REPORT OF THE INQUIRY COMMITTEE

ON

GRID INCIDENT

IN

NORTHERN REGION

ON

1st May 2006

New Delhi
JULY 2006

Acknowledgement

The committee gratefully acknowledges the cooperation extended by the officials of NTPC BTPS, BBMB, DTL, PowerGrid NR-I and NRLDC in the collection of information pertaining to Grid incident and its analysis.

The committee places on record its appreciation of the assistance provided by Shri PP Francis, DGM (OS) NTPC, Shri S R Narasimhan, CM, NRLDC, Shri Rajesh Kumar, DM, NRLDC, Shri R M Malhotra, DGM (Prot.), DTL, Shri A K Singh Sr. Manager, NRPC and Shri Vikram Singh, AEE of NRPC in analysing the causes of the Grid incident and preparation of the report.

-sd-
(S R Sethi)
Director(operation), DTL
Member

-sd-
(S K Soonee)
Executive Director, NRLDC
Member

-sd-
(R N Sen)
GM, BTPS
Member

-sd-
(T Chatterjee)
CE, GMD, CEA
Member

-sd-
(Ramesh Bahri)
GM (O&M), NR-I, PowerGrid
Special Invitee

-sd-
(Niraj Gulati)
Dy. Chief Engineer, BBMB
Special Invitee

-sd-
(R P Aggarwal)
SE(O), NRPC
Convener

-sd-
(B.K. Misra)
Member Secretary, NRPC
Chairman Inquiry Committee

Report of the Inquiry Committee on Grid incident in Northern Region on 1st May 2006

1.0 INTRODUCTION

1.1 Northern Regional Power System experienced a grid incident between 18:11 to 19:00 hours on 1st May 2006. No loss of life was reported but equipment failures/loss took place. About 1040 MW generation was lost and around 950 MW consumer load was interrupted during this event. The power system was back to normal by 20:00 hours on the same day as far as the electrical network is concerned while the generating units were synchronised by 0054 hours of 2nd May 2006.

1.2 The event was triggered at 18.11.42.305 by the failure of a 315 MVA, 400/220 kV Inter Connecting Transformer (ICT-I) at 400kV Ballabhgarh (Samaypur) sub station of POWERGRID, due to a Y-phase (of RYB) to ground fault. Restricted Earth Fault (REF) protection of the transformer operated and the fault was cleared by opening of the breakers on both the 400 kV and 220 kV side. This ICT caught fire immediately and the fire could not be controlled with the mulsifier system.

1.3 At 18.19.36.450 a second fault on Blue phase (of RYB) to ground occurred, when the fire damaged the Lightning Arrestor (LA) and the transformer bushing on the 220 kV side of the ICT-1.The jumper connecting the 220 kV side Circuit Breaker (CB) Blue phase pole (top terminal) to the transformer bushing broke off from the bushing terminal and fell down. This fallen conductor connected to the top dead terminal of the vertical CB chamber bridged the CB and created Blue phase -Earth fault from the bottom live terminal of the CB to the operating mechanism chamber. The 220 kV side isolator had remained closed and hence the broken terminal of CB had remained charged from 220 kV side. **(Refer exhibit#1)**.

1.4 The Blue phase to ground fault thus created falls within the zone of protection (CT to CT) of the ICT#1 but outside the bus bar protection zone of 220 kV Bus-2B at Samaypur (BBMB) substation. Since the CB on either side of the transformer was already open, the fault would have appeared as a case of Breaker failure (Trip command & Current in the CB circuit) and would have initiated back up tripping of all circuit breakers connected to the 220 kV bus#2B at BBMB Samaypur **(Refer exhibit#2).** Thus the fault would have been cleared in 300 ms (max) as per protection scheme. This protection however, could not be initiated since DC supply was unavailable (operators switched off the DC supply to the ICT#1 bay at 18:15:11.710 Hrs).

1.5 The fault was now an undetected bus fault (but beyond the zone of bus bar differential protection of 220 kV Bus 2B) at 220kV BBMB Samaypur and had to be cleared by remote end back up protection in Zone-II.

1.6 The three 220 kV inter-connectors between Ballabhgarh 220kV (BBMB) and Samaypur 220kV (BBMB) detected the un-cleared fault in Zone-II at Ballabgarh (BBMB) end. While circuit#1 and #3 tripped correctly in approx. 380 ms, Blue phase pole of the Ckt#2 failed to open at Ballabgarh (BBMB) end. Eventually the Blue phase fault was cleared by the tripping of 220 kV Bus coupler Breaker E-15 (between Bus 1 and 2B at 18.19.37.113 hrs) and Bus section Breaker E-10 (between Bus 2A & 2B at 18.19.37.233 hrs) at Samaypur 220kV on earth fault/overcurrent relay protection. An unbalance load current still continued to flow on the Blue phase on 220 kV Ballabgarh-Samaypur Ckt 2 due to this stuck blue phase breaker. Ideally Local Breaker Backup (LBB) protection of this breaker should have operated but it failed to operate.

1.7 Sensing the single phase unbalance current, 220 kV Badarpur – Ballabhgarh ckt #2 tripped at Ballabhgarh (BBMB) end sensing earth fault (incorrect direction sensing) at 18.19.37.393 hrs. Followed by tripping of 220 kV BTPS – Ballabhgarh ckt #1 on IDMT E/F protection from BTPS end on residual current sensing at 18:19:39.102 hrs.

1.8 BTPS Unit#3 tripped on over voltage protection at 18:19:40.537 hrs after tripping of BTPS – Ballabhgarh ckt #1 on earth fault.

1.9 BTPS at this point of time remained connected to the Northern Grid only on single 220kV BTPS- Alwar line. The system operated in this manner for 29 minutes till 18.48.19.577 Hrs when 220 kV BTPS Alwar line tripped on Single phase (R-Phase) to ground fault. This tripping caused islanding of BTPS/GT station/Pragati along with part of Delhi load.

1.10 The islanded system continued to operate, albeit with wide frequency fluctuations, for 12 minutes and collapsed when Delhi GT station isolated at 47.75 Hz disturbing Load Generation balance in the BTPS/Pragati Island. All the remaining 4 units at BTPS tripped on underfrequency.

1.11 The 220 kV BTPS Alwar- line was charged within one minute of BTPS tripping and supply taken by BTPS.

1.12 Total loss of generation was about 1040 MW. (BTPS –620 MW, Faridabad (T)-82 MW, FGPS- 179 MW, Pragati-160 MW)

1.13 There was a complete black out in part of Delhi system which includes Sarita Vihar, Lodi Road, Park Street, Gazipur, Okhla, and Mehrauli area (around 950 MW load) from 1900 hrs to 1935 hrs and it was normalised by about 20:07 Hrs.

1.14 The incident in question can be described as a series of incidents/ events in which some are related and some not related as summarized below:

1. Tripping of 400 kV Bawana- Bamnauli line at 18:00:00 Hrs (Later it was analyzed that it had no relevance to the main incident. However it diverted the attention of operators).
2. Tripping of ICT –I (400/220kV, 315 MVA) at Ballabgarh sub station of POWERGRID at 18:11:42 Hrs.

3. Blue phase jumper breaks off from ICT-I bushing and fall on CB. Caused Blue phase earth fault on 220 kV system at 18:19:36 Hrs. This fault was not cleared as explained above
4. B Phase of 220 kV Ballabgarh- Samaypur –II Line CB did not trip and continued to feed the unbalanced load current.
5. Tripping of 220 kV BTPS- Alwar line at 18:48:19 Hrs.
6. Non-operation of UFRs in Mehrauli disturbed Load –Generation (L-G) Balance in the island and consequent to the above incident all BTPS units tripped and loss of power supply occurred in part of Delhi.

1.15 Central Electricity Authority vide its order no. 5-41(12)/ Secy. / 2006/ 584 dated 2.05.06(**Annexure-I**) constituted a Committee comprising the following members to inquire into the incident and ascertain the cause of grid disturbance and suggest remedial measures to avoid recurrence of such incident:

Shri B.K. Misra, Member Secretary, NREB	Chairman
Shri S R Sethi, Director (operation), DTL	Member
Shri S K Soonee, Executive Director, NRLDC	Member
Shri R N Sen, GM, BTPS	Member
Shri T Chatterjee, CE GMD, CEA	Member

1.16 The terms of reference of the Committee are as under:

(a) To analyse the cause leading to grid incident on 1st May 2006.
(b) To suggest remedial measures to avoid recurrence of such disturbance in future including modification/revision of islanding scheme of Badarpur Thermal Power Station.

1.17 The committee visited the 400 kV Ballabgarh Sub Station of POWERGRID and 220 kV Samaypur Sub Station of BBMB located at the same place to have a first hand account of the incident and held its First meeting at BTPS on 8th May '06.Representatives from BBMB, NTPC, DTL, BTPS, NRLDC, NRPC and POWERGRID NR-I participated in the meeting and discussed the cause and sequence of the incident.

1.18 The Committee analyzed information supplied by BTPS, NTPC, BBMB, DTL, POWERGRID and NRLDC in detail, in a series of meetings held at NRLDC and NRPC secretariat and finalized the report.

2.0 Overview Of Northern Regional Grid

2.1 Northern Region is the largest in geographical area amongst the five regions in the country covering approximately 30.7% of the area and having largest number of constituents (9 states/UT's, 4 Central Generating Companies, one Central Transmission Utility and Bhakra Beas Management Board). It has largest sized hydro unit (250 MW at Nathpa Jhakri) in the country. Northern Grid has an Effective capacity of 33,256 MW as on 31.03.06. The Thermal-Hydro mix is of the order of 67:33.

2.2 Northern Region has country's first High Voltage Direct Current (HVDC) long distance transmission system in the country (2x750 MW, ± 500 kV Rihand-Dadri HVDC bipole) and first HVDC back-to-back interconnection with Western Region (2x250 MW back-to-back HVDC station at Vindhyachal). It has 1 x 500 MW HVDC back-to -back interconnection with Eastern Region at Pusauli. NR has country's first and only 400 kV Static VAR Compensators (SVC's) (2x ± 140 MVAR SVC at Kanpur).

2.3 The large Coal pithead thermal power stations are located in the extreme Southeastern part of the Regional Grid constituting generation capacity of around 6000 MW against which normal generation level is 5000-5500 MW.

2.4 Under deficit conditions in Northern region, imports up to 500 MW each from ER & WR take place and this increases the total power availability in Eastern part of NR Grid to 6000-6500 MW. The power consumption in Eastern part remains in the range of 2500-3000 MW. Thus remaining power of the order of 3500 to 4000 MW has to flow from Southeastern part of the grid to Central and Western part of grid.

2.5 To handle this bulk transmission of power, a point to point high voltage DC line viz. HVDC Rihand-Dadri bipole with capacity of 1500 MW exists and operates in parallel with nine 400 kV AC transmission lines connecting Eastern part (Eastern UP subsystem) with Rest of Grid besides under lying 220 kV network.

2.6 With the commissioning of Tala transmission system and the East – North AC interconnector, Northern Region would come in synchronism with the Central Grid (ER, NER and WR) shortly.

2.7 The operation of the entire Northern Regional grid is co-coordinated in real time by the Northern Regional Load Despatch Centre (NRLDC) and eight State Load Despatch Centres (SLDCs).

The Map indicating 400 kV and above lines in NR is enclosed at **Exhibit- III.**

3.0 ANALYSIS OF CAUSE OF GRID DISTURBANCE

Antecedent conditions:

System Conditions at 1800 hrs on 01st May 2006

A. Frequency 50.4 HZ

B. Voltage Profile

	Station	*kV*		*Station*	*kV*
1	Badarpur	222	7	Hissar	412
2	Salal	220	8	Jallandhar(PG)	416
3	Bhakra	228	9	Kanpur	408
4	Ballabgarh	415	10	Kishanpur	405
5	Bassi	421	11	Moga	409
6	Dadri	417	12	Panipat	406

C. Generation

	NTPC	MW
1	Singrauli	1515
2	Rihand	1514
3	Unchahar	840
4	Dadri NCTPS	575
5	Anta GPS	363
6	Auraiya GPS	268
7	Dadri GPS	650
8	Badarpur	620
9	Faridabad GPS	175
10	Tanda	296
		6816

	NPC	MW
1	NAPS	162
2	RAPS-A	142
3	RAPS-B	308
		612

	NHPC	MW
1	Bairasiul	60
2	Salal	654
3	Tanakpur	45
4	Chamera-I	180
5	Chamera-II	254
6	Uri	480
7	Dhauliganga	129
		1802

	BBMB	MW
1	Bhakra Complex	869
2	Dehar	560
3	Pong	258
		1687
1	SJVNL	1197

	Delhi	MW
1	Indraprastha	95
2	Rajghat	56
3	Delhi GT	174
4	Pragati	309
		634

	Haryana	MW
1	Faridabad	80
2	Panipat	905
3	WYC	34
4	Magnum	0
		1019

	Punjab	MW
1	Ropar	1050
2	Bhatinda	304
3	Lehra	212
4	Punjab(H)	374
		1940

	Rajasthan	MW
1	Kota	966
2	Suratgarh	1130
3	Ramgarh GT	44
4	RPS+ JS + Mahi	0
5		
		2140

	Uttar Pradesh	MW
1	UP (Th)	2201
2	UP (Hy)	105
		2306

	Uttranchal (Hy)	431
	Jammu & Kashmir (Hy)	130
	Himachal Pradesh (Hy)(Assumed)	202

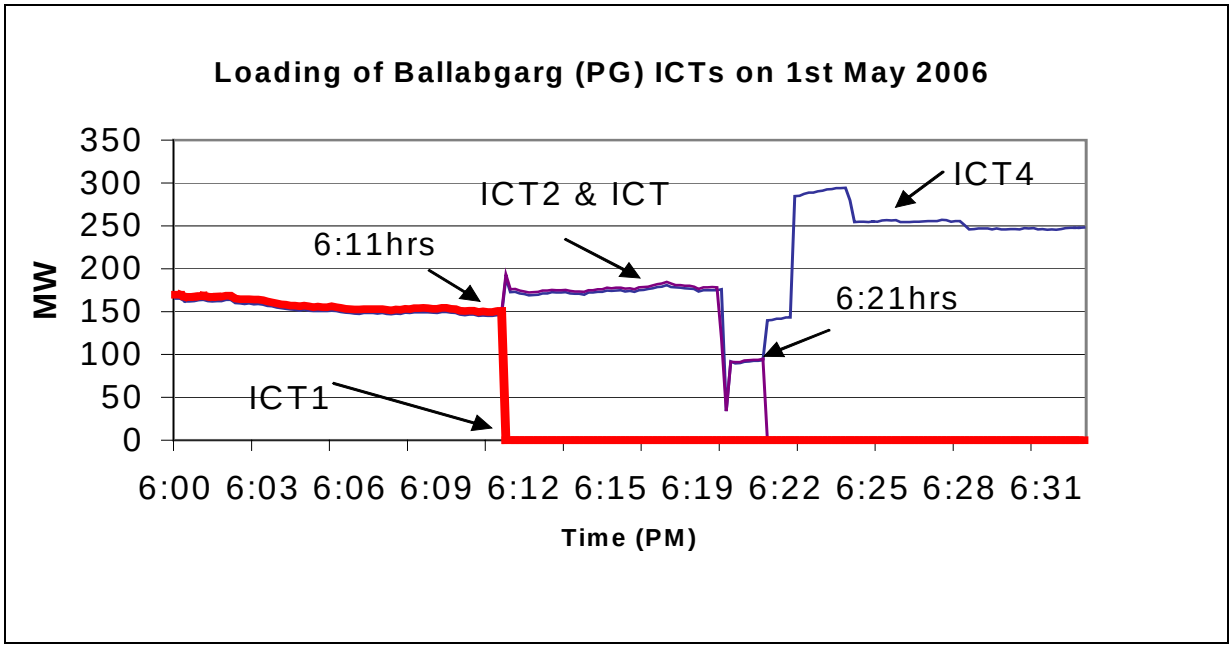
A.	Total NR Generation	20916
B.	ER-NR Corridor	296
C.	HVDC BTB Vindhyachal	0
E.	NR Load (E=A+B+C)	21212

D. Loads,Schedules & Drawls

	States	Gross Load(MW)	Central Sector Schedule(MW)	Actual Drawal from grid(MW)	Overdrawal / Underdrawal(MW)
1	Punjab	3857	1725	1799	74
2	Haryana	3004	1331	1799	468
3	Rajasthan	2802	1419	496	-923
4	Delhi	2956	1596	1808	212
5	Uttar Pradesh	5082	2399	2969	570
6	Chandigarh	180	171	180	9
7	Himachal Pradesh	356	562	168	-394
8	Jammu Kashmir	940	813	810	-3
9	Uttaranchal	403	258	194	-64
		19580	10274	10223	-51

	Inter Regional Exchange (+ import/- Export)	Scheduled Exchange (MW)	Actual Exchange (MW)
1	ER-NR Corridor	142	296
2	HVDC back to Back Vindhyachal	0	0

3.1 ICTs loading at Ballabgarh (POWERGRID) from 18:00 hrs to 19:00 Hrs



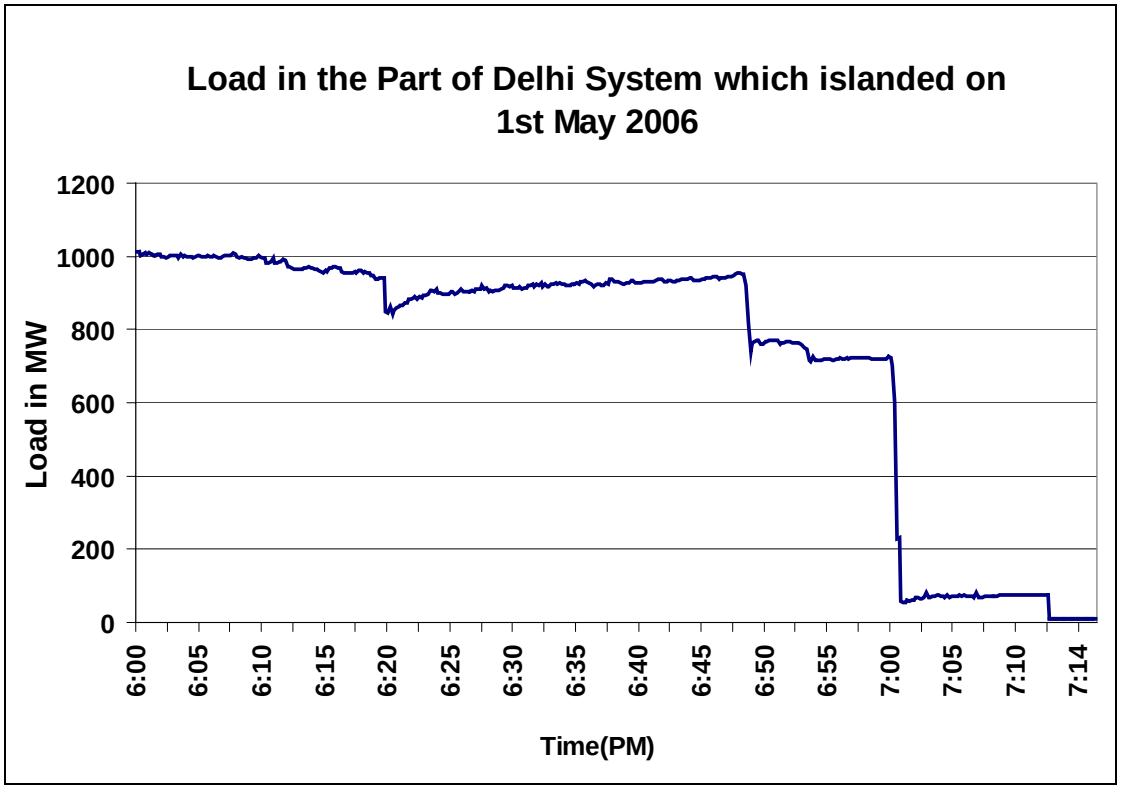
Ballabgarh 400/220 kV substation (POWERGRID) houses four ICTs of 315 MVA each, which were in operation at the time of incident and were equally loaded as shown above .At 18:11:42 hrs ICT- I tripped and reportedly caught fire. ICT 2 and 3 were manually tripped at 18:21:10 Hrs as they were adjacent ICT -I, in the proximity of fire. ICT -4 however continued to remain in service.

The above graph shows the loading of ICT 1, 2 and 4. The loading of ICT 3 was same as that ICT 2.

3.2 Load in part of Delhi system which islanded during disturbance

The system includes 220 kV Sub Stations at Sarita Vihar, Lodi Road, Park Street, Gazipur, Okhla and Mehrauli. (Refer Delhi power map placed at exhibit -IV) As shown in the graph the load was around 1000 MW at 18:10 hrs (6.10 PM).

This part of Delhi system experienced a load throw off of about 90 MW at 18:20 hrs at the time of second incident. The load stabilized at 910 MW at 18:25 and was slowly building up and reached about 953 MW just before islanding of BTPS at 18:48 hrs. The islanded mode carried a load of about 740 MW to 725 MW for about 12 minutes as shown in figure below.



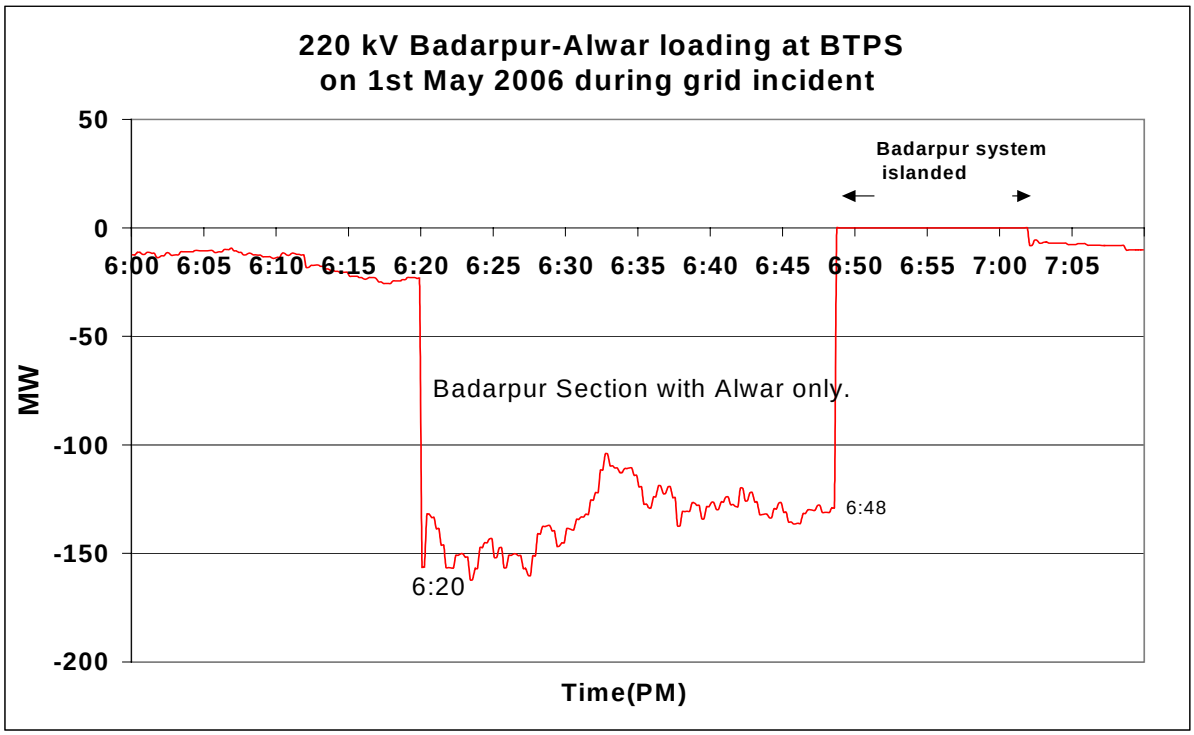
3.3 Line loading at BTPS at 1800 Hrs

The loading details of lines connected to BTPS bus at 1800 Hrs are as under

Line	Sarita Vihar I&II	Mehrauli I & II	Ballabgarh I & II	Alwar	Okhla	Noida
MW	165	230	-170	-10	270	85
MVA	30	0	-60	-20	20	-10

3.4 220 kV Badarpur –Alwar line loading (from 18:00 to 19:10 Hrs)

There was an import of about 10 MW to Delhi system through 220 kV Badarpur –Alwar line as shown below at 18:10 Hrs and about 20 MW at 18:19 Hrs. The import increased to 150 MW after tripping of 220 kV BTPS-Ballabgarh circuits at the time of incident and the line stabilized at 130 MW feeding Delhi area before BTPS islanding.



3.5 Timeline of incident on the 1st May 2006:

- The timeline of incident events given below is based on the reports received from BBBM, NTPC, POWERGRID, Sequence of Events (SoE) recorded at NRLDC, Historical Data Recording (HDR) at NRLDC. The timings are as recorded at NRLDC (GPS time-synchronized). *Sequence of Events recorded at different control Centres in the Region and merged at NRLDC is enclosed at* ***Annexure –II.***

Since there were a series of incidents/ events, in which some are related and some non-related to the main incident. These are summarized below:

- The first incident was the tripping of 400/220 kV ICT-1 at Ballabgarh (POWERGRID) on restricted earth fault (REF) for the fault in Y-Phase and OLTC Surge relays trip at ***18.11.42.305 hrs.***

- The second incident is considered when the 220 kV side Blue phase jumper breaks off from the 400/220 kV ICT –I bushing at Ballabgarh (POWERGRID) and fell on Circuit breaker, causing Blue phase earth fault on 220 kV side at 18.19.36.450 hrs.

- The third incident was the tripping of 220 kV BTPS- Alwar line, causing islanded operation of BTPS with part of Delhi system at 18:48:19 hrs.

3.5.1 Tripping of 400 kV Bawana- Bamnauli-I from Bawana end at 18:00:00.478 hrs

DTL has intimated that 400 kV Bawana-Bamnauli-I tripped at Bawana end at lock out (85 LO) and no other log details appeared at either end. The reason for the tripping could be the spurious Carrier signal received from Bamnauli end. **This event was however**

not related to the main incident The line was restored at 18:14:54.467 Hrs, about 5 min prior to the tripping caused by fault due to falling of jumper on 220 kV side Circuit breaker of ICT-I. (**Second incident**)

3.5.2 First incident: Tripping of 315 MVA ICT-1 at Ballabgarh (POWERGRID)

The first incident was the tripping of the 315 MVA 400/200 kV ICT-1 at Ballabgarh (P0WERGRID) on Restricted Earth Fault (REF) for the fault in Y-Phase and OLTC Surge relays trip at ***18.11.42.305 hrs (taken as t=o)***

Event start time: 18:11:42.305 taken as zero time for first incident (ICT-I failure)			
S. No.	**Time t =**	**Event**	**Remarks**
1	-11m: 41 sec .827 ms	400 kV Bawana- Bamnauli ckt-1 tripped from Bawana end at 18:00:00:478 hrs	85 LO, spurious tripping
2	-59 ms	220 kV Samaypur-Dadri tripped from Samaypur end at 18.11.42.246 hrs	Mal operation of LZ96.
3	**t= 0 (Start)**	400/220 kV ICT-1 at Ballabgarh (POWERGRID) Tripped on REF for the fault in Y-Phase and OLTC Surge relays trip at 18:11:42.305 Hrs	This transformer caught fire during this as oil reportedly spilled out of bushing.
4	558 ms	220 kV Samaypur – Badshahpur-II tripped at Badshahpur	Appears to be a case of maloperation.
5	5 sec 29 sec 843ms	Faridabad (Th) Unit-1 Tripped at 18.16.12.148 Hrs.	---
There was no effect on the grid by this incident (Tripping of ICT -I).			

3.5.3 Operators action after the fault

The operators at 400/220 kV Ballabgarh (POWERGRID) switched off the DC supply of 400/220 kV ICT-1 bay at 18:15:11.710 hrs and opened the 400kV side isolator manually, but the 220 KV side isolator could not be opened even manually due to its proximity to the transformer on fire. The adjacent 400/220 kV ICTs 2 & 3 was opened manually as a precautionary measure

3.5.4 Second incident: Fault due to Snapping off of jumper from 400/220 kV Ballabgarh ICT –1 220 kV side bushing after it caught fire.

Event start time: 18.19.36.450 hrs taken as zero time for second incident (Earth Fault on 220 kV side of ICT-1 at Ballabgarh POWERGRID)			
S. No.	**Time t =**	**Event**	**Remarks**
1	**t =0 (Start)**	A second fault on Blue phase to ground occurred, when the fire damaged the LA and the transformer bushing on the 220kV side of the ICT-1.The jumper connecting the 220kV side CB Blue phase pole (top terminal) to the transformer bushing broke off from the bushing terminal and fell down.	This fallen conductor connected to the top dead terminal of the vertical CB chamber bridged the CB and created Blue phase -Earth fault from the bottom live terminal of the CB to the operating mechanism chamber.
2	393 ms	220 kV Samaypur-Ballabgarh-1 & 3 Tripped from Ballabgarh (BBMB) end at 18:19:36.843 hrs and 18.19.36.849 hrs.	Line Tripped in Zone-II at Ballabgarh (BBMB). B-Phase CB of 220 kV Samaypur –Ballabgarh-II failed to open and fed fault as evident from DR received from Ballabgarh (BBMB).
3	649 ms	220 kV Samaypur-Badshahpur-1 tripped from Badshahpur end 18.19.37.99 Hrs	However the delayed tripping (greater than Zone-II timing of 350 ms needs to be investigated.
4	683 ms	220 kV Bus Coupler (E_15) at Samaypur tripped at 18.19.37.113hrs.	On over current/earth Fault Relay
5	783 ms	220 kV Bus Sectionalizer (E_10) at Samaypur tripped at 18.19.37.233 hrs	On over current/earth Fault Relay. This Isolated the B-Phase fault that appeared on the 220 kV side of ICT-1. **Fault was cleared at this time**.
6	943 ms	**220 kV BTPS-Ballabgarh-II tripped at Ballabgarh end at 18.19.37.393 hrs.**	**On operation of numerical over current protection P-127.Wrong direction sensing. This is of academic interest, as the circuit would have tripped in any case from BTPS end in Sl no. 9.**
7	1 sec 324 ms	220/66 kV ICT-2&3 at Ballabgarh (BBMB) tripped at 18.19.37.774 hrs.	

Event start time: 18.19.36.450 hrs taken as zero time for second incident (Earth Fault on 220 kV side of ICT-1 at Ballabgarh POWERGRID)			
S. No.	**Time t =**	**Event**	**Remarks**
8	1 sec 719 ms	220/66 kV ICT-2 Ballabgarh (BBMB) restored 18.19.38.169 hrs	
9	**2 sec 652 ms**	**220 kV BTPS-Ballabgarh-I tripped at Badarpur end at 18.19.39.102 hrs.**	**On IDMT Earth Fault Protection.**
With the tripping of 220 kV BTPS-Ballabgarh D/C, BTPS/GT Station/Pragati-GT-1, the system remained connected with Northern Grid through 220 kV BTPS-Alwar line only.			
10	4 sec 87 ms	BTPS Unit-3 tripped at 18.19.40.537 hrs	On Generator Over voltage.
11	7 sec 969 ms	Faridabad Th (HPGCL) Unit-3 tripped at 18.19.44.419 hrs.	
12	8 sec 650 ms	Faridabad Th (HPGCL) Unit-2 tripped at 18:19:45.100 hrs	
13	14 sec 750 ms	Faridabad GAS (NTPC) Unit-2 and Unit-3 tripped at 18:19:51.200 Hrs.	GT (Unit-2) tripped when load throw off occurred and fuel firing system change over from "Pre-mix" mode to "Diffusion" mode failed. STG (Unit-3) tripped on interlock on all GTG trip.
14	23 sec 74 ms	Faridabad Th (HPGCL) Unit-1 tripped at. 18.19.59.524 hrs	
15	4 min 34 sec 310 ms	**400/220 kV ICT-2 at Ballabgarh (PG) opened from 400kV as well as 220 kV side at** 18.21.10.760 hrs.	**(Manual operation as a precautionary measure considering the possibility of the fire spreading from ICT-1 to this transformer)**
16	5 min 38sec 530 ms	400/220 kV ICT-3 at Ballabgarh (PG) opened from 400 kV side18.22.14.980 hrs.	**(Manual operation as a precautionary measure considering the possibility of the fire spreading from ICT-1 to this transformer)**
17	8 min 39sec 527 ms	220 kV Samaypur-Dadri closed at 18.28.15.977 hrs.	
18	13 min 520sec 680 ms	220/66 kV ICT-3 at Ballabgarh restored 18.33.29.133 hrs	

3.5.5 Tripping Details of Generating Units

1. Faridabad thermal (HPGCL) Installed Capacity = 3x60 = 180 MW

Unit #	Time of tripping	MW at 1800 hrs.	Reason of tripping	Remarks
2	18:16:12.148 Hrs.	42 MW		
3	18:19:44.419 Hrs.	40 MW		
1	18:19:45.100 Hrs.	0 MW		
Total		**82 MW**		

2. Faridabad GPS (NTPC) Installed Capacity = 2x143 +1x144 = 430 MW

Unit #	Time of tripping	MW at 1800 hrs.	Reason of tripping	Remarks
2	18:19:51.200 Hrs.	114 MW	GT (Unit-2) tripped when load throw off occurred and fuel firing system change over from "Pre-mix" mode to "Diffusion" mode failed. STG (Unit-3) tripped on interlock on all GTG trip	
3 (STG)	19:0:8.751 Hrs.	65 MW		
Total		**179 MW**		

3.5.6 Third incident: Tripping of 220 kV BTPS-Alwar line.

The tripping of BTPS -Alwar line is considered as third incident which caused islanding of BTPS with Delhi system.

Event start time: 18.48.19.577 hrs taken as zero time for third incident (220 kV BTPS- Alwar Tripping)

S. No.	Time t =	Event	Remarks
1	t =0 (Start)	*220 kV BTPS- Alwar tripped at* 18.48.19.577 hrs*. (Antecedent import by Delhi on this line was 130 MW)*	On R-Phase to ground fault as evident from DR received from Badarpur of this line, resulting in islanding of BTPS system. Relay Indication at Alwar-Phase-A, Zone-II, Trip A, B, C. Distance 134.4 Km From Alwar. (Line length 136 kms.)

Resulted in formation of BTPS/Pragati/GT island with generation of 810 MW, and load of 940 MW. There was a decline in frequency due to loss of this import and Pragati GT-1 tripping at sl no.2 below and UFR shedding occurred to quickly cause frequency recovery to 51.0 Hz.

Event start time: 18.48.19.577 hrs taken as zero time for third incident (220 kV BTPS- Alwar Tripping)			
S. No.	**Time t =**	**Event**	**Remarks**
2	6 sec 16 ms	*Pragati unit GT # 1 Tripped. At* 18.48.25.593 hrs	This event didn't appear in DTL SLDC system SOE. Tripping time taken from Pragati event logger send by DTL. Unit tripped on flame failure.
3	1 min 3 sec 363 ms	220 kV Ballabgarh-Samaypur-1 restored at Ballabgarh. 18.49.22.940	
4	1 min 41 sec 636 ms	220 kV Ballabgarh-Samaypur-3 restored at Ballabgarh at 18.50.0.986 Hrs.	
5	11 min 34 sec 490 ms	220/66 kV, 2 x 100 MVA transformers at 220 kV Pragati substation in Delhi tripped at 18:19:54:067 hrs.	Tripped on under frequency set at 47.75 Hz.
Delhi GT station is connected on the 66 kV side of this station and tripping of these ICTs caused further sub-islanding of the GT station. Before this tripping, the GT station was injecting 100 MW to the BTPS main island. This caused a frequency dip in the BTPS island and the trippings at S. nos. 6 onward followed.			
6	11 min 34 sec 797 ms	220 kV BTPS-Ballabgarh-2 tripped from Badarpur end at 18.59.54.374 hrs. (It had already tripped from Ballabgarh (BBMB) end in the second incident as mentioned earlier.	Tripped on under frequency set at 47.6 Hz.
7	11 min 49 sec 174 ms	BTPS #2 tripped at 19.00.08.751 hrs.	Due to tripping of both FD fan.
8	12 min 01 sec 125 ms	BTPS #4 tripped 19.00.20.702.	Due to Excitation system fault.
9	12 min 3 sec 648 ms	BTPS #5 tripped 19.00.23.225.	Due to Excitation system fault.
10	12 min 06 sec 633 ms	BTPS #1 tripped 19.00.26.21.	Emergency Stop Valve (ESV) closing due to pressure drop.
	Badarpur Island collapsed approximately 12 minutes after its formation at 18.48.19.577 hrs.		

3.6 Analysis of the various trippings:

3.6.1 Fault in the 400 /220 kV, 315 MVA ICT-1 at Ballabgarh (POWERGRID)

This ICT (an autotransformer) was manufactured by BHEL in the year 1986 and was commissioned on 26th September 1988. POWERGRID has intimated that the transformer was maintained as per their normal schedule and there was no history of any abnormality in this transformer. In October 2004, conditional monitoring of this transformer including tanδ, Dissolved Gas Analysis (DGA), Residual voltage measurement (RVM), di-electric test etc. were carried out and no abnormal conditions were reported. After that during regular annual maintenance as per schedule no abnormalities were found. The transformer loading before the time of fault was approximately 170 MVA.

The transformer caught fire (most likely oil splashing from the OLTC chamber cover / bushing flange rupture caught fire, outside the tank) and the mulsifier was not effective in containing this magnitude of fire. The transformer has handled the fault current for approximately 50 msec. POWERGRID informed that the mulsifier system was not designed to extinguish this magnitude of fire.

The internal fault in ICT was cleared by opening of 400kV/ 220 kV main CBs at 18.11.42.305 on Restricted Earth Fault (REF) & OLTC surge relay operation. Differential protection (RADSB of ABB) of the transformer did not operate in this incident. POWERGRID felt that differential protection non-operation may be in order considering the restraint features in the relay, but other members of the committee felt that it should have operated in much less than 60ms of fault clearance.

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3.6.2 Tripping of 220 kV Samaypur-Dadri and 220 kV Samaypur Badshahpur-II.

The 220 kV Samaypur -Dadri tripped from Samaypur end (in the wrong direction) for the fault on 400/220 kV ICT-I. The flag indications were LZ-96 scheme – DHRS, MM3V scheme- 85X3, 30k. This is a clear case of maloperation.

220 kV Samaypur-Badshahpur-II tripped from Badshahpur end at 18:11:42.244 Hrs. need more investigation by the protection engineers and appears to be a case of over reach.

These trippings however, had no significant effect on the subsequent events.

3.6.3 Effect of DC Supply Switching off to ICT -1 at Ballabgarh (POWERGRID) after the fire incident on 400/220 kV ICT-1.

Although the breakers of this ICT tripped, the circuit was not isolated by opening the isolators on both the 400 kV and 220 kV side from the Control Room. POWERGRID stated that the isolators are normally not opened as a matter of practice until the circuit is required to be taken out for longer duration. The ICT caught fire and the operators in their best judgment switched off the DC Supply of ICT-1 bay at 18:15:11.710 hrs. This prevented any possibility of remote opening of the isolators.

Though the 400 kV side isolator was opened locally, the 220 kV side isolator at Ballabgarh (POWERGRID) side was not possible to be opened locally as the location was very close to the ICT on fire. POWERGRID operator also did not inform the adjacent BBMB switchyard about the fire and the need for opening the isolator at their end. Had DC of the Bay not been switched off, the 220 kV isolator could have been opened from control room.

Further even if the isolator was not opened, the bay would continue to have been protected and LBB Protection would have operated when the second fault on 220 kV side occurred. This would've tripped breakers connected to 220 kV Bus 2B of BBMB Samaypur detecting failure of ICT-I circuit Breaker (which were already opened). So the second fault would have been cleared by the loss of only Bus-2B at BBMB Samaypur 220 kV substation and BTPS and Faridabad GPS system would not have been affected.

3.6.4 Why did 220 kV Faridabad GPS- Samaypur D/C, 220 kV Samaypur-Palli ckt 2 not trip from Samaypur in Zone-II?

The Faridabad - Samaypur ckts did not trip possibly due to under reach due to low in-feed and the reason for non-tripping of Palli ckt 2 is also not known and needs further investigation by POWERGRID and HVPNL.

The Faridabad GPS units had reportedly tripped when load throw off occurred on the GTG#2 and fuel firing system change over from "Pre-mix" mode to "Diffusion" mode failed. This problem needs to be looked into by NTPC for necessary corrections in the process control.

3.6.5 Why did the blue pole of the breaker of 220 kV Samaypur-Ballabgarh BBMB ckt 2 at Ballabgarh end fail to open? Why didn't the LBB protection of this breaker operate?

It was informed that the Blue phase pole of the Breaker had failed to open.. Had this blue pole breaker opened, the 220 kV BTPS-Ballabgarh D/C line would not have tripped as there would have been no unbalance currents fed. Even if this blue pole had failed to trip, LBB protection of this breaker should have operated and tripped all the other lines connected to this bus as well as the Samaypur end breaker of this line. This did not take place and reportedly the LBB protection relay (Alstom make) was found defective and has been since replaced.

3.6.6 Why did 220 kV BTPS – Ballabgarh -II trip at Ballabgarh end?

At 18:19:37:393 hrs, 220 kV BTPS-Ballabgarh-II tripped from Ballabgarh end on operation of numerical over current protection P-127.From the DR forwarded by NTPC (enclosed at annexure), it can be derived that 'B' phase fed a fault current of the order of 3.55 kA for about 600 msec and voltage dip in the B phase touched 104 KV on BTPS side. The direction of fault sensing by the Ballabgarh BBMB end is incorrect and needs to be corrected. But this tripping in this case is of academic interest only and the breaker at BTPS end would have any way tripped.

3.6.7 Why did 220 kV BTPS – Ballabgarh I trip at BTPS end?

220kV Badarpur - Ballabhgarh # 1 tripped after feeding the Blue phase unbalanced current for more than 2.5 seconds on IDMT Earth Fault protection. This has been attributed to an unbalance in the system as the Blue phase of 220 kV Ballabgarh BBMB-Samaypur BBMB Ckt-II was still connected and feeding the healthy 220 kV circuits from Samaypur BBMB.

3.6.8 Why couldn't the 220 kV BTPS-Ballabgarh circuits be quickly closed and the BTPS/Delhi system made more reliable between 18:19 to 18:48 hours?

It was opined that as the fault was cleared from BTPS 220 kV bus and Ballabgarh 220 kV bus, the line between BTPS (NTPC)-Ballabgarh (BBMB) should have been closed. BTPS and BBMB station engineers informed that they had contacted NRLDC and were waiting for the code from NRLDC to close the line section.
The matter has been examined in detail and it has transpired that BTPS has informed NRLDC at around 1826 hours of the status of the circuits to Ballabgarh BBMB viz. Ckt 2 was charged from BTPS end while Ckt 1 was tripped at their end. NRLDC engineers did not immediately give any instruction to BTPS as the matter required further examination; particularly as the 400/220 kV ICTs were being opened manually at Ballabgarh POWERGRID.

In order to avoid an overload of alarms and thereby confusing the operator, only important 400 kV and 220 kV element alarms appear in the ALARM list at NRLDC while alarm on other 220 kV and 132 kV circuits appear at the SLDCs. Therefore, the tripping of 220 kV circuits between Samaypur and Ballabgarh were not noticed by the NRLDC operator and he did not attempt closing of the 220 kV BTPS-Ballabgarh fearing that it might overload the lone 400/220 kV, 315 MVA ICT-4 at Ballabgarh POWERGRID. Of course, if the operators at NRLDC had opened the 220 kV Samaypur or Ballabgarh BBMB switching diagram, things might have been more clear i.e. the 220 kV Ballabgarh BBMB sub-station was disconnected from Samaypur BBMB substation and connecting the 220 kV BTPS-Ballabgarh D/C sections would have had no effect on

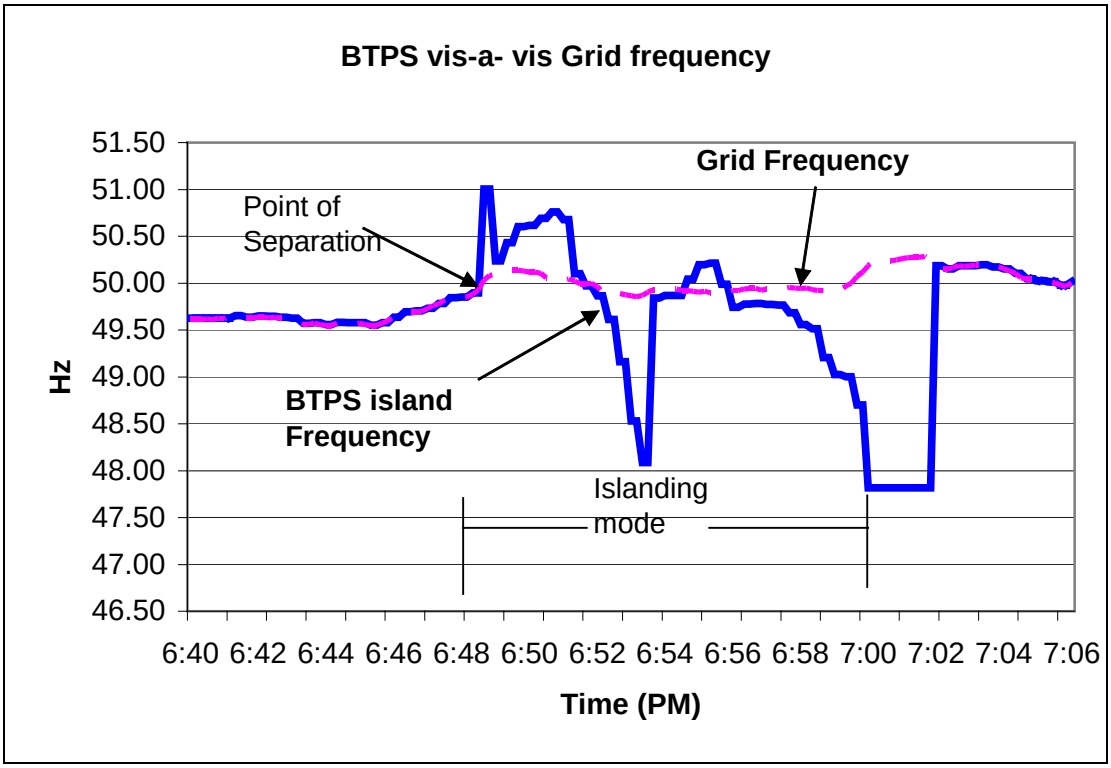
the loading of the 400/220 kV 315 MVA ICT-4 at Ballabgarh (POWERGRID).

Other options such as closure of 220 kV bus coupler at Mehrauli or closure of 220 kV Bamnauli-Mehrauli were being explored in consultation with DTL SLDC. Even before this could be effected, the 220 kV BTPS-Alwar line tripped on fault and resulted in islanding of BTPS/GT/Pragati-I system from rest of the grid. Had NRLDC permitted the closure of one of the BTPS –Ballabhgarh circuits during the intervening period the islanding and partial collapse of Delhi could have been avoided. 220 kV BTPS-Alwar line unexpectedly tripped before this could be done.

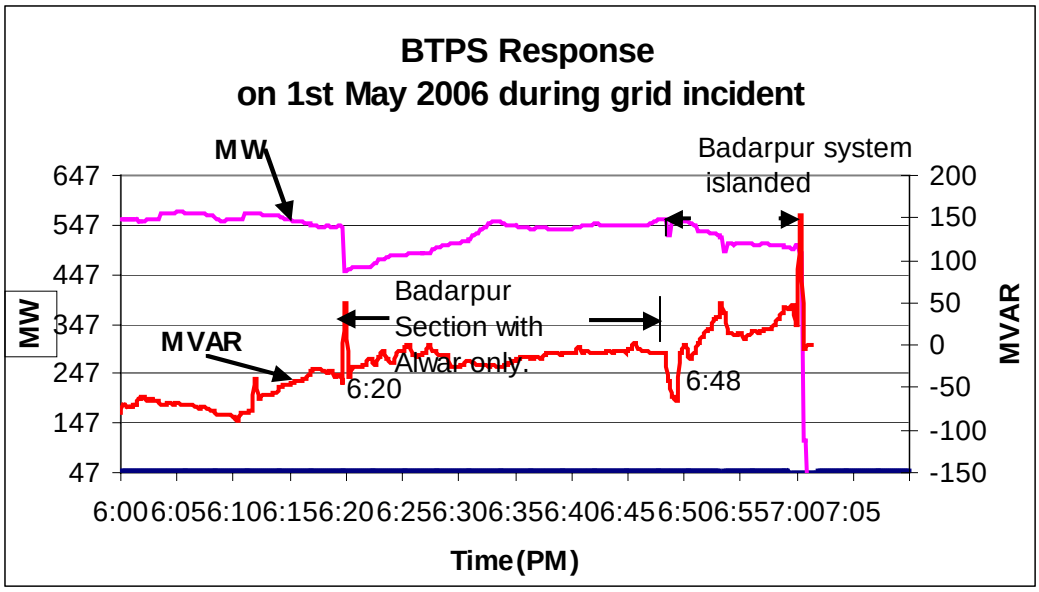
This incident highlights the need for proper situational awareness & security assessment at the SLDC level. This would ensure coordination with NRLDC during a crisis so that corrective actions can be taken quickly.

3.6.9 Performance of BTPS during the incident.

As per report received from NTPC BTPS was generating about 620 MW at 18:00 Hrs.



BTPS unit # 3 tripped at 18:19.44.419 Hrs on over voltage, at the time of second fault (Blue phase - earth fault). The output reduced to 455 MW and stabilized at around 550 MW at this point of time till islanding. During islanding, it generated from 500 to 550 MW with varying frequency as shown above.



The committee feels that Governor Control (FGMO) of the Generating units is quite important for the survival of the islands formed during system disturbances. It was noted that a task force set up by CEA is working on the subject on the basis of the matter being referred to it by the CERC.

3.6.10 Under Frequency Relay (UFR) operation in Delhi system

The frequency varied from 47.81 Hz to 51.03 Hz during islanding mode. The UFRs operated and provided relief. The details of UFR operation are stated below.

S.no	Location (220kV s/stn)	UFR settings (Hz)	Time of operation	Load Relief
1	Gazipur	50.0 Hz/ 0.4 Hz/ sec (df/dt) 47.0 Hz (UFR)	18:45:01:441 18:48:20.078	3 MW
2	Park Street	48.0 Hz (UFR) 48.1 Hz (UFR)	18:48:20.795 18:48:20.795	143 MW
3	Okhla	48.0 Hz (UFR)	18:48:20.850	41 MW
4	Lodhi Road	47.0 Hz (UFR)	18:48:23.213	34 MW
5	Sarita Vihar	48.80 Hz (UFR)/ 0.12 Hz/ sec slope	18:53:29.519	45MW
6	IP Extension	47.7 Hz (UFR)	18:48:23.126	
7	Mehrauli	48.0 Hz (UFR)	Did not operate due to defective PLC.	

3.6.11 Effect of splitting of 220 kV ring in Delhi system

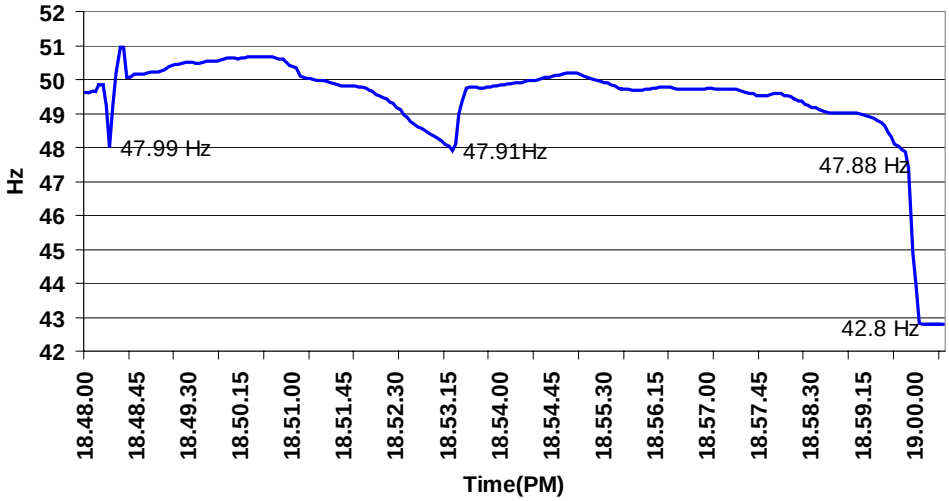
The 220 kV Delhi ring is split at four locations namely at Narela, Najafgarh, Mehrauli, and Pragati 220 kV substations. BTPS / IP / Pragati Generating Station and a large part of Delhi are connected to the Regional Grid only at two locations. One at Ballabhgarh (through D/C line) and the other at Alwar (S/C line). The situation has arisen out of the fact that with the establishment of the 400kV ring, it has become impossible to keep the 220 kV ring also closed due to increased Short Circuit levels, which is beyond the capability of the switching devices and loop flows over the 220kV system. Within these constraints, the system is being operated with reduced relaibilty.

3.6.12 Non Operation of UFRs in Mehrauli area

Committee feels that BTPS islanding scheme performance was quite satisfactory. The island would've survived for more time if relief had been provided by Mehrauli area. The UFRs in Mehrauli (set at 48.0 Hz) did not operate at islanding and the load on the island was such that at around 1900 hours when IP Gas units separated as frequency dropped, the island collapsed. Even during this event, UFRs at Mehrauli failed to operate because of faulty programmable logic controller (PLC) provided for load rostering.

BTPS frequency plot based on 3 sec data received from BTPS during grid disturbance on 1st may 2006.

BTPS Frequency in Islanding mode on 1st May 2006



4.0 Review of Restoration

The system restoration started within one minute after BTPS tripping
The final restoration sequence is as under:

S.No.	Tine (hrs)	Restoration Event	
1	19.01.47.589	220 kV BTPS-Alwar restored	**Start up supply extended to BTPS within 1 minute. Code for closing the ckt was given at 1857 hrs much before the collapse of Delhi island.**
2	19.02.02.108	220 kV Sectionalizer closed at Samaypur.	
3	19.03.18.167	220 kV Mehrauli-Bamnauli-1 opened from Mehrauli end.	
4	19.06.15.102	220 kV Mehrauli-Bamnauli-1 closed from Bamnauli end.	
5	19.09.52.729	220 kV Mehrauli-Bamnauli-1 closed at Mehrauli.	
6	19.09.57.421	220 kV Bus Coupler at Mehrauli closed.	
7	19.11.45.124	220 kV Badsahpur-Samaypur-2 restored.	
8	19.12.57.269	220 kV Badsahpur-Samaypur-1 restored.	
9	19.14.05.113	220 kV Bus Coupler at Samaypur closed.	
10	19.14.17.697	220 kV Samaypur- Palwal-2 opened.	
11	19.15.05.439	220 kV BTPS- Ballabgarh-1 restored.	
2	19.15.59.937	220 kV BTPS- Mehrauli-1 restored.	
13	19.16.14.297	220 kV BTPS- Mehrauli-2 restored.	
14	19.19.38.152	220 kV BTPS- Ballabgarh-2 restored.	
15	19.25.21.899	220 kV BTPS- Sarita Vihar-1 restored.	
16	19.25.35.353	220 kV BTPS- Sarita Vihar-2 restored.	
17	19.25.46.119	220 kV Samaypur- Badsahpur-2 opened.	
18	19.25.49.528	220 kV Samaypur- Badsahpur-1 opened.	
19	19.35.28.336	**400/220 kV ICT-3 at Ballabgarh restored.**	
20	19.43.09.281	220 kV Samaypur-Badsahpur-2 restored.	
21	19.43.50.781	220 kV Samaypur-Badsahpur-1 restored.	
22	20.26.07.463	220 kV BTPS- Okhla-1 restored.	
23	20.27.05.749	220 kV BTPS- Okhla-1 restored.	
24	20.41.15.628	Faridabad Gas #2 synchronized.	
25	21.56.23.500	**400/220 kV ICT-2 at Ballabgarh restored.**	
26	22.00.30.826	220 kV Samaypur Palwal-2 restored.	
27	22.02.20.266	Faridabad (Th) #3 Synchronized.	
28	22.21.04.826	220 kV BTPS-Noida restored.	

29	22.25.05	Faridabad Gas #3 synchronized.	**This event did not appear in SOE recorded in ULDC system. Synchronisation time taken from Historical data recording system at NRLDC.**
30	22.52.13.110	BTPS Unit #5 Synchronized.	
31	23.23.47.391	BTPS Unit #3 Synchronized.	
32	23.33.50.463	**BTPS Unit #5 tripped.**	
33	23.35.15.195	Faridabad (Th) #2 Synchronized.	
34	23.41.18.305	BTPS Unit #2 Synchronized.	
35	00.31	BTPS unit 1 Synchronised.	These events not reported in the SOE recorded at ULDC system. Synchronisation time taken from BTPS (NTPC) report.
36	00.49	BTPS unit 5 Synchronised.	
37	00.54	BTPS unit 4 Synchronised.	

The Committee feels that the restoration and normalization of system was done quite quickly. As seen from the sequence of events, the last unit viz. unit-1 tripped at 19:00:26:21 and this could be taken as the collapse of the island. Starting from 19:1:25 (i.e. in less than a minute of blackout at BTPS), the BTPS operator opened all the outgoing 220 kV circuits (seven nos.) in 11 seconds as per the standing instructions available.

5.0 OTHER ISSUES

5.1 Loss during the incident:

While no human life was lost or injury sustained in the above incident, equipment damage such as that of the 400/220 kV ICT-1 at Ballabgarh POWERGRID (complete damage) and minor damage to nearby equipments such as LA, Circuit Breaker and loss of cabling etc was a significant loss. The following generating units also tripped.

Sl no.	Plant Name	MW Loss	Loss duration	Energy Lost (MUs)
1	Faridabad GPS(NTPC)	179	2 hrs	0.358
2	Faridabad Th(HPGCL)	82	3.5 hrs	0.287
3	Pragati Gas	160	1.2 hrs	0.192
4	BTPS	620	3-6 hrs.	2.50

5.2 Operator's actions at the following locations

I. POWERGRID's Substation at Ballabhgarh

The operator's action of switching off DC supply to the 400/220 kV ICT-1 bay at Ballabhgarh was not desirable. There seems to be lack of proper written instruction at sub stations during emergency conditions. The urgency in this operation appears to have been misplaced. The committee deliberated this issue at considerable detail. The gist of these deliberations is as follows:

What if the DC supply is not switched off? The argument in favour of putting off is that the DC supply is extended to the transformer marshalling box and the entire station DC might be affected by the fire. Even assuming that the above argument is valid as the marshalling box was on fire, what can happen? If the DC cables catch fire affected two things could result

- The DC system may get an earth fault on one pole,
- The DC system may get short circuited due to earth fault on both poles or by direct connection.

In the former case, there is no risk normally involved as the system is expected and envisaged to operate with earth fault. DC system is designed as ungrounded system with this precise consideration. In the latter case the affected supply fuse blows and the rest of the system remains healthy. Each DC feeder for each service is separately fused, on both poles, for taking care of such an eventuality only.

The operator's action of switching off the adjacent 400/220 kV ICT-2 and ICT-3 bay for safety deserves appreciation.

II. BBMB's 220 kV substation at Samaypur

The feedback from the affected substation on the actual ground situation to the sub stations/ SLDCs/RLDCs is of prime importance. In this entire incident, it is clear that the Ballabgarh (of POWERGRID) and Samaypur substation (of BBMB) have not communicated properly to handle such emergency. Had operators at BBMB station and Ballabgarh POWERGRID situated in the same compound talked to each other and switched off the isolator from BBMB end, the influence of the fault would've not extended to other areas.

The committee feels the need of better coordination between neighbouring substations.

III. NRLDC Control Room in Delhi

For about 30 minutes BTPS was operating with one tie line to the NR system. 220 kV Badarpur – Ballabgarh circuits were both live with either one remaining open at one end. NRLDC did not allow the closure of these lines because their endeavor was to first safe guard the main 400 kV system. The explanation offered was that there was a fire at Ballabhgarh Station and many trippings, which were to be understood before re-connecting that part with Delhi system. Since BTPS was already connected to 220 kV Alwar line, NRLDC tried to assess the situation further before allowing closing of Ballabhgarh line. Attempts were also being made to close the 220 kV Mehrauli-Bamnauli section but before all such attempts could fructify, the 220 kV BTPS-Alwar line tripped.

5.3 Freak tripping of Faridabad GPS units and Pragati GT-1

Stray tripping of the gas turbine units due to process related protection operating for a fault very far away in the system merits detailed investigation by experts. Such tripping could compound the disturbance in the power system further.

5.4 Disturbance Recorder/Event Logger outputs from the affected installations:

While analyzing the event, the following shortcomings were observed in the input data, which is not fully in line with Clause 5.9.6 of the Indian Electricity Grid Code (IEGC).

i) Disturbance Recorder (DR) outputs wherever available are truncated. Waveforms for the complete duration, although captured by the DR are not selected while printing. As the DR outputs are useful in case of a disturbance, there should be no need to apply these shortcuts while taking a hard

copy. Further, photocopies of DR outputs are not of very good quality in terms of legibility.

ii) Sequential Event Recorder (SER) readings were provided only in respect of Ballabgarh (POWERGRID) tripping. No SER output was made available for 220 kV Samaypur (BBMB), 220 kV Ballabgarh (BBMB), 220 kV Faridabad GPS (NTPC) and 220 kV BTPS (NTPC). NTPC clarified that Event loggers are not available in BTPS and in any case they do not provide Sequential logging of the event. They are normally used to log all events in the S/S.

iii) Power stations, particularly the recent ones have good Data Acquisition Systems (DAS) in place. In this case, the outputs at Faridabad GPS (NTPC), BTPS (NTPC), Pragati (Delhi) and GT station (Delhi) would have been extremely helpful in understanding the event. However, these outputs were not made available.

The DR timings for Ballabgarh (POWERGRID) and 220 kV BTPS match well and are consistent with other events reported at NRLDC and the other control centres in Northern Region. However, the timings in respect of the numerical relay outputs at Ballabgarh (BBMB) and Samaypur (BBMB) 220 kV substations do not tally with the timings recorded at NRLDC. The NRLDC SoE timings were taken as the base in drawing up the timeline.

5.5 Non-availability of line CVTs on all the phases, accelerated tripping through carrier inter trip, single pole autoreclosure facility on the 220 kV lines emanating from BTPS and other important lines in the 220 kV systems:

Committee noted that BTPS presently has bus VT output used for line protection and that BTPS has already initiated action to provide dedicated line CVTs.

The committee further noted that some of the 220kV lines from BTPS are not equipped with carrier aided protection and consequently do not have auto-reclosing feature. The committee feels that important features like single pole auto reclosure, carrier aided protection etc must be provided on these lines by the respective owners of these lines.. It must be pointed out that the event of Delhi islanding might not have arisen if 220 kV BTPS-Alwar line had autoreclosed. That it could successfully be closed 12 minutes later, clearly hints at the fact that the line would have successfully autoreclosed.

6.0 Points of Concern

The committee based on the analysis, felt that the series of incidents of 1st May 2006 merit the attention of all concerned agencies and planners of the power system. Considering the circumstances, which led to the event, it is evident that a series of protection and human failures was the cause of the event. The basic causes are:

a. Failure of differential protection of ICT –I of Ballabgarh sub station (POWERGRID) though of no consequence in this case, was deliberated by the committee. POWERGRID felt that differential protection non-operation may be in order considering the restraint features in the relay, but other members of the committee felt that it should have operated in much less than 60ms of fault tenure. The nominal operating time of the relay is 30ms at twice the current setting..

b. Switching off of DC supply by operators at 400 kV Ballabgarh sub station (POWERGRID). Ideally, the isolators on both sides must be opened to de-energise the entire protected zone and then only the DC supply may be switched off. Opening of isolator on 220 kV side could have prevented the second fault. The committee was of the view that the protected zone must be fully isolated and de-energised before DC supply is switched off.

c. Lack of a proper verbal communication between the operators of Ballabgarh substation of POWERGRID and Samaypur substation of BBMB.

d. Distance protection relays of 220 kV Faridabad GPP – Samaypur at Faridabad GPS lines did not operate. Needs checking by POWERGRID, although remote end in-feed could have been the probable reason for non-operation of these distance relays.

e. The failure of B pole of Breaker at 220kV Ballabgarh end circuit –II and failure of LBB operation in Samaypur station of BBMB were the last erratic functioning of system elements, which led to the partial black out. It was reported by BBMB that the LBB relay of Alstom make was defective and has been replaced. The B phase limb of ABB make breaker at 220kV Ballabgarh end circuit –II has also been replaced by BBMB.

f. Protection scheme of Badarpur – Ballabgarh # 2 which tripped from Ballabgarh end without proper direction sense needs checking.

g. With the tripping 220 kV BTPS-Ballabgarh-I at Badarpur end at 18.19.39.102 hrs, BTPS was connected to the Grid with only BTPS Alwar line till 18.48.19.577 hrs. Heightened situational awareness under such conditions, despite trippings occurring at several substations could have strengthened BTPS system by restoring either the 220 kV BTPS-Ballabgarh section or the 220 kV Mehrauli-Bamnauli section.

h. Availability of Free Governor Mode of Operation (FGMO) at BTPS during islanding and adequate UFR load shedding in Delhi system could have helped in survival of the Delhi system even after islanding. NTPC pointed out that for proper functioning of FGMO, constant frequency operation of the Grid is a pre-requisite.

i. Integrated operation of Delhi ring: Though the 400 KV ring main has been completed but integrated parallel operation of 400 kV and 220 kV systems has not been achieved due to load flow constraints. The loop power flows are feared if the 220kV ring is closed under some operating regimes. Long term operation with split interconnections is not desirable, as it compromises reliability as evidenced in this incident.

7.0 Recommendations to avoid reoccurrence of such incidents

1. In case of fire in a transformer it is necessary to electrically isolate the faulted equipment and associated elements falling in its protection zone in full (Opening of the Breaker is certainly not adequate isolation) by opening the isolators on either side of the equipment. As the transformer 220kV isolators were not physically approachable, either it should have been opened electrically before switching off DC or if not successful the 220kV bus isolators at BBMB should have been opened. **Necessary instructions to the operator must be displayed in the control room as the operator is not in a position to logically conclude the correct operating procedure during such emergencies**.

2. Written unambiguous instruction prohibiting switching off of DC supply to any service until complete de-energization and isolation of the primary circuit is doubly confirmed, may be issued to each EHV sub station operator. A small task force may be created under the Protection Committee of NRPC to draw up suitable Emergency Operation Procedure applicable to all EHV Substations in the Region. The same may also be forwarded to other RPCs for suitable application in their respective region as well.

3. Emergency Operating instructions for operation of thermal units under such emergency situations, including islanded operation may be drawn up and issued to all power stations by NRLDC.

4. The committee feels that mulsifier system was not effective in controlling this fire. There is a need to **review the design of the mulsifier system**, including the provision of Nitrogen injection, may be by a specialist consultant. The norms of separation and / or fire wall also may be so reviewed, for suitable amendment if necessary in the safety regulations. It is suggested that POWERGRID may take up this review by an independent expert consultant for examining any possibility of improvement.

5. The failure of the Ballabhgarh end 220kV Breaker on 220 kV Samaypur-Ballabgarh-II to open and the failure of LBB protection of the failed Breaker (Blue Phase) be revived by BBMB and if the same was due to insensitive LBB protection relaying, the same needs to be reviewed and changes incorporated quickly. The committee suggests that the LBB protection for all critical circuit breakers may be periodically tested for healthiness and also be reviewed by the protection committee.

6. The 220 kV switching devices in the Delhi ring needs to be replaced with higher interrupting capacity ones along with matching associated equipment. Alternatively, Series Reactors at strategic locations can also be considered. The committee feels that the views of the planners of the transmission system in this regard may be sought and a long-term solution found. (CEA planner's views that alternative provision is not a desirable option).

Pending this long term action plan to restore the 220kV ring, the committee feels that the existing interconnection from BTPS to Noida may be established immediately. The matter has also been recommended by Operational Coordination Committee of NRPC. The committee further recommends that at least one D/C connection from the upcoming Maharani Bagh 400/220kV S/S to BTPS must be considered. LILO of BTPS IP circuits at Maharanibagh can be considered in this regard.

7. The Island formation at BTPS, as existing, was felt to be fairly appropriate. The committee however felt that further improvement can be achieved by disconnecting Mehrauli also from BTPS, thus making BTPS Island with Okhla and Sarita vihar radial feeds. OCC of NRPC may examine this aspect in detail, before implementing the same. In the meanwhile, DTL should make the UFR operation at Mehrauli reliable.

8. Before formation of the BTPS / part Delhi Island, there was a very valuable period of 29 minutes when the island was operating radially connected to Alwar only. If another connection could be established during this period the islanding and collapse could have been avoided. NRLDC and DTL shall pre-agree on the points where connection can be established to avoid indecision. Mehrauli / Bamnauli and Ballabgarh prima facie appears to be the best options. The final scheme for the same shall be worked out by NRLDC/DTL.

9. Tripping of 220 kV Badarpur – Alwar line on Red phase Ground fault resulted in islanding of BTPS with part of Delhi. Single phase auto reclosure if available on this circuit might have still saved the day. Single phase auto reclosure and carrier aided distance protections are provided and successfully in operation on all 400 kV circuits. The Committee recommends up gradation of all 220 kV circuits in National Capital Region by providing single phase auto reclosure and carrier aided protections on all meshed 220kV lines.

10. To ensure survival of grid after separation/islanding, secondary UFR load shedding may be considered. The secondary UFR settings should be set at a lower frequency say at 48.0 Hz which should be independent of programmable logic controller installed for routine load management.

11. It is desirable that Thermal units are capable of surviving on house-load in case of grid failure. The design requirements in this regard like Free Governor Operation, Fast operating HP/LP Bypass, unit feeding of all essential auxiliaries etc may be included in the connectivity Standards under finalization, by CEA.

12. Continuous training of operators of substations, generating stations & load dispatch centers is of prime importance, particularly in handling a crisis. Heightened situational awareness and decision enabling is the need of the hour. The committee recommends creation of a simulator for training of EHV substation operators say under NPTI.

13. It is suggested that the nomenclature of substations be revised so that substations with similar names are not used. This would avoid confusion, particularly at the time of restoration. It is suggested that 400 kV Ballabgarh substation of POWERGRID be renamed as 400 kV Samaypur substation, as it is physically situated at Samaypur adjacent to 200 kV Samaypur substation of BBMB. The 220 kV Ballabgarh substation of BBMB, being situated at Ballabgarh, (at quite a distance of Samaypur) be continued to be named as such. Similar confusion wherever existing also need to be corrected.
14. It is also recommended that various condition monitoring tests like tan δ, Dissolved Gas Analysis (DGA), Residual voltage measurement (RVM) and partial discharge etc should be carried out at regular intervals to ensure healthiness of 400/220 kV power transformers.