power Hub Plant, HUB;
vi) Port Qasim Power Plant, Karachi;
vii) GM (GSO) North NTDC, Lahore;
viii) CE (Protection & Control) NTDC, Lahore;
ix) Member Power, WAPDA, Lahore;

x) GM (NPCC), NTDC, Islamabad;
xi) Tarbela Power House;
xii) Mangla Power House.

During the visits, the management/engineers of the above stations/entities briefed IC and provided the relevant information and documents. Moreover, relevant information from Uch I, Uch II and Engro Powergen Thar was obtained via email. (**Annex 7**) At Guddu Power House, the concerned staff was interrogated and their statements were recorded. (**Annex 8**)

4. OBSERVATIONS:

Following has been observed from visit to sites, discussions and record placed before IC:

4.1 NTDC Power Supply Position Before Event:

Following was the power supply status immediately before the collapse on 09.01.2021 at 23:40 Hours:

Total System Generation:	**10,311 MW**
WAPDA Hydel:	**1257 MW**
GENCOs:	**983 MW**
IPPs:	**8,071 MW**
System Frequency:	**49.85 Hz**

Plant wise sheet is attached at **Annex 9**

4.2 KE Power Supply Position Before Event:

Power Station	MWs	Remarks
BQPS-I	350	U1, U2 and U6 were in operation
BQPS-II	382	GT1, GT3 and ST were in operation
KCCPP	0	Complex shutdown at 22:30hours due to low GP
KGTPS	0	Plant Standby due to low gas quota
SGTPS	0	Plant Standby due to low gas quota
KANUPP	60	
Tapal	10	As per Economic Merit Order/Network Requirement
Gul Ahmed	0	As per EMO
FPCL	0	Annual Outage
SNPC	74	
WPPs	79	
NTDC	468	Import from NKI Interconnection only due to shutdown of 220kV KDA-Jamshoro Circuits 1 & 2 for rehabilitation
Captives	04	
Supply	1427	
Demand	1461	
Load Shed	34	Policy LS

4.3 Occurrence of Fault:

On 08.01.2021 at 00:49 hours, yellow phase pole of the 220kV Circuit Breaker D12Q1 damaged due to which machine G5 tripped at Guddu Power House. The middle 220kV circuit breaker D12Q3 of the same diameters was already under PTW. PTW # 89 was obtained on 08.01.2021 at 09:50 hours to repair the Circuit Breaker D12Q1. The damaged circuit breaker pole was replaced with a healthy pole of the same make and type and PTW # 89 was cancelled on 09.01.2021 at 21:00 hours. While the replacement work of Circuit Breaker D12Q1 was in progress, PTW # 90 on the 220kV isolator D12Q31 of the same diameters was issued on 08.01.2021 at 16:15 hours which was canceled on 09.01.2021 at 21:25 hours just after the cancellation of PTW # 89 without carrying out any maintenance work. The concerned staff of TPS Guddu being satisfied with the test results closed the Circuit Breaker D12Q1 with the intention to ensure its healthiness in live condition while keeping the associated G5 machine isolated. As soon as the Circuit Breaker D12Q1 was closed at 23:41 hours, the power system collapsed and resulted into black out of whole country.

4.4 Sequence of Events and Indications:

Following sequence of events and indications occurred at units/machines and transmission lines as per record provided by TPS Guddu **Annex 10**:

4.4.1 Units/Machines:

Sr. #	Block	Unit No.	Load Before Tripping (MW) at 2300 Hrs	Tripping Time	Indications appeared / Relays operated
1.	I	11to13	-	-	Complete block under shutdown before tripping
2.	II	5	-	-	Under shut down before tripping
3.		6	-	-	Under shut down before tripping
4.		7	100	23:41:10	- Turbine Inlet Differential pressure high - Emergency seal oil pump motor running - Hydraulic protective trip VPR - Generator lube oil pressure low - MCC under voltage alarm - Generator casing pressure low/high - Generator lube oil low tripped.
5.		8	-		Under Shut down before tripping
6.		9	100	23:41:11	Generator differential lock out
7.		10	70	23:41:10	Transformer differential lock out
8.	V	14	235	23:40:00	Unit differential lock out and transformer protection relay (T-60).
9.		15	235	23:41:43	Generator protection relay (G-60)
10.		16	244	23:41:43	Customer Trip

4.4.2 Transmission Lines:

Sr. #	Transmission Lines	Load Before Tripping (MW) at 2300 Hrs	Tripping Time (Hrs.)	Indications appeared/ Relays operated
1.	500kV Muzaffargarh	826 (EXP)	23:41:29	- Distance Relay REL 670 - Trip Phase A, B & C
2.	500kV Guddu G/S	341	23:41:43	DTT received
3.	500kV R.Y.Khan	231	23:41:43	- Inverse time Over voltage - GE Multan F850 596kV
4.	220KV Shikarpur 2	80 (EXP)	23:40:00	No Indication appeared
5.	220kV Shikarpur 1	60 (EXP)		
6.	220kV Sibbi	60 (EXP)		
7.	132kV Multan – L1	13 (IMP)		
8.	132kV Multan - L2	23 (IMP)		
9.	132kV Daharki – L3	-		
10.	132kV Kashmore – L4	18 (EXP)		
11.	132kV Kashmore – L5	17 (EXP)		
12.	132kV Rojhan – L9	85 (EXP)		

4.4.3 Log Sheet

As noted from Log sheet attached at **Annex 11** following indications appeared on 220kV CB D12Q1:

i) Distance relay Razoa – Operated on RST N – 2
ii) Ciruit Breaker Failure Trip Lock out – Operated

4.4.4 Comments:

- The physical inspection of 220kV Isolator D12Q31 revealed that this equipment was in open condition, whereas, it's earthing switch was in closed position before closing of 220kV Circuit Breaker D12Q1. There were sparks and carbonization on contacts of the earth switch of 220kV Isolator D12Q31 and the grounding wire found damaged on its yellow phase. The relevant photos are attached at **Annex 12**. Further, the indication of Circuit Breaker Failure (CBF) of the breaker D12Q1 indicates that it did not operate on the operation of relevant protection due to bolted fault caused by the closed position of earthing switch of 220kV Isolator D12Q31. It was further noticed that the operation of CBF protection failed to trip the circuit breakers of relevant 220kV Bus Bar-I. The persistence of this fault is further confirmed through tripping of 3 x 220kV lines from Shikarpur and Sibi ends where these lines tripped on distance protection zone 2.

- Further, the comparison of log sheet and operation/indication record provided by TPS Guddu shows following contradictions;

  - As per indication record, G9 & G10 machines tripped on differential, whereas, as per log sheet, G9 & G10 tripped on distance relays;

- Moreover, the tripping of machine GT-14 on 'Unit Differential' is not justified as it operated during through fault condition;
- As per log sheet, it is amazing to note that Circuit Breaker D12Q1 was closed first at 23:35 hours, but, the earth switch of Isolator D12Q31 was opened later on at 23:37 hours and tripping occurred on 23:40 hours. The fact remains that the system tripping occurred at 23:40 hours on closing of the circuit breaker D12Q1 while earth switch of Isolator D12Q31 remained in closed position.

- Symbols of earth switches installed with 220kV isolators neither shown in Single Line Diagram nor marked on mimic diagram in the control room;

- Overall interlocking among the 220kV switch yard equipment such as earth switches, isolators and circuit breakers does not exist.

- Operation of 220kV Circuit Breaker D12Q1 and its Isolators D12Q11 and D12Q12 was done without instructions of National Power Control Center (NPCC);

- No proper preventive maintenance of switchyard equipment done;

- No periodical testing of relays, control and other switchyard equipment done;

- Unawareness of even implementation of settings.

- Non-availability of apparatus for testing and instrumentation;

4.5 Impact of 220kV Persistent Fault on the Power System:

A 3 phase to earth persistent fault at 220kV Guddu Switchyard affected both 220kV and 500kV transmission lines. Following 220kV circuits tripped on distance relay in zone 2:

- 220kV Guddu-Shikarpur circuits I & II at Shikarpur end;
- 220kV Guddu-Sibi circuit at Sibi end.

Moreover, the persistent fault was reflected on 500kV Guddu and other connected sub stations thereby causing the tripping of 500kV transmission lines on "Unstable Power Swing" at 23:41 hours as detected by the protection system installed on 500kV transmission lines, mentioned below:

- 500kV Transmission Lines Shikarpur – Guddu I & II at Shikarpur end
- 500kV Transmission Line Guddu - Muzaffargarh at Guddu end
- 500kV Transmission Line Guddu – D.G. Khan at both ends
- 500kV Transmission Line 747 Guddu – Muzaffargarh at 747 Guddu end
- 500kV Transmission Line RYK – Multan at Multan end

Above cascade tripping resulted in the isolation of South Region (Shikarpur – Dadu – Jamshoro – Karachi – Matiari – Moro - Rahim Yar Khan). Since the power of about 3000 MW (**Annex 13**) was being exported from South to North before happening of the event, hence the South Region experienced overvoltage/over speed /over frequency and North Region faced under frequency.

As a result of overvoltage, some of the major generating plants, like China Power Hub, Port Qasim Electric Power, Uch I & II and 500kV transmission lines in South Zone tripped on overvoltage/over speed/over frequency. Due to this loss of generation, under frequency condition was created in South zone where, in spite of under frequency load rejection, the remaining system/machines including those of K-Electric and Engro Powergen Thar could not survive resulting in total failure of the supply at 23.51 hours.

North Region, which faced the shortage of 3000 MW, came under the situation of Under Frequency and did not survive although a load of about 2350 MW was rejected through under frequency relays, as evaluated from the information provided by NPCC (**Annex 14**). This depicts that the quantum of load to be rejected through under frequency along with time coordination between the field relays and those of machines did not prove to be helpful.

Every entity has provided information regarding tripping of their machines& lines. It may be noted that there is no centralized event recorder for the entire power system. Therefore, the sequence of tripping of the machines and transmission lines cannot be precisely ascertained in the power system.

Though there has been cascade tripping and blackout in the country, but by the grace of GOD there has been no damage to any equipment or injury to any person.

4.6 Restoration:

4.6.1 Restoration of NTDC System:

Synchronization of Power Plants: The sheet regarding availability and synchronization of different power plants as provided by NTDC/NPCC (**Annex 15**) is reproduced below:

Time of Restoration of Supply Power Plants & Synchronization of Unit after Complete System Breakdown dated 09-01-2021						
Sr	Plant Name	Supply Restoration Tim	NTS as per PPA	Synchronization time of 1st unit		Difference
		Dated 10-01-2021		Time	Date	
1	AGL	03:44	05:44	03:54	10/Jan/2021	-01:50
2	Hubco (N)	06:58	08:58	07:16	10/Jan/2021	-01:42
3	ATLAS	07:18	09:18	09:18	10/Jan/2021	00:00
4	Kel	08:09	10:00	08:33	10/Jan/2021	-01:27
5	Saba	08:00	09:30	11:54	10/Jan/2021	02:24

6	Npl	08:10	10:10	08:30	10/Jan/2021	-01:40
7	NCPL	08:05	10:05	08:30	10/Jan/2021	-01:35
8	Liberrty Tech	06:00	08:00	06:03	10/Jan/2021	-01:57
9	Balloki	10:00	11:40	12:29	10/Jan/2021	00:49
10	Kapco	09:21	09:31	10:46	10/Jan/2021	01:15
11	Orient	07:21	07:57	10:04	10/Jan/2021	02:07
12	Saif	08:12	08:48	11:17	10/Jan/2021	02:29
13	Saphire	07:40	08:20	11:23	10/Jan/2021	03:03
14	Halmore	09:25	10:01	13:04	10/Jan/2021	03:03
15	Chashnupp-I	09:52	16:52	14:24	12/Jan/2021	45:32
16	Chashnupp-II	09:52	16:52	03:32	12/Jan/2021	34:40
17	Chashnupp-III	09:52	16:52	14:46	12/Jan/2021	45:54
18	Chashnupp-IV	09:52	16:52	11:47	11/Jan/2021	18:55
19	Sahiwal Coal	10:40	16:07	03:06	11/Jan/2021	13:01
20	Pakgen	11:25	13:35	22:00	11/Jan/2021	32:25
21	Lalpir	12:00	14:12	13:54	10/Jan/2021	-00:18
22	Uch-I	11:04	15:54	12:51	10/Jan/2021	-03:03
23	Uchi-II	11:22	11:57	12:53	10/Jan/2021	00:56
24	Foundation	12:06	13:11	13:14	10/Jan/2021	00:03
25	Engro power	11:57	12:23	13:44	10/Jan/2021	01:21
26	Bhikki	09:13	10:43	00:14	11/Jan/2021	13:31
27	H.B.S	12:44	14:14	01:20	11/Jan/2021	11:06
28	Port Qasim	15:00	23:00	14:27	11/Jan/2021	15:27
29	China Hub	16:00	19:15	08:12	11/Jan/2021	13:15
30	Engro Thar	19:36	22:06	12:00	11/Jan/2021	13:54
31	Guddu Old	12:04	13:44	10:28	11/Jan/2021	27:16
32	Guddu -747	10:38	11:28	16:37	10/Jan/2021	05:09

From the above table, it has emerged as under:

Synchronization Time	Number of Power Plants
Less than 1 hour	03
1 – 10 hours	06
Above 10 Hours	13

Restoration of NTDC Circuits: The breakdown occurred on 23.40 hours. The restoration was initiated from Mangla Power House at 03:48 hours, continued gradually and was accomplished at 19:40 hours on 10.01.2021 when all 500/220kV NTDC grid stations/circuits from Sheikh Mohammadi up to Jamshoro were restored and KE network was synchronized with NTDC network. Overall normalcy was regained within 20 hours.

Duration for Restoration	Number of 500 and 220kV circuits
Up to 6 hours	09
6 to 12 hours	67
12 to 20 hours	21

Detail is attached at **Annex 16**

4.6.2 Restoration of Hydel Power:

First Unit Restoration Duration	Number of Power Plants
Less than 1 hour	03
1 – 04 hours	03
Above 04 Hours	10

Detail is attached at **Annex 17**

4.6.3 Restoration of K-Electric System:

Due to system breakdown, KE went under dark on 23.51 hours. The power restoration was initiated through Tapal Energy Limited on 00:47 hours and full restoration was attained at 21:15 hours on 10.01.2021. This means total normalcy time was 21 hours and 34 minutes.

- **Restoration of KE Service:**
  - i) Restoration work was taken in hand by KE and energization of all KE grid stations was achieved on 10.01.2021 at 13:35 hours after the duration of 13 hours and 56 minutes;
  - ii) 75% of the area was normalized at 19:15 hours after the duration of 14 hours and 19 minutes;
  - iii) All the residential and commercial feeders were normalized at 18:44 hours after the duration of 19 hours and 03 minutes;
  - iv) The industry was normalized at 21:15 hours after the duration of 21 hours and 34 minutes.

- **Energization of KE's own Power Plants on 10.01.2021:**

KE's Plants	External Supply to Plant at	Time to synchronize
BQPS-I	04:03 hours	15:13 hours to 16:59 hours
BQPS-II:	04:22 hours	09:12 hours to 11:45 hours
CCPP	06:11 hours	08:10 hours to 14:41 hours

- **Synchronization between KE and NTDC system:**
  K-Electric was synchronized with NTDC on 10.01.2021 at 18:48 hours after the duration of 19 hours and 03 minutes.
  Detail is attached at **Annex 18**

4.7 Previous Inquiry Reports:

Following is the statement of inquiry reports, copies of which were supplied by NTDC (GM (GSO) North and GM (NPCC)) (**Annex 19**):

4.7.1 Brief of Inquiry Reports:

Sr. #	Title of Inquiry Report	Time and Date	Remarks
1.	Power Breakdown at CPGCL Guddu	23:26 hours on 24.02.2013	System suddenly collapsed. Both 220kV and 500kV bus bars became dead Inquiry conducted by CE/TD Guddu.
2.	Major System Disturbance	12:50 hours on 12-12-2014	Power Transformers T1 & T2 at 500kV Guddu grid station tripped on over current. As a result, north system from Muzaffargarh to Peshawar went under dark. In Southern part, two islands were created. Report by NTDC.
3.	System Disturbance	05:15 hours on 08.01.2015	North system got disturbed due to trippings caused by heavy fog in Guddu, Dadu, Sukkur and Shikarpur area. Report by NTDC.
4.	System Disturbance	23:53 hours on 24.01.2015	Major disturbance occurred on the system causing frequency collapse. As a result, major part of the network from Guddu to Peshawar and Guddu to Hubco & KE suffered disturbance. Report by NTDC
5.	System Disturbance in North Region	09:21 hours on 15.01.2016	A heavy jerk was observed on the system due to damage of isolator controlling 220kV Muzaffargarh-Multan circuit. Report by
6.	System Disturbance in North Region	15:07 hours on 21.01.2016	System Disturbance occurred due to tripping of

			auto transformer T-3 along with 500kV Guddu Old-Guddu 747 circuit. Report by NTDC
7.	Power Breakdown in Sindh	Sehri Time – 28.05.2017	Power breakdown/partial system collapse of the southern power system occurred comprising of KE and HESCO areas. Report by NTDC.
8.	Partial System Collapse	16.05.2018	Incident of tripping occurred beacsue of flash on yellow phase bushing of shunt reactor at Guddu plant.
9.	Southern System (Guddu-Hubco) Collapse due to Heavy Fog in Guddu, Dadu & Shikarpur Region	25.01.2019	Due to heavy fault in Guddu, Dadu, Shikarpur & Multan regions, various 500kV and 220kV lines tripped intermittently that resulted in disturbance in the power network.

4.7.2 Consolidated Implementation Status of Above Reports:

Sr. #	Year	Action proposed	Status
1.	2015	Implementation of Under Frequency load shedding schemes to cut off the load of DISCOs at 11kV Feeders	Implemented
2.	2015	Under Frequency load shedding schemes to cut off the load at 132kV lines of NTDC/DISCOs	Implemented
3.	2016	Implementation of Cross Trip Schemes at grid stations to avoid tripping of important 500kV transmission lines and 500/220kV auto transformers during heavy load conditions	Implemented
4.	2016	During the canal closure and foggy seasons i.e. 15th Dec to 15th Feb, Hydel Generation is recommended to be maintained at 1500MW (minimum) at all times and at 2000MW during peak hours.	Not implemented.
5.	2016	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

6.	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
7.	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 in case of failure to follow the same, penalty be imposed on the power plant	Cannot be confirmed due to non-availability of online data of the system as informed by NTDC
8.	2018	Although the Under Frequency schemes/Cross Trip Schemes implemented in network successfully operated, the healthiness of the same needs to be ensured	Implemented
9.		Delay in system restoration has also been caused due to non-availability of 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
10.		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	SCADA 3 launched. Work is in progress as informed by NTDC
11.	2018	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.	In progress
12.		Study of islanding schemes needs to be carried out by International Consultants to avoid the system going towards Out of Step/Out of Synchonism.	Not implemented

Note: Despite assurance by Member (Power), the office of Member (Power) failed to provide the copy of the Inquiry Report regarding black out which occurred in Feb, 2013

5. FINDINGS:

i. On 09.01.2021 at 23:41 hours, 220kV Circuit Breaker D12Q1 at Guddu Switchyard was closed without opening the earth switch of 20kV Isolator D12Q31 which resulted in a 3 phase to earth (bolted) fault. The fault persisted as 220kV Circuit Breaker D12Q1 failed to trip;

ii. The above persistent fault reflected on 220kV and 500kV system and caused tripping of 220kV and 500kV lines;

a. Following 220kV lines tripped on operation of Distance Relays in Zone 2;

- 220kV Guddu-Shikarpur circuits I & II at Shikarpur end
- 220kV Guddu-Sibi circuit at Sibi end.

b. Following 500kV transmission lines tipped on Unstable Power Swing at 23:41 hours

- 500kV Shikarpur – Guddu I & II at Shikarpur end
- 500kV Guddu-Muzaffargarh at Guddu end;
- 500kV Guddu-DG Khan at both ends;
- 500kV 747 Guddu – Muzaffargarh at 747 Guddu end;
- 500kV RYK – Multan at Multan end.

iii. Following are the deficiencies noticed in 220kV switchyard and control room at Guddu Power House:

- Operations of 220kV Circuit Breakers D12Q1 and its relevant Isolators were carried out without instructions of NPCC;
- No interlocking arrangement among the isolators and circuit breakers;
- Symbols of earth switches installed with isolators neither shown in Single Line Diagram nor marked on mimic diagram in the control room;
- No proper preventive maintenance of switchyard equipment done;
- No periodical testing of relays and other switchyard equipment done;
- Inadequacy testing equipment;
- The switchyard equipment are in poor condition
- No routine check of control and protection schemes;
- Unawareness of even implementation of settings.

iv. As per indication record, G9 & G10 machines tripped on differential protection relays, whereas, as per log sheet, G9 & G10 tripped on distance relays;

v. The tripping of machine G14 on Unit Differential protection is not justified as it operated during through fault condition;

vi. As per log sheet provided by Guddu management, it is surprisingly noted that on 09.01.2021, 220kV Circuit Breaker D12Q1 was closed first at 23:35 hours, but, the earth

switch of 220kV Isolator D12Q31 was opened later on at 23:37 hours and tripping occurred at 23:40 hours. However, the fact remains that the system tripping occurred at 23:40 hours on closing of 220kV Circuit Breaker D12Q1 while earth switch of Isolator D12Q31 remained in closed position;

vii. The single line diagram available with NPCC does not contain symbols of earthing switches installed with isolators which actually exist in the switchyard, in the absence of which the system operator will not be able to issue proper operational instructions. This is a serious irregularity and may cause a mishap;

viii. The Internal Inquiry has been initiated by the Guddu management against the staff who are responsible for their negligence regarding improper operation of the equipment in the switchyard of Guddu Power House. However, lack of supervision is also evident in this incident;

ix. In winter season, Hydel generation is minimum. Power generated in South zone (China Power Hub, Port Qasim, Engro Thar, Uch I & II) flows to North to meet the load requirement of that zone. The tripping of 220kV and 500kV transmission lines was caused by operation of the distance relays in zone 2 and Unstable Power Swing mode respectively due to persistent bolted fault at Guddu. This tripping resulted in separation of South and North zones. (**Power Swing** is described at **Annex 20**);

x. Separation of North and South zones caused cascade tripping which resulted in the unbalance of power generation and connected load in both the zones. The power system in the South zone, including KE experienced over voltage/over speed/ over frequency due to excessive generation as compared to connected load. Whereas in North zone, where the generation was lesser as compared to the existing load, faced under frequency situation. Hence the both zones plunged into darkness;

xi. There is no centralized event recorder available with NPCC. So the sequence of tripping of transmission lines and machines in the power system cannot be ascertained precisely;

xii. It is observed that the distance relays in the system have operated randomly which is undesirable;

xiii. Both machines of China Power Hub as well as of Port Qasim power station tripped simultaneously which contributed in further aggravating of the power supply;

xiv. Most of the power plants are without black start facility except Tarbela, Mangla, Warsak and Uch Power. The black start facility was used for the restoration of power supply at Tarbela and Mangla whereas, the black start facility in Uch Power did not work. Had the black start facility of Uch powe plant been operational, it would have facilitated the restoration and curtailed the restoration time of power supply in South zone.

xv. It is noticed that none of the machines in power plants which were operational at the occurrence of event went into the islanding mode during under frequency situation which could have helped in early restoration of supply;

xvi. There are no contingency plans and the agreed procedures between the System Operator, NTDC and power plants for restoration of supply during total and partial shut downs;

xvii. Synchronization of some of the machines of Hydel power plants was within time, whereas, some units took much long time.

xviii. It is noted that the thermal power plants failed to start up and synchronize within the specified time, though notice to synch (NTS) was issued to such power plants by NPCC/NTDC. This is a major cause for delayed restoration of supply;

xix. 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 of BQPS-II came on island for short interval, but could not survive. Further, KE's own power plants took up to 17 hours for synchronization of their all units which is unreasonable time for KE being a vertically integrated utility;

xx. KE lacks black start facility on its own power plants. The IPPs i.e. Tapal and Gul Ahmed came to KE's rescue as those are equipped with black start facility;

xxi. Overall time for restoration was 20 hours and 21:34 hours for NTDC and KE respectively, which is obviously longer;

xxii. Review of the previous inquiry reports regarding the power failures revealed that the recommendations made therein were partially implemented. Proper implementation of such recommendation could have helped in avoiding the complete power system collapse/black out and reduced the restoration time.

6. CONCLUSION:

6.1 Fault, Causes and Responsibility:

The 3 phase to earth bolted fault was caused by gross negligence of Guddu Power Plant staff who operated the 220kV Circuit Breaker D12Q1 (CB) without opening the earth switch of the 220kV Isolator D12Q31 and that too without the permission of NPCC. Unfortunately, not only the CB failed to trip but CBF scheme also did not operate. As a result, cascade tripping occurred due to bolted fault which divided the power system in South and North zones. Consequently, there was sufficient unbalance between the generation and the load. In the South zone including KE, there was more generation as compared to load, which at first experienced tripping due to over voltage /over speed/over frequency and consequently on under frequency. The power system of North zone tripped on under frequency condition where the generation was too less against the load;

6.2 Restoration:

The System Operator/NTDC together with the Power Plants took around 20 hours and KE took about 22 hours for complete restoration of the power supply in their respective jurisdictions. No doubt, under such circumstances, the complete restoration of the power system takes considerable time, however, the companies could have taken lesser time for

restoration had their power plants responded appropriately. Lapses are observed on the part of power plants which despite prior notice by NPCC to synchronize failed to restart and synchronize their all units with the system in specified time. It is the obligation of System Operators of both NTDC and KE to establish contingency plans and SOPs for system recovery following the total and/or partial shutdown, however, no such document was placed in this regard before the IC. Hence, NTDC, KE together with concerned power plants are responsible for delay in complete restoration of power system.

6.3 Previous Inquiry Reports:

The review of the previous reports revealed that the recommendations made therein have been either partially complied with or still in progress or pending. Further, there are some recommendations given in previous reports which need to be carried out and monitored regularly.

6.4 Recommendations:

Following are the measures recommended in order to avoid the recurrence of such events in future;

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;

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;

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;

6.4.4 No operation of Power Houses and Grid stations be carried out without the knowledge and directions of NPCC;

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 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;

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;

6.4.8 Tripping of generating machines on over frequency/over voltage/over speed shall be managed through settings for their sequential tripping instead of their simultaneous outage;

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;

6.4.10 The power plants which were not available for synchronization despite the notice of NPCC shall be dealt with under PPA;

6.4.11 Grid Station Equipment and Protection/Control System of 220kV Switchyard Guddu shall be maintained in accordance with SOPs issued by TSG NTDC/manufacturer of the equipment;

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;

6.4.13 Interlocking scheme of equipment installed at 220kV switchyard Guddu shall be checked and ensured for proper working;

6.4.14 Indiscriminate tripping GT 14 at Guddu on Unit Differential Relay shall be checked and set right;

6.4.15 Routine testing of HV equipment at Guddu switchyard including protective relays shall be carried out regularly;

6.4.16 Technical trainings be arranged for staff and engineers at TPS Guddu for their skill improvement and capacity building;

6.4.17 The departmental enquiry initiated by Guddu Power Plant management against the delinquent staff regarding the instant breakdown be concluded;

6.4.18 Management reforms are required at TPS Guddu for systematic working;

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08/02/2021

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POWER SWING AND OUT OF STEP PROTECTION

1. Introduction:

A balance between generated and consumed active power exists during the steady-state operative condition and is necessary for the stability of the power system. Power systems are subjected to a wide range of small and large disturbances during operating conditions. Small changes in load occur continually. The power system must adjust these changing conditions and continue to operate satisfactorily and within desired bounds of voltage and frequency. The power system should be designed to survive larger types of disturbances i.e. faults, loss of a large generator, or line switching. Certain system disturbances may cause loss of synchronism between a generator and the rest of utility systems or between the interconnected power system of neighboring utilities. If such a loss of synchronism occurs it is imperative that the generator or system operating synchronously are separated immediately to avoid widespread outages and damages.

2. Definition of Power Swing:

Power swing is a variation of power flow as a result of loss in synchronism of generators which leads to a change in rotor angle. An interconnected power system has all generators running in synchronous under steady-state condition. During the steady-state condition, there is a balance in generation and load characteristics, therefore the rotor angle is constantly in steady-state condition but as soon as the fault occurs this balance between rotor angle and load characteristic is disturbed, therefore the rotor angle is changed. **The variation of power flow which occurs as a result of rotor angle change is referred to as Power Swing.** Power swing is referred as oscillation in active and reactive power flow on a transmission line consequent to a large disturbance. The oscillation in apparent power and the bus voltage is seen by the relay as an impedance swing.

3. Effects of Power Swing:

Power flow in a transmission line depends upon the voltage at both ends of the transmission line and the phase difference between the two voltages is proportional to the rotor angle. Since the rotor angle is changing, the phase difference also keeps changing, as a result the change in impedance in the transmission line occurs. Therefore power swing affects the distance relay scheme in the system. Hence the power swing becomes a need of concern.

4. Classification of Power Swing:

Power swing has two characteristics (i.) Stable Power Swing, (ii) Unstable Power Swing.

Stable Power Swing: Disturbances in load causes an imbalance in generator and load characteristics, resultantly the rotor angle is disturbed. This rotor angle tries to maintain or achieve a new angular position in an oscillatory manner. If the rotor angle can achieve a new angular position, this is called a stable power swing.

Unstable Power Swing: The generator experiences pole slip as a result of the loss of synchronism in the case of an unstable power swing. The generator rotor angle is not able to achieve a new angular position, this is called Unstable Power Swing. Therefore tripping must occur in case of an unstable power swing.

5. Consequences of Power Swing:

Depending on the severity of disturbance and the actions of power system controls the system may remain stable or experience a large separation of generator rotor angles and eventually loss of synchronism. **Large power swings can cause unwanted relay operations that can further aggravate the power system disturbance and cause major power outages and blackouts.** The

occurrence of power swing condition on a power system must be detected and appropriate protective action needs to be taken.

6. **Power Swing Blocking:**

A power swing blocking function is available in modern distance relays to prevent unwanted distance relay element operation during the power swing. **For a Stable Power Swing,** it is possible that the positive sequence impedance trajectory will traverse the operating region of a distance element. In this case, the distance element needs to be blocked from operating using power swing blocking (PSB); otherwise, an unwanted operation of a distance element can occur, further weakening an already weakened system. Therefore, all power swing conditions must be detected as rapidly as possible to prevent any unwanted operation of the protection system.

For Unstable Power Swings (or out-of-step conditions), out-of-step tripping (OST) is implemented to separate the network into islands with a generation-load balance. Stability studies determine the locations where it is best to detect the out-of-step conditions and separate the system into islands. All other locations need to implement PSB so as not to separate the system at unwanted locations. OST comes with its challenges, such as when a trip command should be issued or if the system can regain stability after experiencing a pole slip.

7. **Out of Step Protection:**

Certain power system disturbances may cause loss of synchronism between a generator and the rest of the utility system, or between neighboring utility interconnected power systems. If such a loss of synchronism occurs, it is imperative that the generator or system areas operating asynchronously are separated immediately to avoid widespread outages and equipment damage. An

effective mitigating way to contain such a disturbance is through controlled islanding of the power system using out-of-step protection systems. Controlled system separation is achieved with out-of-step tripping (OST) protection system at preselected network locations. OST systems must be complemented with out-of-step blocking (OSB) of distance relay elements, or other relay elements prone to operate during unstable power swings. OSB prevents system separation from occurring at any locations other than the preselected ones.

8. Conclusion:

i. Power systems must be designed to maintain system stability during large disturbances and utilities must take every action economically justifiable to prevent system instability, by using remedial actions or special protection systems.

ii. Out-of-step (OOS) relaying systems should be applied to preserve system stability and minimize the consequences of major disturbances. Out-of-step relaying should be depended upon as the last resort before a complete system shutdown.

iii. Out-of-step relaying systems prevent uncontrolled tripping of transmission lines, minimize the extent of the disturbance, and protect equipment from being damaged, thus ensuring personnel safety and faster service restoration.

iv. Out-of-step tripping systems should be applied at proper network locations to detect OOS conditions and separate the network at pre-selected locations only to create system islands with balanced generation and load demand that will remain in synchronism.

v. Out-of-step tripping systems must be supplemented with out-of-step blocking systems to block relay elements prone to operate during stable or unstable power swings.