CASE STUDIES ON GRID DISTURBANCES IN WESTERN REGION OF INDIA DURING 2003-04 AND DEFENCE PLAN FOR GRID SECURITY

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Abstract-- **Western regional grid is the largest of the five regional power grids in India with an installed capacity of 31932 MW and meeting a peak demand of 25000 MW. Western regional grid operates synchronously with Eastern and North Eastern power grids and asynchronously connected to Northern and Southern grids. During the period October, 2003 to March 2004, the onset of agricultural demand along with 2000 MW power imports caused critical loading of lines in the East-West corridor and poor voltage profile. Five major grid disturbances occurred during this period leading to partial collapse of the grid. The paper discusses in detail the underlying causes for the above grid disturbances, the operation of protection systems, long term stability problems in the split systems and islands. The paper also discusses in detail the operation of various defence schemes and their operation during the above disturbances. Based on the identification of security constraints, a defence plan was drawn up to prevent recurrence of such disturbances in the future. The paper discusses the defence plan in detail.**

I. INTRODUCTION

THE Indian power system is having an installed capacity of 1,12,706 MW and is meeting a peak demand of around 76000 MW. The Indian power system is operated as five Regional grids viz., Northern Regional grid (NR), Western Regional grid (WR), Eastern Regional grid (ER), Southern Regional grid (SR) and North Eastern Regional grid (NER). Since last few years, Eastern and North Eastern regions were operating in synchronous mode through AC inter-ties. Since 2nd March 2003, Western and Eastern grids were synchronously connected through two 400kV lines and three 220kV lines forming Central grid. The Central grid is having installed capacity of over 50000 MW and meets demand of over 34000 MW. The inter connection largely benefited Western regional grid which is importing power to the tune of 1200-1800 MW from ER & NER grids. In WR grid, most of the generation is located in Eastern part and load centres are located in Western part of the grid. The typical East-West power flows are of the order of 6000 MW with all the East-West corridor critically loaded mainly due to non availability of one HVDC pole between Chandrapur and Padghe capable of carrying 750 MW. The region is suffering power shortage of 6000 MW due to which grid frequency is maintained between 49 Hz and 49.5 Hz during peak load hours. The lack of adequate reactive compensation has been leading to low voltage profile with 400kV voltages at some sub-stations touching 320kV during the agricultural season (October to December). The import of additional power from Eastern region also led to reduced margins on the transmission network especially in the East-West corridors. In the backdrop of the above scenario, five grid disturbances took place in the period October 2003 to March 2004.

II. OVERVIEW OF WESTERN REGIONAL GRID

[1]. Western regional grid comprises the power systems of the States of Maharashtra, Gujarat, Madhya Pradesh, Chhattisgarh, Goa; Union Territories of Daman & Diu and Dadra & Nagar Haveli; the Central Sector power stations owned by NTPC & NPC; the inter state transmission system owned by POWERGRID and power systems owned by the private utilities such as TPC, BSES, BEST, AE.Co etc. The installed capacity as on 30.6.2004 is 31932 MW. The region is catering to a peak demand of around 25000 MW. The daily energy consumption is 530 MUs/day. The region has hydro-thermal mix of 14:86. The region has been facing power shortage (peak) of 18% and energy shortage of 11%. The transmission network of the region comprises 19500 ckt. Kms of 400 kV lines and 30000 ckt. Kms of 220kV lines. 500kV bi-pole HVDC link between Chandrapur and Padghe connects Eastern & Western Maharashtra systems. The region is connected to NR and SR asynchronously through HVDC back-to-back links at Vindhyachal and Bhadravati respectively. The Eastern, and North Eastern regions operate in synchronization with Western region.

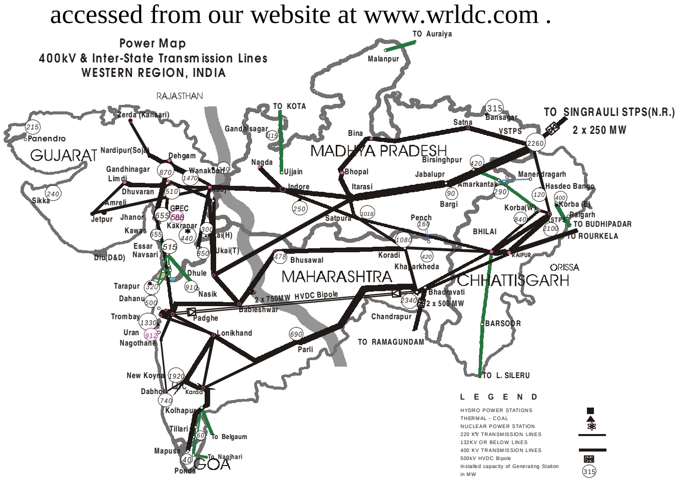
[2]. The region is having full fledged SCADA system with sufficient information for effective monitoring of the grid. However, the non-availability of Energy Management System (EMS) is a handicap especially felt during contingencies. The SCADA system is also having facility to trigger disturbance report in response to tripping of identified breakers and gives pre-fault, fault and post-fault

information which is useful for analysis of grid disturbances.

[3]. Low voltage profile persists during Rabi season (October to March) due to the onset of low power factor agricultural pump sets, loading of several lines above SIL and inadequate reactive power compensation. The low voltage pockets are situated mostly in Western part of the grid with bulk load centres whereas the Eastern part of the grid with surplus of generation has fairly good voltage profile.

[4]. The automatic under frequency load shedding scheme (AUFLS) comprise load shedding through UF relays at 48.2 Hz (750 MW), 48 Hz (750 MW) and 47.9 Hz (1000 MW) in addition to 4778 MW load connected to df/dt relays with settings of 49.2 Hz, 0.4 Hz per sec, and 48.8 Hz, 0.2 Hz per sec. Islanding schemes have been provided for TPC, BSES & A.E.Co., .systems and for Kakrapar, Uran, Utran, GIPCL, Panandro and ESSAR power stations.

[5]. A grid map of Western region indicating generating stations, inter-state/ inter-regional interconnections and 400kV lines is at Fig.1. Detailed grid map can be accessed from our website at www.wrldc.com .



III. OCCURRENCES IN BRIEF

A brief description of the five occurrences is given in the ensuing paragraphs.

On 6.10.2003, a disturbance led to splitting of the grid and ultimately collapse of Western Maharashtra. During the pre-fault conditions, five 400kV lines were under planned outage in addition to the HVDC pole-I of Chandrapur-Padghe. Three of these AC lines and the HVDC pole emanate from 400kV Padghe substation. The disturbance was triggered due to tripping of one more 400kV line from Padghe on fault leading to increased power flow on another 400kV line between Padghe and Kalwa. The increased loading on the line led to sparking on C-phase isolator which ultimately led to melting of conductor which snapped and fell on ground leading to bus fault at 400kV Kalwa substation. Two more 400kV lines were lost due to this bus fault at Kalwa. Number of 400kV lines in East-West corridor tripped on power swing and over voltage leading to splitting of the grid into two parts. Frequency in Eastern part comprising of Eastern part of Maharashtra, M.P, Chattisgarh, ER & NER regions rose to 51.9 Hz leading to loss of generation of 1870 MW with generating units tripping on high frequency. The Western part comprising, Western Maharashtra and Gujarat survived with 220kV ties between Gujarat and Western Maharashtra holding the system together. However, after 47 minutes, one 220kV tie-line tripped due to snapping of Y-phase wave trap jumper. Since Western Maharashtra was drawing heavily from Gujarat, other three 220kV lines tripped on over load. Western Maharashtra and Gujarat separated with frequency in Western Maharashtra dipping to 47.6 Hz from 49.27 Hz. At 47.6 Hz, two islands (TPC & BSES) formed as per the designed islanding scheme while Western Maharashtra collapsed due to tripping of generating units on under frequency relay operation (set at 47.5 Hz). Gujarat system survived due to adequate under frequency load shedding. The frequency in one of the islands (TPC) rose to 51.97 Hz causing tripping of gas units on over frequency.

On 5.11.2003 (1024 hrs), a grid disturbance caused total collapse of Western Maharashtra. Prior to the occurrence, three 400kV lines were not in service, low voltages persisted at some 400kV buses with Indore and Nagda bus voltages as low as 326 kV. The disturbance was initiated due to tripping of a long 400kV line on load encroachment which was mainly due to high power flow at reduced voltage. The voltages further dipped leading to tripping of three more 400kV lines on load encroachment. Power swings on East-West corridor led to tripping of number of lines leading to splitting of the system into two parts; Part-I comprising Eastern Maharashtra, M.P, Chhattisgarh, ER & NER grids survived with number of units tripping on high frequency. Part-II comprising Western Maharashtra and Gujarat attained new stable operating point after tripping of number of lines on load encroachment/power swing due to voltage collapse of 300kV and below. This part survived for 9-minutes but Western Maharashtra was unable to control the load generation balance with drawal from Gujarat exceeding 1000 MW. Tripping of one 400kV line inter-connecting Western Maharashtra and Gujarat on power swing led to tripping of the remaining three 220kV lines and one 400kV line also on power swing. Frequency in Western Maharashtra decayed to 47.6 Hz which further led to islanding of TPC & BSES. Western Maharashtra collapsed due to tripping of units on U/F protection. Gujarat system survived due to adequate under frequency load shedding.

Another occurrence took place on 7.11.03 at 1303 hours which is exactly similar to the occurrence on 5.11.03. This occurrence was also triggered due to severe low voltages in Western Madhya Pradesh due to onset of agricultural loads and 400kV lines tripping on load encroachment of distance relays and not triggered by any fault. Prior to the occurrence, four 400kV lines were not in service and WR grid was importing 1800 MW from ER grid. In this occurrence, Western Maharashtra did not collapse totally as 220kV lines between Western Maharashtra and Gujarat were able to hold the systems together.

During the occurrence on 6.12.03 at 1221 hrs, Western Maharashtra once again collapsed. Prior to the occurrence, low voltages persisted in Western M.P with Indore 400kV voltage touching 320kV. The disturbance was triggered due to the tripping of Talcher-Kolar HVDC bi-pole carrying 1050 MW from ER grid to SR grid. About 900 MW power rushed to WR grid dipping the voltages of East-West corridors and critically loading the corridor. Four 400kV lines tripped on load encroachment followed by number of lines tripping on power swing in the East-West corridor. System split into two parts with Part-I comprising Eastern Maharashtra, M.P, Chhattisgarh, ER & NER grids surviving after tripping of number of units on high frequency. In Part-II comprising Western Maharashtra and Gujarat frequency rose to 50.92 Hz initially and fell to 48.4 Hz in four seconds due to tripping of few generating units. The low frequency and rate of fall of frequency led to operation of under frequency and frequency trend relays in Gujarat with frequency once again rising to 50.3 Hz. The HVDC pole between Chandrapur & Padghe with inverter (at Chandrapur) and rectifier (at Padghe) located in two parts that had split was varying power flow from 700 MW to zero due to operation of HVDC frequency controller. After 16 minutes, Gujarat and Western Maharashtra systems separated from each other due to tripping of inter-ties on power swings and over loading. Western Maharashtra system collapsed while TPC & BSES islands separated from Western Maharashtra. TPC island survived even though the gas units tripped on high frequency. The BSES island did not survive due to adverse load generation balance. Gujarat system survived due to UF load shedding. The excess under frequency load shedding led to frequency rise and tripping of some generators on high frequency.

On 5.2.2004 at 1414 hrs, a grid disturbance occurred leading to collapse of Western Maharashtra. Prior to the disturbance, frequency and voltage profile were normal. However, four 400kV lines and one 220kV line were under outage. A line fault on a 400kV line from Chandrapur was cleared, but failed to re-close at Chandrapur. Subsequently, the breaker at Chandrapur bursted leading to a bus fault. However, the bus bar protection did not operate. Even breaker failure relay did not operate. All the transmission lines from Chandrapur tripped at remote ends after 350 milli seconds. However, one 400/220kV transformer did not trip leading to feeding of the fault till tripping of 220kV lines cleared the fault. About 1750 MW generation was lost at Chandrapur. Number of 400kV lines in the East-West corridor tripped on power swings leading to splitting of the system into two parts. Part-1 comprising Eastern Maharashtra, M.P, Chhattisgarh, ER & NER grids survived after tripping of few generating units on high frequency. Part-II comprising Gujarat & Western Maharashtra survived for few minutes till one of the 400kV inter-tie was hand tripped by sub-station operator in Gujarat as the line loading increased beyond 600 MW and Maharashtra was unable to control their load generation balance. Remaining ties between Gujarat & Western Maharashtra tripped on power swing and over loading. TPC & BSES islands separated from Western Maharashtra as frequency fell to 47.6 Hz and survived. Western Maharashtra collapsed. Gujarat system survived due to adequate under frequency load shedding.

IV. ANALYSIS

1. *Underlying Causes for the grid disturbances.*

- ✓ High imports leading to critical line loadings
- ✓ Low voltages due to low power factor loads of agricultural pump sets
- ✓ Lack of reactive support in Western part
- ✓ Non availability of one pole of Chandrapur-Padghe HVDC line
- ✓ Grid operating at voltage stability and dynamic stability limits
- ✓ Non compliance of (n-1) security criterion
- ✓ Generators in Western part at high Var limits and lack of dynamic Var support
- ✓ Low generation in the Western part at gas based power stations.

Table-I gives details of pre-fault conditions, initiating causes and the compounding events that led to occurrence of these grid disturbances. In three out of the five occurrence, the pre-fault conditions have a strong bearing on the disturbance. Ignoring the symptoms of blackouts is a major cause of blackouts. Control centres should immediately plan counter measures and enforce (n-1) security criterion. Predominantly low voltage profile, important transmission elements not in service and significant amount of import especially from ER leading to critical loadings on East-West corridor have profound impact on the later events. Three of the occurrences (5/11, 7/11 & 6/12) were not initiated by faults, but voltage collapse which led to tripping of lines due to load encroachment of Zone-III of distance relays. Two of the occurrences (6/10, 5/2) were initiated by bus faults and delayed fault clearance has significant impact on the disturbance of 05.02.04. Ageing and not properly maintained equipment is a major cause for these blackouts. Bursting of a breaker led to the blackout on 05.02.04. The compounding events that led to spreading of the grid disturbance mainly consist of tripping of lines on power swings, high voltage, tripping of generating units on under frequency protection and high frequency trippings. The grid splitting occurred as described in Table-I. Fast and adequate operator actions could have saved the grid collapses. Inadequacy of important defence mechanisms like AUFLS has also led to collapse of Western Maharashtra. The behaviour of some of the protections also is a major concern. The HVDC frequency control feature also operated against the requirements of the Western part of the system and made operator response futile. By and large, the islanding scheme and the AUFLS performed and restricted the extent of disturbances.

Table-I

V. Overview of disturbances

Significant factors	06.10.03	05.11.03	07.11.03	06.12.03	05.02.04
A) Pre-fault conditions					
Low voltages		✓	✓	✓	
High imports	✓	✓	✓	✓	✓
Transmission constraints	✓	✓	✓		
B) Initiating causes					
Distance relay operation on load encroachment		✓	✓	✓	
Bus fault	✓				
Bus fault due to equipment failure					✓
C) Compounding Events					
Power swings	✓	✓	✓	✓	✓
Over voltage	✓				
Tripping of generators on under freq.protection	✓	✓	✓	✓	✓
Tripping of generators on high frequency	✓	✓	✓	✓	
HVDC control operation				✓	
Inadequate operator response	✓	✓	✓		✓
D) Extent of collapse					
Splitting of the system into Eastern & Western parts	✓	✓	✓	✓	✓
Collapsed part	Western Maharashtra (W.Mah)	W.Mah	Some areas of W.Mah	W.Mah	W.Mah
Total loss of generation (loss of generation on high frequency	3619 (1870)	4149 (2000)	2419 (2419)	4572 (3060)	5158 (1910)
Islanding of TPC system	✓	✓	Not called upon	✓	✓
Survival of TPC island	✓	✓	-do-	✓	✓
Islanding of BSES system	✓	✓	-do-	✓	✓
Survival of BSES system	✓	✓	-do-	✓	Collapsed
E) Disturbance phenomenon	Transient & dynamic instability	Voltage collapse	Voltage collapse	Voltage collapse & dynamic instability	Transient instability
F) Time taken for restoration	2 hrs 5 min.	4 hrs 36 min.	58 min.	3 hrs 39 min.	3 hrs, 36 min.

VI. Long Term Stability Problems

A. HVDC controls during split system operation

During occurrence on 6.12.2003, HVDC flow was 700 MW with Chandrapur & Padghe in two different split systems. Both these split part systems survived without any problem for about 16-minutes after which 400kV Jhanor-Padghe S/C line tripped on fault and auto-reclosed but during reclosing Nasik-Navsari line tripped on power swing which led to tripping of other 220kV and 400kV ties between Western Maharashtra & Gujarat. Western Maharashtra collapsed as frequency dipped to 47.5 Hz and below. Due to failure of AC supply at Padghe, the HVDC link also tripped. During the 16-minutes of split system operation, the HVDC flow varied from 75 MW to 700 MW in order to maintain Chandrapur frequency to pre-split frequency with ramp rates of 3000 MW per Hz. This feature is conceived to protect Chandrapur unit islanding with only DC line but has become counter productive in case of split-system operation adversely affecting Western part. The variation on import resulted in difficulty in controlling power flows on Gujarat-Western Maharashtra inter-ties often leading to critical loadings.

B. Frequency Dynamics and Islanding.

The pattern of system splitting is identical in all the five grid disturbances. While splitting of the grids, frequency fell at the rate of 00.8 to 1.00 Hz/sec in Western part with df/dt relays in Gujarat (set at 49.2 Hz, 0.5 Hz/sec and 49.0 Hz, 0.3 Hz/sec) achieving load-generation balance in Western Maharashtra – Gujarat part system. The rate of fall of frequency during separation of Western Maharashtra from Gujarat system observed was of the order of 2.5 – 3.0 Hz/sec. The separated Gujarat system frequency rise was of the order of 1.80-2.0 Hz per second. These rates however depend on load generation balance and rotating inertia.

C. Voltage Dynamics

The occurrence on 05.11.2003, 07.11.2003 and 06.12.2003 are characterized by voltage collapse. Maharashtra reported voltage fluctuations of 7 kV at Dhule and Padghe sub-stations during the first week of November. These fluctuations occurred when one group of agricultural loads are disconnected (through load shedding) and other group of agricultural loads are energised in M.P. Reactive power of 400 MVAR was flowing towards Dhule and Itarsi from Padghe. The use of auto starters by agricultural motors (pump sets) led to severe dip in voltage (as soon as one group of agricultural loads are given power supply) due to heavy starting currents. Dips as low as 250 kV were reported and fluctuations observed at several sub-stations in M.P and Maharashtra during load change over (1200 Hrs to 1230 Hrs).

During the disturbances, number of lines also tripped on high voltage due to sudden reduction in loading of these lines due to load shedding (automatic through UF & df/dt relays) during system splitting or loss of feed due to tripping of lines in the same corridor due to power swings.

D. Operator Response

During the occurrence on 06.10.2003, Gujarat and Western Maharashtra remained in synchronism. And survived for 47 minutes till the tripping of all the 220kV ties (three more) on power swing due to inability to control power flow. On 05.11.2003, Western Maharashtra and Gujarat systems were in synchronism for about 9-minutes. The inability of operators to control the tie line flows led to tripping of these lines on over load and led to separation of the two parts. On 07.11.2003, the two separated parts were integrated within 30 minutes. However, heavy drawal of power by Western Maharashtra from Gujarat led to once again splitting of the grid after 22-minutes of first integration. On 05.02.04, the combined Western Maharashtra & Gujarat systems separated from the rest of the grid. Due to heavy power flow towards Western Maharashtra, the operator opened a 400kV inter tie between Western Maharashtra and Gujarat, the remaining one 400kV and four 220kV inter ties tripped on power swing and led to separation.

The operators have to achieve active power balance in Western Maharashtra by shedding excess load and stepping up hydro generation at Koyna so that the two 400kV inter ties and four 220kV inter ties between Gujarat and Western Maharashtra remain within safe loadings (n-1 security criterion). Strict discipline in maintaining frequency close to 50 Hz by regulating the loads is required for about 30 to 45 minutes till integration with rest of the grid. Adhering to these basics would have prevented the extent of collapses in all the five occurrences.

E. Security Criterion

On 05.11.03, 07.11.03 and 06.12.03, there was no fault in the grid. However, tripping of one line led to cascade trippings of several lines leading to system splitting. The active power and reactive power have to be controlled so that (n-1) security criterion is not violated.

VII. OPERATION OF PROTECTION SCHEMES

On 05.11.03, 07.11.03 and 06.12.03, the occurrences initiated due to tripping of lines on load encroachment of distance relays. This requires a review of Zone-III settings. The reach of Zone-III should be reduced to such an extent that load encroachment into Zone-III do not take place for voltage of 320 kV with power flow of 750 MW for 400kV lines (normal power flow permitted is 500 MW).

On 05.02.2004, non operation of bus bar protection at Chandrapur (generating 1741 MW) led to tripping of all 400kV lines at remote end in Zone-II. The bus bar protection did not operate for bursting of a breaker. It is suspected that non operation could be due to bypassing of the bus bar protection during transferring the line from TBC to main breaker or possibility of having horn gaps across the CT secondaries. The arcing across the gap could create a short circuit across the secondary thus bypassing the current through differential relay. The breaker failure relay (BFR/LBB) also did not operate for the stuck breaker condition. After examination, it was found that following the bursting of the breaker, the tubular conductor (IPS tube) snapped and fell to ground causing a high resistance fault. Since the CT was on the line side, the CT did not carry the fault current after snapping of the bus conductor. The back-up over current and earth fault relays on 220kV side of 400/220kV transformer-II at Chandrapur did not operate thus delaying the fault clearance. The delayed fault clearance gives rise to severe transient instability as critical clearing time is an important factor for ensuring transient stability.

Most of the generating units tripped due to operation of generator under frequency protection set at 47.50 Hz instantaneously. A delay of few seconds (3 to 5 seconds) for the U/F relay of the generators at 47.50 Hz or having instantaneous tripping at 46.50 Hz is required to allow time for frequency recovery following AUFLS operation.

VIII. OPERATION OF DEFENCE MECHANISMS

The AUFLS in Gujarat operated satisfactorily shedding excess load to counteract rapidly falling frequency. Both UF relays and df/dt relays operated as desired whereas in Western Maharashtra, the performance of AUFLS is inadequate. The islanding schemes of TPC and BSES operated successfully. However, BSES island did not survive on 05.02.04 due to inability to control the active power imbalance in the absence of one 250 MW unit at Dahanu. The trippings of units on high frequency occurred during all the occurrences. FGMO operation is somewhat adequate only on 05.02.04. The HP/LP bypass facility available on all 210/500 MW units has not been effectively utilized by the generators in controlling high frequency. None of the units could island on house load.

IX. DEFENCE PLAN FOR GRID SECURITY.

A. Automatic Under Frequency Load Shedding Scheme (AUFLS)

Additional load shedding planned in Western Maharashtra to ensure active power balance after separation from the grid.

B. Free Governor Mode of Operation (FGMO)

The Western region has implemented FGMO from 2nd January 2004. The tripping of generating units could be avoided with FGMO available on all the generating units.

C. Islanding Schemes

In order to ensure quick restoration and protect generators in Western Maharashtra from tripping during grid disturbances, more islanding schemes have been planned. Islanding scheme for Uran was already implemented while schemes for Parli, Nasik and Bhusawal are under implementation.

D. Network Strengthening

In the open access regime, it is required to plan the network that allows power transfer from any one node to any other node without causing congestion and with sufficient redundancy. The network planning should also plan for reactive power support and FACTs devices in order to control power flows and maintain voltage profile. Already, the Standing Committee came up with plans for augmenting and strengthening the network enabling 2500 MW import by 2007 and 4000 MW by 2009.

E. Under Voltage Load Shedding Scheme (UVLS)

Under voltage load shedding is the most important counter measure against voltage instability. The scheme can be implemented on various feeders using IDMT type voltage relays. However, the scheme implemented at 400kV Indore S/S is most suitable to maintain voltage profile at the EHV transmission level. The scheme trips loads in Indore area through carrier in case of 400kV Indore voltage falls below 350 kV and remains below 350 kV for more than 5-minutes. The time delay needs to be reduced to 5-10 seconds. Application of dv/dt relays can also be considered

F. Runback scheme at Talcher

Run-back scheme already implemented at Talcher power station (Stage-II) effects reduction of generation by 1000 MW when the Talcher-Kolar bi-pole (2500 MW capacity) trips with 1500 MW reduction coming from generators on FGMO in ER, WR and NER grids. Discussions are also going on to trip one or two units through automatic means.

G. HP/LP bypass facility

All generators of 210/500 MW capacity would actuate HP/LP bypass facilities to match the turbine load and boiler output. HP/LP bypass has to be actuated based on frequency and rate of frequency rise.

H. Islanding on house load

This facility would enable faster restoration of generators as some generators in each power station can go to house load operation and survive supplying their own auxiliaries.

I. HVDC controls

Action plan prepared to ensure proper operation of the frequency control feature of the Chandrapur-Padghe HVDC bi-pole. The plan envisages discriminating between islanding of Chandrapur units and split system operation with rectifier and inverter are on different part systems with different frequencies. In case of split system operation, inverter end frequency should also be controllable if required. Further, the control of HVDC flow also considers the evacuation facilities at the inverter end.

J. Equipment Maintenance and R&M

Refurbishment or replacement of ageing and old equipment is one of the top most priorities. The failure of ageing equipment has led to number of grid disturbances in the past. R&M of the sub-station equipment based on residual life analysis would reduce probability of failure of equipment. Improved methods of maintenance through condition monitoring would reduce failures. Some of the old relays should be replaced by numerical relays. Some of the relays like bus bar protections are not called upon to act frequently and as such the expected performance of such relays can be assessed through periodic testing of the relays. In Western region, POWERGRID conducted workshops for all utilities on modern maintenance practices. A regional level workshop on O&M was also conducted at Mumbai.

K. SCADA & EMS

Western region is in the process of replacing the existing SCADA system with the state-of-the-art Unified Load Despatch & Communication Scheme (ULD&C) by the end of this year. This would provide operator with better monitoring and control facilities. The new system would have capabilities matching those available in the developed countries.

L. Wide Area Protection Schemes (WAPS)

Phaser Measurement Units (PMU) can be used [1] for data acquisition and protection functions. These units sample current and voltage phasers of various nodes in a power system and calculate various power system quantities. PMUs can be time synchronised with GPS signals to ensure that the measurements across the entire power system are taken precisely at the same instant. The instantaneous values and phase angles can be time stamped with an accuracy of one micro second. The PMUs also would eliminate errors in data as transducers are not required. The data acquired from PMUs would ensure the state estimation function of EMS system. Protection applications include monitoring steady state as well as transient state of the power system and to actuate corrective actions like load shedding, switching of reactive power control devices, tap changing, adaptively changing relay settings. Two of the major disturbance phenomenon – Voltage instability and out of step conditions can be detected and counter measures initiated through WAPS from the system protection centre (SPC) where the data is processed and analysed. Most of the present protections for detecting out of step conditions use local measurements and are not therefore reliable whereas WAPS uses system wide area measurements. The present difficulties in selecting zones to be blocked or allowed to trip on power swing detection, selecting quantum of load shedding and suitable locations to counter voltage instability could be resolved with WAPS.

M. Analysis of Relay Operations

Disturbance Recorders (DRs) and Sequential Event Loggers (SERs) have to be provided at all sub-stations and generating stations and time synchronised to GPS signals. These would help in analysis of the relay operations. Numerical relays also store pre-fault data and fault data which would help in analysing the relay operations.

N. Dispersed Generation

Dispersed generation facilities should be encouraged as these would provide local supplies and reduce power flows on transmission corridors.

X. REFERENCES

[1] *Mehmit Kaba & Joachim Bertseh* , “Wide Area Protection Solution for enhancing power system security and performance”, Second International Conference on Integrated Protection Control and Communication – Experience, Benefits & Trends, 2001.