IMPLEMENTATION OF FREE GOVERNOR MODE OF OPERATION IN WESTERN REGION OF INDIA

Anjan Roy V.K.Veluchamy P.Pentayya R.K.Mediratta Pushpa.S
Power Grid Corporation of India Ltd., WRLDC, Mumbai

***Abstract*-- Due to wide excursions of frequency, the generating station operators blocked the turbine governors and did not allow active power (MW) output variation in response to frequency variation. With implementation of ABT in all the regions and synchronous inter-connection of WR grid with ER & NER grids helped in frequency stabilisation between 49.5 to 50.5 Hz for greater part of the day. The time was ripe to bring the governors once again into operation. However, during disturbances, system frequency was excursing to 52 Hz or below 48 Hz resulting in tripping of units either on high or low frequency. The solution to this was to vary generation to match with the load demand through turbine governors so that tripping of generators could be avoided. The Indian Electricity Grid Code (IEGC) approved by Central Electricity Regulatory Commission (CERC) provided with enabling provisions. Despite some constraints, the implementation of free governor mode of operation even on 18160 MW capacity has been encouraging as frequency fluctuations have reduced and a grid collapse was averted.**

The paper explains in detail the implementation aspects of free governor mode of operation – primary control provisions, secondary control provisions, settings, the experience of last few months, constraints faced by the generators and response of governors to various grid events.

1. INTRODUCTION

Frequency control requires provision of primary regulation and supplementary regulation as basic requirement. Primary regulation is provided through speed governors which respond to frequency changes by varying turbine outputs. Keeping governors free to operate in the entire frequency range enable smooth control of frequency fluctuations as well as security against grid disturbances. In India, due to wide range of frequency fluctuations, speed governors are prevented from responding by the utilities with dead band configuring from 47.5 Hz to 51.50 Hz with emergency unloading available only when frequency goes above 51.50 Hz. The paper describes the efforts made to enable speed governors responding in the entire frequency range which has come to be known as free governor mode of operation (FGMO).

Western regional power grid is the largest among the five regional power grids in the country with an installed capacity of 31932 MW and catering to demand of 25000 MW. Due to shortage of power to the tune of 18%, the frequency profile during peak hours used to be 49 Hz or below. However, during night hours and day off peak hours, high frequency use to occur touching upto 51.5 Hz. The frequency stabilized in the band of 49-50.5 Hz after introduction of Availability Based Tariff (ABT) w.e.f 1st July, 2002.

In the case of Eastern and North-Eastern regions operating in parallel with an installed capacity of 18102 MW (ER - 15810, NER: 2292) and catering to demand of 9361 MW (ER: 8290, NER: 1071), high frequency used to prevail during most part of the day with frequency touching even 53 Hz and severe low frequency even touching 48 Hz during two hours in the evening (1700-1900 Hrs). Since 2nd March,2003, the Central Grid comprising of three regions WR, ER and NER is operating in synchronism with installed capacity of 50GW meeting peak demand of 34GW. The introduction of ABT though stabilized frequency in a narrower band, the rapid fluctuations continued to occur with frequency excursions of 0.5 Hz over a period of 10 minutes and frequency shooting up 51Hz and above when sudden bulk load shedding or maximization of generation takes place before evening peak hours. Dipping of frequency takes place during onset of peak loads or unit trippings. Such frequency fluctuations during normal operation in the grid leads to complex counter actions by the control centre operators at regional and state level. Further, the fluctuating frequency even in a interval of 15 minutes do not give out clear signals to operators to plan generation changes, load shedding or to draw/inject unscheduled interchange (UI) power responding to signals generated by the commercial mechanism (ABT). Under the new commercial mechanism, the price of UI power is linked to frequency with price of UI power at zero paise per unit at 50.5 Hz and increasing linearly in steps of 0.02 Hz to 600 paise per unit at 49 Hz. Under ABT mechanism, frequency is allowed to float between 49 Hz and 50.5 Hz (acceptable to KWU generators) and drawal / injection of UI power is permitted in this frequency range. However, fluctuating frequency masks the frequency based ABT signals.

In most of the grid disturbances over the last few years, Western regional grid used to split into two parts in the post fault scenario due to tripping of various lines in the East-West corridor due to power swings. The Eastern part used to have surplus of generation over load resulting in frequency shooting up to 52 Hz and above leading to tripping of several generating units on high frequency. Another pattern observed was isolation of Gujarat grid from the Western part followed by severe frequency decay and under frequency load shedding through df/dt relays which brings up frequency above 52 Hz once again leading to tripping of some generators on high frequency. After inter-connecting with ER & NER grids, also similar pattern continued in the post fault scenario with tripping of generating units on high frequency in Eastern part of WR and ER grids. With implementation of free governor mode of operation on generating units, tripping on high frequency could be avoided during grid disturbances as load generation balance can be attained at a faster rate. FGMO would increase system stiffness significantly and avoid large frequency dips in the event of unit trippings. For example, 10000 MW generation on FGMO with 5% droop in Central grid would increase system stiffness by 2500 MW per hertz.

2. ACTION PLAN FOR FGMO IMPLEMENTATION

POWERGRID, the Central Transmission Utility (CTU) and Western Regional Load Despatch Centre(WRLDC) conducted various awareness programmes, made visits to power stations and carried out trial operation at one of Hydel station (Koyna) to convince the SEBs and Central generators to hasten implementation of FGMO in the wake of frequency stabilization following successful implementation of ABT. The matter was also put up for discussion in various meetings of the regional fora to achieve consensus among the utilities. Eventually on 19th May, 2003, 9900 MW capacity of KWU machines were put on FGMO with 8% droop settings and load limiters set at 105% of the set point. The KWU make machines have electronic governors(electro hydraulic governors – EHG) with capability to configure the governor characteristic with selection of droop settings for different frequency ranges, selection of dead band etc. Most of the machines responded to frequency changes encouraging putting of LMW/LMZ machines also on FGMO from 21st May, 2003. Since LMW/LMZ machines have only hydraulic governors with fixed droop setting of 5%, these machines would respond more than KWU machines. Since, LMW/LMZ machines do not have auto combustion controls, the parametric(pressure and temperature) variation might lead to tripping of the units. It was therefore decided to have a common droop setting of 5% for all the machines irrespective of the make.

The FGMO operation was implemented on all the 200 MW and above machines with effect from 19.05.2003 based on various clauses of Indian Electricity Grid Code (IEGC). The implementation was mandatory as per IEGC unlike in some countries where primary regulation, load following, 5-minute and 15-minute responses etc., can be provided by generators on a commercial basis through specific contracts with the system operators. Since the governors were kept blocked over the years by the utility generators, no generators would come forward to provide primary regulation on a commercial basis due to variation in frequency profile in the region. Since the increased system security and system stiffness are the objectives to be achieved, the regulators rightly thought it prudent to implement FGMO on a mandatory basis initially. Once the experience is gained and confidence built, the primary regulation can be offered on a commercial basis also in the near future. To begin with, it was required to put sizeable capacity (atleast 10000 MW out of around 30000 MW capacity on bar) on FGMO simultaneously so that the load variations on generators would not be significant to cause large parameter variations. Due to some commercial problems and technical constraints with LMW/LMZ machines, the effect of FGMO slackened and taken note of by CERC. The Central Electricity Regulatory Commission (CERC) once again directed for implementation of free governor operation all over the country from 2nd January, 2004.

On 2nd January 2004, 77 generating units of about 18160 MW generation comprising 10090 MW of KWU machines; 6470 MW of LMW/LMZ machines and 1600 MW of hydro machines were identified for free governor mode of operation. However, only 49 generating units could be put on free governor mode of operation with a capacity of 10870 MW.

3. IMPLEMENTATION ASPECTS

Settings

Compliance of IEGC clauses 6.2(a) to 6.2(e) stipulate primary regulation mandatory on all generating units above 200 MW size with 3-6% droop and no deliberate dead bands. The primary regulation is to be provided by speed governors by varying turbine active power output in response to frequency changes and the response has to be instantaneous. No other controls like coordinated master controls (CMC), limiters, dead bands etc., are allowed to inhibit or bypass primary response. The setting of upper load limiter should be at 105% of the set point so that the machines can pick up upto 105% of the set point for frequency dips and shall be able to sustain this level of outputs for about 5-minutes. The supplementary control would bring back the generator outputs back to the original set point in a slow manner at a ramp rate of 1% output per minute in about 5-minutes time to enable operators to take other control actions like load shedding etc. Accordingly, the following settings were adopted:

- Speed droop of 5% on all KWU and LMW/LMZ machines.
- Upper load limiter at or above 105% of set point.
- No deliberate dead band to be introduced in configuring EHG of KWU machines.
- In KWU machines with CMC, ramp rate would not be moderated.

Primary Regulation:

In case of a sudden frequency fall, all the machines under governor operation would pick up load upto 105% of the set point (load limiter to be set at 105% of the set point). There is no problem with the part loaded machines in picking up generation. However, the machines which are operating at full load are also required to pick up to 105% and maintain this level of generation for about five minutes using the thermal inertia. In India and other developing countries, all the machines are normally operating at full load due to shortages. This helps in taking measures like load shedding etc., in about five minutes. In case of frequency rise, all generators would drop load and are allowed to go back to the set points or to a new set point (based on the frequency linked dispatch guidelines) in a slow manner (1% MW per minute) in about five minutes. The machines with variable cost greater than the UI price would not go back to the original set point. In essence, it is mandatory for all the generators to provide instantaneous load change in response to frequency change and sustain the same for about five minutes.

Secondary Regulation:

The secondary regulation is manual unlike AGC in some countries and is linked to cost economics – the Unscheduled Interchange(UI) prices except for the cases – machine unable to generate at full load due to partial outages, coal problems, reactive power generation requirement etc., or the machine has to generate at full load even above this frequency to control line loading etc. The threshold frequency for each generator is computed as the frequency at which the UI price (frequency linked) is equal to the average variable cost of generation of the unit. In case frequency is below threshold frequency for a particular power station, the generating units in the station can increase their generation and come back to the original schedule in a slow manner at a rate of 1% MW/minute. In case frequency goes above threshold frequency, the generating units need not have to come back to the original schedule. The Regional Load Despatch Centre has issued frequency linked dispatch guidelines for secondary control.

Frequency Linked Despatch Guidelines:

As per IEGC, all generators have to follow frequency linked dispatch guidelines with set points of Central generators determined by RLDCs while those of State generators determined by SLDCs. Figures 1 illustrates the frequency linked dispatch guidelines.

The generator whose variable cost is about 120 paise per unit can generate at set point given by RLDC/SLDC till frequency reaches 50.2 Hz. At 50.2 Hz, the cost of UI power from the regional pool is also equal to 120 paise per unit. In Fig.1, the generator(say 500 MW cap.) is operating at ‘A’ with 5% droop and contributing to primary regulation and the set point given is 100% i.e., 500 MW. When frequency falls from 49.6 Hz, the generator pickes up load upto 105% of the set point (525 MW and limited by load limiter set at 525 MW) instantaneously and operates at ‘B’. The load on the generator is reduced in a slow manner back to the set point that is 500 MW in about 5-minutes time and the new operating point is ‘C’ with frequency stabilized at 49.4 Hz. The machine can once again respond to frequency changes from ‘C’ with a droop of 5% (dotted line CD). In case of frequency rise, the machine reduced output from ‘A’ to ‘E’ instantaneously. The load on the generator is once again increased to ‘F’ in a slow manner and the frequency stabilized at 49.8 Hz. At point ‘G’ corresponding to 500 MW load and 50.2 Hz, the machine is operating at cut-off frequency. In case of frequency rise, the machine can drop generation and can operate at reduced level of generation and need not come to the original set point that is 500 MW. The generator can also choose to further reduce its set point from ‘G’ as for frequency above 50.2 Hz, the cost of UI generation is lower than the generator’s variable cost of generation.

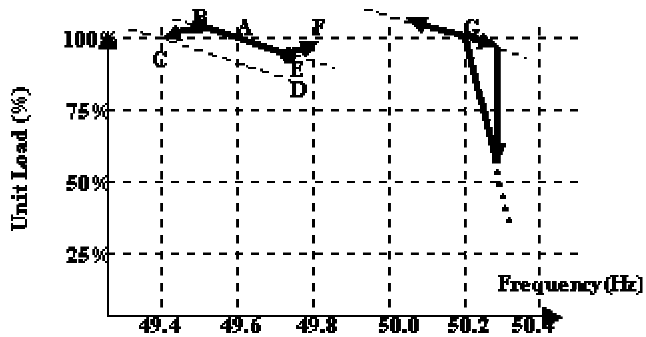

Fig. 1: Primary and Secondary regulation adopted

4.PERFORMANCE OF FGMO

Even though all the utilities agreed to put their generators on FGMO, the response from some of the generators is not as per the settings i.e., 20 MW change per 0.1 Hz for 500 MW units and 8.4 MW per 0.1 Hz for 210 MW units due to the reasons explained in the ensuing paragraphs. However, all the generators agreed to demonstrate the effect of FGMO in a committed way on 25.01.2004. A comparison of the frequency charts for 25.01.04 and 18.01.04 indicates (Fig.2 and 3) reduced frequency fluctuations on 25.01.04. The measure of reduced frequency fluctuations has been computed based on the standard deviation, absolute moving deviation and deviations from the 15-minute block-wise frequency (Table-1). All these indicators point out to reduction of fluctuations on 25.01.04. The generators also contributed in arresting the frequency rise in two of the disturbances on that day (discussed in detail under case study #3). The system stiffness increased by 1500 MW/Hz due to FGMO. With units under FGMO, the increased stiffness can also be seen from the two cases of 500 MW unit trippings illustrated through figures 4 and 5. Before FGMO on generators, the transient frequency dip as well as steady-state frequency variation are higher as load damping alone is counteracting frequency fall. With FGMO, the transient frequency dip as well as steady-state frequency deviation showed marked improvement

Table-1 :Frequency improvement after FGMO:

Indices	18.01.2004	25.01.2004
Average freq.	49.78 Hz	50 Hz
Std deviation	0.3 Hz	0.2 Hz
Average of squares of frequency deviation	0.0030 Hz	0.0017 Hz
Average of deviations from 15-minutes average frequency	0.040 Hz	0.004 Hz

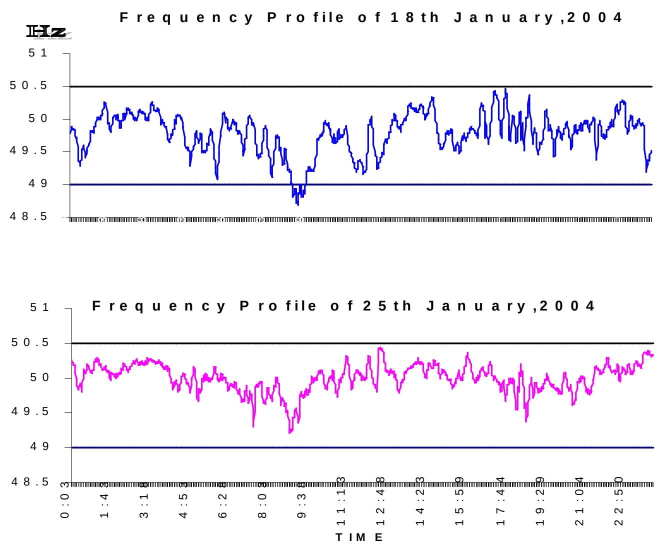

Fig.2 and 3: Frequency improvement after FGMO

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5. MONITORING GOVERNOR RESPONSE

All the utilities in Western region agree that if all the machines (about 30000 MW capacity on bar) in WR-ER-NER grid are kept on FGMO, the response required by any single machine would be hardly 5 to 10 MW from the set point and no machine would be subjected to large pressure and temperature variations. Even the machines without auto combustion controls could also cope up without any difficulty. It is, therefore, important to create trust among the utilities by monitoring response of various machines by RLDCs/SLDCs and reporting the same to all utilities. The following means have been adopted:

- ➢ RLDCs and SLDCs to monitor through data logged by the SCADA systems. A typical plot is given at Fig.6.
- ➢ Generating stations to furnish plots of turbine load variation, frequency, HP inlet pressure, steam temperature, superheat & reheat temperature and control valve opening etc., whenever asked by RLDCs & SLDCs.
- ➢ All generating stations to submit certificates to RLDC certifying that their machines are on FGMO with the recommended settings.
- ➢ All generating stations to obtain permission of RLDCs in case of requirement of any unit to be kept out of FGMO.

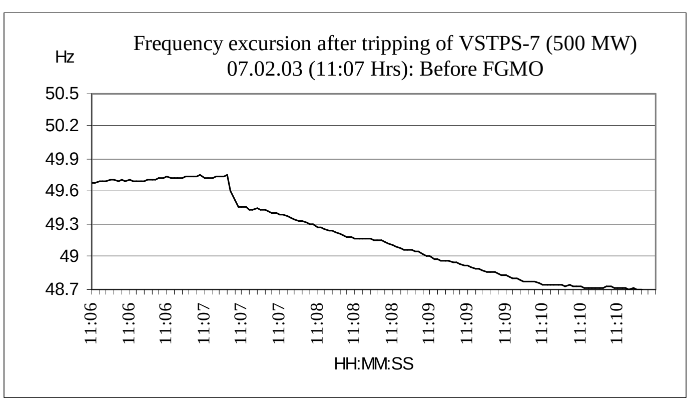

Fig.4: Frequency excursion due to tripping of 500 MW unit before FGMO

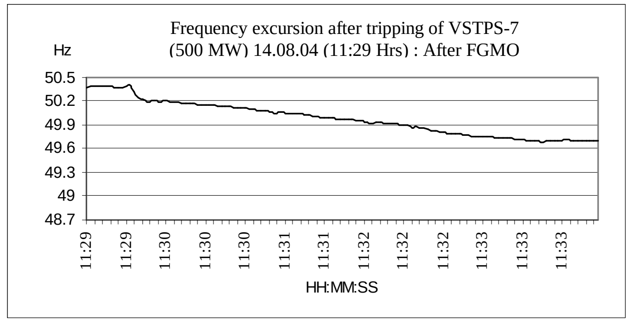

Fig.5: Frequency excursion due to tripping of 500 MW unit after FGMO

- ➢ Testing/checking by SLDCs/RLDCs. This can be done by creating frequency changes by modulating inter-regional power flows on HVDC links.
- ➢ Monitoring performance of FGMO for unit trippings and grid disturbances.
- ➢ Installation of slow scan disturbance recorders at a future date to log various parameters by the generating stations.
- ➢ Quantifying the response from various generators – adequate, partial, no response.

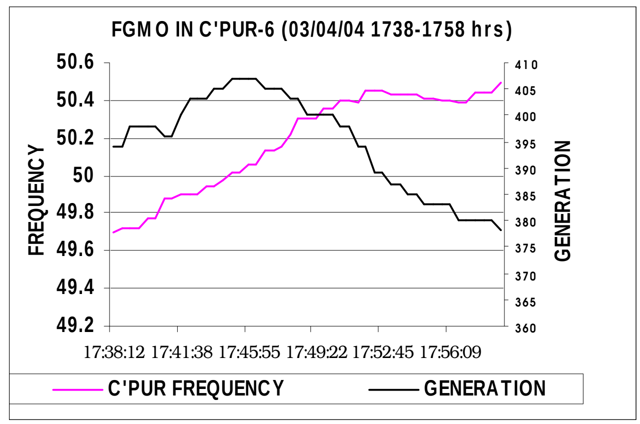

Fig.6 : Typical plot recorded at WRLDC.

6. CONSTRAINTS REPORTED BY GENERATING STATIONS

[1]. Some of the KWU machines and almost all LMZ/LMW machines have no auto combustion controllers. The operators faced difficulty in controlling the coal feeding, air flow etc., to match with the load changes and to control pressure and temperature variations. This has become more challenging with poor quality of coal.

[2]. Power plant operators had to adjust generator outputs frequently through supplementary control to get back to the original set point.

[3]. Some power stations reported disturbance in steam temperature and pressure, drum level during throttling of control valves.

[4]. Some of coal-fired power stations reported variation in super heater temperature by about 40deg.centrigrade due to load variations, frequent economizer tube leakage and stuck HP control valve.

[5]. At one of the power station, one unit responded to high frequency by dropping load which led to steep

increase in pressure resulting in popping up of safety valve.

[6]. At one power station, load on the 500 MW KWU machines started hunting between 150-450 MW due to problem with one HP control valve due to which control had to be shifted from EHG to hydraulic governor. The unit was kept out of FGMO and put back after cleaning of pilot valve spool of HP control valve.

[7]. Five stations owned by one utility could not provide adequate response from LMW/LMZ machines operating in turbine follow mode. The turbine load variation occurs in response to frequency changes but the original load is restored by a boiler control loop which opens / closes control valves to maintain HP turbine inlet pressure constant thus suppressing free governor operation. These stations now have taken up measures to provide auto combustion controls on all the machines. These stations also are now going for washed coal and blending of coal with imported coal to improve boiler response and provide margins in coal mills to enable faster and adequate response.

[8]. The poor quality of coal and lack of margins in coal mills led to lack of response upto 105% of the set point during frequency fall. As such, some of the power stations kept the load limiter at set point itself.

[9]. No constraints were faced on thermal units using oil/gas firing.

[10]. One hydro station faced the problem of conservation of water and usage of water as per irrigation requirements. The set point on machines was too low to keep FGMO in operation.

[11]. One hydro power station with 280 MW units with FRANSIS turbines did not keep the units on FGMO as varying load below 200 MW may lead to cavitation problem and hunting for particular gate opening.

[12]. One Central utility cited commercial problems as a major constraint. These stations are not paid in case of generation pick up above the declared capability. However, this problem has now been solved under the new tariff norms where Central generators are paid above the declared capability also.

[13]. One Central utility also apprehended that sudden loading / unloading of turbines may lead to vibration, increased rotor stress and blade fatigue / failure, super heater and re-heater tube failures and frequent manual intervention.

[14]. One private utility reported inability to keep one of their machine on FGMO due to very low schedule (150 MW for a 500 MW unit). In case of frequency rise, the machine may further drop load and may trip.

[15]. Two of the private utilities reported commercial problems. In case of generation variation, the import / export schedules with State Electricity Boards (SEBs) gets disturbed and differential rates are applicable for import and export. For instance, import of power from SEB is priced higher than export to the SEBs and in some cases exports are not paid for.

[16]. The KWU machines with Iskamatica controls for EHG (designed upto 1990) have centre frequency of the frequency influence circuit set at 50 Hz and this can not be changed due to which generator response for frequency fall can not be obtained for frequency below 49.875 Hz. The problem was taken up with the manufacturers who are in the process of providing solution to this problem.

[17]. Some of the stations with auto combustion controls and operating in CMC mode restricts/suppresses speed of response by adopting higher ramp-up / ramp-down rates.

[18]. Some of the stations with KWU units configured dead bands through EHG to suppress response upto the threshold frequency and FGMO available only when the frequency goes above the threshold frequency.

[19]. Some of the power station operators reduced the MW response to around ± 20 MW by configuring the governor characteristics. In case of LMW/LMZ machines, the response was somewhat adequate but lack of response from KWU machines at times led to more variation of load on LMW/LMZ machines. This caused large changes in pressure and temperatures which have to be manually controlled as most of these machines are not provided with automatic combustion controls. At times, the speeder gear moves to over run position blocking governor operation due to large pressure changes.

[20]. The turbine governors are supposed to pick up upto 105% of the set point in case of frequency fall and allowed to come back to the original set point in about 5-minutes time in a slow manner to allow for other manual and automatic actions to contain fall in frequency. However, the response of the machines was not adequate to sustain for about 5-minutes. It is being examined to review the capability of the boilers to hold on to 105% loading for 5-minutes using thermal inertia.

7. CASE STUDIES OF FGMO OPERATION DURING DISTURBANCES.

Case Study-1: ER-WR grid separation on 18.07.2004.

On 18.07.04, ER-WR-NER grids were operating in synchronism with one 400kV line between Rourkela in Eastern region and Raipur in Western region under planned shutdown since 0801 Hrs. The power flow on the remaining inter-regional ties viz., one 400kV line (Raipur-Rourkela-II) and three 220kV line between Korba(East) and Budhipadar was restricted to 850 MW. At 0937 hrs, the 400kV Raipur-Rourkela-II also tripped due to relay maloperation leading to overloading of the 220kV ties which ultimately led to tripping of 220kV Tarkera-Budhipadar D/C line on overload leading to separation of the Central grid into two parts viz., WR grid with generation of IB power plant and loads of Budhipadar with 165 MW injection from IB to WR grid. The above disturbance led to frequency in Eastern region to swing from 50.27 Hz to 50.87 Hz (change of 0.6 Hz) due to load throw off on Eastern region of 679 MW. The turbine governors responded to this frequency change by reducing generation in ER from 8550 MW to 8015 MW which works out to 370 MW after accounting for loss of IB generation and Budhipadar loads. Without FGMO, the frequency rise would have been 3.80Hz i.e to 54.07 Hz with load damping alone (of the order of 180 MW/Hz at this time corresponding to load demand of 8000 MW). In WR grid, the loss of import of 679 MW led to frequency drop of 1.3 Hz from 50.27 Hz to 48.97 Hz. The generation change in WR is from 19100 MW to 19280 MW and accounting for IB, the generation pick up due to FGMO is almost negligible and load damping alone had stabilized the frequency. The stiffness of WR grid due to load damping at this time corresponding to 20250 MW demand met works out to 522 MW per Hz. Frequency charts at Fig 7 and Fig 8.

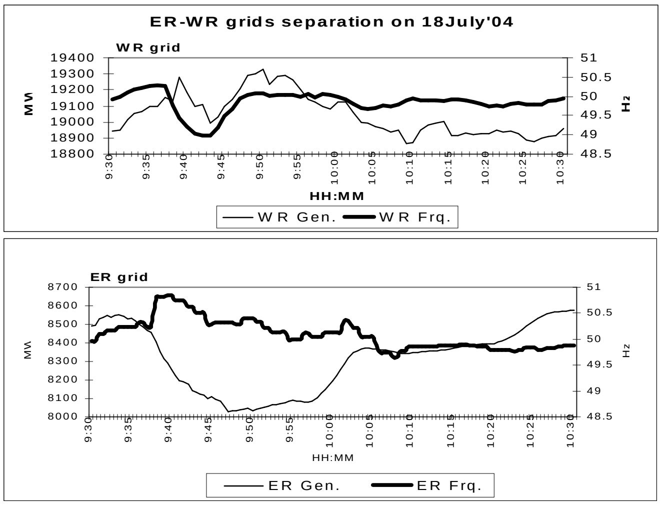

Fig.7 & 8 : Generation & Frequency profile of separated WR & ER grids

Case Study-2: System disturbance on 04.02.2004.

On 04.02.04 at 1351 hrs, four disturbance events took place in the Central grid. Event-1 occurred at 1351 hrs due to tripping of Talcher-Kolar HVDC bi-pole carrying 1500 MW. The Central grid frequency rose from 50.1 to 50.86 Hz with FGMO contributing to 758 MW of generation reduction. Event-2 corresponds to separation of WR grid from the Central grid with WR grid loosing 1400 MW import. Frequency in WR grid decreased from 50.86 to 49.72 Hz (1.08 Hz) with contribution from FGMO. Frequency in ER grid rose from 50.16 Hz to 52.24 Hz (2.08 Hz) with 594 MW contribution from FGMO. In the separated WR grid, one 500 MW unit at Vindhyachal tripped resulting in frequency dropping from 49.3 to 48.26 Hz (1.04 Hz) with only load damping stabilizing frequency. In the ER-NER grid, one 500 MW unit at Talcher tripped resulting in frequency fall from 52.20 Hz to 51.20 Hz (1 Hz) with FGMO contributing 350 MW generation reduction. The stiffness of Central grid was 1447 MW/Hz with FGMO.

Case Study-3: Events on 25.01.2004.

On 25.01.04 at 1105 Hrs, Talcher-Kolar HVDC pole-II tripped which led to the other pole operating on earth return mode. The pre-fault power flow on both the poles is 1458 MW and after tripping of pole-II, pole-I power was ramped up to 914 MW. The injection of 544 MW power to ER-WR grid due to the above led to frequency rise of only 0.268 Hz as the generators in WR & ER contributed 278 MW and 98 MW respectively due to governor operation. At 1223 hrs, pole-I carrying 914 MW also tripped with frequency in WR-ER grid rising only by 0.64 Hz. For this event, the WR & ER generators contributed 380 MW and 221 MW respectively due to governor operation. The system stiffness was computed for both events and compared with stiffness due to load damping. The increased system stiffness due to FGMO is around 1000-1500 MW per Hz.

Case Study 4: Event on05.03.04

On 05.03.04, Talcher-Kolar bipole was carrying 1415 MW, one pole tripped leading to other pole going on metallic return mode and carrying only 150 MW. Thus, 1265 MW of power was diverted to WR-ER-NER grid. The frequency rise was arrested due to FGMO operation with frequency rise observed from 49.56 Hz to 49.73 Hz in about 18-seconds and touched 50.5 Hz in about 4-minutes. Turbine governors helped in reducing generation in WR by 300 MW and in ER by 508 MW. Without FGMO, the additional injection of 1265 MW could have critically loaded ER-WR ties possibly leading to a grid separation.

8. CONCLUSIONS:

Primary regulation is through FGMO which is available for about five minutes and secondary regulation is manual and set points of generating units decided based on frequency linked dispatch guidelines. In the Indian context, secondary regulation is to bring back the MW output back to the set point and not to restore the frequency to 50 Hz. FGMO increased system stiffness significantly. FGMO helped in raising the first stage of under frequency load shedding from 48.20 Hz to 48.50 Hz. Also helped in reducing bypassing of UF relays by the utilities. FGMO reduced frequency fluctuations to a large extent and helped in grid security and has formed part of the defense plan against grid disturbances. Even though, response is limited at present, the actions being taken by the generators in association with manufacturers is expected to yield desired goal of frequency stabilization.

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