Operating Strategies for Generation Deficient Power System

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***Abstract*— Operating deficient power system is an onerous task and calls for meditative deep reflection on all aspects of the system to take care of the peculiar operating and commercial problems. Many developing countries have to devise the operating strategies for sustained deficient operation which are of different nature than occasional reduced generation operation. Such systems are characterized by typical feature like large frequency fluctuations and are susceptible to even small disturbances. Innovative solutions are needed to deal with the situation. After considerable debate, India has adopted commercial mechanism known as Availability Based Tariff (ABT) which has a component linked with frequency deviation. The major advantage of using the frequency signal is its availability throughout the system without any burden on the communication channels. The frequency control and voltage control mechanisms are revisited in the context of the generation deficiency covering normal, abnormal, and emergency system conditions. Frequency linked generator dispatch stems from the commercial mechanism which deviates from the conventional dispatch. The contingency management, demand management etc. are also given a fresh look. The security strategies adopted by the Western Regional Load Dispatch Center, Bombay, India along with some countermeasures are described. The strategies are implemented on the grid and are working in satisfactory manner.**

***Index Terms*— generation deficient power systems , Operation and Control**

I. Introduction

The developing countries have sustained power shortage problems compared to developed countries for many reasons mostly financial in nature. The developed countries have to address the power deficient areas occasionally [1], [2]. The research literature on operation of generation deficient power system is scanty. Ref.[1] deals with temporary formation of deficient areas. Other work [2] considers double contingency which leads to deficit conditions. The problems faced by developing countries are fundamentally of different nature. The developing countries have to search for alternatives to suit their requirement. The deficient systems have typical features like frequency deviations, abrupt arising of deficiencies of power, low voltages and lack of coordination among the constituents under a region due to indiscipline. Central Electricity Regulatory Commission (CERC) [3] has boldly taken a decision to implement ABT [4] and the results after two years of implementation are very encouraging. This paper elaborates the strategies for operating the deficient system. The paper covers all the operational aspects in the light of the new strategies.

The paper is organized as follows. Section II overviews the Indian Power System in general and Western Region in particular. Section III describes the conditions leading to deficiency because of generation constraints. Section IV reports the frequency linked commercial mechanism ABT. Next section is on most important aspect of frequency control in normal and emergency conditions. Frequency linked generation dispatch is elaborated. Section VI reports voltage control policy. The security issues are discussed in next section about managing contingencies and power oscillations. The countermeasures against disturbances follow in section VIII. Section IX considers some allied issues like demand forecasting, demand management, and effect of open access which is recently introduced. Finally, last section concludes the paper.

II. The Indian System

The Indian power system is having an installed capacity of 110 GW and is meeting a peak demand of around 70 GW. 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). Three of the regions viz., NR, WR and SR suffer from severe power deficits while ER is having surplus generation of about 2500 MW and NER is having marginal surplus based on hydro reservoir levels. The regions are connected to each other mainly through asynchronous links (HVDC back-to-back) to enable exchange as and when available surpluses. Since last few years, Eastern and North Eastern regions were operating in synchronous mode through AC inter-ties. Since 2^{nd} March 2003, Western and Eastern grids were synchronously connected through two 400kV lines and three 220kV lines. Thus, at present, WR, ER and NER grids are operating in a synchronous manner. However, Northern and Southern regional grids were operating asynchronously and connected to neighboring regional grids through HVDC back-to-back links. The Central grid comprising Western, Eastern and North Eastern regional grids is having installed capacity of over 50 GW and meets demand of over 34 GW. The generation deficient conditions are common for various reasons as discussed in III. The inter connection largely benefited Western regional grid which is importing power to the tune of 1200-1800 MW from ER and NER grids. In WR grid, most of the generation is located in Eastern part and load centers are located in Western part of the grid. The

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typical East-West power flows are of the order of 6000 MW with the entire 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 whereas the nominal frequency is 50 Hz. 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.

Western regional grid comprises the power systems of the States of Maharashtra, Gujarat, Madhya Pradesh, Chhattisgarh, Goa; Union Territories of Daman and Diu and Dadra and Nagar Haveli; the Central Sector power stations owned by National Thermal Power Corporation (NTPC) and Nuclear Power Corporation (NPC); the inter state transmission system owned by POWERGRID and power systems owned by the private utilities such as Tata Power Corporation (TPC), Reliance Energy Limited (REL), Brihanmumbai Electric Supply and Transport (BEST), Ahemdabad Electric Co. etc. The installed capacity as on 31^{st} October 2004 is 32.032 GW. The region is catering to a peak demand of around 25 GW. The daily energy consumption is 560 MUs. The region has hydro-thermal mix of 16:84. 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 and 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.

The structure of ownership of generation and transmission facilities is based on the federal structure in the country. In each of the states in the region, most of the generation is owned by the state owned State Electricity Boards (SEB) which are vertically integrated utilities with generation, transmission and distribution under their control. In some urban centers, private utilities which are also vertically integrated utilities operate. The Union Government owned utilities called Central utilities also own generation and transmission. The Central utilities NTPC, and NPC operate generating stations which supply bulk power to the SEBs based on the allocations to the States made by the Union Government. The transmission network to evacuate these Central power projects and the inter-state / inter-regional network is owned and operated by the Union Government Corporation - POWERGRID.

Even after connecting with ER and NER, the diversity of demand is hardly 1.035. The peak demand of ER and NER grids comes about one hour prior to WR peak demand. The grid operates without any spinning reserve as the entire generation is dispatched due to power deficit of 18%. The daily load shedding carried out is about 5000 MW during peak hours and some load shedding ranging from 1500 to 5000 MW exists throughout the day. Despite load shedding, about 500 MW liquid fuel generation is not dispatched due to high cost. Some generation is also bottled up with private licensees, captive power plants (CPPs) and independent power producers (IPPs). The pumped storage schemes (150 MW at Bhira and 240 MW at Kadana) are also not being utilized. Due to import of about 2000 MW from neighboring regions, number of 400kV lines are critically loaded in the East-West corridor. The frequency profile is between 49.5 to 50.5 Hz due to the commercial signals of Availability Based Tariff (ABT).

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

III. GENERATION CONSTRAINTS

The generation constraints in deficient power systems have large bearing on partial and major blackouts. The pre-fault operating conditions are likely to be de-graded due to generation constraints and any medium/high risk contingency can lead to a grid collapse. Out of the total installed capacity, about 70% is only available to meet the loads due to planned outages, forced outages and generation constraints [6]. In case of Western region, an installed capacity of 32.032 GW is capable of meeting about 24 GW only. The generation constraints include fuel shortages, less hydro reservoir levels, problem with plant auxiliaries, quality of fuel, reduction of active generation to produce reactive power, reduction of active power on generators due to transmission line outages or overloads and generation reduction due to high frequency. On 30^{th} July 2002, a major grid disturbance occurred in Western region leading to total collapse of WR grid. The analysis of the disturbance reveals the significant impact of generation constraints on the pre-fault conditions as well as events leading to the disturbance. The effective installed capacity on that day was 31186 MW whereas 23450 MW capacity was on bars due to planned and forced outages. However, the total generation available to meet consumer load was hardly 19578 MW. A staggering 4830 MW generation was lost due to constraints out of which 2761 MW generation was not available due to partial outages, fuel related constraints. The deficit of power led to low frequency operation around 48 Hz which ultimately led to a major grid disturbance.

In Western region, out of the total installed capacity, only 16% capacity is from the hydro resources. More than 5000 MW generation is based on gas and naphtha. Due to high cost of naphtha, some of the generation is not scheduled. Most of the thermal plants operate on base load and are not suitable for two shift operation. The night off-peak demand is around 70% of the peak demand and thermal generators are required to back down to 80% level. Under ABT, the backing down is done on a merit order basis with cheaper pit-head thermal generators operating at full throttle. Some of the new trends on the anvil to improve generation levels are:

- Use of blended coal by blending imported coal with domestic coal to improve calorific value and reduce outages.
- Setting of generating stations in other regions near pit head sources. The States of Western region are having

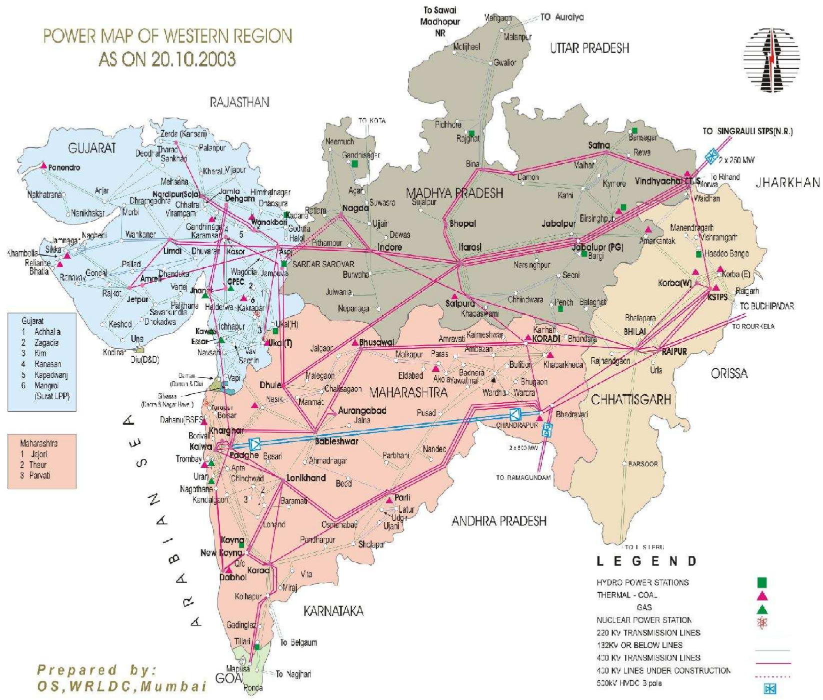

Fig. 1. Western Region

allocations at upcoming power stations like Barh and North Karanpura in Eastern region.

- Implementation of intra-state ABT for the State utilities (following restructuring) which would help in increasing the availability of State generating stations as well as ensure merit order scheduling.
- Renovation and modernization of the existing generators.
- The Electricity Act provides for competition in generation whereas no competition exists at the distribution level. The distribution companies have their tariffs regulated by the regulatory commissions. Further, the Act did not have provisions for creation of Load Serving Entities. Separation of wire business and supply business with wire business as monopoly and supply business thrown open to competition should have been right mechanism. Due to competition at one end and capping of the prices at the other end, a California like situation may arise. To take care of such a situation, the Central regulator has issued guidelines for procurement of power by the States through competitive bidding.

Every thing put together, the Indian grid has to find solution for a generation deficient power system. More often than not, in a developing country like India the problem is coupled with the wire network which poses additional problem since extra flows were not envisaged at the planning stage. There are bottlenecks at the regional interconnections also. Moreover, the seamless integration is not an easy task. Next section describes a commercial mechanism which can give some relief. It can be thought of as a self balancing system for generation adjustments.

IV. THE COMMERCIAL MECHANISM

Due to severe deficit of power, low frequency operation is a major concern. The financial constraints typical of a developing country with large population and unequal distribution of resources also led to inadequacies of transmission and distribution network with critical line loadings and low voltage profile. The consumer demands far exceed the available generating capacity. The scarcity of power and the commercial mechanism before ABT (based on drawal of power by States rather than schedules from Central pool) led to low frequency operation with overdrawal by one or more states or high frequency operation with under drawals or excess generation. The tariff mechanism did not provide any incentive to reduce generation under high frequency or to maximize generation under low frequency. In other words, the tariff mechanism encouraged grid indiscipline. The new commercial mechanism (Availability Based Tariff) was introduced in the country with Western region being the first to introduce the mechanism from 1^{st} July, 2002. The commercial mechanism is specifically defined to suit the deficit power systems. The mechanism streamlined the operation of regional grids. The scheduling mechanism entails the utilities to follow the given schedules for generation and drawal. Any constituent which helps the regional grid by underdrawing in a deficit situation would be compensated while those states overdrawing at low frequency have to pay for deviation from schedules at high prices. The pricing of deviations is linked to system frequency. The mechanism enable separation of fixed and variable charges of generating stations which helped in merit order scheduling based on variable charges. The fixed charges are linked to availability rather than plant load factor (PLF). The third part of ABT is related to pricing of deviation from schedules at frequency linked prices. The UI price curve is shown in Fig. 2 The UI price curve has two slopes. The price of UI at

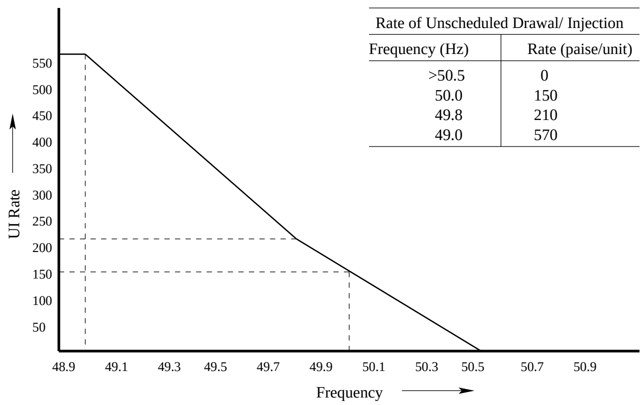

Fig. 2. UI Price Curve

50.5 Hz is zero and increased unto 49.80 (210 paisa per unit) linearly with a slope of 6 paisa per 0.02 Hz. The price of UI thereafter linearly increased at the rate of 9 paisa per 0.02 Hz till 49 Hz. At 49 Hz and below, the price of UI power is 570 paisa per unit. The UI mechanism of ABT serves the purpose of balancing market in real time. Any generator or utility is allowed to inject power into the pool or draw from the pool at UI prices as long as the frequency is maintained within the stipulated band of 49-50.5 Hz. The frequency is not tightly controlled and allowed to vary within the band and the constituents of the power pool need not have to exert tight control over their schedules. Such a loose power pool with floating frequency best suits the deficient power systems as it achieves the twin objectives of exchanging as and when available surpluses without loss of time due to negotiations and curb grid indiscipline. Further, the changeover costs to ABT mechanism from the pre-existing mechanism are minimal as only special energy meters are required.

The ABT helped in flattening of the load curve as some of the utilities shifted their peak loads to off-peak hours. Next section deals with the vital issue of frequency control.

V. Frequency Control

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 were 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. Efforts have been made to enable speed governors responding in the entire frequency range which has come to be known as free governor mode of operation (FGMO) [7].

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 to 51 Hz 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 center 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. 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 and 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.

Even during normal operation, tripping of a 500 MW unit leads to frequency drop of around one hertz due to low system stiffness as the frequency has to be controlled only by load damping effect in the first 20-seconds after the tripping. 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 2000 MW per hertz.

A. Primary Regulation

In case of a sudden frequency fall, all the machines under governor operation would pick up load up to 105% of the set point (load limiter to be set at 105% of the set point) instantaneously. There is no problem with the partly 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. The trapped steam in the pipings (thermal inertia) is used to pick up extra load during frequency fall by the governors. 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.

B. 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 Dispatch Center has issued frequency linked dispatch guidelines for secondary control.

C. Frequency Linked Dispatch Guidelines

Figures 3 and 4 illustrates the frequency linked dispatch guidelines. In Fig.2, the generator whose variable cost is about 120 paisa 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 paisa per unit. In Fig.3, 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. For example, when frequency falls from 49.6 Hz, the generator picks up load up to 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 can reduce 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.

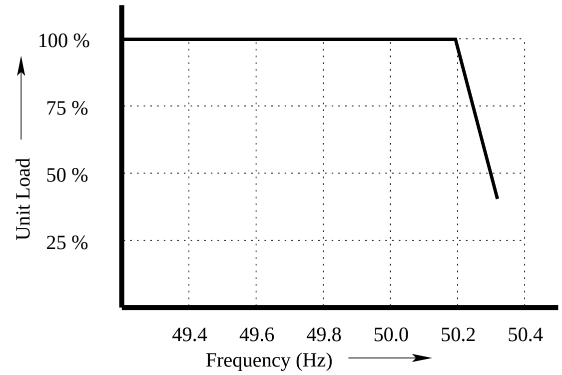

Fig. 3. Frequency linked dispatch

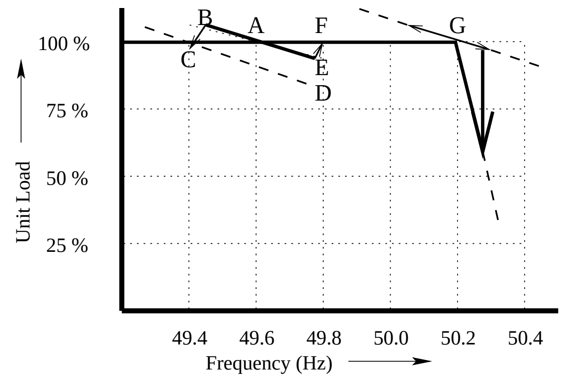

Fig. 4. Primary and Secondary Regulation adopted

D. Emergency Frequency Control

Emergency frequency control is required in real time grid operation either to control or restore frequency to safe level. Whenever sudden frequency fall occurs, the usual corrective action under deficit scenario is to shed load and especially by the overdrawing constituent. This require about 10-15 minutes time for Regional Load Dispatch Center (RLDC) to direct the State Load Dispatch Centers (SLDC) and SLDCs in turn to inspect the sub-station. When large frequency deviations occur, RLDCs immediately use the HVDC back-to-back facilities connecting other regions to ramp up or ramp down power which helps in arresting the frequency change. This action is also supplemented by FGMO for about 5-minutes. The action plan in terms of time horizon is as follows:

- FGMO (2 seconds to 5 minutes)
- HVDC Back to Back ramp up/ramp down (2 minutes to 15 minutes)
- Manual load shedding (10 minutes to 20 minutes)
- Generation pick up (5 to 10 minutes)

Figure 5 indicates the HVDC and AC interconnections among the regions. The HVDC links are used not only for emergency frequency control but also for controlling the power flow on AC interconnections. For instance, control of power flow on WR-ER AC interconnection requires stepping up power flow on some links and ramping down power flow on other HVDC links.

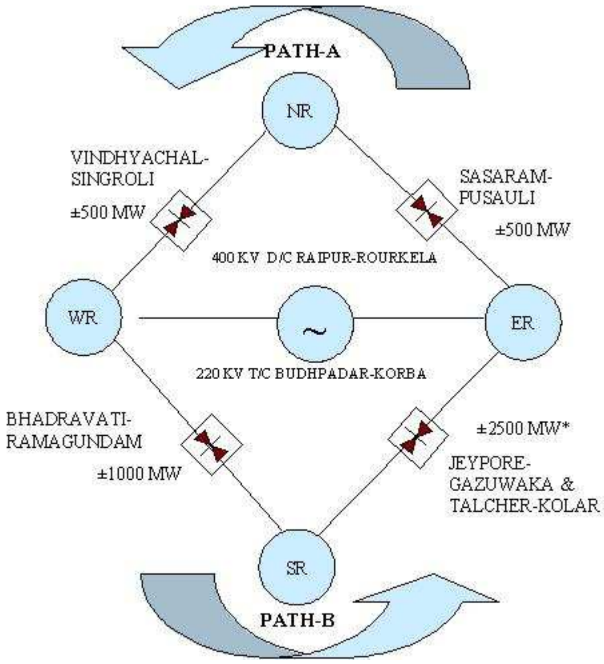

Fig. 5. Emergency Frequency and tie-line power Control

Next section deals with the voltage control policy.

VI. Voltage Control

The States in Western region are not investing adequately for providing shunt capacitors 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 the active power outputs. The low voltage problem contributed to operation of distance relays on load encroachment and led to two major grid disturbances in the year 2003-04.

The voltage profile of the 400kV grid is alarming during the Rabi season (October to March) due to onset of agricultural loads which are of low power factor. The 400kV voltage at Indore goes as low as 320 kV. Once again the less investments in transmission and distribution networks are a major cause. To promote measures for voltage improvement, a commercial mechanism was introduced in the country. The scheme provides for penalizing Var drawals below 97% voltage and provides incentive to injection of Vars. The scheme penalizes injection of Vars above 103% voltage and provides incentive for consumption of Vars at high voltage. Incentive/penalty is linked to carrying capacity of shunt capacitors. The Electricity Act did not provide for ancillary services. However, some utilities hire capacitors to be provided at the consumer's locations. At distribution level, the industrial consumers are also subjected to reactive power tariff based on power factor.

Two major security issues like contingency management and power system oscillations in a generator deficient system need attention now.

VII. Security Criterion

A. Contingency Management

In India, the regional grids are planned based on the transmission planning criteria stipulated by Central Electricity Authority. The transmission system shall be capable of withstanding and be secured against outage / tripping of a single transmission line or transformer or one HVDC pole or loss of most severe single system in-feed without necessitating load shedding or re-scheduling of generation. The above contingency is considered assuming a pre contingency planned outage of single transmission line or transformer or one HVDC pole in another corridor and not emanating from the same sub-station. All the generating units operate within the reactive capability curve and network voltage profile within prescribed limits. The network is not planned to withstand multiple contingencies without loss of stability and requires load shedding / generation re-scheduling. Often, due to delays in commissioning of transmission projects, the network is inadequate, leading to overloading of corridors, degraded voltage profile and oscillations. This requires operational planning on yearly, seasonal, monthly horizons to prepare contingency plans such as load shedding, generation re-scheduling, removal of line reactors, opening of certain lines etc. Further, number of constraints such as line overloads and voltage profile are to be addressed during real time operation. Security based risk assessment led to various contingency plans as defense during constrained operation. At times, the power system is operated without N-1 security criteria. Under very low risk contingencies, N-1 security criteria are complied with. Under low risk contingencies, N-1 criteria are not complied but emergency loadings can be managed with emergency control actions and such actions are required in only one corridor and by one agency. Under medium risk contingencies, N-1 criteria are not complied with and emergency loadings require corrective actions by more than one agency and in multiple corridors. Stability may not be lost till few minutes. Examples of such contingencies are loss of 400kV Bhilai-Koradi Single Circuit (S/C), 400kV Bhilai-Satpura S/C, and 400kV Bhadrawati-Chandrapur S/C etc. In case of high risk contingencies, N-1 criteria is not complied with and emergency loadings are likely to cause protection operations on load encroachment or overload trips and may lead to cascade trippings and the system is likely to be first swing unstable. Examples of such contingencies include loss of 400kV Korba-Vindhyachal S/C.

B. Oscillations Management

In Western region, the problem of low frequency oscillations (0.1-1.2 Hz) was rampant since 1995. In 1995, five major grid disturbances occurred affecting the entire grid. The disturbances were characterized by low voltage problem or transmission constraints during pre-fault and tripping of any line further leading to oscillations, power swings and compounding the extent of disturbances. A 0.6 Hz oscillation was detected during 2001 under East dispatch scenario i.e., large power flows from East to West associated with low voltage profile. The tripping on fault/opening of 400kV Vindhyachal-Korba line was found to be triggering 0.6 Hz oscillations even during normal operating conditions. As the power system stabilizers were not tuned, system operators resorted to measures like; moving away from oscillatory state of power system by generation re-scheduling (active and reactive powers), load shedding and taking some generators out of AVR control. These measures were adequate to suppress the oscillations. However, subsequent corrective actions led to tuning of power system stabilizers at some of the power stations and commissioning of thyristor control series capacitor (TCSC) on ER-WR interconnection. The defense plans against disturbances are discussed next.

VIII. COUNTER MEASURES AGAINST DISTURBANCES

Western region being a deficient power system in terms of active and reactive power resources, the defense plans against disturbances include the following:

- Under-frequency load shedding is provided through discrete under frequency relays set at 48.5 Hz, 48.2 Hz and 48.0 Hz contributing to 3200 MW load relief and frequency trend relays (df/dt) at settings of 49.2 Hz, 0.4 Hz per second and 49 Hz, 0.2 Hz per second contributing to 4778 MW load relief. The total load shedding through automatic means is about 33% of the load demand of the region. Since Western region is synchronously connected with Eastern and North Eastern regions, the under frequency settings are coordinated in all the three regions.
- Free governor mode of operation helps in preventing tripping of generators on high frequency during system splitting into parts.
- Number of islanding schemes has been conceived in Western region. These islanding schemes have been formed around major power stations or encompassing small private utilities, designed to separate from the grid at 47.6 Hz. The islanding schemes reduce the extent of blackouts by saving parts of the grid from collapse and also enhance the rate at which grid restoration takes place. The operating experience of the islanding schemes has been satisfactory.
- In Western region, under voltage load shedding schemes have been installed at Indore and Nagda 400kV sub-stations. If the voltage dips below 350kV and stays for 500 milliseconds, the under voltage load shedding scheme operate by sending carrier to remote sub-stations for load shedding.

IX. SOME ALLIED ISSUES

The load shedding has to be redefined in new context and is classified in three categories as described in IX-B. The short term load forecasting in new scenario has new dimension discussed in next section.

A. Demand Forecasting

The States in the region are having entitlements in the Central Sector generating plants and WRLDC schedules this generation based on the requisitions from States. For computing requisitions, the States have to precisely forecast their demand which is a difficult proposition due to the absence of adequate tools and non-usage of weather models. The forecasting errors have financial implications as the states have to replace this power either by injecting or drawing from the power pool at frequency based UI prices. In the deficit scenario, it is extremely difficult to compute the demand of a State or region. In order to overcome this difficulty, the demand data is categorized into registered demand (demand met which is equal to generation availability plus import minus export), computed demand and unrestricted demand. The computed demand is the sum of load met; load shedding and frequency correction (applied to refer the loads to 50 Hz and calculated using system stiffness). The unrestricted demand is the sum of computed demand, power cuts, restrictions and effect of recess holiday staggering, and staggering of agricultural loads etc. The registered demand does not actually reflect the load demand of the utility but is a function of generation availability. The computed demand data is unreliable due to non availability of precise data on load shedding and errors introduced by frequency correction. Due to non availability of precise data on power cuts, restrictions and staggering, the unrestricted demand data can not be relied upon. The above problems can introduce appreciable errors in the short term load forecast (STLF) model as well as make it difficult to validate the model parameters. Due to the peculiarities explained above, it is difficult to forecast demand that can be easily interpreted by the load dispatchers.

B. Demand Management

The States of the region implement load regulatory measures through power cuts on HT industries, LT industries, rostering of agricultural loads, holiday and recess staggering and some planned load shedding in rural / semi urban areas termed as scheduled load shedding. This scheduled load shedding is expected to take care of the long term capacity shortages (seasonal and yearly). To account for the forced outage of the generating units, forecasting errors and generation constraints, additional manual load shedding is planned on a daily basis (day ahead) which is termed as unscheduled load shedding. However, to take care of sudden frequency variations due to unit tripping in real time, emergency load shedding is also planned. The States identify some radial 66kV, 132kV and 220kV feeders which can be tripped for emergency frequency control. The automatic under frequency load shedding is provided to take care of sudden contingencies when frequency dips below 48.5 Hz or to counter rapid decay of frequency.

C. Open Access

Open Access for short term and long term transactions have been introduced in the country from 6th May 2004 [8]. Due to open access, the existing transmission network in

Western region is getting critically loaded with more than 1000 MW additional power being evacuated. The existing ABT mechanism takes care of scheduling open access transactions and also for pricing the deviations from schedule. However, the network planning is not done to allow injections and drawals at any point in the grid. The low voltage profile and higher line loading also contributed to increase in losses. At present, the open access is implemented using the inherent design margins in the network. The open access wheeling charges are not based on the direction of power flow and the distance traversed. A simple postage stamp based system is in place with each of the State transmission systems, Regional systems owned by POWERGRID and inter-regional links charging their wheeling charges for the transactions. Due to congestion in the inter-regional corridors, many of the transactions are not able to be executed and major augmentations are required for inter-regional links.

X. Conclusions

The Western region power system of India is a typical case of generation deficient power system among developing countries. The frequency deviations are tactfully coupled with the commercial mechanism ABT component, for Unscheduled Interchange. This arrangement is equivalent to self balancing real time power market. It will be further useful when fully restructured system becomes operational. Linking of frequency signal with tariff facilitates price signal availability at no extra cost to whole of the system since same frequency prevails the entire synchronized network saving burden on communication and eliminating possible errors. The generation dispatch has to follow the frequency signal. Even though the frequency is contained in a narrow band, frequency of frequency deviation is large indicating problem with settling the system. The varying frequency encourages implementation of free governor mode of operation on generating units. The voltage control is through devising price signal for reactive power beyond the allowed voltage band. The demand management through various load shedding schemes is unique to the country which tries to balance load and generation and at the same time take care of requirement of different categories of consumers. From the experience gained up till now, ABT could successfully address some of the difficult issues and has brought in more grid discipline among the various constituents of the grid. The defense plans have been suggested. The regional interconnections have brought some relief by increasing the stiffness of the region but requires more attention for seamless integration.

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