NORTHERN REGIONAL ELECTRICITY BOARD

KATWARIA SARAI, NEW DELHI

REPORT OF THE COMMITTEE ON GRID INCIDENT IN NORTHERN REGION ON 6TH JULY 2005

AUGUST 2005

Report of the Inquiry Committee on Grid incident in Northern Region on 6th July 2005 at 01:23 Hrs

1.0 INTRODUCTION

1.1 Northern Regional Power System experienced a grid incident at 01:23 hours on 06.7.05 resulting in tripping of whole NTPC Dadri complex, outage of HVDC Rihand Dadri bipolar line, and few important 400 kV lines of East-West corridor.

1.2 The incident occurred at 01:21:31 hrs on 06.7.05 when the "Y" phase conductor near location 166 A (approximately 29 % from Agra end) of 400kV Muradnagar-Agra line snapped and fell on the ground. This fault was cleared from Agra end in Zone –I but could not be cleared from Muradnagar end due to the breaker gone under air pressure ***Lock out*** at Muradnagar.

1.3 As the Muradnagar end breaker for Agra feeder failed to open on operation of distance protection, LBB of this breaker operated. Except for the Dadri feeder all the other breakers tripped and Dadri NTPC thus continued to feed the fault on 400 kV Agra-Muradnagar line.

1.4 Due to the uncleared fault, Inter Connecting Transformers (ICT) # 3 and ICT#4 tripped at Dadri GPS sensing the earth fault, causing tripping of all four units of Dadri GPS. The LBB operation initiated due to mal functioning of ICT #3 LBB protection causing tripping of 400 kV Bus #1 at Dadri switchyard.

1.5 The fault was still persisting in the system and resulted in tripping of all four units of Dadri TPS, three units at Panipat TPS, one unit at Dehar and unit #4 of BTPS.

1.6 Both Pole of HVDC Rihand Dadri also tripped on DC Harmonic Protection.

1.7 Total loss of generation was about 2000 MW.

1.8 The situation was controlled by reducing the regional imports, backing down of generation at Singrauli-Rihand-Anpara complex and operation of UFRs.

1.9 The system was normalized at about 02:30 Hrs when Muradnagar station tried to open the 400 kV Dadri- Muradnagar breaker at Muradnagar end by manual tripping and the breaker blasted. Dadri protection sensed this earth fault and finally 400 kV Dadri -Muradnagar line breaker tripped at Dadri end in Zone –II, isolated the Dadri- Muradnagar line, thereby isolating the faulty element in the system.

1.10 Central Electricity Authority vide its order no. 5-41(24)/ Secy. / 2005/ 491 dated 6.07.05(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 K Soonee, Executive Director, NRLDC Member
Shri R K Gaur, AGM(O&M), Dadri GPS Member
Shri Rafi-ud-din, Director, GMD, CEA Member
Shri A.K. Malik, S.E. (Operations), NREB Member-Convenor

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

(a) To analyse the cause leading to grid incident on 6th July 2005.
(b) To review the restoration of system.
(c) To review the performance of the protection system.
(d) To suggest remedial measures to avoid recurrence of such disturbance in future.
(e) Any other relevant issues connected with safe and secure operation of the Grid.

The Enquiry Committee was advised to furnish the cause of disturbance by 18.7.05.

1.12 The Committee held its First meeting on 14th July'05 at NREB. and in the meeting Sh. Ramesh Bahri, General Manager (O&M), PowerGrid, NR-I, Shri R S Rathee, DGM (MTC), BTPS and Sh. Ashok Kumar, GM, UPPCL were nominated as co-opt members. Representatives from UPPCL, NTPC, BTPS, NRLDC, and PowerGrid NR-I participated in the meeting and during discussion Members discussed the cause and sequence of the incident.

1.13 Based on the discussion of First meeting, the committee decided to visit the 400 kV Sub Station of Muradnagar and NTPC Dadri to have a first hand account of the incident at Muradnagar and Dadri. The Committee members visited 400 kV Muradnagar (UPPCL) station and Dadri NTPC on 20th July 2005.

1.14 The Committee analyzed information supplied by NTPC Dadri, incident captured by NRLDC on its SCADA system, and PowerGrid in detail.

2.0 OVERVIEW OF NORTHERN REGIONAL GRID

2.1 Northern Regional Grid comprises of 9 States/UTs namely Chandigarh, Delhi, Haryana, HP, J&K, Punjab, Rajasthan, UP and Uttaranchal. NR Grid has an Effective capacity of 31,977 MW. The Thermal-Hydro mix is of the order of 65:35.

2.2 The large Coal pithead thermal power stations are located in the extreme South-Eastern part of the Regional Grid constituting generation capacity of around 6000 MW against which normal generation level is 5000-5500 MW. Northern Region is also asynchronously connected with Eastern Region and Western Region through HVDC Back-to-Back links viz. Sasaram (Pusauli) (1x500 MW capacity) with ER and Vindhyachal (2x250 MW capacity) with WR. Regional power exchanges up to 500 MW (both ways) can flow on each of these links.

2.3 Under deficit conditions in NR, 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 MW is to flow from South-Eastern part of the grid to Central and Western part of grid.

2.4 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 following 400 kV AC transmission lines connecting Eastern part (Eastern UP subsystem) with Rest of Grid besides under lying 220 kV network.

i) 400 kV Kanpur-Ballabgarh (PowerGrid)
ii) 400 kV Kanpur-Agra (PowerGrid)
iii) 400 kV Lucknow-Moradabad (PowerGrid)
iv) 400 kV Panki-Muradnagar (UPPCL)
v) 400 kV Unnao-Agra (UPPCL)
vi) 400 Kv Mainpuri- Ballabgarh- D/C (PowerGrid)

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

3.0 ANALYSIS OF CAUSE OF GRID DISTURBANCE

3.1 Antecedent Conditions

- The Initial Report issued by NRLDC on Partial Grid Disturbance in NR on 06.7.05 is enclosed at **Annex-II.**
- Prior to the incident, all the Constituents of Northern Region were operating in an integrated mode.
- Due to high silt conditions, the generation at NJHPS, Baspa and Ganga Yamuna Hydro complex in Uttaranchal was nil.
- System frequency – 50.32 Hz
- Total System Size – 19,195 MW (Low due to rains in many parts of NR)
- Important line flows: Main East-West corridor (01:15 hrs)

▪ Rihand Dadri HVDC bipole	:	1200 MW (23 Degree angular separation)
▪ 400 kV Kanpur- Ballabgarh	:	265 MW
▪ 400 kV Kanpur- Agra	:	293 MW
▪ 400 kV Panki-Muradnagar	:	422 MW
▪ 400 kV Lucknow- Moradabad	:	338 MW
▪ 400 kV Unnao- Agra	:	244 MW
▪ 400 kV Mainpuri- Ballabgarh-II	:	300 MW
▪ 220 kV Panki-Mainpuri	:	170 MW
▪ 220 kV Kanpur-Mainpuri	:	145 MW
Total	*:*	*3377 MW*

- **Inter-regional Exchange:**

  Import :

  - On HVDC Vindhyachal BTB – 230 MW
  - On HVDC Pusauli BTB – 350 MW

  Export :

  - Nil

  Net Import : 580 MW

- **Flow conditions of ICT/ Line at NTPC Dadri (01:15 hrs)**

400 kV Dadri-Muradnagar	:	328 MW
400 kV Dadri-Panipat		365 MW
400 kV Dadri-Ballabgarh-I	:	158 MW
400 kV Dadri-Ballabgarh-II	:	153 MW
400 kV Dadri-Malerkotla	:	166 MW
400 kV Dadri-Mandaula-I	:	634 MW
400 kV Dadri-Mandaula-II	:	632 MW
Total	*:*	*2436 MW*

- **Flow of lines/ ICTs at 400 kV Muradnagar Substation (01:23 hrs)**

400 kV Dadri-Muradnagar	:	343 MW
400 kV Muradnagar-Agra	:	(-)191MW
400 kV Muradnagar-Moradabad	:	65 MW
400 kV Muradnagar-Rishikesh	:	212 MW
400 kV Panki- Muradnagar	:	403 MW
ICT-I	:	181 MW
ICT-II	:	253 MW
ICT-III	:	181 MW

3.2 Timeline of incident events on the 6th July 2005:

- The timeline of incident events given below is based on the reports received from UPPCL, 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 –III.***
- The first event was a Y-phase (of RYB) to ground fault on the 400 kV Agra-Muradnagar line, approximately 29% from Agra end at around 01:21:31 hrs. The fault was cleared from Agra end in Zone - I but could not be cleared from Muradnagar end due to the breaker being under lockout. The first event recorded at NRLDC was operation of elements connected to 400 kV Bus 'B' at Muradnagar substation (on LBB protection).

Event start time: 01:23:31:436 taken as zero time (Agra end breaker already tripped on Zone –I)			
S. No.	**Time t =**	**Event**	**Remarks**
1	0 (Start)	400/220 kV, 240 MVA ICT-3 at Muradnagar tripped	LBB of 400 kV Agra feeder at Muradnagar operated leading to isolation of these elements connected to 400 kV Bus 'B'. 400 kV Dadri feeder did not trip and remained connected to Bus 'B' along with the Agra feeder which was faulty. Refer sketch of bus arrangement at Muradnagar 400 kV sub station enclosed *at* ***Exhibit – II.***
2	12 ms	400/220 kV, 240 MVA ICT-1 at Muradnagar tripped	
3	36 ms	400 kV Moradabad line at Muradnagar tripped	
4	51 ms	400 kV bus coupler at Muradnagar tripped.	
5	5 sec 427ms	400/220 kV, 315 MVA ICT-2 at Muradnagar tripped	Tripped on over-current relay operation (IDMT characteristic) as ICTs 1 and 3 tripped above and the 220 kV buses were running coupled.
With the above tripping, 400 kV Bus A at Muradnagar had only the Panki and Rishikesh feeders connected to it.			
6	7 sec 416ms	220 kV Saharanpur - Shamli tripped	Tripped on distance protection at Saharanpur end.
220 kV Khara-Shamli has also tripped at the same time. This resulted in load			

Event start time: 01:23:31:436 taken as zero time (Agra end breaker already tripped on Zone –I)			
S. No.	**Time t =**	**Event**	**Remarks**
throw off at Shamli, Baraut, Sahibabad and Noida 220 kV substations as all feeds to this area were lost. Refer sketch for 400/220 kV system of Uttar Pradesh for the relevant area (enclosed ***at Exhibit –III***). Uttar Pradesh's net drawal came down by 472 MW due to these tripping (from 2855 MW to 2383 MW) and the frequency increased from 50.2 Hz to 50.6 Hz. The loads at 220 kV Saharanpur, Khara, Khodri, Chhibro and Majri (HP) continued to be fed on the lone 220 kV Rishikesh-Khodri feeder. (85 MW loading at 0100 hours, gone up to 230 MW after the above trippings)			
7	12 sec 135ms	400/220 kV, 500 MVA ICT-3 at NTPC Dadri TPS tripped	As per NTPC Dadri this tripped on operation of earth fault relay (67N) (CDD 41 relay, PS = 0.2A, TMS=0.5)
8	12 sec 362ms to 12 sec 377ms	All the breakers connected to 400 kV Bus-I at Dadri tripped. Mandaula-I, Panipat, Ballabgarh-I, Ballabgarh-II, ICT-4, ICT-1 main bays and HVDC Bus - I interconnection tripped	LBB of ICT-3, 400 kV Bus-I breaker operated. As Dadri TPS has a breaker and half switching scheme (single line diagram at **Exhibit -IV**), no element was affected at this stage.
9	14 sec 488ms	400/220 kV, 500 MVA ICT-4 tripped	As per Dadri TPS, this tripped on operation of earth fault relay (67N) (CDD 41relay, PS = 0.2A, TMS=0.5)
All the units at Dadri GPS got isolated from the grid and power supply to Railways was also affected.			
10	31 sec 9 ms	Dadri(T)-2 tripped	As per Dadri TPS, this tripped on Generator Transformer back-up earth fault protection. (CDG14 relay, PS = 0.2A, TMS=0.7)
11	32 sec 567ms	Dadri(T)-4 tripped	As per Dadri TPS, this tripped on Generator Transformer back-up earth fault protection. (CDG14 relay, PS = 0.2A, TMS=0.7)
12	34 sec 85 ms	Dadri(T)-1 tripped	As per Dadri TPS, this tripped on Generator Transformer back-up earth fault protection. (CDG14 relay, PS = 0.2A, TMS=0.7)
13	37 sec 845ms	Dadri(T)-3 tripped	As per Dadri TPS, this tripped on Generator Transformer back-up earth fault protection. (CDG14 relay, PS = 0.2A, TMS=0.7)
14	42 sec 632 ms	400 kV Dadri-Ballabgarh-I tripped from Ballabgarh end only.	Main-I protection (RALZB) operated. The timing at NRLDC matches with the SER output at Ballabgarh enclosed at ***Annexure -IV***.
15	44 sec 77 ms	400 kV Dadri-Ballabgarh-II tripped from Ballabgarh	Main-I protection (RALZB) operated. The timing at NRLDC matches with

Event start time: 01:23:31:436 taken as zero time (Agra end breaker already tripped on Zone –I)			
S. No.	**Time t =**	**Event**	**Remarks**
		end.	the SER output at Ballabgarh enclosed at ***Annexure -IV.*** However the DR triggered on Main-I operation does not appear to be time synchronized with GPS. System frequency as per this DR output is 49.54 Hz (fallen due to Dadri(T) and Dadri(Gas) units going out as above).
16	44 sec 632 ms	Rihand-Dadri HVDC bipole tripped due to DC harmonic protection operation at Dadri end. (excessive unbalance in voltages also observed)	At HVDC Dadri, the SER has lost a large number of events during this period. HVDC Rihand SER shows a protection block from other side. The timings at Rihand HVDC SER are not time synchronized through GPS and reported to be 10 seconds behind GPS.. Copies of SER enclosed at ***Annexure-V***

As would be seen, the above events are occurring in a time span of 45 seconds (indicating the slow nature of event as far as the power system is concerned) but well beyond the operator's perception at the control centre as a slow event. The operator at the control centres at SLDC Lucknow and NRLDC could in no way have seen these events as discrete unless he went through the Sequence of Events carefully.

3.3 The following change in power flows occurred during this period as captured from the Historical Data Recording (HDR) facility at NRLDC.

- After the 400 kV bus B at Muradnagar had separated, the 400 kV Bus A had the 400/220 kV (315 MVA) ICT-2, Panki and Rishikesh feeders connected. The power flow on 400 kV Panki-Muradnagar line increased from 413 MW to 632 MW momentarily during this period while 400 kV Muradnagar-Rishikesh flow reduced from 213 MW to 114 MW implying that the flow on ICT-2 at Muradnagar increased to 518 MW. After ICT-2 tripped, power flow on 400 kV Panki-Muradnagar came down to 350 MW (same quantum flowing onward to Rishikesh). Similarly, 400 kV Lucknow-Moradabad flow went up from 338 MW to 419 MW and then reduced to 369 MW.
- As the units at Dadri (GPS)& Dadri (TPS) had tripped, the power flow on the 400 KV lines connecting from Dadri NTPC gradually declined. After Rihand-Dadri HVDC bipole had tripped, the power flows at 01:24:30 at Dadri were as under.
  - 400 KV Dadri-Mandaula D/C : (-)422 MW
  - 400 KV Dadri-Panipat : 109 MW
  - 400 KV Dadri-Malerkotla : 37 MW
  - 400 KV Dadri-Muradnagar : 227 MW

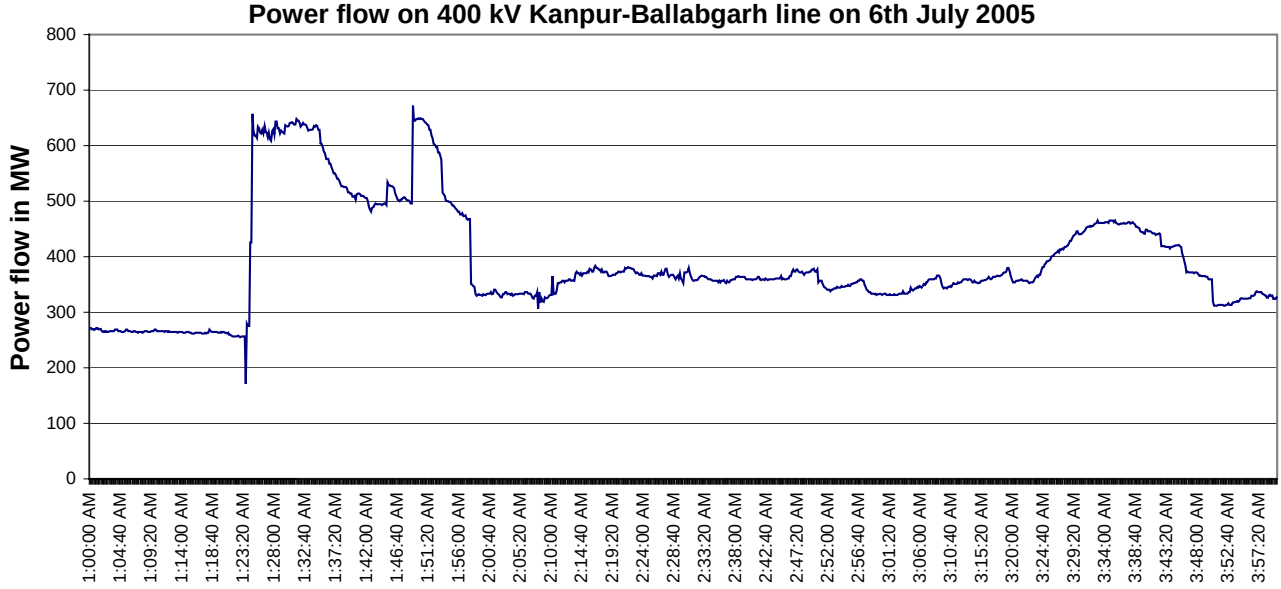
NOTE: See Para 5.2 for reason of Dadri Muradnagar flow

- After the tripping of Rihand-Dadri HVDC bipole, the 400 kV AC lines connecting Kanpur/Lucknow axis to the Ballabgarh/Agra axis became heavily loaded. The situation got aggravated as the 400 kV Panki-Muradnagar and 400 kV Lucknow-Moradabad lines (which otherwise provide a parallel path in normal circumstances) now became effectively radial. Refer 220 kV network sketch of UP at ***Exhibit -III.*** It would be seen that the two 400 kV lines were further connected to the Western part through the weak 220 kV Narora-Harduaganj-Agra (UP) link and 220 kV Moradabad-NAPS-Simbhauli-Meerut (POWERGRID) link. NAPS had observed a sharp increase in the 220 kV Narora-Simbholi power flow around this time (778 Amps. at 01:24:27hrs). This 220 kV weak link however survived.

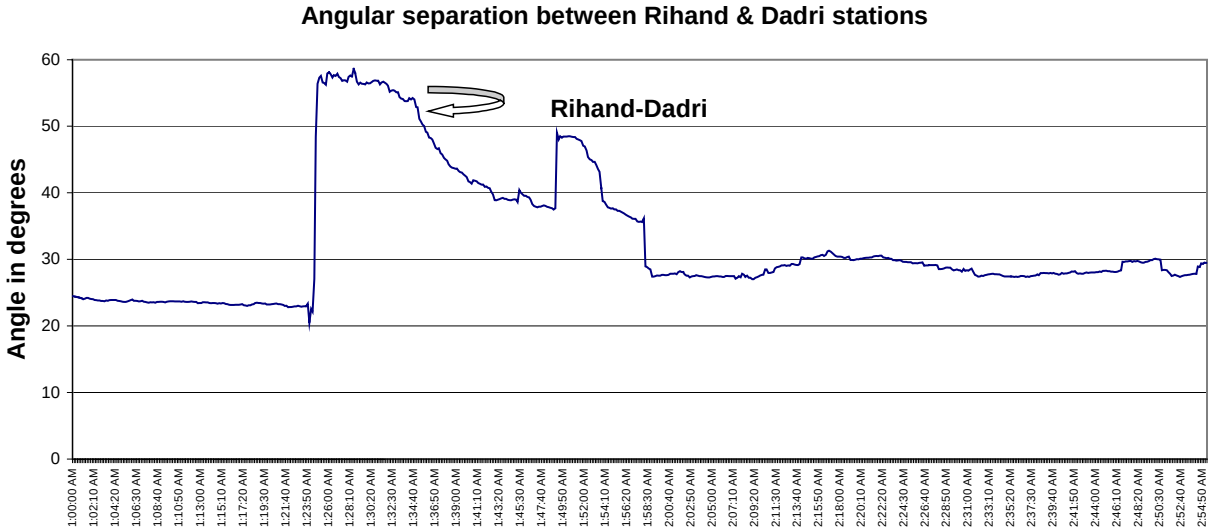
Increase in the 400 kV line loadings as observed in NRLDC were as under:

- 400 kV Kanpur-Ballabgarh from 276 to 657 MW (FACTS at Ballabgarh was off since 01:13 hrs. on 5th July, 2005 due to low loading / high voltage at Mainpuri / Allahabad).
- 400 kV Kanpur-Agra from 284 to 632 MW
- 400 kV Unnao-Agra from 231 to 507 MW.
- 400 kV Allahabad – Mainpuri - Ballabgarh ckt.-II from 291 MW to 563 MW (400 kV ckt. I of this section kept off since 0308 hrs. of 5/07/05 to control high voltage at Mainpuri/Allahabad)
- 220 kV Kanpur-Mainpuri from 139 MW to 184 MW.

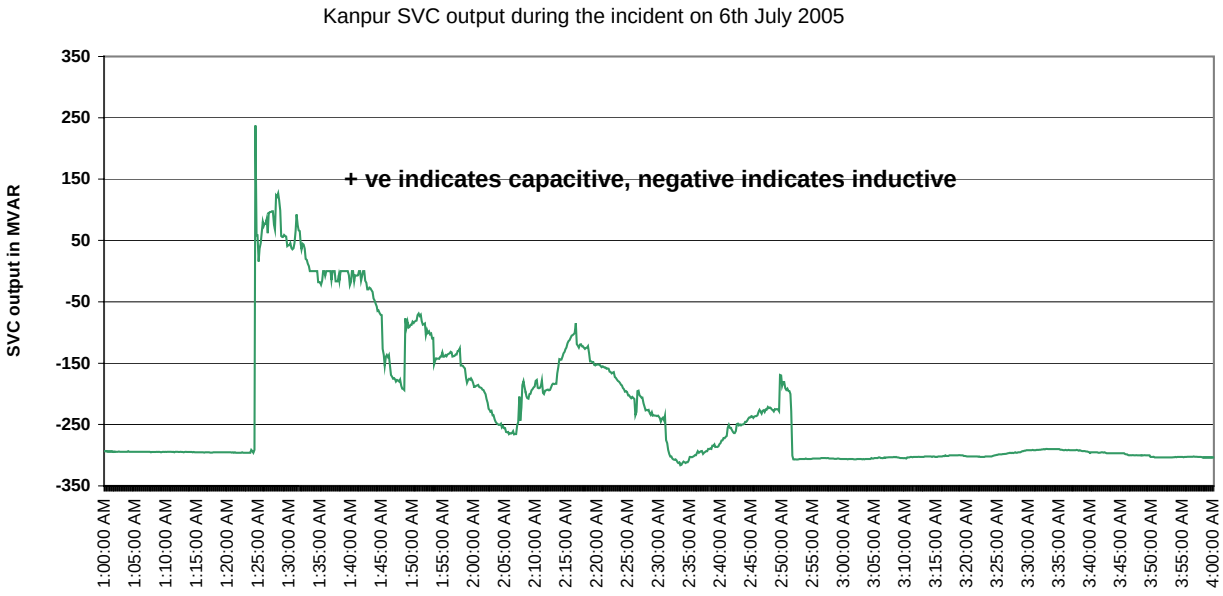
Power flow on 400 kV Kanpur-Ballabgarh line on 6th July 2005

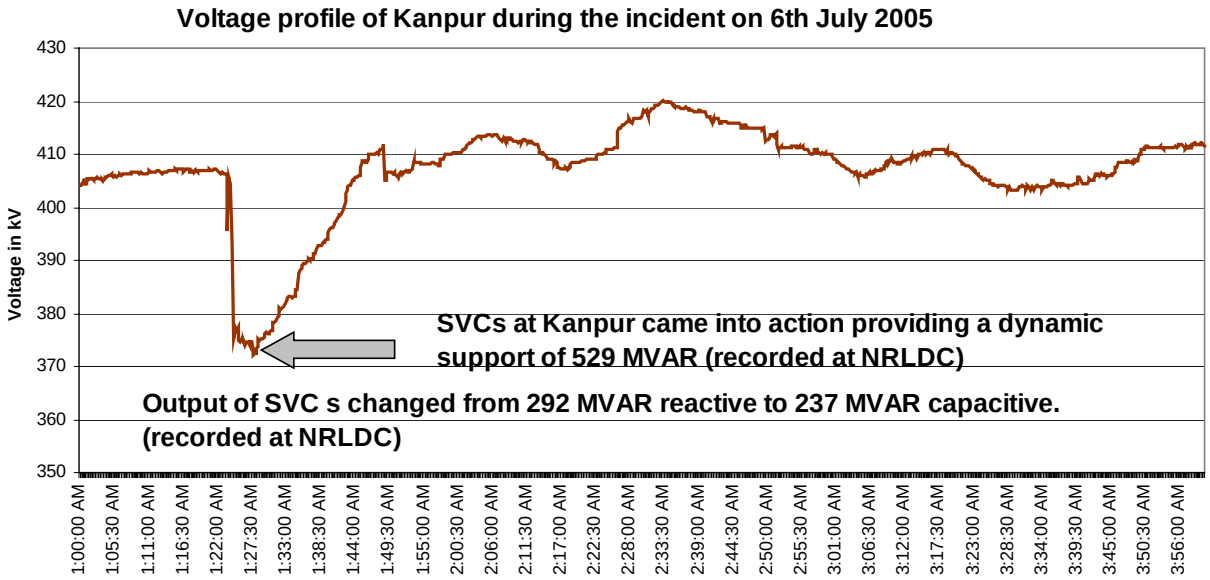


The angular difference between Rihand & Dadri bus bars also increased from 23 degrees to 59 degrees. This is graphically shown below as captured from the Data Acquisition System at NRLDC.



The 400 kV Kanpur voltage declined sharply from 406 kV to 375 kV and the dynamic support from the SVCs at Kanpur helped in saving the system from cascade tripping. Voltage profile at Kanpur S/S is depicted below.





Actions were immediately initiated to control the line loading by reducing generation at Singrauli/Rihand/Anpara complex & import from the neighbouring regions and raising generation in Rajasthan, Punjab & BBMB systems and load shedding in the Western part. The frequency profile , voltages, line loading & inter regional imports during the incident illustrated graphically at ***Exhibit- V.***

The following tripping occurred subsequently.

S.No.	Time	Tripping	Remarks
1.	01:25:17	BTPS-4 (210 MW)	Negative phase sequence protection.
2.	01:26:44	Panipat-I (110MW)	Ckt. I & III (220 kV) to Panipat (BBMB) have also tripped from Panipat TPS at this time. Reason not intimated by HVPNL.
3.	01:26:51	Panipat-2(110 MW) Panipat-6(210 MW)	
4.	01:28:01	Dehar-I (165MW)	Reportedly tripped on excitation failure.
5.	01:40	220 kV Saharanpur - Shamli closed	
6.	01:44:52	220 kV Rishikesh-Khodri tripped on operation of distance protection. Failure of power supply at Khara, Saharanpur, Shamli, Khodri, Chhibro & Majri (HP). Frequency rise from 49.48 to 49.80 Hz. and gradually to 50.28 Hz. At 01:50 hrs. 220 kV Muradabad-Nehtaur also tripped at this time resulting in further load throw off.	

S.No.	Time	Tripping	Remarks
7.	01:48:39	400 kV Mainpuri-Ballabgarh-II on over voltage at Mainpuri end (Antecedent flow : 473 MW) Ballabgarh voltage: 401 kV Mainpuri voltage:408 kV : Allahabad : 422 kV)	400 kV Mainpuri substation has a fairly low fault level of the order of 2700 MVA under normal circumstances. This would have gone down further with the tripping of Dadri - Ballabgarh D/C line, Bus reactor at Agra, Ballabgarh and Bassi were switched off to control low voltage following the HVDC bipole tripping. 400 kV Allahabad-Mainpuri-Ballabgarh ckt. I which was in open condition was sought to be restored by NRLDC. In this process, the 80 MVAR line reactor of 400 kV Mainpuri Allahabad at Mainpuri end which was being used as a bus reactor had to be first opened. Opening of this reactor caused high voltage and tripping of Ckt II.
8.	01:53:21	Singrauli unit-7 (500 MW) hand tripped.	High turbine vibrations and HP turbine casing intact pipe U-seal ring leakage Unit taken out for 25 days.
9.	01:56:15	400 KV Mainpuri-Ballabgarh-I restored as 400 KV Allahabad-Mainpuri-II was already in service with all the above actions, the line loadings and voltage came under control.	
10	*02:14*	*220 kV BTPS-Ballabgarh D/C lines opened from BTPS end manually. This saved the other units from tripping as the negative phase sequence alarm disappeared immediately after opening of this line. Tripping of all the BTPS units could have resulted in a disturbance in Delhi system.*	

3.4 Around 02:25 Hrs, UPPCL Muradnagar requested Dadri for opening of Dadri TPS end breaker on Muradnagar feeder as the breaker at Muradnagar end had developed heavy sparking. The Dadri NTPC end breaker on Muradnagar feeder tripped (02:30:50:864 as per NRLDC SoE) on distance protection Main –I ,Zone – II on account of the fault at Muradnagar switchyard due to breaker blasting / fire. 400 kV Panipat feeder at Dadri NTPC which was on the same diameter of the one and a half breaker scheme also tripped.

- ***The fault was finally cleared at 02:30:50.865 Hrs on tripping of Dadri end breaker of 400 kV Dadri Muradnagar line, isolating the faulty section.***

3.5 Analysis various elements

3.5.1 400 kV Agra-Muradnagar line

- The initiating cause of the incident was a Y-phase (of RYB) to ground fault on the 400 kV Agra-Muradnagar line (194 kms. length) at 01:23:31 hrs approximately 29% from Agra end. As per UPPCL's inspection of the site on 6th and 7th July 2005, it was concluded that the Y-phase conductor near location no. 166A, had snapped either due to joint failure or suspension clamp failure and the entire insulator of Y-phase string scattered into small pieces and the conductor fell on the ground. The tower no. 166A is situated near Gyan Deep High School in village Gahlau on Eglash-Khair Road near Aligarh.
- This fault was cleared by the distance protection at Agra end on Zone – I, although there is no evidence other than relay flag indications in support of the same from Agra either in the form of a Disturbance Recorder (DR) output or a Sequential Event Recorder (SER) output. The only indication that the fault was cleared in time from Agra end is the fact that there was no tripping at 220 kV and 400 kV around Agra during that period.

3.5.2 Operation of protection at Muradnagar on 400 kV Agra-Muradnagar line:

- The distance protection of this line at Muradnagar operated. Again there is no evidence of the same from Muradnagar either in the form of a DR or SER output. The breaker at Muradnagar end failed to open on operation of this distance protection. **This failure of the Muradnagar end breaker of 400 kV Agra-Muradnagar line to open and clear the fault was the first major contingency.**
- Tripping of the Agra end breaker of 400 kV Agra-Muradnagar line on Zone-I should have resulted in a inter trip command sent to Muradnagar on carrier for accelerated tripping of the line from Muradnagar. However the Power Line Carrier Communication (PLCC) receive counter at Muradnagar end of this line had not advanced. The signal for inter trip command to Muradnagar probably did not reach Muradnagar end.
- This breaker at Muradnagar is a SF_6 circuit breaker of CGL make. SF_6 gas is used to quench the arc. This gas is maintained at 6 kgf / cm^2 pressure. At 5.5 kgf/cm^2 pressure, alarm is provided while at 5.0 kgf/cm^2 pressure, the breaker goes under lock out. The operating mechanism for these breakers is a pneumatic system using compressed air. Unlike ABCBs, which have a common compressed air system for all breakers, SF_6 breakers follow a unit system concept with each breaker having an individual air compressor. The air pressure has to be maintained at 15 kgf/cm^2 for these breakers with an alarm provided at 13.2 kgf/cm^2 and lock out at 12.0 kgf/cm^2. It was not clear why this breaker failed to open and when the low air pressure alarm or lock out alarm appeared for this breaker. This breaker had successfully autoreclosed twice on 29th June 2005 at 04:16 and 21:59 hours for a fault on 400 kV Agra-Muradnagar line.
- Subsequently around 0530 hours on 6th July 2005 when the switchyard was being inspected, it was observed that the Miniature Circuit Breaker (MCB) of the air compressor unit of this breaker was found tripped.

UPPCL explained that this MCB might have tripped during the night when it was raining. This did not appear convincing as it would still take at least 24 hours for the air pressure to fall to breaker lock out level. UPPCL reported that this breaker successfully operated several times while testing in the morning of 6th July 2005. The fact that the Muradnagar operator failed to observe that the breaker had gone under lock out is a cause for serious concern. At Muradnagar also, no Disturbance Recorder & Event Logger printouts were made available in support of the events. (The DR & EL are stated to be not working for quite some time).

3.5.3 Operation of Local Breaker Back up (LBB) protection at Muradnagar:

- As the Muradnagar end breaker for Agra feeder failed to open on operation of distance protection, LBB of this breaker operated. This LBB operation should have sent a trip command to all the breakers connected to 400 kV Bus B at Muradnagar (the bus to which the Agra feeder was connected) as well as a carrier trip to the Agra end (although the breaker at this end tripped in time). The send PLCC counter at Muradnagar for Agra feeder had advanced nine counts during this incident. The other breakers connected to 400 kV Bus 'B' at this instance were :
    - 400 kV Moradabad
    - 400/220 kV, 240 MVA ICT-1
    - 400/220 kV, 240 MVA ICT-3
    - 400 kV bus coupler
    - 400 kV Dadri
- Except for the Dadri feeder all the other breakers tripped and thus 400 kV Bus 'B' had only the Dadri and Agra feeders connected to it. Dadri switchyard thus continued to feed the fault on 400 kV Agra-Muradnagar line. **The failure of the Dadri feeder breaker at Muradnagar to open on LBB operation was the second major contingency.**

3.5.4 Why did the Dadri feeder breaker at Muradnagar fail to trip?

3.5.4.1 This could have occurred due to the following plausible reasons:

- The LBB command went but the breaker did not trip as it was under lock out.
- The LBB command did not go to the breaker at all.

3.5.4.2 Taking the first reasoning that the LBB command went but the breaker did not trip, then this should have resulted in operation of the LBB protection of this breaker and a trip command sent to the Agra breaker at Muradnagar as well as to Dadri. Neither of this happened. While investigating this line of reasoning, the Committee was also informed that even if the LBB of the Dadri breaker at Muradnagar had operated, a direct trip command could not have been sent to Dadri TPS end as the PLCC channel for sending this command from Muradnagar had been faulty for the last 5/6 months. Although this aspect is not material to the incident on 6th July 2005,

the problem in the PLCC channel at Muradnagar for the Dadri-Muradnagar line needs to be immediately attended to for ensuring a reliable protection system.

3.5.4.3 Another argument as to why the first reasoning is untenable is that the Dadri feeder breaker could not have gone under lock out at 01:23 hours as about an hour later it had opened on a manual command from remote. Of course the B-pole of this breaker at Muradnagar had caught fire at this instant but it is clear that the breaker could not have been under lock out at 01:23 hours. Therefore it is concluded that the LBB command had not gone to the Dadri feeder at all.

3.5.4.4 The question then arises 'Why didn't the LBB command go to the Dadri breaker at Muradnagar?' In discussion with UPPCL engineers at Muradnagar, it transpired that the sensing connectivity of elements to the bus is through a VAJC relay which is set manually while charging any feeder and not automatically. For instance if the 400 kV Dadri feeder has to be connected to 400 kV Bus B at Muradnagar, the operator after closing the bus isolator of Bus 'B' for this feeder would have to physically drop the VAJC flag for this bus isolator and only then close the line breaker. This would ensure proper tripping of elements whenever the bus bar protection or LBB protection gets activated. It appears that this was not done resulting in the LBB command not going to the Dadri feeder breaker at all.

3.5.5 Operator actions at Muradnagar after the above major contingencies:

3.5.5.1 The operators at Muradnagar could not immediately visualize the tripping at Muradnagar at 01:23 hours. The immediate action they took after these tripping was to open all the 220 kV feeders. After the arrival of senior personnel, they also noted down the relay flag indications. Around 0200 hours, they attempted to open the Agra feeder breaker when Agra substation informed them about the unbalance in voltages. However, this breaker failed to open. The Muradnagar operator also observed that the currents in the three phases of 400 kV Dadri feeder was different. Of course, this could be done only by going to the panel and observing the same through changing the selector switch.

3.5.5.2 SLDC Lucknow was reportedly informed by Muradnagar of this unbalance and feeding of the fault on Agra line from Dadri. They reportedly advised for opening of the Dadri feeder breaker at Muradnagar. Its 'B' pole burst and caught fire when it was being opened. In panic, the operators opened all the 400 kV lines at Muradnagar thinking that all the lines were feeding the fault. This indicates that they were not aware that the 400 kV Bus coupler had tripped and opening the Panki and Rishikesh lines on the other 400 kV bus 'A' was really not required.

3.5.6 Blasting of the Dadri feeder breaker at Muradnagar at 0226 hours?

This breaker is an ABCB of HBB make (now ABB) owned by POWERGRID but operated and maintained by UPPCL on contract basis. This breaker was last overhauled in September 1994. On 20th May 2005, ABB Ltd. had attended to air leakage on the B-pole. This breaker had last tripped on 9th June 2005 and its operation was also checked on 11th June 2005 while energizing the 400 kV Dadri-Muradnagar line after a shutdown.

Inspection of the site revealed that while the moving contact of the breaker was intact, the fixed contact had blasted. (Photographs enclosed at **Exhibit -VI).** The position of the blast was such that it would surely have fallen in the bus bar protection zone of 400 kV Bus 'B'. However there was no evidence of operation of bus bar protection at Muradnagar. UPPCL informed that the bus bar protection was out of service at that point of time. While this aspect was not material to the incident on 6th July 2005, outage of bus bar protection is a serious issue in the protective systems at 400 kV Muradnagar.

The damaged breaker is under replacement by a new SF_6 Circuit Breaker of CGL make, made available by PowerGrid. Action has been initiated to set right PLCC link between Muradnagar –Dadri –station.

3.5.7 'Why didn't the 400 kV Dadri-Muradnagar line trip at Dadri end in Zone-III to clear the fault?'

In line with the general protection philosophy, the 400 kV Dadri-Muradnagar line should have cleared the fault before the tripping of generator transformers at Dadri and the ICTs at Dadri. This would have minimized loss of system elements.

During discussion, it emerged that the settings on the 400 kV Dadri-Muradnagar line had been given by POWERGRID and agreed to by NTPC. The Zone-3 setting for the line has been kept at 50 ohms (which works out to 117 kms. beyond Muradnagar). This has been decided to ensure that the Zone-III reach does not go beyond the 400/220 kV transformer at the adjacent substation viz. Muradnagar. The rationale for 50ohms has not been explained. NTPC had quoted '*CBIP Publication no. 274 October 1998: Manual on Protection of Generators, Generator Transformers and 220 kV and 400 kV networks'.* Page 23, Clause no. 4.1(iii) states as under:

'*Zone-III: For 400 kV lines Zone-III to be set to cover 120% of principle section plus adjacent longest section subject to a reach restriction so that it does not reach into next lower voltage level. For 220 kV lines, Zone-III reach may be provided to cover adjacent longest section if there is no provision of LBB or all protection are connected to single DC source at remote end sub-station'*

Thus the Dadri end of the 400 kV Dadri-Muradnagar line was designed to operate in Zone-III only up to a fault approximately 110 kms. Away on the Agra feeder from Muradnagar (considering maximum fault level at Dadri 400 kV) while in this case the fault was 137 kms from Muradnagar.

Therefore there was no way in which the Dadri end could have seen and cleared this fault in Zone-III, even assuming zero fault impedance.

3.5.8 Operation of protective systems at Dadri:

As indicated above, the fault continued to be fed from Dadri. The ICT-3 and 4 at Dadri (GPS) sensed this fault and tripped on operation of back-up earth fault relay. The 400 kV side of the ICTs are reported to have sensed this fault and tripped the ICTs which, as acknowledged by NTPC, was not in order as far as direction is concerned. It is the 220 kV side which should have seen this fault and tripped the ICTs. However this is not material to the incident as even the 220 kV side relays would have sensed and tripped the ICTs. Nevertheless, this direction problem for the relays has since been set right by NTPC.

The ICT-3 breakers (both the breakers) opened immediately when the earth fault relay operated. However the LBB of the breaker connected to Bus-I also operated. During investigation by Dadri TPS, it was observed that this was due to failure of the current sensing relay (CTIG39) to reset even though the breaker had opened in time. This CTIG39 relay failed to reset due to a partially dropped flag, which mechanically obstructed the movement of the contacts. This was therefore seen as a breaker fail condition resulting in LBB operation and tripping of all the breakers connected to 400 kV Bus-I at Dadri. Considering the breaker and a half scheme at this station, no elements were lost.

DR or SER output to substantiate the exact time of tripping of the ICTs and units was not available. The DR installed on 400 kV Dadri-Muradnagar line had reportedly triggered 200 times during the above period on overcurrent. Four such outputs taken at 01:23 hrs, 01:43 hrs, 0212 hrs. and 0222 hrs are enclosed. In the first two instances, the current in the Y-phase (of RYB) had increased to over 2000 A while in the last two cases, the current in the Y and B-phases had crossed 2000 A. R-phase current appeared to be normal.

The above does not tally entirely with UPPCL's report that the fault on 400 kV Agra-Muradnagar line started with a Y-phase to ground fault which got converted to a R-Y phase to phase to ground fault. The B-pole of the breaker at Muradnagar end had actually blasted at 02:26 hours. Therefore the high current in the B-phase at 0212 and 0222 hrs. is not understandable unless there is a confirmation from UPPCL that it was actually a Y-B phase-to-phase to ground fault, which could not be ascertained due to absence of DR outputs.

3.5.9 Operation of protection of 400 kV Dadri-Ballabgarh D/C at Ballabgarh end:

While the 400 kV Mandaula, Panipat and Malerkotla feeders emanating from NTPC Dadri did not trip at the remote end, the Ballabgarh circuits tripped. This needs to be examined by Protection Committee, as this tripping was not really desirable for a fault two sections beyond,

considering that the distance relay at Dadri on 400 kV Muradnagar feeder is not to clear the fault 137 km off Muradnagar.

3.5.10 Adverse effect of the continuous fault current:

The fault on 400 kV Agra-Muradnagar line thus continued to be fed from Dadri for nearly sixty three (63) minutes. As regards loss to equipment, extracts from UPPCL's report are quoted below.

- *'Since the fault continued to be fed from Muradnagar, the earth wire of both sides of tower from loc. No 165 to 168 became red hot and broke and fell on 'R' phase conductor in between location no. 166 and 167 due to which one conductor of 'R' phase also broke and fell on ground.*
- *The severity of the fault due to continuous feeding of high fault current according to villagers for about one and a half hours continuously can be gauged from the following damage that took place on the line.*

i) At Loc. 166A which was the worst affected, there was a 600 mm dia and 2 metre deep hole at one leg which was earthed and its complete chimney of 45 x 450 mm concrete was totally damaged up to bottom and one hole was also observed at 2.5 metre distance where earth electrode was pierced inside the ground.
Not only this leg the remaining three legs of this tower were also badly damaged inside ground and the concrete of chimney up to 400 mm deep was blown into pieces. (Photographs enclosed).
Further with the breaking of conductor and earth wire many bracing of 'K' frame including its main leg also melted. 25 nos. such bracing got melted at this tower.

ii) At loc. 167A two leg chimney towards loc. 168 'A' also damaged as 400 mm deep. Chimney concrete was also found blown to pieces. R phase string was also broken and one conductor snapped, 25 pieces of members also melted at this loc.

iii) The earth wire in the entire section from loc. No. 159B to 169B was damaged and need to be replaced.

iv) One conductor of R phase between Loc. No. 166 & 168 found broken.

v) Conductor between Loc. No 165-168 damaged in 'Y' phase (both) and one end in 'R' phase.

vi) The earth along entire route where conductor fell on ground the earth became coal type.'

- Photographs of the damaged 400 kV Agra -Muradnagar line is enclosed ***at Exhibit -VII.***
- Regarding other equipment in the system, apart from the tripping of all the units at Dadri (TPS) and Dadri (GPS), three units at Panipat, one unit each at BTPS and Dehar, there was no adverse effect except for the fact that negative sequence alarm started appearing on many units located nearby.
- As regards the Northern Regional grid, except for loss of generating units as above, some lines and load, the entire regional grid remained interconnected.

4.0 Review of Restoration

The system could be normalized after the faulty 400 kV Dadri-Muradnagar-Agra section was isolated at **02:30:50:864** hrs (as per NRLDC SOE) the restoration sequence is given below

The final restoration sequence was as under:

02:46 hrs.	400 KV Dadri-Ballabhgarh-I restored
02:50 hrs.	HVDC Rihand-Dadri Pole-I restored
03:09 hrs.	400 KV Dadri-Panipat restored
03:13 hrs.	ICT-4 at Dadri restored
03:18 hrs.	400 KV Dadri-Ballabgarh-II restored
03:20 hrs.	Unit # 2 at Panipat synchronised
03:27 hrs.	220 KV Dadri GPS-Railways feeder restored
03:30 hrs	400 KV Bus-1 at Dadri charged
03:37 hrs.	HVDC Rihand-Dadri Pole-2 restored
03:39 hrs	GT-I at Dadri GPS synchronised
03:41 hrs.	GT-2 at Dadri GPS synchronised
03:42 hrs.	400 KV Mainpuri-Ballabgarh-II restored
03:50 hrs.	400 KV Allahabad-Mainpuri-I restored
04:36 hrs.	400 KV Moradabad-Muradnagar restored
0452 hrs.	400 /220 KV, 240 MVA ICT-I at Muradnagar restored
04:53 hrs.	400/220 KV, 315 MVA ICT-2 at Muradnagar restored
05:12 hrs.	400 kV Panki-Muradnagar restored.
05:20 hrs.	400/220 KV, 240 MVA ICT-3 at Muradnagar restored
05:30 hrs.	GT-3 at Dadri synchronised
05:58 hrs.	GT-4 at Dadri synchronised
06:10 hrs	BTPS# 4 synchronised
06:21 hrs.	400/220 kV ICT-3 at Dadri restored
06:37 hrs.	Unit # 1 at Dadri (T) synchronised
06:51 hrs.	ST-1 at Dadri synchronised
06:54 hrs.	Unit # 3 at Dadri (T) synchronised
07:24 hrs.	ST-2 at Dadri synchronised
07:48 hrs.	Unit # 4 at Dadri (T) synchronised
09:24 hrs.	Unit # 2 at Dadri (T) synchronised
09:28 hrs.	400 KV Dadri-Muradnagar restored through the transfer bus coupler breaker at Muradnagar as its main breaker (B-Pole) had blasted. Due to this 400 KV Rishikesh-Muradnagar line had to be kept off.

The committee felt that there might not have been tripping of 400 kV Allahabad-Mainpuri-II due to high voltage at 01:48:39 hrs if there was anchoring load at Mainpuri.

400 KV Agra-Muradnagar line was declared under breakdown and restored at 1620 hrs on 20th July, 2005

The Committee members noted with satisfaction that the normalization of Grid was done quickly except the resoration of supply to railways, which was slightly delayed.

5.0 OTHER ISSUES

5.1 Supply to railways

- The 400/220 kV ICTs 3 and 4 at Dadri had tripped at 01:23 hours resulting in isolation of the Dadri GPS units from the grid. The 220 kV supply to Railways from Dadri GPS was also affected. This was restored at 0327 hours after charging the 400/220 kV ICT-4 at 0313 hours.
- Incidentally in this incident, the 220 kV Dadri (TPS) bus was live throughout and a 220 kV interconnector between the thermal and gas station exists which could have been utilized to provide power supply to the Railways immediately. (Single line diagram enclosed at ***Exhibit – VIII***)
- Dadri TPS had stated in discussions that this 220 kV interconnector was basically for providing start-up supply to Dadri TPS from Dadri GPS in a black start scenario. Accordingly, interlocks had been provided in the switching arrangement and therefore extending supply from Dadri TPS to Dadri GPS and there from to the Railways was not possible.
- From a system perspective, this does not appear to be in order. The possibilities of having enough flexibility in operation of the 220 kV interconnector between the thermal and gas stations at Dadri need to be examined by NTPC separately.

5.2 Active energy consumed during the fault:

4 The Special Energy Meters (SEMs) installed at Dadri and Muradnagar ends on the 400 kV Dadri and Muradnagar line have recorded active energy flows during the period of fault. For instance, the Dadri end meter has recorded 15-minute energy as under:

S. No	Time period	Energy flow (MWh) on 400 kV Dadri-Muradnagar at Dadri end (Meter NT-0009A)	Remarks
1	0000-0015	72.90	
2	0015-0030	61.59	
3	0030-0045	68.14	
4	0045-0100	68.06	
5	0100-0115	80.76	
6	0115-0130	57.16	Period of fault 0123-0226 hrs. These meters did not have any * mark
7	0130-0145	20.36	

8	0145-0200	21.56	did not have any * mark from 0115-0215 hours. * mark occurs when the voltage in any one phase goes below 70% even for an instant. Thus Dadri voltage has not gone below 70% between 015-0215 hours when the fault was being fed.
9	0200-0215	32.51	
10	0215-0230	27.34	
11	0230-0245	0	Feeder tripped from Dadri end at 0230 hours.

No 400 kV element had been charged at 400 kV Muradnagar during the period of this fault. Even then, it appears implausible that close to 118 MWh had been consumed by the fault in 63 minutes (average load 118 MW). This is against common logic that faults are characterized by heavy MVAR flows and negligible MW flows. Incidentally, the IEC standards for 0.2S accuracy class meters (IEE 62053-22) are silent on the active energy accuracy if the power factor is close to zero, which would be the situation during a fault. However the damage caused at the fault site as explained by UPPCL correlates the fact that enough energy has been consumed.

5.3 Operator's actions at Dadri:

Operation of LBB protection and leading to isolation of 400 kV Bus-I at Dadri TPS had no relation to the fault on 400 kV Agra-Muradnagar line and its continuous feeding from Dadri NTPC. Nevertheless, this and the loss of thermal and gas units at Dadri deflected the attention of the Dadri TPS switchyard and NRLDC engineers.

In fact even when BTPS engineers were contacting NRLDC to complain about unbalance in the system, NRLDC operators had an apprehension that a jumper might have disconnected somewhere in the system.

Dadri TPS switchyard control room has the facility of separate ammeters in the panels indicating phase-wise currents for each feeder (unlike the phase selector switch at Muradnagar which had to be physically changed). However, as the operators were busy in examining the relay flag indications and inspection of switchyard considering that LBB had operated, this unbalance aspect was not noticed immediately. The unbalance voltage was detected when Dadri TPS could not their thermal auxiliaries . The current unbalance on the 400 kV Dadri-Muradnagar line could not be noticed.

5.4 Actions at SLDC Lucknow and NRLDC:

An uncleared fault in the 400 kV system for 63 minutes was an unacceptable situation for the system operators. Availability of real time data, its visualization and a good two - way communication system (both the physical facility and the human element) between the control centre and the power stations / substations is of prime importance.

NRLDC's immediate counter actions to control voltage, line loading, angular difference etc were as under:

Backing down of generation at Singrauli / Rihand / Anpara Complex.
Reduction of imports from neighboring regions.
Raising of generation in Rajasthan, Punjab & BBMB system
Load shedding in Western part of the grid.

Feedback from the substations on the actual ground situation to the SLDCs/RLDCs become very important. In this entire incident, it is clear that the Agra and Muradnagar substations have not communicated in clear terms on the actual ground situation at their stations to SLDC Lucknow/NRLDC. It is also clear that these two substations have not communicated effectively even between themselves.

In all the discussion that the Committee had, there was a general consensus that a neighbouring substation operator or the system operator cannot be expected to clear faults manually when all automatic protective systems had failed.

6.0 Points of Concern

Based on the above analysis, it is clear that the incident of 6th July 2005 is a serious event meriting the attention of all concerned agencies. The basic causes are:

a. Operational failure of two 400 kV circuit breakers at Muradnagar.
b. Non availability of PLCC for the last several months on 400 kV Dadri-Muradnagar line(one channel) at Muradnagar end.
c. A failure in 400 kV LBB protection system at Muradnagar .
d. Simultaneous incident of LBB protection system maloperation at Dadri NTPC that deflected operator's attention.
e. Revisiting the back-up protection philosophy in respect of Line Distance Protection
f. Inability of the Muradnagar operators to fully comprehend the situation and take action accordingly.
g. Lack of a proper verbal communication between the affected substations and between Load Despatch Centre & substations.

- All these factors resulted in a fault on 400 kV Agra-Muradnagar line being fed for 63 minutes continuously from Dadri TPS which is unprecedented.

7.0 Recommendations to avoid reoccurrence of such incidents

1. It is observed that Fault initiation was due to failures of Conductor joints/suspension clamp of the 400 kV Transmission line between Muradnagar and Agra – Maintenance practices like regular patrolling visual checks/inspections and Thermal scanning to be done regularly and mentioned closely. **(Action -M/s UPPCL , All constituents.)**

2. Poor/Inadequate maintenance and upkeep at 400 kV substations is a matter requiring urgent attention. Minimum standards of testing and Maintenance for the regional system may be laid down under the aegis of REB/RPC. A system of periodic certification by the respective owner of the system for compliance, to be mentioned and reported for deviations by RLDC, may also be introduced. **(Action-NREB,NRLDC)**

3. Power lines Carrier Communication is an important tool in the relaying of the protection signals to the Far end Breakers of a transmission line. They become even more critical when "Fail to trip" conditions develop for an individual breaker and there is need to trip far end breaker to isolate the fault ensuring healthiness of PLCC's protection channels is extremely important and imperative Failure, if any of these must be restored/rectified immediately. Need of Redundant channels for protection signals relaying may be reviewed by protection Committee of NREB. **(Action-All Constituents.)**

4. It is utmost important that the personnel stationed on all 400 kV & 20 kV substations and Switchyard should be able to have clear understanding and comprehension of various annunciations/alarms/trips appearing. Skilled and trained personnel must man these substations/Switchyard. Periodical refresher courses to upgrade the skill and alertness must be conducted **(Action - All Constituents).**

5. The non-receipt of the LBB trip command and thus failing the LBB protection function, by the Dadri line Breaker at Muradnagar end, has been found to be due to the improper trip selection. The bus selection logic has been reported non-functional at Muradnagar and a manual selection by the operator is adoptee. Presumably for the same reason Bus Differential protection has been kept defeated. The situation amounts to rendering LBB protection trip unreliable. In all 400 kV sub stations, Bus Differential and LBB protection must always be kept in service and in healthy condition. Any deviation must be reported to RLDC and necessary back up provisions arranged in such a situation. **(Action - All Constituents).**

6. By the presently recommended/adopted Distance protection Zone-3 reach setting, remote back up is certainly not available to many lines. This was evidenced by the current event. Failure of one Breaker to trip (Agra line Breaker at Muradnagar end) and failure of LBB protection trip command routing (Dadri line Breaker at Muradnagar) resulted in the fault being un-cleared for over 63 minutes. There is a need to revisit the Zone-3 reach setting criteria of Distance

protection relays, as laid down by the CBTP report no.274, need for an additional IDMT, Directional Earth fault relay for lines, by a body of protection experts. **(Action - All Constituents).**

7. Event Logger (PL) and Disturbance recording (DRs) systems being not available in Muradnagar, the analysis of the sequence of events was very difficult. This aspect had been emphasized by various enquiry committees in the past also. This is vital not only for the event analysis and investigation but also for the operators learning. Numerical relays having in DR & ER facilities with GRS should be provided in all 400 kV substation and important 220 kV Substation. **(Action - All Constituents).**