Operating Experience of Regional Interconnections In India

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***Abstract*— That regional interconnections can benefit interconnected grids is accepted by the decision makers owing to optimal utilization of resources, diversity of load patterns, increased security and improved system performance. However, there are ”opportunities and threats” depending on how commercial, operational and security issues are tackled. The threats stem from potential seaming problems in the integration or lack of adequate defense plans. In India, five large sized regional grids operate and these are interconnected either synchronously or asynchronously. The operating strategies for interconnections have evolved through experiments on exiting system which are covered in this paper. The paper overviews the salient features of all the regional interconnections in India. The commercial mechanism, Availability Based Tariff (ABT), adopted by India has facilitated seamless integration on commercial front to a good extent as described in this paper. ABT links part of tariff with a universally available signal of system frequency. From experience gained over last two years, the operational and security issues have been discussed. With Open Access in operation, the interconnecting corridors have to play a significant role in the operation of the interconnected system. The need for evolving standards for the integrated operation became evident from the experience. The guiding principles for such standardization are also reported in this paper.**

***Index Terms*— Regional Interconnections, Operation and Control**

I. Introduction

WITH population over 1 billion people, India is one of the fastest growing economy. Electric Supply Industry plays a key role in development. The regional interconnections, though a most welcome step, remains a complex and challenging task for planning and operation. In literature, [1] [2] and [3] have dealt with Interconnection issues in China and Arab world. In [2], it is pointed out that if the growth rate is low, the weaker links may be preferable. This is at the cost of potential problems of stability. Though there are generic principles governing the philosophy of interconnections, some issues are system specific to nation. India has to deal the system specific issues in an innovative way. The special features of Indian power system include generation deficiency, large frequency deviations, and different operational practices in different regions. Some references to Indian power systems conditions are reported in literature. One of them deals with Chandrapur HVDC interconnecting link design details [4]. In [5], [6], interconnections in South Asia in Indian context are briefly described. Building of Indian Grid and how it can benefit China is discussed in [7]. The international interconnection scheme for Greater Mekong Subregion connecting six Asian countries is reported in [8]. In India, the regional interconnections have become operational since last two years. The experience gained from these operations is subject matter of this paper. The paper overviews all regional links with their special features in an exhaustive manner. The paper also comments on possible National grid operation. The standard practices for regional link operation have been suggested.

The Indian power system is having an installed capacity of 110 GW and is meeting a peak demand of around 70 GW [9]. 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 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 through asynchronous links (HVDC back-to-back) or AC links to enable exchange as and when available surpluses. The objectives of interconnecting the five regional grids in the country through synchronous and asynchronous links are to enable transfer of power from surplus regions to deficit regions, to enable optimal development and utilization of coal, gas and hydro resources in the overall interest of the nation and to improve economy, reliability and quality of power supply.

With the Open Access in transmission since May 2004, the interconnection of grids shall achieve the objective of cheaper power displacing the costlier power and reduction of cost to the consumer. The regional interconnections involve operating large grids in tandem and there are opportunities as well as threats to deal with and these are summarized below:

Opportunities:

- Helps in exchanging power as and when available i.e., infirm and economy exchanges.
- Increased stiffness in case of synchronous interconnection.
- HVDC back to back helps in inter-connecting regions with different frequencies.
- Faster emergency frequency control.
- Evacuation of surplus power in some regions like ER and NER.
- Increased open access transactions with cheaper power displacing costlier power.

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Threats:

- Weak synchronous ties may lead to tripping due to difficulty in controlling tie line flows.
- Oscillations in case of weak ties. TCSC with Power Oscillation Damping (POD) controller commissioned on Raipur-Rourkela lines to counter such problems.
- Difficulty in controlling UI power.
- Reduction in operating costs due to dispatch of cheaper power. At times, this may lead to imports exceeding the capabilities of lines and difficulties in controlling line loadings.
- Coordination of different mechanism like Automatic Under Frequency Load Shedding (AUFLS) required.
- Back to back link requires a bypass breaker to have AC inter-connection during restoration.
- Synchronous inter-connection may transfer a disturbance from one region to other region whereas back-to-back links do not have such problem.

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 inter connection largely benefited Western regional grid which is importing power to the tune of 1200-1800 MW from ER and NER grids. Figure 1 depicts the regional grids and their interconnections in India.

II. Development of regional interconnections

The power development in the country started with small isolated power systems. In the evolution of grid, these small power systems were interconnected to form state grids. In the seventies, the inter-connection of state grids with each other began in order to exchange surplus power available occasionally. The state grids did not operate continuously in parallel with each other. In some cases, power exchanges took place in radial mode in which the recipient state intending to import power disconnects part of their grid and connects it to the states exporting power. The radial mode however suffers from the disadvantage of power interruption while paralleling with the other grid. Even the interconnection of state grids in parallel mode was not continuous and the state grids used to separate from each other after the power exchange.

In the eighties, the Union government stepped into power development on a regional basis by dividing the country into five regions as described above. The Central utilities had set up large pit-head power stations and allocation from these power stations were given to all the states within the region. The Central utilities also developed the transmission network for evacuating the power from the Central stations to the state grids as well as inter-state / inter-regional network. The development of Central sector power stations and transmission network led to continuous parallel operation of the state grids with each other thus forming a synchronous regional grid. Subsequently, the opportunity available for exchanging seasonal surpluses as well as infirm power available during certain hours of the day due to diversity of peak demands has induced the need for development of regional interconnections. Due to weak inter-ties, parallel operation was not conceived between the regions as tripping of weak ties may lead to disturbances in both the regions. Since different regional grids were operating at different frequencies - widely varying, the favored regional interconnection mode is through HVDC back to back links. Such links enable connecting two grids operating at different frequencies and do not transfer disturbances from one region to the other.

These interconnections helped in exchanging sizable amount of infirm surplus power among the regions as indicated in Fig. 2 In the late nineties, the Eastern region has become surplus in generation and due to the absence of adequate regional interconnections between Eastern and other regions, the surplus power available could not be utilized. However, efforts have been made to maximize utilization by radially connecting loads of other regions with Eastern region and effecting parallel operations of Eastern and North Eastern regions. For instance, the *Ib* power station of Eastern region was connected to Western region in a radial mode and some radial loads of Raigarh in Western region connected to Eastern region.

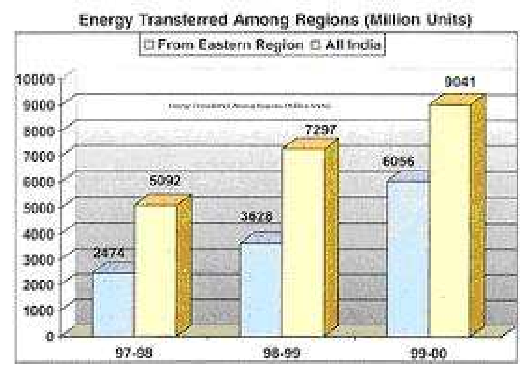

Fig. 2. Energy transferred among regions [10]

The plan for formation of national grid led to thinking towards AC interconnections among the regions. As a first step in the direction, the 400kV Raipur-Rourkela double circuit line was commissioned. On 2nd March 2003, ER-NER grids were synchronously connected with WR grid forming Central grid.

A. Perspective plan for National Grid

At present three synchronous grids viz., NR, SR, WR-ER-NER(Central grid) grids are operating in the country. The plan for formation of national grid include interconnection of NR grid with the Central grid by December 2005 under the Tala transmission project in which 1020 MW hydro power from Bhutan would be delivered to Eastern and Northern grids. The last leg in the race for formation of National grid would be

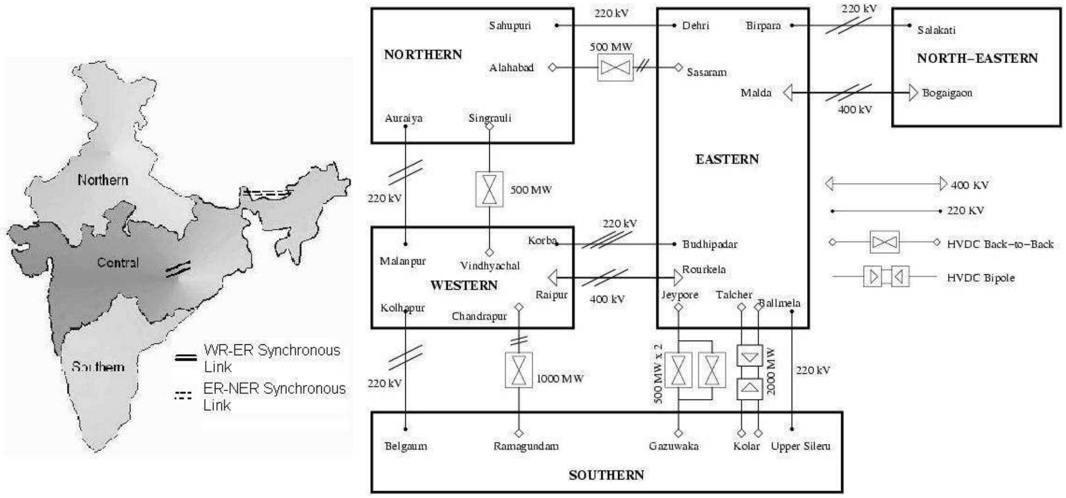

Fig. 1. Interconnections in operation in India

to connect SR grid with the rest of the Indian power system. Two options exists here.

Option-1: To connect SR grid synchronously

Option-2: To connect SR grid asynchronously

The advantage with the second option would be in case of a major disturbance, part of the Indian power system would remain healthy and can help in restoration. However, this would be an extreme case as several islanding schemes and black-start hydro and gas generators available in all the regions would help in restoring each regional grid separately and after sufficient stabilization the regional grids can be connected with each other. With the introduction of Open Access in the country and development of power projects close to the natural resources, the need increases for transferring power from anywhere to anywhere and this requires sufficient inter-regional transfer capacity. Figure 3 depicts the projected growth of inter-regional transfer capability.

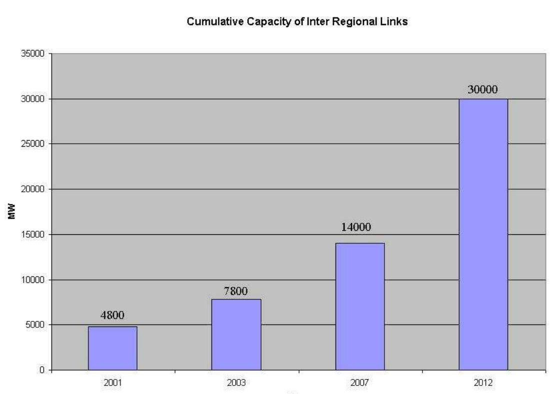

Fig. 3. Cumulative capacity of inter-regional links

III. EXPERIENCE OF SYNCHRONOUS OPERATION OF REGIONAL GRIDS [11]

In September 1991, trial parallel operation of Western and Southern Regional grids was attempted for two hours and no technical problems were encountered. Therefore, it was decided to operate both the regions in synchronism from 8^{th} October 1991. The objective was to export off-peak surplus from thermal power stations in Western region during night hours. The demand in Western region reduces by 30% during off-peak hours and requires generation reduction on thermal generators and this surplus can be exported to Southern region. The second objective was to draw surplus hydro power from Southern region during peak hours when Western region is having deficit. The hydro reservoirs in Southern region would have adequate water levels by first week of October and some reservoirs may start spilling. The regions are to be inter-connected through 400kV Chandrapur-Ramagundam double circuit lines. The parallel operation of the regions continued from 1222 hrs of 8^{th} October 1991 to 1726 hrs of 14^{th} October 1991. The synchronous operation led to better frequency stability and reduced frequency fluctuations as the stiffness of the combined grid increased significantly. Frequency and voltage profile during peak hours vastly improved. The sharing of spilling reserve and optimization of generation availability in both regions were the other advantages. Due to various difficulties, the synchronous operation was discontinued after 14^{th} October 1991. The major difficulties faced include:

- The operating practices in WR and SR were vastly different. WR constituents prefer to maintain frequency around 50 Hz while SR constituents prefer to maintain frequency around 48 Hz in order to reduce the quantum of load shedding. During parallel operation, no actions were forthcoming from SR to increase frequency profile or to control the power flow on inter-connecting links till frequency reduced to 48 Hz.
- The automatic under frequency load shedding starts in WR at 48.8 Hz while in SR the first stage is set at 47.8 Hz. In case of any generating unit trippings in SR, the load shedding used to take place in WR which was not acceptable to WR constituents. With the implementation of Indian Electricity Grid Code (IEGC) both the above problems do not exist at present.
- No firm commercial agreement existed prior to parallel

operation of the grid. It was agreed by both the regions to price the exchanges at pooled cost of thermal generation (including lignite and nuclear) of both the regions plus fuel price adjustment charges. However, there is no settlement system existing and it is difficult to identify the buyer and seller. With implementation of ABT all over the country, such commercial problems do not arise now.

- The regions are under the control of their respective RLDCs and no agency to coordinate inter-regional exchanges and grid indiscipline in case of over drawals, low/high frequency, Var exchanges etc. Now, the National Power System Desk(NPSD) can deal with matters related to inter-connected operation of regional grids.
- In Southern region, the practice then is to pick up generation from all sources at 0500 hrs without any coordination. This resulted in large inadvertent power flows towards Western region with number of 220kV lines in Western region getting overloaded and threat of system disturbance looming large.
- Due to power deficits in both the regions, it was decided to keep the inter-regional link at floating level during peak hours but could not be achieved due to indiscipline on the part of some of the states in both the regions and coordination to control large inadvertent power flows was missing. The ABT mechanism implemented now can take care of such situations due to commercial implications.
- There was no SCADA system available in SR due to which SRLDC faced difficulties in controlling the line overloads.

The lessons learnt from the WR-SR operating experience has greatly helped in developing modalities in parallel operation in the subsequent years.

IV. Commercial Mechanism [12]

Commercial mechanism called Availability Based Tariff (ABT) has been implemented in all the five Regional Grids of India. Under ABT, each state and each central generating stations are designated as control areas with schedules for the stations and states issued a day in advance. These schedules consider central allocations, open access scheduled transactions in to account. Deviations from schedules are termed as unscheduled interchanges (UI) and priced at frequency linked prices. The tie lines between the regions have schedules. Under ABT, all UI power is injected into the regional UI power pool and all UI drawals by the participant utilities are from the UI power pool. Thus the UI power pool of a region comprise:

1) All the states in the region with pre-determined drawal schedules
2) All central generators with pre-determined injection schedules
3) All other regions with pre-determined tie line schedules

The introduction of Availability Based Tariff (ABT) in all the regions of the country enabled exchange of power through scheduled bilateral contracts or as unscheduled power without any commercial problems and need for prolonged negotiations. In fact, a decision can be taken in real time itself to effect transfer of power from one region to other region and there is no need to negotiate price as the price of such exchanges are determined by linking to frequency. However, the grid connected asynchronously shall have two different frequencies and the UI price of power in both the regions will be different. This problem also could be handled under ABT and is described in section VI-A.

The next section describes salient features of each of the inter-regional links in India.

V. Overview of Regional Interconnections in India

As explained earlier and apparent from Table I, two regions can have multiple corridors connecting them. The cumulative capacity of all the lines between two regions, reserved for schedule transactions is 10% lesser than the actual capacity. This 10% is reserved for any Unscheduled Interchanges (UI) taking place during real time operation.

A. ER-WR Links

The two regions are connected synchronously. ER and NER being power surplus, power always flows from ER to WR on this link. The details of the links connecting ER and WR is given in the Table I. The two regions are connected at two voltage levels: 400 kV and 220 kV. Due to different impedances of the paths of different voltage levels, the actual power flow capacity has to be derated (1200 MW instead of 1450 MW) so that overloading of 400 kV line does not take place. Some of the salient points pertaining to this interconnection are as follows:

- Interconnection helped in frequency improvement for WR and ER.
- TCSC commissioned to enable tight coupling.
- The problem of oscillations in WR was solved due to this interconnection.
- UI power from NER is passed on to WR which creates more losses in ER and controlling burden of Raipur (WR)-Rourkela (ER) loading comes on ER.
- Tripping of Talcher (ER)-Kolar (SR) bi-pole (2x1000 MW, DC) is a major threat as 2000 MW power would rush to WR on ER-WR interconnection.
- During restoration, ER and WR are separately restored and interconnected.

B. WR-NR Link

The two regions are connected with asynchronous tie, the details of which are given in the Table I. The power flow takes place in both the directions with emergency exchanges for frequency control along with some scheduled open access transactions. Some of the salient points pertaining to this interconnection are as follows:

- Import of power by WR increases East-West power flows overloading the E-W corridors and voltage dips at Indore. In NR system, E-W power flows would reduce due to export. (vice-versa for export by WR and import by NR)
- Wheeling of ER power to NR through WR would lead to critical loading of Vindhyachal-Korba 400kV S/C line.

C. WR-SR Link

The two regions are connected with asynchronous tie, the details of which are given in the Table I. Some of the salient points pertaining to this interconnection are as follows:

- Used for open access transactions and UI power for economy and emergency frequency control by fast ramping.
- For import by WR, the limitation is overloading of 400kV Bhadravati-Chandrapur line, which is in WR itself. Also, outage of one pole of Chandrapur-Padghe HVDC line, which is also in WR imparts restriction of import.
- In case of Talcher (ER)-Kolar (SR) bi-pole (2x1000 MW) tripping, emergency control actions in WR require ramping up power to SR on this link to control line loading in WR and frequency control of SR.

D. ER-SR Link

The details of the links connecting ER and SR are given in the Table I. Talcher-Kolar links is primarily meant for evacuating 4x500 MW Talcher Stage-II and III power plant located in Eastern region to beneficiaries in Southern region. The Gazuwaka back-to-back HVDC is used for open access transactions and UI power exchanges. Both the DC links enabled evacuation of surplus power in Eastern region to a great extent. Some of the issues related to this interconnection are as follows:

- Low voltage profile in SR was a major concern for evacuating power from ER on the above links as well as from WR on Bhadrawati back to back HVDC. However, the additional filter banks provided at Kolar and 400kV lines commissioned for evacuation of power from Kolar helped in improving voltage profile and no constraints are observed presently.
- Talcher Stage-II and III power station is also connected to Eastern region through bus coupler to Talcher Stage-I power station of ER. Due to typical configuration - rectifier end at ER frequency and Kolar at SR frequency, the UI power on this link is priced at ER frequency unlike for other links where different frequency has been used for respective region at either end of the links. Due to the above problem, negative UI generated whenever ER frequency is higher than SR frequency for most of the time. Further, SR states prefer to draw power from ER-SR (Talcher-Kolar) links rather than drawing from WR on Bhadrawati back-to-back link. These anomalies are being rectified.

E. NR-NER Links

The details of the links connecting ER and NER are given in the Table I. Some of the salient points pertaining to this interconnection are as follows:

- The link capacity has been determined as 1050 MW. However, due to stability problems - oscillations and considerable angular differences, the power flow is restricted to 300 MW only.
- Dumping of power from NER due to over flowing of reservoirs in NER is a difficult problem to control. Further, ER due to its surplus capacity wheels this power to WR. Sine this is UI power, no wheeling charges and losses can be charged by ER.
- WR sheds load even at 50 Hz to control power dumping from ER/NER to bring up frequency to 50.20 Hz or above as at this frequency ER generators backdown generation.

F. ER-NR Links

The details of the links connecting ER and NR is given in the Table I. The link capacity is not being augmented even though more power can be evacuated from ER to NR as it is planned to interconnect ER and NR grid synchronously through *Tala* transmission system by December 2005.

VI. Issues related to Grid Interconnections

A. Commercial Issues

- The inter-regional links carry allocation from Inter State Generating Stations (ISGS) in one region to the States in other region and open access scheduled transactions. The link capacity is pre-determined and priority is given to ISGS allocations and long term open access transactions. The remaining capacity (ATC) is used for short term open access transactions. About 10% of the capacity is also reserved as security margin to allow inadvertent power flows (unscheduled inter-changes - UI). The system operators control the power flow if it exceeds the link capacity. However, on AC interconnections it is difficult to control the inadvertent power flows(UI). For instance, the States in Eastern region operate their generators at maximum possible outputs till frequency of 50.1 Hz as the variable cost of the ER generators approximately is 120 paise/unit and the cost of UI power at 50.1 Hz is 120 paise/unit and they would reduce generation only when frequency goes above 50.1 Hz. At times, the ER-WR link goes to 1800 MW to 2000 MW as against the link capacity of 1200 MW due to surplus in ER and deficit in WR The ER constituents refuse to reduce generation in case frequency is below 50.1 Hz as the economic signals generated by the commercial mechanism (ABT) gives incentives to maximize generation thereby creating a conflicting situation - economy versus security and coordination problem arise for the RLDCs of both the regions to avert the alert situation. Often, the strategy adopted is to shed load in WR and push frequency above 50.1 Hz which would immediately relieve the link overload as ER generators reduce their generation. The link overload is also relieved in case of emergencies by diverting power to other regions from ER through HVDC links if margins permit.
- The regions connected through asynchronous links have two different operating frequencies and price of UI power is linked to the frequency in that region. For instance, the cost of UI power in WR is 120 paise/unit based on frequency of 50.1 Hz in WR and the cost of UI power in SR is 210 paise/unit based on frequency of 49.8 Hz in SR. Assuming WR is exporting power to SR, the WR power pool expects to receive 120 paise for every unit exported

to SR power pool intends to pay only 120 paise for every unit imported. The settlement systems of both the regions permit for payment of 120 paise for every unit by SR to WR power pool. The difference of 90 paise for every unit exchanged is shared equally and credited towards annual transmission charges of both the regions. In case the power is to be exported from SR to WR in the above scenario, negative UI is generated due to which power flows are permitted from one region to other region based on frequency differential of 0.3Hz with exporting region frequency higher than the importing region frequency.
- In NER, due to overflowing of reservoirs, hydro generators maintain maximum generation above the requirement of the region and inadvertent power flows to ER and ER also being surplus region, flows to WR over ER-WR links. Control of power flow required coordination among three regions. Another issue is that UI power wheeled by ER from NER to WR causes increase of losses in ER for which the ER constituents are not compensated. There is no stipulation for accounting losses and payment of wheeling charges for UI power. The dumping of power also takes place due to frequent splitting of NER system.
- The congestion of the links has to be handled at the approval stage for the open access transactions as well as during real time operation. At the approval stage or in day-ahead scheduling, the congestion management and control is done through e-bidding with the highest bidder getting the transmission capacity reserved. During real time operation, the congestion control is done through proportionate curtailment of short term open access transactions and on some rare occasions through generation re-scheduling.

B. Security Issues

- The tripping of one 400kV line in ER-WR interconnection may lead to overloading the other four lines and may possibly lead to cascade tripping on certain occasions. Such an eventuality may lead to 1200 MW loss of import to WR and frequency may fall rapidly by about 2 Hz which is handled through automatic under frequency load shedding. In case of ER whose stiffness is of the order of 200-300 MW per Hz may face rapid rise of frequency by about 4 to 6 Hz and the generating units in ER may trip on high frequency. The Free Governor Mode of Operation (FGMO) is made mandatory in the country which would help in reducing the generation to control the frequency rise in ER. However, possibility of collapse of ER-NER grid can not be entirely ruled out.
- Tripping of 2000 MW Talcher-Kolar link (ER to SR) may result in severe frequency rise in ER-WR-NER grid by about 2.5 Hz. This frequency rise is to be handled by generation reduction through FGMO. This is also backed up by another defense mechanism viz., run back scheme at Talcher power station which would ramp down generation by sensing the trip signal from Talcher HVDC terminal. The frequency in SR also would decrease by more than 3 Hz due to loss of 2000 MW import. To counter the frequency fall, a defense mechanism was conceived in SR which is based on sending carrier from Kolar HVDC terminal for remote load shedding.
- The sudden inrush of power to WR grid due to tripping of Talcher-Kolar link is a major threat due to already overloaded downstream network (due to evacuation of additional 1600 MW import from other regions) and low voltage profile. WR grid already faced one major grid disturbance on 6^{th} December 2003 due to the above initiating cause.
- The regional grids were not planned for handling the additional imports due to inter-regional interconnections. The additional imports would create the transmission line overloads even during normal operation and may reach emergency loading levels under contingencies.
- The ER-WR interconnection helped in eliminating inter-area oscillations of 0.6 Hz that used to occur prior to the interconnection under certain operating conditions. However, studies indicate possibility of 0.42 Hz inter-area oscillations in the present configuration in case of tripping of one 400kV line between ER and WR. To sustain the remaining lines without tripping and to damp out oscillations, a thyristor controlled series capacitor (TCSC) was commissioned on both the 400kV lines between ER and WR.
- During restoration, it is not possible to operate the HVDC back to back links and AC bypass links in parallel. At HVDC back to back stations, bypass breakers have been provided to effect AC interconnection when one of the regions collapse and start-up power can be availed from the healthy region [13].

C. Operational Issues

Table-2 gives an overview of regional interconnections in India among the five regional grids. There are also number of 220kV/132kV/110kV lines interconnecting regions but operated in radial mode. The discussion is limited to those lines in which power is exchanged in synchronous mode or through HVDC back to back links.

- The interconnection helped in frequency stability in both exporting and importing regions. Higher system stiffness achieved in case of synchronous interconnection.
- The diversity of peaks in different regions is effectively used in optimizing capacity utilization.
- Emergency frequency control has become possible as frequency fall can be arrested by ramping up and ramping down on HVDC back to back links to supplement the effect of FGMO.
- The East-West power flows in WR and NR grids determine the exchanges possible between these grids.
- At times, low voltage problems in a region restricts the capability to import power and also restricts third party wheeling.
- For the purpose of implementation of open access in transmission, the State systems, regional transmission system of Central Transmission Utility and the interconnection links between regions are treated as separate

systems for the purpose of levying transmission charges in Rs/MW/day. The links are treated as separate systems even for the congestion management.

- The HVDC back to back links have been provided with frequency controllers to enable ramping up or ramping down power on the HVDC links based on frequency differential with respect to a set frequency and the current frequency of one region or frequency differential of actual frequencies of both regions. This would enable weaker regions to control frequency under emergency and alert situations.
- Additional filter banks have also been provided at some of the HVDC terminals in order to supply Vars under low voltage conditions.

From the experience based on the Indian regional interconnections, it can be inferred that there is a need for standardization of inter-regional links. The next section states the requirements for the same.

VII. Standardization of Inter-Regional Links [14]

Standardization of inter-regional links is required in order to foresee the operational, commercial and security constraints before hand and take corrective actions at the planning stage itself. Further, it has to be ensured that equitability in benefits are accrued to both the grids. An attempt has been made to list out the requirements for interconnections based on the experience of India.

1) Strong ties are required so that strong synchronous coupling would minimize oscillations and steady state stability problems.
2) The link capacity of the ties should be determined to take care of contingency in either grid that would result in emergency loading on the ties.
3) Tripping of the links leads to separation of the grid. This may require automatic under frequency load shedding in the importing region and FGMO as well as run back /unit tripping schemes in the exporting region to stabilize frequency and avoid grid disturbances.
4) In case both the grids to be connected cannot be operated in mutually agreed upon frequency band, then the solution lies with HVDC back- to- back links.
5) The interconnection links should be monitored by both the regions through SCADA. Both the grids must have SCADA and EMS facilities so that the power flow control over the links could be achieved faster.
6) The AUFLS of both the regions should be coordinated so that load shedding is done equitably in both the regions as a measure of security.
7) The commercial mechanism must exist in order to price inadvertent exchanges over the interconnections. The tie line flow need not be tightly controlled if such a mechanism exists. UI mechanism in ABT serves the purpose in the Indian context.
8) The commercial mechanism in both the regions should permit economy exchanges as well as open access scheduled transactions without loss of opportunity or due to problems of congestion.
9) Mechanism for congestion control at the time of approval (e-bidding) and in real time operation (through curtailment/generation re-scheduling/diversion of path) shall be in place.
10) The protection schemes with redundancy and adequate back ups shall be available.
11) Procedures for planned, forced, emergency outages, line charging modalities during normal operation and restoration should be documented.
12) The terminal points of inter regional links should have proper communication facilities to their respective load dispatch centers in order to receive instructions of emergency control.
13) Commercial mechanisms in both the grids should have provisions to price power exchanges during grid restoration. In case of difficulty in pricing, the power can be returned in kind. However, pricing mechanism would be more desirable.
14) The scheduling procedure for exchanges over the links should be in place with provisions for revision of schedules on mutual consent.
15) It should be made mandatory while planning to strengthen downstream network in both the grids to ensure power exchanges, to avoid critical loadings and ensure stability. During real time operation, N-1 stability criteria shall have to be complied with.
16) It is required to plan FACTS devices with damping controller for control of active and reactive power flows over the links.
17) Security measures to arrest propagation of disturbances from one grid to the other grid shall be planned in advance and implemented.
18) Coordination Committee shall be formed to deal with various coordination matters and formulate interconnection code, metering, sharing of losses and settlement system and mechanism for dispute resolution shall be devised.
19) Control of interconnections during normal disasters, War etc., shall have to be planned. Emergency control powers could be vested with one of the load dispatch centers. The other load dispatch center shall act as back up.
20) Method of recovering annual transmission charges for the links shall be devised by the Coordination Committee. Necessary agreement should be signed by both the grids. Ideally the charges should be shared in 50:50 by both the grids.
21) There must be islanding schemes to facilitate restoration during disturbances in large grids as a National Grid or Transnational Grids may collapse leading to total failure of supply.
22) It is prudent to provide 0.2s class identical meters at both ends with provision of check and standby meters. The CT/PTs should also be of same accuracy class. It is also necessary to determine the point of drawal/injection and preferably this should be at mid point of the interconnection.

TABLE I

SALIENT FEATURES OF REGIONAL INTERCONNECTIONS IN INDIA

Regions	Links	Link Capacity for Scheduled Transactions	Type	HVDC bypass facility	Frequency Controller	Filter banks
ER-WR	Two 400 kV lines with TCSC (Raipur-Rourkela) Three 220 kV lines (Korba-Budhipadar)	1200	Synch.	NA	NA	No
WR-NR	500 MW HVDC Back-to-Back (Vindhyachal-Singrauli)	450	Asynch.	Yes	Yes	No
ER-SR	500 MW HVDC Back-to-Back (Jeypore-Gazuwaka) 2000 MW HVDC Bi-pole (Talcher-Kolar)	2250	Asynch.	Yes	Yes	Yes
WR-SR	1000 MW HVDC Back-to-Back (Bhadravati-Ramagundam)	900 MW	Asynch.	Yes	Yes	No
ER-NER	Two 400 kV AC Lines (Malda-Bogaigaon)	1050 MW	Synch.	NA	NA	No
ER-NR	500 MW HVDC Back-to-Back (Sasaram-Pusauli)	450 MW	Asynch.	Yes	Yes	No

VIII. CONCLUSIONS

The six regional interconnecting links of India with their features have been described in this paper. The commercial, security, and operational philosophy of the interconnecting links have been discussed. The Indian experience gathered over years has build confidence and has helped in evolving the better operational policies. The harmonious concurrence over standard operating practices among constituents is the key to reap all fruits of the regional interconnections. Some guidelines for such standardization are suggested in this paper. Also, ready defense plans for plausible encounters can negate the cons of interconnections. The developing countries can benefit from the policies reported in this paper. This will go long way to help building national and international interconnections.

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