WIDE FLUCTUATIONS IN FREQUENCY AND VOLTAGE – CASE STUDIES IN WESTERN REGION

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SYNOPSIS

The paper describes the causes and impact of frequency and voltage variations in large power grids, especially with power starved utilities. Scarcity leads to various players of the interconnection in failing to discharge their commitments to the grid. It is interesting to note that some of the major reasons for such parametric variations are managerial, commercial and administrative constraints. These factors could become relevant even in developed countries also in future with number of players participating in grid operation with differing interests and degree of control. Frequency and voltage variations put the grid operators in alert situation and security levels are lowered with some of the security measures bypassed. Case studies of Western regional grid (India) have been considered for a period of three months in the year 2001. The paper also suggests the solutions planned for reducing the frequency and voltage excursions.

1. INTRODUCTION

The frequency and voltage variations not only reduces the life of power generation equipments and consumers' electrical appliances but also creates continuous alert situation to the grid operators. Maintaining a tight frequency control is essential in operating major power grids as any variation (than the dead band of the governors) can alert the operator about the possibility of generation loss, load throw-off or islanding. During normal operation of the grid, tight frequency control around 50 Hz nominal frequency could be accomplished through seizeable system stiffness (percentage load variation ÷ percentage frequency variation). A major part of the stiffness is contributed through governor response while load damping also contributes to stiffness. In case of sudden generation loss, the system frequency fall and rate of fall is arrested initially through inertia of the rotating machinery comprising generators and motors (significantly through generators). After the initial steep fall of frequency, the turbine governors will respond with time lapse of 2-10 seconds and provide instantaneous generator response. The contribution of load damping also arrests the frequency decline. When the frequency stabilizes at lower value, it has been observed in Western regional grid that the frequency further decays due to reduction of generation of gas turbines occurring in 20-60 second horizon and further frequency decay takes place 3-4 minutes due to reduction of thermal generation due to the effect of frequency on their auxiliaries. The frequency has to be brought back to the normal value through secondary control either through AGC or manually. However, in the Indian context, turbine governors are blocked with large dead bands such that their influence will not come during the normal operation of the system. One of the reasons claimed for keeping the governors blocked has been that large excursions of grid frequency that takes place. On the other hand, keeping the governors in service would reduce the frequency variations and stabilizes frequency. The main reason for frequency fluctuations is that the generators do not track the continuously changing demand with the result that frequency continuously varies widely due to the imbalance thereof. Due to non availability of governors, frequency variations are arrested only through load damping and in the event of tripping of a 500 MW unit, frequency dips by around 0.8 Hz during peak hours and when the agricultural loads are in service. However, during times when less amount of rotating machinery and agricultural loads are in service, the frequency even falls by 1 Hz with the tripping of a 210 MW unit. In the absence of reliable AUFLS scheme, frequency may fall to 47.5 Hz or lower and may cause tripping of generators on UF protection leading to total collapse of the grid except for few islands which separate out at 47.6 Hz. Such an occurrence is the mother of all contingencies as total grid may be affected. Even during normal operation of the grid, the wide variations of frequency takes place as the generators are tracking demand changes only in half hourly horizon. Sudden variation of frequencies takes place creating confusion as to whether the cause is a grid incident or normal variation in demand. The system operators have to take certain corrective action through shedding of loads which may have to be restored again as there is no grid incident.

In the Western region, wide variation of voltage profile takes place even at the 400kV levels with high voltages during parts of the day and extremely low voltage during other parts of the day. The 400kV voltage at Indore S/S even touched as low as 320kV. In a number of low voltage pockets, the voltage levels at EHV S/Stns dips to as low as 0.8 p.u. The seasonal voltage variation also takes place in Western region with predominantly low voltages during the rabi season (October to March) due to the onset of agricultural loads of power factor around 0.7 lag. Similarly, during monsoon months (June to August), high voltage conditions persist all over the grid. Due to lack of adequate shunt compensation, the low voltages persist and grid incidents lead to voltage collapse in these areas. During monsoon period high voltage persist, due to which number of 400kV lines have to be kept out to maintain acceptable voltage profile. This lowers the security levels of the grid. The reluctance of generators to absorb VARs and lack of reactive compensation devices is the major handicap. During rabi season, the generators generate reactive power even by reducing active power generation which is not acceptable in a grid which is operating with power deficits as high as 5000 MW. During grid incidents, the voltage variations can not be arrested due to lack of SVCs. Even lines carry reactive power with large difference between sending and receiving ends voltages. In addition to the above, voltage fluctuations also take place causing great concern in grid operation due to the effects of sudden bulk load shedding. On certain occasions, the bulk load shedding cause oscillations in the system with voltages fluctuating widely. On certain occasions, bulk load shedding cause sudden rise in voltages at number of locations leading to tripping of 400kV lines on over voltage protections (set at 110%) and tripping of transformer on over-fluxing leading to alert state of the grid.

The paper considers Western regional grid as the study system to examine the causes and implications of frequency and voltage variations that have been taking place presently. It has been observed that number of reasons for the frequency and voltage variations include administrative and commercial factors in addition to the technical reasons.

2. OVER VIEW OF WESTERN REGIONAL GRID

The Western Regional Power Grid comprises power systems of States of Maharashtra, Gujarat, Madhya Pradesh, Chattisgarh, Goa and Union Territories of Daman & Diu and Dadra & Nagar Haveli. Generation, transmission and distribution in some parts of the region are also owned by licensees, IPPs in the private sector. Some of the major generating stations are owned by Central Sector utilities like NTPC, NPC. The backbone transmission in the region is owned and operated by Powergrid which forms the inter state transmission system. The installed capacity of the region is 30793 MW and the region caters to a demand of 22000 MW. The region has severe long term capacity shortages with the result that the average demand met is of the order of 21000 MW as compared to the unrestricted demand of around 27000 MW. A number of generation constraints exists in the form of poor coal quality, wet coal, coal mill problems, partial outages on auxiliaries etc and on any given day about 800 MW generation is not available due to these constraints. The forced outages further have impact on the generation availability. About 1800 MW of generation available at liquid fuel based IPPs is not being used due to high cost. Further, the surplus generation available with the captive power plants is yet to be harnessed. These above factors lead to low frequency operation during major part of the year. However, during monsoon months, high frequency prevails in the grid due to total absence of agricultural loads which constitute about 28%. These factors cause low and high frequency problems as the demand exhibits both daily and seasonal variations. The region is predominantly thermal with hardly 13% hydro generation which is affected by the vagaries of monsoon. The hydro generation is not really available for load following as most of the generation is either run only during peak hours with no surplus hydro capacity available. The demand variations are tracked effectively on 3-4 hours horizon and to some extent half hourly horizons. However, the absence of turbine governors leads to inability of the generating units to track momentary and minute to minute fluctuations. This precisely leads to frequency variations.

The States in the region are having entitlement in the Central Sector generating plants (ISGS) and WRLDC schedules this generation based on their requisition as well as formulates drawals/schedules to the States on a daily basis which are binding on the states. However, due to deficit in one or more states at any given point of time, the states attempt to overdraw from the grid at low frequency and underdraw at high frequency if the states are having a surplus. This attitude of the states leads to grid indiscipline and is a major factor for continuous frequency variations. The states in the region are also not able to precisely forecast their demands due to the absence of adequate tools and non usage of weather models in their experience based or heuristics based forecasting methods. The errors on this account also contribute to frequency variations taking place all over the day and results in the states overdrawing/underdrawing from the Central pool. Due to inadequacies in the existing commercial mechanisms and lack of framework for trading, some of the generation available with private licensees, IPPs & CPPs remains underutilized. For instance, the regional peak occurs between 1800 hours and 2200 hours while the peak hours for Mumbai area controlled by Tata Power are between 1100 hours to 1400 hours. The off peak hours for Mumbai area coincide with the regional peak hours. Further, the grid frequency would be around 50 Hz during the time of peak hours for Tata system. Tata Power runs about 300 MW hydro between 1100 and 1400 hours instead of drawing power from the grid while the hydro generation is kept off during the evening peak hours. Shifting of this 300 MW hydro to regional peak hours will reduce regional deficit and improves frequency profile significantly. Another case in point is that the 150 MW pumped storage plant of Tata Power at Bhira is not being utilized since Tata Power can not draw cheaper grid power out of the regional surplus during night hours and use for pumping water due to deficiencies in commercial mechanism. Non availability of cheaper power for pumping comes in the way of using the 150 MW pumped storage plant during regional peak hours.

The States of the region implements load regulatory measures through power cuts on HT industries, LT industries, roastering of agricultural loads, holiday and recess staggering and some planned load shedding in rural/semi-urban areas which is termed as scheduled load shedding. This scheduled load shedding is expected to take care of the long term capacity shortages. To account for the forced outage of generating units, forecasting errors and generation constraints, additional manual load shedding is planned on a daily basis which is termed as unscheduled load shedding. However, due to inconvenience to the public and other political reasons, the unscheduled load shedding is inadequate and the States prefer to overdraw from the central pool or maintain low frequency operation taking calculated risks of anticipated contingencies. The Automatic Under Frequency Load Shedding (AUFLS) scheme has been provided to take care of contingencies of loss of generation but due to continued low frequency operation around 48.5 Hz, the UF relays set at 48.2 Hz and 47.9 Hz are often bypassed with a result that the grid is not adequately protected and the emergency capability is not known.

The States in the region are not investing adequately for providing shunt capacitors (which are cheaper) to take care of low voltage problems. The inadequacies in the sub-transmission and distribution system also contribute to low voltages. Some generators are reluctant to generate adequate reactive power while some of the generators in the low voltage pockets are generating VARs even by reducing active power outputs. The generators at Parli operate almost at 0.7 p.f. The lack of dynamic VAR support at locations far from generating stations is a cause of concern and leads to voltage collapse in these parts during grid disturbance occurring elsewhere. The low voltages cause load encroachment in distance relays during grid disturbances leading to tripping of several lines and compound the extent of disturbances.

The Western regional grid is monitored through hierarchical of Load Despatch Centres of the States (SLDCs) with WRLDC at the top of the hierarchy. All these control centers have been provided with SCADA systems with fairly good amount of data available. However, EMS functions are yet to be provided. In order to describe the constraints in maintaining steady frequency profile, the operating practices of the states in the region, power shortages, technical constraints and commercial and managerial problems have to be resolved. The study period for the case study was selected between January 2001 to March 2001.

3. FREQUENCY FLUCTUATIONS

General observations on constraints in maintaining steady frequency in the Western regional grid are discussed below:-

3.1 Inability to forecast the demands precisely

3.2 Tracking Demand

The main reason for frequency fluctuations is that generation and load shedding are not able to track the demand and lags occur. To maintain steady frequency, the demand has to be tracked in the horizons of

a) in 3-4 hours time blocks when demand significantly changes (night off peak, morning peak, day off peak, evening peak etc) i.e., basically hour to hour fluctuations.
b) Load following in 5-15 minute time blocks (supplementary control based on frequency linked dispatch guidelines.
c) Moment to moment fluctuations (2 seconds to 10 seconds) controlled through generator response which is available with free governor operation on all generating units (50 MW & above) is not implemented at present.

3.3 Sudden Corrective Actions

Sudden actions like bulk load shedding or generation withdrawal/ reduction causes frequency fluctuations. In the absence of free governor operation unit trippings, load throw-off causing severe frequency fluctuations cannot be controlled.

As Koyna Hydro generation (4x280 MW) comes up suddenly without giving advance intimation to WRLDC. Since the unit size is 280 MW, sudden generation of either 200 MW or 280 MW for each unit is expected.

3.4 System inertia and load damping

Due to absence of agricultural loads and other rotating type loads (fans etc) during parts of the day, load damping has come down. The system stiffness has reduced as low as 360 MW/Hz. Even loss of one 500 MW unit could cause frequency dip of 1.50 Hz. On 8-4-2001, Chandrapur-6 (500 MW) tripped and frequency dip of 1.3 Hz occurred (net loss of 400 MW).

On 9.4.2001 at 1843 hrs., system frequency was 50.70 Hz and frequency gradually decreased to 48 Hz by 1921 hrs. i.e. in 18 minutes time. The frequency decay was due to onset of evening peak loads only and no loss of generation occurred. About 1800 MW load has come up in 18 minutes.

On 27-3-2001, frequency gradually decreased from 50.15 Hz to 49.40 Hz (0.75 Hz) in 9 minutes i.e. from 1210 hrs. to 1219 hrs. About 235 MW generation loss occurred at Dahanu power plant.

3.5 Frequency dynamics

Frequency continues to decay in case of sudden loss of generation. No generator response (instantaneous) is available to arrest the step change in frequency. Even after the df/dt is reduced (slope corresponding to normal load changes) due to onset of demand, frequency stabilizes at a lower value (after 5-10 minutes). Inability to follow this demand change by generators and manual load shedding is the main constraint. On 11-1-2001, 350 MW load throw-off occurred and frequency shot upto 51.48 Hz from 51.08 Hz. Similarly, on 26-1-2001, 3500 MW load throw off along with 2600 MW loss of generation occurred in Gujarat due to earth quake and frequency rose to 51.50 Hz from 49.40 Hz. Load throw off events also occurred on 17-1-2001 at Vapi and on 9-2-01 at Anjar. There is a risk of grid occurrence as gas turbines and nuclear units are set to trip at 51.50 Hz.

3.6 Commercial Problems

MPSEB is not in favour of CSEB exporting 200 MW to APTRANSCO on a bilateral basis. Normally, the bilateral transactions are terminated by WRLDC, when frequency touches 49 Hz and likely to remain low. Due to overdrawal by MP, frequency touches 49 Hz during evening peak hours and the plea of WRLDC to carry out distress load shedding to control overdrawal is disputed by MPSEB. MPSEB refuses to shed load until the bilateral transaction is terminated and continues overdrawal.

MSEB's constrained to maintain hydro generation to prop up frequency above 48.50 Hz irrespective of its drawal to facilitate export to Tamil Nadu. The constituents actually overdrawing wait for the bilateral transaction to be terminated rather than carrying out load shedding. This would lead to low frequency operation and/or depletion of hydro resources when not required.

3.7 Poor Hydro Generation in Gujarat & MP

It is possible to use hydro units in Gujarat and MP only during peak hours. In MP, hydro generation of about 70 MW possible at Bango and all other hydro stations have no water. Due to low hydro generation, it is not possible to control frequency as thermal units operate without any spinning reserve.

3.8 Hydro Generation in Maharashtra

Koyna IV generation (4x280 MW) is available only between 0600 hrs. to 2200 hrs. The Koyna IV units are shut down by 2130 hrs. even if the frequency is low. On 5-4-2001, Koyna IV units were withdrawn between 2041 hrs. & 2103 hrs. Due to loss of 800 MW to the grid, frequency decayed to 48.50 Hz.

3.9 Wait and Watch attitude

Unless frequency dips below 48.50 Hz, no constituent initiates action despite appeals from RLDC. The SLDCs still think (even after IEGC) that frequency should be maintained above 48.50 Hz and not above 49 Hz (49 Hz is luxury). Based on the previous day frequency profile and demand profile, actions can be initiated well in advance to avoid sudden dips due to sudden onset of load demand at peak hours (1820 hrs., 1850 hrs., 1920 hrs., 0440 hrs., 0540 hrs., 0930 hrs.). Actions are taken only after frequency dip, or actions are postponed for scheduled load shedding to increase at the next nearest hour (eg. 0500 hrs., 1000 hrs., 1900 hrs. etc.) . Further, the load shedding effect comes about 15-20 minutes after the command is given and meanwhile the frequency continues to be low. Sometimes frequency touches high values due to delayed LS effect which occurs even though other states have taken action to improve frequency.

The constituents carryout load shedding only at 0600 hrs. while frequency dip occurs at 0540 hrs. Similarly between 1730 hrs. and 1830 hrs. generation is maximized and evening peak loads are yet to come. Frequency remains high during this period (close to 51 Hz) During day off-peak, high frequency occurs close to 51 Hz between 1230 hrs. & 1330 hrs. Even though generation tries to track the regional demand on a block basis (morning peak, day off-peak, evening peak, night off-peak), due to time lags frequency dips and rises occurs. Sharp frequency dips/rises on a typical day in Mar'2001 are as follows:-

S.No.	Time (Hrs.)	Sharp Dip/rise	Cause
1.	0540	Dip	O/D by MPEB
2.	0700	Dip	O/D by GEB and slight O/D by MSEB
3.	0930	Dip	O/D by GEB & MPSEB
4.	1308	Rise	U/D by MP
5.	1730-1800	Rise	U/D by GEB, hydro gen. Pick up by Maharashtra
6.	1915-1930	Dip	O/D by MP
7	2315	Dip	O/D by MP
8.	2130	Dip	Removal of hydro generation by Maharashtra.

The present load shedding also do not track the frequency.

3.10 Scheduled Load Shedding

No control over scheduled load shedding (cannot be advanced or delayed). The scheduled load shedding comes in bulk causing sudden frequency rise. Scheduled load shedding should be backed up by distress load shedding to take care of forced outage of units.

3.11 AUFLS as a tool for manual load shedding

Below 48.50 Hz, the frequency is in the decaying trend, M.P. & Gujarat wait for AUFLS to operate but do not take initiative to improve frequency. As AUFLS is used as a substitute for manual load shedding, the emergency capability becomes uncertain.

3.12 Constraints at NTPC stations

Generation is backed down at NTPC stations during high frequency. If any constraints occur during this period, NTPC would be unable to maximize generation. After code is given to them when the demand picks up, NTPC informs the constraints only after one hour of the request for maximization. One such constraint is with VSTPS-7 & 8 units due to coal mill changeover problem. SLDC & RLDC expecting generation pick up and frequency improvement thereof could not plan other actions. Proper information with RLDC helps in taking advance actions and planning so that frequency do not drop severely. The generation at Kawas & Jhanor stations suddenly reduces/increases as per the gas availability. NTPC can take up with GAIL/ONGC to maintain required pressure so that increase/decrease can be done gradually.

3.13 Co-ordination problems

MSEB withdraws hydro generation and reduces Dabhol generation even when frequency is below 48.5 Hz if they are underdrawing. MSEB do not intimate in advance Koyna-IV generation schedules, synchronization and shutting down programme.

Between 2130 hrs. & 2200 hrs., frequency dips to 48.50 Hz or below due to removal of hydro generation. Between 2200 hrs. & 2300 hrs., frequency fluctuations occur due to withdrawal of load shedding (restoration of shed loads) and reduction of demand and the time lags between the two.

Though reduction of generation to schedule and increase of generation at a frequency below 50.0 Hz at ISGS on a voluntary basis are in order with IEGC, but causes fluctuations in frequency. This is due to:

1) RLDC uses other resources to improve frequency, or RLDC allows frequency to be between 49.0 – 49.5 Hz for some time in anticipation of scheduled load shedding effect or to reduce exports to other regions. Simultaneous increase at NTPC stations causes high frequency.
2) Once the generation at NTPC stations increased/reduced, RLDC has to issue code again to normalise and NTPC stations take time to normalise, also they often complain of frequent codes from RLDC.

3.14 Sudden effects

a) The load shedding done in bulk and in less than 5 minutes can cause sudden frequency rise. Similarly load shedding is also restored in bulk. MPSEB did sudden load shedding of 800 MW at 1600 hrs. and sudden restoration of 900 MW at 1800 hrs. on 18/2, 19/2 and 20/2. Sudden load shedding is done by MPSEB also at 1000 hrs (500 MW to 800 MW) and at 0600 hrs (900 MW). The details are enclosed.
b) The pattern of manual load shedding scheme implemented by MPSEB is not suitable to the requirements of grid operation. MPSEB carries out bulk load shedding in the day off peak hours (1200 hrs. to 1600 hrs.) when the frequency is normally high. MPSEB overdraws during morning peak hours and evening peak hours (due to inadequate load shedding) when the frequency is normally low. Frequency profile is affected adversely due to such a pattern of load shedding.
c) Tripping of 400 kV Dabhol-N.Koyna S/C line can cause islanding of Dabhol power station of 740 MW capacity and may cause sudden frequency dip.

3.15 Delayed Actions

MSEB promptly backs down thermal generation during night for high frequency control. But when Maharashtra demand increases by 0415 hrs., thermal generation pick up is not initiated. Thermal generation maximization should have been completed by the time of onset of load.

In MP, control actions are delayed. Load shedding can not be implemented as required by RLDC. Gujarat do not normalize load shedding even if frequency improves.

3.16 Unusual problems

On 28/2/2001 at 0646 hrs., frequency was 48.50 Hz. Maharashtra could not bring Koyna IV hydro units on bar due to some technical problem. MSEB requested Dabhol to bring up units and also carried out distress load shedding. However, suddenly Koyna IV units (three units) came on bar along with simultaneous effect of load shedding and increase in Dabhol generation. All of a sudden, frequency shot up from 48.50 Hz to 50 Hz and then on 51.20 Hz.

3.17 Delays in following the backing down instructions

3.18 Frequency fluctuations due to Transmission Constraints.

a) Simultaneous outage on Chandrapur-Parli ckts. 2 & 3

To control loading, Maharashtra regulates hydel generation from time to time. WRLDC regulates ISGS generation to control frequency. This phenomenon was observed on 11.4.01 & 12.4.01.

b) Outage on one Itarsi-Indore ckt.

To control loading, Gujarat does load shedding by which frequency increases, but the line loading reduces only with b/d at VSTPS or export to NR and hence frequency reduces again.

c) Outage Bableshwar-Dhule D/C on 30-3-2001

As a result more than 1000 MW power was flowing to Gujarat causing critical loading of Itarsi/Satpura-Indore corridor. Load shedding done by Gujarat to control the drawal, followed by backing down effected at VSTPS cause frequency fluctuations.

3.19 Maximum ramp up/down rates of demand

a) Long Term

Time block (Hrs)	Demand change (MW)	(+) Ramp up / (-) Ramp down rate (MW/Minute)
0400-0700	(+)3246	(+)18
0600-0700	(+)1803	(+)30
1000-1300	(-)1808	(-)10
1200-1300	(-)754	(-)12
1700-1900	(+)3729	(+)31
2200-2300	(-)2608	(-)43

b) Short Term

Time block (Hrs)	Ramp up/ramp down rates (MW/Minute)
0515-0525	(+)30
0535-0540	(+)80
0900-0905	(+)60
1235-1305	(-)95
1415-1445	(+)10
1810-1830	(+)30
1910-1930	(+)49
2145-2200	(-)50
2245-2300	(-)26

The load shedding/withdrawl is sudden and can not follow the load variation. The response rates of generators should be able to follow these demand variations through manual control with the governors blocked.

3.20 Operating Practices

The States in Western region maximise generation at around 1730 hours as peak demand hours approach. Depending on the onset of lighting load (related to sunset and cloud cover), the actual peak of each States occurs between 1830 hours and 1930 hours (based on time zone effect). In the meantime, ie., between 1730 and 1830 hours, high frequency of about 51 Hz prevails in the grid and frequency comes down to 48.5 Hz by 1900 hours.

3.21 Effect on generation

Due to low or high frequency operation, the generation changes occur due to the effect on auxiliaries. Significant change can be observed in generation of gas units.

4. PERFORMANCE INDICES FOR FREQUENCY MONITORING IN WESTERN REGION.

WRLDC continuously monitors frequency excursions through a set of performance indices and takes up with the states for proper planning of corrective actions. These include monitoring minimum, maximum and average frequencies and the percentage of time frequency remain in various bands, number of times frequency touches 48 Hz, 51 Hz, system stiffness, etc. As per IEGC, system frequency has to be maintained within a band of 49.0 Hz to 50.5 Hz. In this band, the overdrawals/underdrawals by the states are permitted by the commercial mechanism ABT while the extreme frequency excursions during normal operation are controlled by the incentives/dis-incentives offered by the ABT and in emergencies handled through directives and operating instructions issued from WRLDC. A typical frequency profile for a day and frequency profile in various frequency bands is enclosed which reveal the excursions in grid frequency. WRLDC also monitors frequency through a performance index called Frequency Variation Index (FVI). It has been defined in IEGC as the degree of frequency variation from the nominal of 50 Hz over a specified period of time and is computed as under:

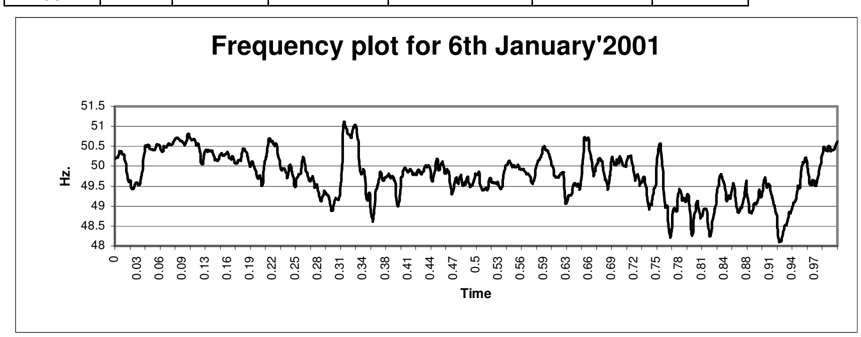
$$FVI = 10 \times \frac{\sum_{i=1}^{N} (f_i - 50)^2}{N}$$

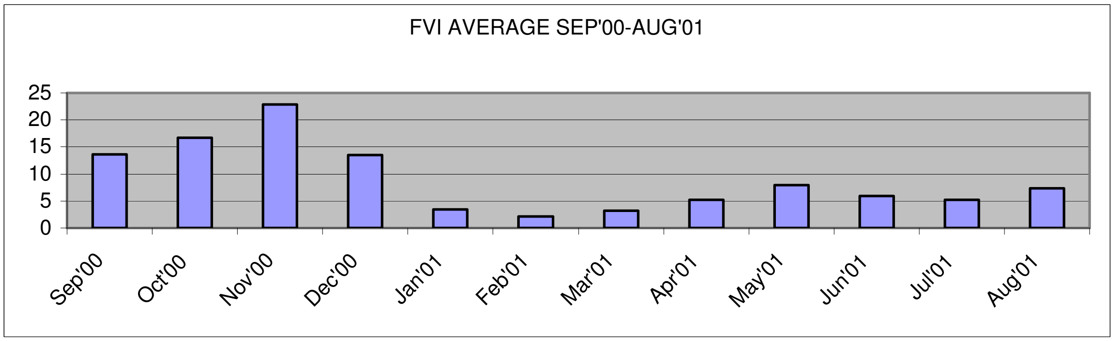
Where
f_i : actual frequency in Hz at i_{th} time period
N: number of measurements over the specified period of time.

The FVI varies from 1.30 to 30 during the year for Western region. WRLDC also monitors the frequency dynamics during grid incidents involving generation loss or load throw off and monitors the system stiffness and frequency excursions. A few of the events on which analysis has been made are described in Tables 1,2,3 & 4. The frequency plots recorded at WRLDC during for such grid incidents are enclosed to depict the frequency variations and their impact.

a) Frequency Profile (% time) in the quarter

Month	<48 Hz	48-49	49-49.5	49.5-50.5	50.5-51	>51Hz
Jan 2001	0.04	6.52	13.37	62.99	14.78	2.30
Feb 2001	Nil	2.84	15.08	72.21	9.13	0.74
Mar 2001	Nil	8.28	16.75	65.84	8.41	0.73

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25
20
15
10
5
0
Sep'00
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Mar'01
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Jun'01
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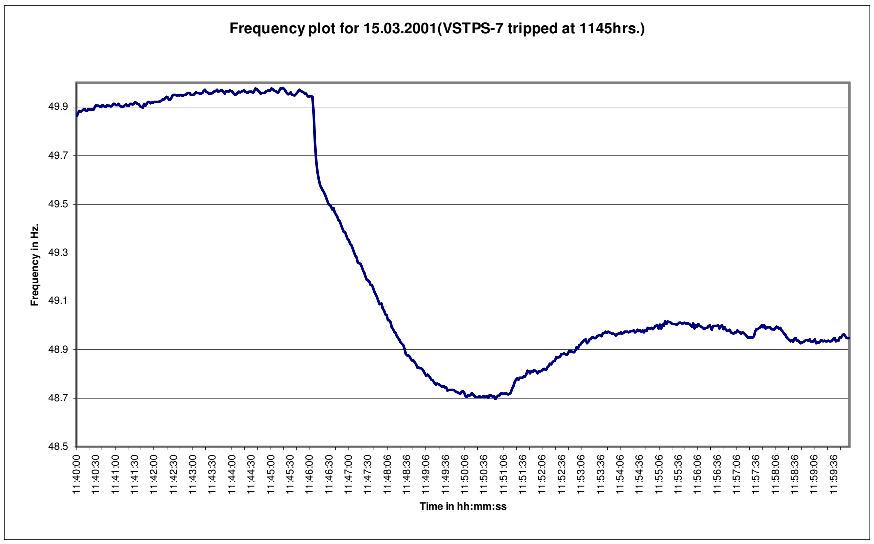

Frequency plot for 15.03.2001(VSTPS-7 tripped at 1145hrs.)
Frequency in Hz.
Time in hh:mm:ss

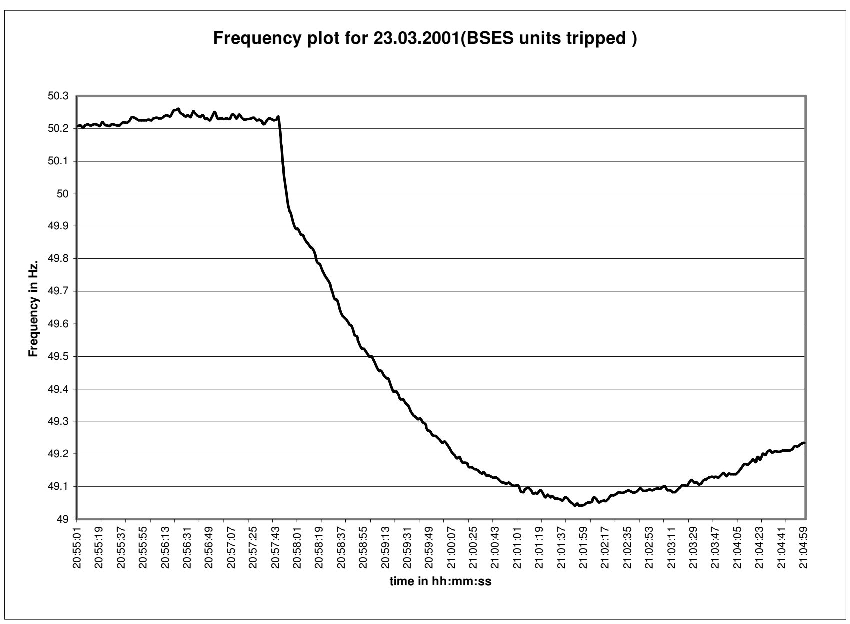

Frequency plot for 23.03.2001(BSES units tripped)
Frequency in Hz.
time in hh:mm:ss

Table I **Composition of Loads**

S. No.	Type of Load (92-93 data)	% in WR. Demand	p-f characteristic (D)
1.	Agriculture	27.25	4.5
2.	Commercial	5.41	1.2
3.	Residential	17.58	1.0
4.	Industrial	43.00	2.5
5.	Other (Railway, Water Work, Street lighting etc.)	6.76	3.0

Table-II Steady State Frequency Variation of the System

% of load agricultural	D	Stiffness (% demand/Hz)
0%	1.7917	3.5834 %
25%	2.25137	4.50274%
50%	2.39961	4.79922%
75%	2.56426	5.1286%
100%	2.74477	5.4896%

Table-III **Frequency dynamics – Transient**

S.No Event No.	Time	Date	Details of tripping	Step change in Gen. (Net)	Step change in freq.	Demand	Transient gain	Settling time (sec.)	Transient gain (%)
1.	114557	15.03.01	VSTPS-7 tripped	475 MW	0.35	19088	1357	10 sec.	7.1 %
2.	205741	23.03.01	BSES Units (1 & 2 tripped)	465 MW	0.32	21442	1453	13 sec.	6.77 %
3.	124423	30.03.01	VSTPS-7 tripped	320 MW	0.17	18192	1882	6 sec.	10.34%
4.	191618	05.04.01	VSTPS-7 tripped	340 MW	-	20570	-	12 sec.	-
5.	193818	07.04.01	Load throw off in MSEB	L/S of 425 MW	0.49		867	14 sec.	
6.	160000	19.02.01	Sudden load shedding by MPSEB	L/S of 800 MW	-	19088	-	-	-
7.	180000	19.02.01	Sudden lifting of load shedding by MPSEB	L/S of 800 MW	-	19224	-	-	-
8.(A)	101942	22.03.01	VSTPS-7 tripping and Koyna-IV withdrawal	(349 + 200)MW	0.3	19500	1830	10 sec.	9.38%
8 (B)	102718	22.03.01	VSTPS – 8 tripping	410MW	0.26	19000	1576	9 sec.	8.29%
8 (C)	105132	22.03.01	Load restoration and change in HVDC export/import	-	-	-	-	-	-
9.	064727	28.02.01	Load shedding by MSEB and Koyna-IV units brought on Bar and Dabhol units	-	-	-	-	-	-
10 (A)	0850	26.01.01	Net load throw off of 900 MW (2600 MW gen loss and 3500 MW load throw off)	-	-	-	-	-	-
10 (B)	0850	26.01.01	750 MW b/d + 180 MW loss of gen. At Jhanor	-	-	-	-	-	-
11.	0812	10.04.01	580MW net loss of generation at Parli along with 400MW load throw off.	180MW	0.13	19000	1385	10	7.29

Table-IV **Frequency dynamics – steady state**

S. No.	Time	Date	Details of tripping / load throw off	Frequency change (steady state) Hz	Gen. Loss (MW)	Stiffness (% MW / % Hz)
1.	114557	15.03.01	VSTPS-7 tripped	49.95 Hz to 48.70 Hz(1.25 Hz)	475	0.994 (1.988% per Hz)
2.	205741	23.03.01	BSES units 1 & 2 tripped	50.25 Hz to 49.05 Hz (1.20 Hz)	465	0.908 (1.81% per Hz)
3.	124423	30.03.01	VSTPS-7 tripped	50.35 Hz to 49.50 Hz (0.85 Hz)	320	1.04% (2.08% per Hz)
4.	191618	05.04.01	VSTPS-7 tripped	49.91 to 49 Hz (0.91 Hz)	340	0.906% (1.81% per Hz)
5.	193818	07.04.01	Load throw off in MSEB	48.24 Hz to 49.70 Hz (1.46 Hz)	425	
6.	160000	19.02.01	L/S of 800 MW by MP	49.75 Hz to 51.29 Hz (1.54 Hz)	800	1.38% (2.77% per Hz)
7.	180000	19.02.01	Load restoration of 800 MW by MPEB	49.85 to 489.50 Hz (1.35 Hz)	800	1.53% (3.07% per Hz)
8.(A)	101734	22.03.01	VSTPS-7 tripped and Koyna-IV withdrawal	49.9 to 48.95 Hz (0.95 Hz)	349+200 = 549	1.47% (2.95% per Hz)
8 (B)	102718	22.03.01	VSTPS-8 tripping	49.2 to 48.4 Hz (0.8 Hz)	410	1.32% (2.64%)
8 (C)	105132	22.03.01	Load restoration and change in HVDC export/imports	49.1 to 48.6 (0.5 Hz)	250	1.29% (2.58%)
9	064727	28.02.01	Load shedding by MSEB & Koyna-IV units and Dabhol brought on bar	48.59 to 51.24 (2.65 Hz)	900 MW gen. Change L/S 700 MW	
10 (A)	0850	26.01.01	Net load throw off of 900 MW	49.70 to 51.55 (1.85 Hz)	900	
10 (B)	0850	26.01.01	750 MW b/d and 180 MW gen. Loss at Jhanor	51.50 to 49.40 Hz	930	
11.	0812	10.04.01	580MW net loss of generation and 400MW load throw off	50.67Hz. to 50.10Hz.	180	0.84% (1.68%)

5. VOLTAGE FLUCTUATIONS

5.1 While low and high voltage in parts of the grid continue to be a cause of concern, the sudden variation occurring during certain operations like load shedding carried out by the States had resulted in alert operation. A plot of voltage fluctuations that occurred on 19.2.01 when MPSEB carried out sudden bulk load shedding as well as sudden removal of load shedding is given below.

5.2 Voltage fluctuations were observed all over the grid on 8.3.01 and 17.5.01 due to adverse operating conditions in the grid caused due to the outage of major 400kV lines.

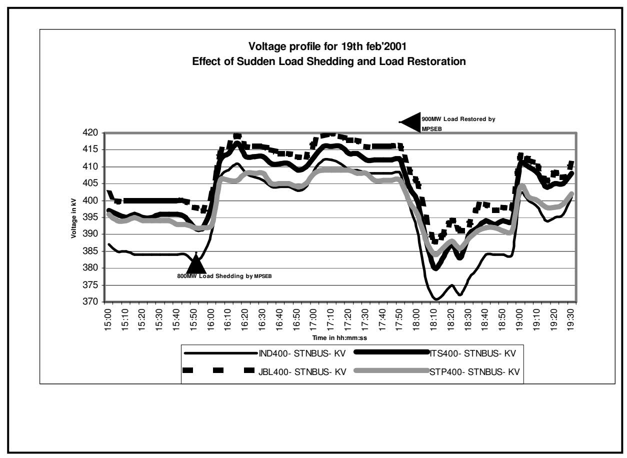
5.3 On 16.6.01 and 17.6.01, 26 Nos. of 400kV lines were kept out to control voltages. This has reduced the security levels of the grid and kept the system operators on tenterhooks.

5.4 Due to sudden bulk load shedding, two circuits of 400kV Jabalpur-Itarsi lines tripped on over voltage during peak hours i.e., at 1800 hours.

5.5 The 400/220kV, 315 MVA transformer at Satna tripped on number of occasions due to over-fluxing. The sudden high voltages leading to over-fluxing operations were caused by sudden bulk load shedding.

FREQUENCY FLUCTUATIONS – SUDDEN ACTIONS BY MPEB

S. No.	Period (Hrs)	Action by MPEB		Frequency change Hz to Hz	Remarks
		L/S done (MW)	L/S relieved (MW)		
18.2.01	0945-0950	1663 – 693		50.08 – 50.5	1
	1555-1620	844 – 1664		49.11 – 51.02	1
	1815 – 1835 – 1845	(1680+611) – 692		49.27 – 50.82 – 49.29	1
19.2.01	0555 – 0610	625 – 1600		49.15 – 50.79	1
	0950 – 1010	1600 – 800		50.46 – 49.19	Drawal increased by 700 MW
	1555 – 1610	800 – 1600		49.62 – 51.24	M.P drawal reduced by 700 MW
	1800 – 1805		1600 – 692	49.7 – 48.82	1
	1850 – 1900		692 – (692+536)	48.21 – 49.73	2
20.2.01	0550 – 610	625 – 1600		49.33 – 50.55	1
	1655 – 1710 – 1730	800 – 1600 – 800		50.01 – 51.22 – 49.08	MP drawal reduced by 650 MW.
	1750 – 1800		835 – 280	50.17 – 50.82	2
	2030 – 2050			50.24 – 48.93	MP drawal increased by 600 MW.
23.2.01	0935 – 1005	270 – 725		49.88 – 50.90	(1) Drawal decreased by 80 MW.



Remarks

1) Change in Scheduled L/S
2) Change in Unscheduled L/S
3) Removal of hydro units
4) Pickup of hydro in other system
5) Bbacking down
6) Other effets like unit trippings.

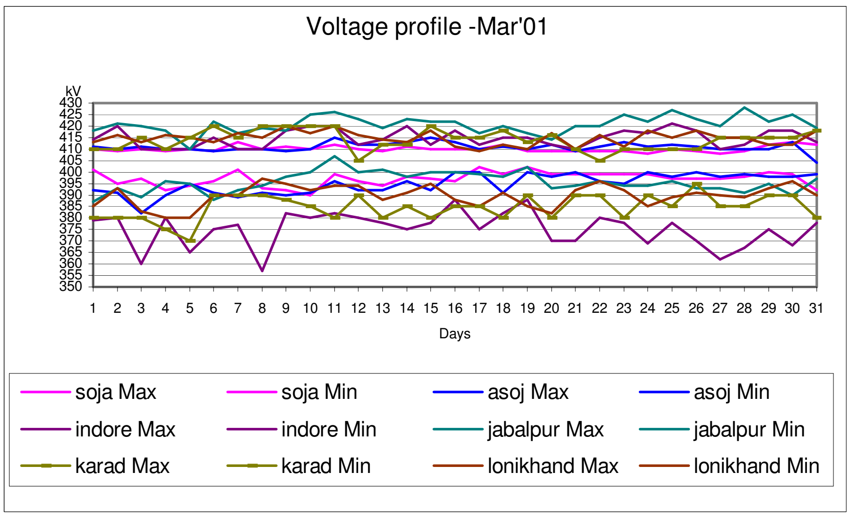
6. PERFORMANCE INDICES FOR MONITORING VOLTAGE VARIATIONS

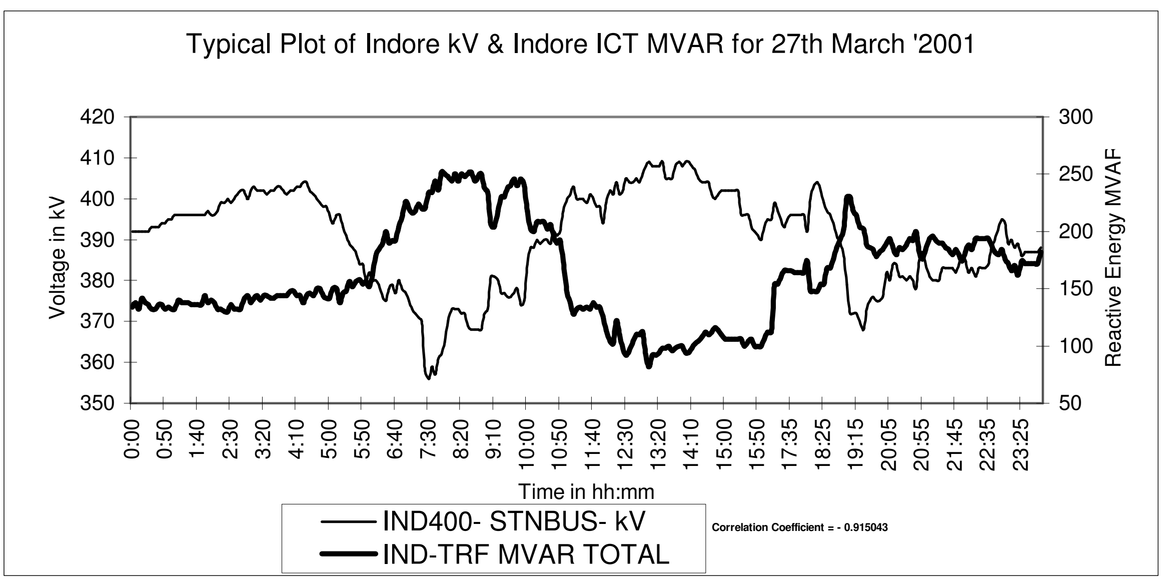
WRLDC monitors the voltage profile of the entire grid. A plot of minimum and maximum voltages along the major corridors is enclosed.

WRLDC carries out sensitivity analysis to understand the predominant factors influencing voltage profile at a particular sub-station using statistical analysis. Large amount of data collected through SCADA is processed and correlation coefficients of the bus voltage with respect to various factors such as:

- active and reactive power flows on lines emanating from bus
- active and reactive power flows on transformers connected to the bus
- influence of the neighbouring bus voltages
- influence of varying generation on various generating stations in the neighbourhood.

Analysis is cross checked with detailed power flow studies. The identification of predominant factors affecting the voltage profile helps WRLDC in formulating action plans and corrective actions. Further, WRLDC also gives feed back to the Study Committee of the region that works out the requirement of shunt capacitors and other reactive compensation devices. A typical plot of Indore voltage versus one such predominant factor is enclosed.





7. IMPACT OF FREQUENCY AND VOLTAGE FLUCTUATIONS

(i) During October & November, 2000 system frequency operated around 48 Hz for significant amount of time and touched 47.6 Hz on three occasions leading to islanding of BSES system and eventual collapse and partial blackout in Mumbai city.

(ii) Tripping of gas turbines at 47.5 Hz or 51.50 Hz on full load would reduce the life by 500 hours for each tripping. Nuclear units are affected by pressure changes in the heat transportation system due to frequency variations. A number of thermal units reported blade failures.

(iii) Slow frequency excursions occurring during normal/alert operation of the grid may not cause operation of df/dt relays and risks of collapse is greater as 2100 MW load shedding is not available.

(iv) The states tend to bypass U.F relays (discrete) carrying low emergency capability.

(v) The VARs provided by shunt capacitors reduce significantly with reduced voltages.

(vi) We are unable to plan SVCs in the low voltage pockets as the SVCs operate as shunt capacitors.

(vii) The frequency variations led to blocking of the turbine governors reducing the system stiffness.

(viii) Voltage variations led to tripping of lines on over voltage, power swings and transformers on over-fluxing even during normal operation and led to blackout of extended areas during disturbances.

(ix) In 9 out of 55 occurrences, low/high frequency and in 10 out of 55 occurrences low/high voltage caused impact during the period 1988-2001.

8. CONCLUSIONS

Various factors such as technical, commercial, managerial affecting frequency and voltage variations and their impact on grid operation and security have been discussed in the paper. WRLDC takes up with the States in the regional meeting on these issues to solicit solutions and agreements. The proposed Availability Based Tariff (ABT) to be implemented in Western region from 1st October 2001 is expected to maintain the frequency in a close band. Further, initiatives for implementing free governor mode of operation on generating units as per the clauses of IEGC was taken up by Powergrid. Once frequency remains in a close band with the new commercial mechanism, the generators would be induced to keep their governors in operation. It is also contemplated that seizeable amount of generation about 60% (10000-15000 MW) to be kept on free governor operation at a pre-agreed time simultaneously. This would increase the stiffness of the system and contain frequency variations which are presently taking place. The commercial mechanism is also expected to solve most of the problems related to frequency/voltage variations through incentives/dis-incentives incorporated in the UI tariff. The ABT also provides for reactive power charges and this would induce the states to improve voltage profile. The commercial mechanism may also provide incentives for utilizing bottled up generation of IPPs and CPPs and allows for using private generation to stabilize system frequency and voltage profiles.

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