A Novel Settlement/Arbitrage Scheme- Use of Asynchronous Inter-Regional links in India

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Abstract--**India has five regional electricity grids namely Eastern, Western, Northern, Southern and Northeastern. Out of these five regional grids, Northeastern, Eastern and Western grids is synchronously interconnected forming the Central grid. The Northern & Southern grids operating at different independent frequencies are connected asynchronously with the Central grid through HVDC Back-to-Back stations to facilitate inter-regional power transfer. Implementation of the Availability Based Tariff (ABT), having self-correcting real time balancing mechanism as one of its main feature, has opened new vistas for arbitrage in inter-regional power transfer. The time stamped deviations from the schedules also called Unscheduled Interchanges (UI) are priced at a rate known as UI rate. The UI rate at any time is the function of the system frequency of that time. The electrical regions in India are in different geographical zones and thus have very wide diversity in type of resources, climate and therefore have different demand pattern over the year and even during the day. The above diversity results in forming of surplus and deficit regions indicated by respective frequency of the region at any particular time of day. The difference in frequencies resulting into different UI rates (price) of power creates a favorable condition for arbitrage between regions. The difference in UI rate is called "Differential UI" which is a derivative of UI.**

This paper is a study of opportunities for such arbitrage in Indian power sector. A substantial savings of the order of Rupees 635 Crores have been made during 2003 to 2005 by replacing costly power by cheaper power through such arbitrage – a win-win situation.

Index Terms-- **Arbitrage, Availability Based Tariff (ABT), Differential UI, Power Market, Unscheduled Inter-change (UI),.**

I. INTRODUCTION

It has been the endeavor of power system operators around the globe to make power system reliable, secure, efficient and economic by devising technical & commercial schemes that are easy to implement and encourage participants to take corrective actions.

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In India, the operations of regional grids have been entrusted upon the Regional Load Dispatch Centers (RLDCs) in coordination with State Load Dispatch Centers. The RLDCs are responsible for integrated, safe, secure and economic operation of respective regional grids.

The concept of regional settlement & accounting also evolved along with the concept of regional grids. Since 2002, implementation of Availability Based Tariff (ABT) has further strengthened the markets with real time price discovery dependent of the frequency of that region. Transfer of power from high cost region to low cost region on inter-regional links between these markets became a facilitating medium for arbitrage and gave birth to a novel settlement scheme benefiting all the constituents and bringing economy & efficiency to regional grids.

II. INDIAN REGIONAL GRIDS & INTER-REGIONAL LINKS

Historically, Indian electricity grids were formed by interconnecting small isolated systems to derive benefits of integrated power system. After independence system size gradually grew and in order to have planned development & ease of operation of power system, in sixties, the whole of India was demarcated into five regional grids. In formative years of the regional grids, the total emphasis of policy makers and planners has been on self-sufficiency of respective regional grids. The generation and transmission planning was carried out keeping in the basic provision of self-sufficient stand-alone regional grids. The inter-regional links were established in nineties to transfer power from adjacent regions under distress condition and thus only marginal power flow over these links was planned. Both the adjacent regions shared the charges of such inter-regional facilities in the ratio of 50:50.

Though administratively, India still has five regional grids however after synchronous inter-connection of NER-ER grid with WR grid in March 2003, there are three electrical regions in India namely North, Central & South Region as shown in Fig. 1.

The above electrical regions operate independently and have independent frequencies. Asynchronous HVDC links interconnects these regions and facilitate the transfer of power from one region to other region.

In additional to asynchronous HVDC links, there are some

AC links between these regions operating in radial mode.

Following inter-regional transfer capacity exits between these electrical Regions (Fig. 2)

A. Central and Northern Regions- 1200 MW

1. *1x500 MW HVDC Pusauli Link* -500 MW
2. *2x250 MW HVDC Vindhyachal Link* – 500 MW
3. *220 kV Pusauli-Sahupuri Radial link* – 200 MW

B. Central and Southern Region- 2000 MW

1. *2x500 MW HVDC Bhadravati link*- 1000 MW
2. *2x500 MW HVDC Gajuwaka link*- 1000 MW

Fig. 1 - Electrical Regions of India

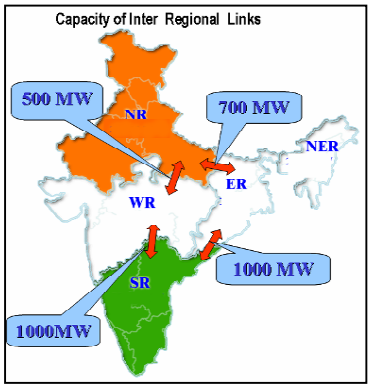

Fig. 2 - Inter-Regional Asynchronous Link Capacity

III. Availability Based Tariff (ABT)

The Availability Based Tariff (ABT), a unique real time balancing and settlement mechanism, is in vogue in India. De-centralized scheduling and frequency linked Unscheduled Interchange (UI) is some of the foundations of the ABT system. The frequency linked UI mechanism, a philosophy unique to India, is based on the principle that maintaining frequency tightly at 50 Hz is neither desirable nor feasible in present scheme of grid operation. Frequency is allowed to vary between 49.0 Hz to 50.5 Hz, the band prescribed by the Indian Electricity Grid Code (IEGC) within which all stem turbines conforming to IEC standards can safely operate.

The generators and purchasers are allowed to deviate from the schedules in real time however these deviations are priced at frequency-linked rate. The deviations from schedules are called Unscheduled Interchanges (UI) and the frequency dependent rate of these deviations is called UI rate. Definitely UI has to be priced in such a way that deviations helpful to the grid are encouraged and vice-versa. Thus at a system frequency lower then 50 Hz, implying higher load or less generation, UI price has to encourage the extra generation from generators and load reduction from the consumers. Similarly when frequency increases above 50 Hz indicating higher generation or less load, UI price has to encourage generation reduction. Obviously UI rate shall increase as frequency moves downwards from nominal frequency of 50 Hz and shall progressively reduce to zero as frequency moves upwards from 50 Hz. As frequency is allowed to vary from 49 to 50.5 Hz, maximum & minimum (zero) UI rates are at 49 Hz and 50.5 Hz respectively. The present UI rate (UI price vector) is depicted in the Fig.3.

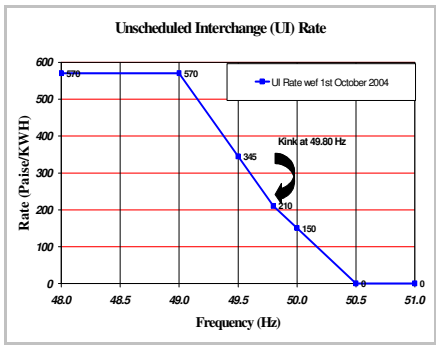

Fig. 3 - UI price vector

The above price vector gives an economic signal to every generator to maximize generation whenever the variable cost of its generation is less than the prevailing UI rate. It automatically gives a frequency linked dispatch guidelines for generators. Therefore, in the ABT mechanism, this UI settlement works as a load-generation balancing mechanism and stabilizes the frequency and no separate balancing market is required for balancing the short falls between generation and loads. The generation beyond contracted (scheduled) values by the generators would be paid as per the frequency linked UI rate, akin to the charges in the balancing market in other countries.

IV. Diversity in Indian Grids

The electric regions in India have wide diversity amongst them in their demand and generation pattern during the day due to following broad reasons:-

A. Geographical Location

India is vast country with wide variation in rainfall and climatic conditions. The country is spread from snow-covered mountain in north & northeast to peninsular India near equator (8 degree 4 minutes to 37 degree 6 minutes north latitude) and from northeast mountain ranges to highly industrialized west (68 degrees 7 minutes and 97 degrees 25 minutes east longitude). This longitudinal

spread gives a time difference of approx 2 hours in sunrise & sunset. This diversity plays an important role in timing of the monsoon rains in different part of the country. These differences apart from other factors give different peak demand timing in the different regions. The average temperatures (Fig.4), level of industrialization, crop patterns, type of land, availability of irrigation facilities etc are vastly different and thus load patterns are vastly different.

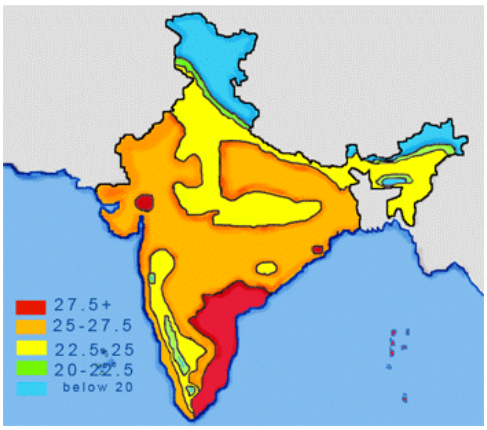

Fig. 4 - Average Annual temperature

B. Natural Resources

Natural resources for power generation and for other industrial use are different in different regions resulting in variation in availability & demand of power. Hydro resources are abundant in Northern & Northeastern Regions while Eastern Region is rich in coal resources. Hence, regions having high density of thermal power plants consequently more base load plant capacity would have surplus generation during off peak hours and hydro surplus region would be better in peaking power. However, in Northern Region during winter season peak demand are very sharp and prominent on one hand and on other hand hydro availability reduces drastically due to less inflow in rivers mostly originating from snow capped mountains. Therefore, at present there are both peak & off-peak shortages in NR.

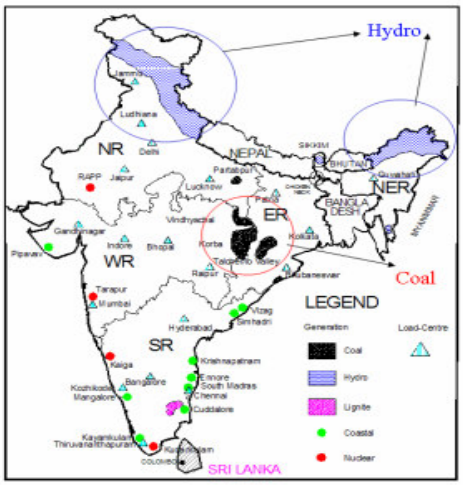

Fig. 5 - Distribution of Natural resources

V. ARBITRAGE

Arbitrage is a practice of taking advantage of imbalances in the market(s). The condition far arbitrage may exits due to Different prices of commodity/assets in different markets.

Arbitrage has the effect of causing prices in different markets to converge. The speed at which prices converge is a measure of market efficiency. Arbitrage tends to reduce price discrimination. The **arbitrage equilibrium** a pre-condition for general market equilibrium and is said to have been achieved when no further profitable arbitrage would be possible. Such arbitrage is totally risk-free and to drive maximum benefit in an efficient market – one must have sound knowledge of the market and should take fast decisions/actions.

VI. ARBITRAGE OPPORTUNITY IN INDIAN ELECTRICITY MARKET

The Regional grids in India, with UI scheme as spot market/real time pricing mechanism, work as regional power market, The regional market operates as a pool with zero sum implying that net UI receivable from regional UI pool shall be equal to net UI payable to that regional pool with all the UI charged at its UI-rate.

Some of the peculiarities of Indian Power Markets are:

1. Transmission prices are regulated and fixed
2. Zonal postage stamp concept is applicable for transmission charges as well as for apportionment of transmission losses.
3. UI Scheme work as real time pricing mechanism for deviations from schedules.
4. Transmission charges and losses are not applicable on UI transactions (UI).
5. Only market player with physical control area in a region can participate in their respective regional spot market. Traders are not allowed to play in the spot market.
6. Market as a whole (Regional Pool or Regional spot market or physical regional control area) can exchange power from adjacent Market. This exchange has to be implemented by the system operator viz Regional Load Despatch Centers (RLDCs). These regional pool-to-pool exchanges in spot market are also free of any additional transmission charges or losses.

Due to diversity in demands of different electrical regions there is difference in availability & demand of power and consequently in frequencies of these regions. Peak requirement times of the day are different for different regions. It generally happens that one regional grid reaches its day's peak power demand while other regional grid is still not having peak requirement.

As the UI rate is dependent on frequency, the rate would be same throughout the synchronously connected electrical systems and would be different for systems having different frequency. Thus if frequency of two electrical systems are different at the same time, there UI rates would also differ.

The region having high requirement will experience lower frequency than the region having lean requirement.

Furthermore, due to diversified concentration of natural resources, the coal rich region is generally having high generation which means high frequency – surplus power – low UI rate in non peak hours. Diversity in frequencies of the regions for a typical month as shown in Fig. 6 indicates that Central region is having frequency higher than Northern Region and Southern Region frequency is higher than central region in that month. It can be inferred form fig. 6 that:-

1. The price of power is in increasing trend from Southern to Central to Northern Region.
2. Northern Region is a deficit region while Central/Southern Region is a surplus region.

To bridge the demand to supply gap in Northern Region, the consumers generally enter into short-term supply contracts with the suppliers located in Central & Southern Regions.

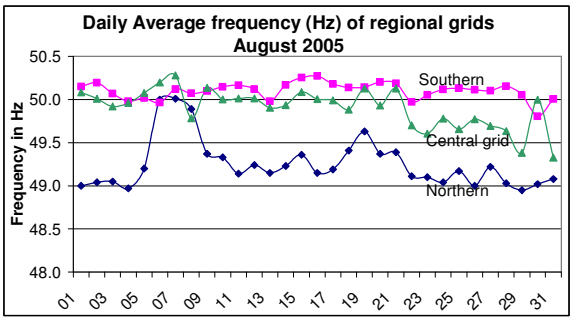

Fig. 6 – Frequency profile of different Regions.

These short-term supply contracts are approved and scheduled under Short-Term Open Access (STOA) by the system operators to the extent of available spare transfer capacity after accommodating long term contract and keeping some security margins as portrayed in Fig. 7.

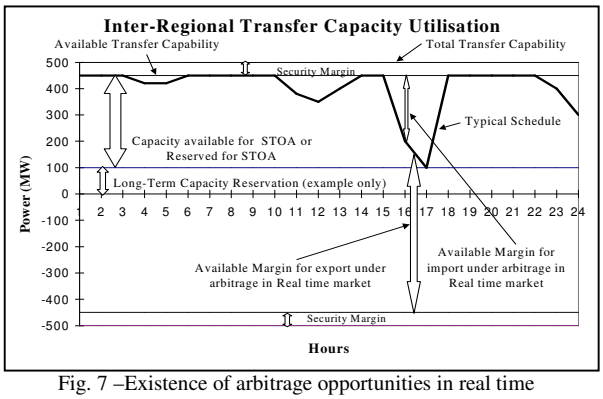

Fig. 7 –Existence of arbitrage opportunities in real time

Following happens in real time despite the best efforts and plans of load generation balance including sale/purchase consideration by utilities

1. System frequencies of all the regions vary due to unforeseen conditions, natural errors in demand/availability/load assessment. Thus differential UI moves in both the direction as depicted in Fig. 8.
2. Actual utilization of all long-term & short-term transactions is in the range of 80% only.

Therefore, the arbitrage opportunities do exist in regional Spot markets as can be inferred from Fig. 7.

VII. Scheme in Vogue for Inter-Market (Regional) Spot Exchanges in India

Presence of such natural conditions for arbitrage shall activate arbitrageur to increase the inter-regional transfer of power till the power price or frequencies of both the region becomes same. However, electricity market is different from other commodity markets in following manner:

1. Electricity cannot be stored.
2. Availability of surplus/deficit changes from moment to moment.
3. Transportation corridor is limited (Capacity for arbitrage is only limited to the balance capacity after scheduled long-term & Short-term Open Access transactions).

Due to above constraints and to derive maximum advantage, decisions for inter-regional power transfer have to be taken

1. Quickly in real time.
2. Availability of margin on inter-regional link to be ascertained in real time.
3. Adverse effect of such power transfer on congestion and security in the respective regional grids has to be considered.

Therefore, only National Load Despatch Centers (NLDCs) in co-ordination with Regional Load Dispatch Centers (RLDCs) or RLDCs in co-ordination with other RLDCs can take the correct decision. Thus RLDCs have implemented following Scheme:

1. RLDCs of the both the region agree for such situation of arbitrage (decision cross check).
2. RLDCs of both the regions after making real-time study for security margin & congestion in their regional network pass instruction to change the set point of the asynchronous inter-regional links in order to facilitate power export from cheaper region to dearer region as shown in Fig. 7.
3. Above actions are repeated as soon as situation changes Viz. differential UI moves to opposite direction.

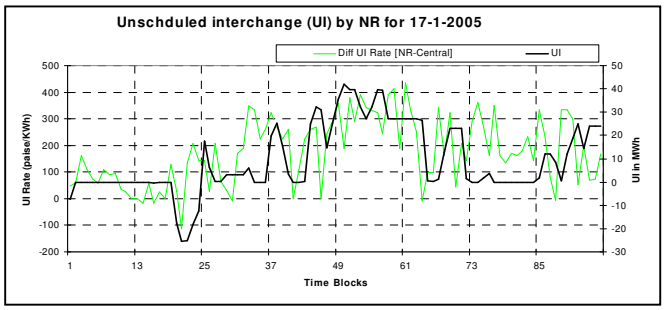

Fig. 8 – UI exchange by NR with WR

To assist the system operators to take correct and appropriate decisions following decision-making tools have been provided in control centers:

1. Real time frequency/UI rate thermometer of adjacent regional markets indicating opportunity for arbitrage and its direction (Fig. 9).

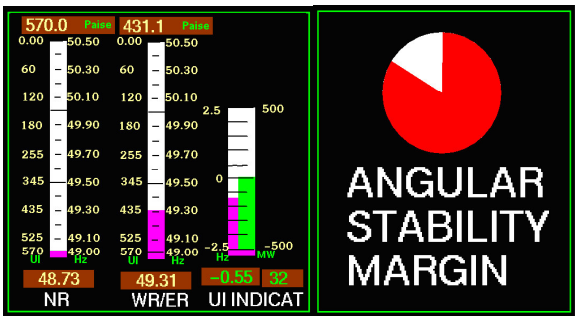

Fig. 9 –Regional UI thermometer and stability margin speedometer

2. Prominent display of available margin on inter-regional link.
3. System security margin speedometer to indicate degree of security in regional AC network (Fig. 9).
4. Facility of Real time contingency analysis to further quickly confirm the availability in regional network for further export/import of power from neighboring regions.
5. Prominent display of quantum of scheduled and unscheduled exchange from neighboring regions.
6. Alarm to catch operator's attention as soon as such arbitrage condition vanishes or reverses.

Analysis of Fig.8 and 9 clearly indicates that system operators uses tools and follows the differential UI pattern and take right decision for transfer of power from one market to other market by varying set point/power order of each inter-regional link about 20 to 30 times a day.

The above actions of RLDCs result in overall national economy as explained below:

1. Give chance to cheaper cost generators in a region having higher frequency to further maximize their generation by increasing power price/lowering the frequency by action of transfer of extra power to the adjacent region.
2. Forcing high cost generators in costlier market (Region) to back down by decreasing power price or increasing the frequency by importing cheaper power form adjacent region.
3. Saving (S_I) due to import of power from low UI rate region to high UI rate region can be calculated by following formula:

$$S_I = (R_I - R_E) \times P$$

Where

R_I = UI Rate in Importing Market,

R_E = UI Rate in Exporting Market,

P = Power transferred.

Saving/benefits accrued from such arbitrage is passed on to the constituents as per following scheme:-

1. Saving amount is transferred to Inter Regional Exchange (IRE) account of both the adjacent regions in the ratio of 50:50.
2. Amount so accumulated in IRE account is used to give credit to constituents/participants of that region against their liability of transmission charges.

The scheme can be further understand with the help of following example:

- Let 10 units of power is transferred from a region 'A' having UI rate of 300 paisa/unit to region 'B' having UI-rate of 310 paisa/unit.
- Region 'B' UI pool account would show Rs. 31 (310*10 paisa) payable to region 'A' and at the same time region 'A' pool account would show Rs. 30 (300*10 paisa) receivable from region 'B'.
- Thus UI pool account of region 'B' would be surplus by Rs. 1.0 even after paying the requisite UI charges to region 'A'.
- Out of surplus Rs 1.0, Rs. 0.5 each is transferred to Region 'A' IRE & Region 'B' IRE accounts.
- This Rs 0.5 is used to give credit to the constituents of that region in proportion to their liability of total transmission charges.

The uniqueness of the scheme lies in the fact that without any formal agreement with the generators in other region, power is being availed by the constituents of other region. The settlement is also very simple, as constituents have to settle their UI amount with their respective regional pool accounts operated by respective RLDCs only and not with the generator/seller in other region. The system operators do not get any monetary benefit from the scheme and use the scheme purely for frequency regulation and mutual benefit of regions.

VIII. BENEFITS ACCRUED

This novel settlement scheme for real time inter-regional power transfer has resulted in numerous technical and financial benefits to Indian Power Sector as a whole. Some of these benefits are enumerated below:

1. Fall back scheme in real time to take care of scheduling assessment and unforeseen errors.
2. Enhanced inter-regional capacity utilization. Even without Open Access in inter-state transmission system being in place in India before May 2004, this scheme has been instrumental for very high degree of inter-regional link capacity utilization. The energy exchanged under this real time scheme during March 2004 to October 2005 is depicted at Fig. 10.
3. Improvement in system parameters of regional power market. The improvement in frequency profile of the regional grids is given at Fig. 11. Clearly, the regional

grid frequencies are remaining within the Indian Electricity Grid Code (IEGC) prescribed frequency band that is between 50.5 Hz and 49.0 Hz most of the time after 2002.

4. While ABT has brought out regional merit order operation, this arbitrage scheme has attempted national merit order operation.
5. Savings to the tune of 635 Crores during 2003 to 2005 has accrued details of which are given in Table 1.
6. Paid off the investment on inter-regional links.
7. Helps in avoiding market power being exercised by regional market players.

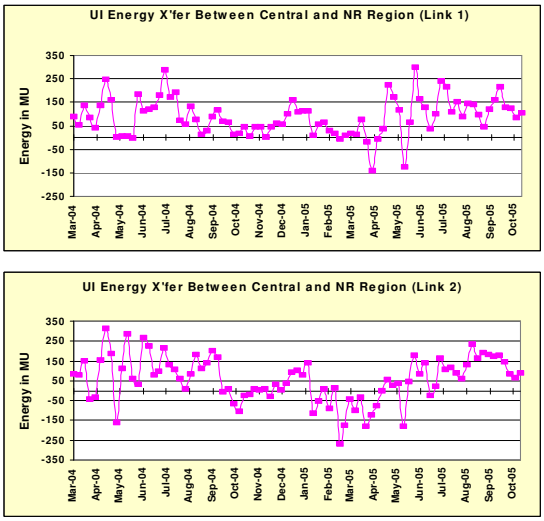

Fig. 10 – UI exchange with adjacent regions.

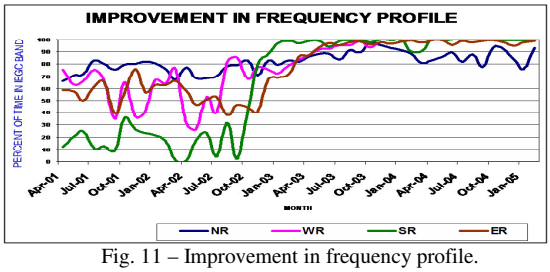

Fig. 11 – Improvement in frequency profile.

TABLE 1

Saving Due to Differential UI (Rs Crores)

Year	ER-NR	WR-NR	SR-ER	SR-WR	Total
2003-04	12	56	0	35	**103**
2004-05	77	109	9	52	**247**
2005-06*	68	90	48	79	**285**
Total	**157**	**255**	**57**	**166**	**635**

* For year 2005-06 upto 18th December 2005 only.

IX. CONCLUSIONS

The inter-regional UI settlement/arbitrage scheme, a very simple scheme, has been a boon to the Indian power sector. The due credit must go to the system operators for their efforts and determination in implementing such a novel scheme so smoothly. In the absence of such a scheme the utilization of inter-regional links would have remained sub-optimal. It has been a phenomenal success in increasing the inter-regional links usage to a very high degree and has justified the investment done on these inter-regional links that were initially planned for power transfer only under emergencies.

The scheme apart from savings has also brought improvement of frequency profile of all the regions, better utilization of national resources by way of replacing costlier generation in one region by cheaper generation from other regions and thus resulting in national merit order.

Some of the new changes in Indian Electricity markets would be implemented in very near future such as:

1. Revised Indian Electricity Grid Code (IEGC) issued by the CERC with effect from April 2006.
2. Operation of Northern Region and Central region with effect from March/April 2006 in synchronism.
3. Directional and distance sensitivity in transmission tariff.

With the above developments the present scheme for real time inter-regional power transfer would also undergo a change. However, arbitrage as means for market stabilization would definitely continue to be used in Indian Power markets in some or other form.

Some such use of the scheme to solve technical/social & commercial problems could be:

1. Congestion management even in synchronously connected transmission system by splitting the market at identified inter-connectors. The gain from arbitrage could be used for augmentation of inter-connector capacity.
2. Planned regional developments by influencing the decision for investment in transmission and generation

X. ACKNOWLEDGMENT

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