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Significance and Impact of Unscheduled Interchange (UI)-Mechanism in Electricity Market

Umashankar Vishnoi[1], Vikas Dadheech[2]

[1]M.Tech, Research Scholar, Mewar University, Chittorgarh, Rajasthan, India

[2]M.Tech, Research Scholar, Mewar University, Chittorgarh, Rajasthan, India

Abstract: ***ABT is a performance based tariff for the supply of electricity by generators owned & controlled by government. It is also a new system of scheduling & dispatch, which requires both generators and beneficiaries to commit to day-ahead schedule. ABT along with the Electricity of Act 2003 is perhaps the most significant & definitive step taken in the Indian power sector. The mechanism is based on financial principle. This paper proposes an approach for analysis & determination of UI based on Frequency based Tariff for competitive electricity market. The power system deviates from the optimized solutions. There is an urgent need for determination of UI revenue paid by such defaulter market participants. Frequency based technique has been applied to double auction modified IEEE30 bus system.***

Keywords: Availability Based tariff (ABT), Deregulated Power Sector, Electricity Market, Central Electricity Regulatory Commission, Utilities, Transmission System, Unscheduled Interchange.

1. Introduction

The main objective of the deregulated power sector market [1] is to decrease the cost of electricity through competition. The market environment typically consists of a pool and privately negotiated contracts. The performance of a market is measured by its social welfare, also called social benefit (SB). Social benefit is the difference of society's willingness to pay for energy and its cost. So in the deregulated environment, the objective functions consist of bid functions offered by generation companies and retailers to the independent system operator (ISO). The term Availability Based Tariff stands for a rational tariff structure for power supply from generating stations, on a contracted basis [2, 3]. The unique feature of this tariff, to tackle the peculiar problems of grid operation in India, is the frequency-linked pricing of the Unscheduled Interchange (UI). In ABT mechanism, fixed and variable cost components of power plant are treated separately. Unscheduled Interchange [4] in a time block for a generating station/load means its total actual generation/demand minus its total scheduled generation/total scheduled drawal. All payments on account of Unscheduled Interchange charges levied under Grid regulations and these shall be utilized for serving of investment of transmission schemes or for providing ancillary services including but not only limited to load generation balancing during low grid frequency to ensure grid security and safety.

Indian energy exchange is India's first electricity exchange [5]. The Indian Electricity Grid Code (IEGC) is a regulation made by the Central Electricity Regulatory Commission [6]. It lays down the rules, guidelines and standards to be followed by various persons and participants in the system. India has a huge power shortage (unmet electricity demand), which is retarding the nation's progress. The mechanism of Unscheduled Interchange (UI) [7, 8] if properly deployed, can help in bringing more power into the electricity grids, enabling the utilities to meet additional consumer load, both short-term and long-term, and significantly reduce the quantum of load-shedding. A real-time balancing market based on real-time price signals derived from frequency to maintain system frequency sufficiently close to nominal value has been proposed [9]. It is used for settlement of real-time imbalance between demand and supply during a trading period in deregulated markets. A frequency-linked bidding structure for the frequency regulation service market has been proposed [10].

Conventional Generation Scheduling GS algorithm is modified to incorporate frequency dependant part of tariff [11]. A technique for determining loop flows and designating contribution factors to utilities in a power system has been discussed [12]. In a competitive electricity market [13], the sellers and buyers submit bids for energy buy and sell. The bids are generally in the form of price and quantity quotations and specify how much seller or buyer is willing to buy or sell and at what price. After the bids are available to the market operator it settles the market based on optimization.

The Wide Open Load Following (WOLF) Method is similar to the UI Pricing Method except that it includes time error, steeper prices, and a continuous pricing formula for reactive power [14]. Prices also vary with locational due to line losses and transmission constraints [14], [15]. Thus, WOLF provides a technique for compensating specifically for unscheduled transmission usage unlike the UI Pricing Method.[12], introduce a technique that shifts the focus from contributions of transmission companies to contributions of GENCOs specifically. The difference between actual flows and scheduled flows along different contract paths is used to estimate minor loop flows in an energy grid. Contribution factors with different weighting mechanisms for each utility are then determined. A suggested "take-or-pay" charge could then be levied to participating GENCOs according to their unscheduled flow contribution as estimated using the minor loop flow assumptions and associated errors. Availability Based Tariff comprises of three components:

(a) Capacity Charge (b) Energy Charge (c) Unscheduled Inter-change (UI) Charge.

This paper proposes an approach based on frequency based tariff for determination of unscheduled interchange revenue as penalty for defaulter demand market participants and profit for generator participants who provides extra power for stabilization to the system in competitive electricity market. This frequency based approach has been applied to a generalized model consisting of the pool and transactions such as firm bilateral and multilateral for competitive electricity market [15]. The proposed frequency based technique has been analyzed on modified IEEE-30 bus double auction test system.

The Impact of UI Mechanism

The UI mechanism was brought in to perform under such trying circumstances. Although the complexities and contradictions in the system still prevail but there is not an iota of doubt that the scheme has delivered results. The UI mechanism rode on the chariot of floating frequency and the used 'the disease' itself for curing the chronic illness of the power system operation. It is the bedrock on which the foundation of competitive electricity market has been built in India and is flourishing. The contribution of UI mechanism Indian power sector has been aptly summarised [14].

UI mechanism has assumed cult-like status in the Indian power sector. It not surprising that the mechanism has split the Diaspora into 'believers' and 'non-believers' . Everyone has interpreted the mechanism in his/her own way and in the process certain misconceptions and misunderstandings have also cropped up. A large section understands UI mechanism to be merely a penal and disciplinary mechanism to deter utilities from deviating from schedule. This view requires reconsideration.

UI as Real-Time Pricing Mechanism: The design of UI mechanism adopted in India is similar to the one proposed [16]. The UI rate is a frequency-actuated signal available at any wall socket. Every utility reacts to this signal in real time and adjusts its generation/ demand and a new equilibrium is achieved. The UI curve by virtue of its design empowers every utility that has some means to regulate supply/demand to readjust its interchange with the grid and gain from the migration of frequency/UI rate from the earlier level. The decreasing marginal returns with every additional unit of deviation from the scheduled interchange acts as a counterweight, which forces the utility to seriously weigh the consequences of its actions. Thus the collective action by all the players in this non-cooperative zero sum game, restores the equilibrium to new value, which may or may not be the same as that before the perturbation. What results is a Nash equilibrium at which every player emerges a winner by having maximized his pay-off.

Capacity Adequacy & UI Mechanism: The UI mechanism has brought about varying degree of results in different regions. It has been observed that during peak demand situations, the absence of matching generation leads to the weakening of the counterbalancing forces that causes the frequency to hit rock bottom rather frequently. Only augmentation of capacity can resolve this situation. Investors could use the UI duration curve for different regions to arrive at nature and cost of generation that they are planning.

Power Exchange and UI Mechanism: There seems to be some substance in the argument put forth by the proponents of Power Exchange in the country that the absence of an organised day ahead-market is one of the reasons for the lack of investor confidence in the Indian market. The setting up of the Power Exchange could provide another option for power procurement. It could promote further competition on the supply side as well as on the demand side by bringing all sellers and buyers together on a common marketplace with standardized contracts, bid formats, and trading procedures. This would set up a transparent price discovery mechanism in day ahead exactly as UI mechanism is doing in real-time. The setting up of a PX would in no way diminish the significance of the frequency-linked UI mechanism. It would in fact enhance its relevance as a real time pricing mechanism. The UI market would continue to compete with the long-term and short- term transactions as a means for trading electricity. The price for un-contracted flows underpins all other contract prices. Hence even if they handle only the deviations, they ultimately determine the viability of competitive generation.

2. Mathematical Formulation of Proposed Technique

A methodology based on frequency linked tariff has been formulated. The generators and loads under this framework can self-schedule themselves based on real-time price signals maximizing their benefit. This scheme does not require any additional control and communication infrastructure as price is communicated by means of frequency that can be sensed anywhere in the grid. Penalty imposed on the defaulter market participants depend on severity of deviation. It will be paid if generator generates less than the schedule, or load overdraws power, thereby decreasing frequency. The Proposed Technique involves the following three steps:-

2.1 **Assumption of frequency of particular region:** - Power system is in balanced condition at nominal frequency of the system, but frequency of the power sector deviates from the nominal value due to imbalance between demand and supply of system. If at any stage, electrical power available is more than required power, then frequency of the system becomes more than the nominal frequency. On the other hand, if the power available is less than the required power, then frequency of the system becomes less than the nominal frequency, D_f is demand of the some particular area at current frequency *f*, whereas D_{nom} is the demand or load of the system at nominal frequency and f_{nom} is nominal frequency of the system.

2.2 Determination of UI price:- In dayahead market, hourly bids are taken from suppliers and load serving entities to discover an hourly locational marginal price (LMP). Based on settlement in day-ahead market an hourly schedule for next day is prepared. This schedule represents a perfect balance of supply and demand resulting in nominal

frequency. Any deviations from schedule will result in deviation from nominal frequency. Locational Marginal Price is the price of power at nominal frequency.

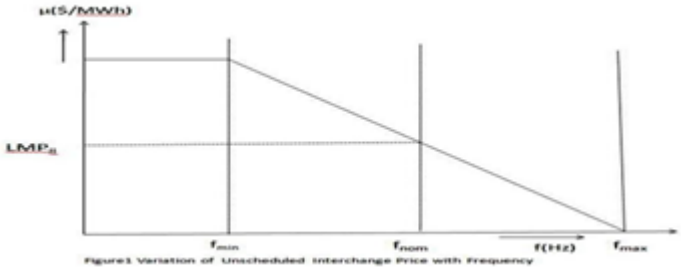


Figure 1: The variation of frequency based unscheduled interchange price with frequency

Taking LMP as a reference point we can construct a curve similar to UI curve to price deviations in schedule for the proposed real-time market, Frequency dependent Unscheduled Interchange Price curve. This curve joins two fixed points on price vs. frequency chart. Let $\{f_{min}, f_{max}\}$ be the range of frequency over which real-time price will vary. The real-time price called as Frequency dependent Unscheduled Interchange Price is higher for frequencies below nominal value (i.e. when demand is greater than supply) and lower for frequencies above nominal value (i.e. when supply is greater than demand). Let f_{nom} be the nominal frequency, f be the current frequency and f_{max} be the maximum frequency, where LMP_{ij} is the locational marginal price in i_{th} trading interval at j_{th} bus.

Frequency based Unscheduled Interchange price μ *($/MWh)* at any frequency f can be determined by the expression

$$\mu = LMP_{ij} * \frac{fmax - f}{fmax - fnom} = LMP_{ij} * \text{Frequency Deviation} \quad (2)$$

2.3 Determination of Profit/ Loss at any bus

Frequency of the grid is a function of supply-demand imbalance and not in control of one particular market participant. The profit (loss) to any electricity market participants is the difference of total revenue received and the cost of power purchase or generation cost in real time market. Therefore Profit/Loss in UI mechanism at any load or generator bus can be defined as a function of deviation of power = (P_{act} - P_{sch}) where is the deviation of power from the schedule in MW and is calculated by subtracting declared schedule from the actual drawal for each 15 minutes time block. Loss or Profit ($/h) in i_{th} trading interval at particular j_{th} bus due to unscheduled interchange of power in the real time market.

$$\alpha_{ij}(\Delta P) = \Delta P * (UIprice_{ij} - LMP_{ij}) \quad (3)$$

where $UIprice_{ij}$ is unscheduled interchange price of j_{th} bus in i_{th} trading interval in the real time market. *is* locational marginal price of j_{th} bus in i_{th} trading interval in the real time market. Net Profit or loss of the system in first trading interval is given.

3. Step by Step Procedure

The main steps of the proposed algorithm can be described as follows:-

Step1 Read the system data of deregulated double auction modified IEEE 30- bus system.

Step2 Run the optimal power flow program in matpower for optimal values of generation and demand at generator and load buses and evaluate locational marginal price at various buses of the system. Under this balance condition, system frequency will be nominal thereby Unscheduled Interchange Price be equal to locational marginal price.

Step3 Note the uncommitted amount of power at various load buses in the pool, bilateral and multilateral transactions in the subject cited system.

Step4 Assume the prevailing frequencies in each of these three areas of the deregulated system

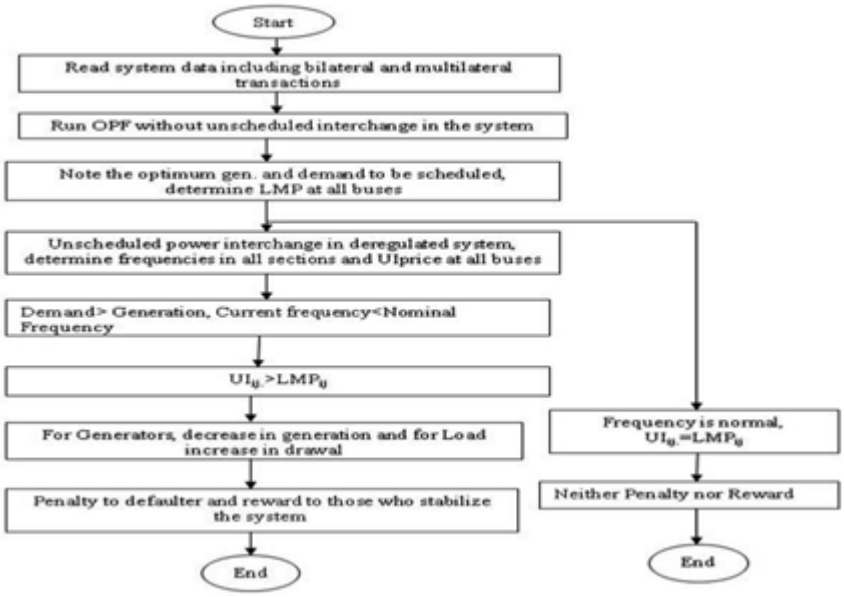
Step5 Calculate the Unscheduled interchange price at various buses of the system by equation (1).

Step6 Run again the optimal power flow for optimization of new generation at various generations buses corresponding to new load at load buses due to unscheduled power exchange.

Step7 Determine the unscheduled amount ($/h) received from each defaulter load of the pool, bilateral and multilateral at each bus for creating the disturbance in the system by equation (2).

Step 8 Determine the unscheduled amount ($/h) paid to generator buses of the pool, bilateral and multilateral for balancing the system by equation (2).

Step9 Determine the net profit/ loss in the pool and transactions by taking the difference between the payment received from the load buses and amount paid to generator buses. The flow chart of the proposed approach is represented in Figure 2



4. Methodology of Work

The proposed frequency based technique has been tested and analyzed on modified IEEE-30 bus test system shown in figure 3. It consists of 30 buses, 41 branches and six generating units. The whole deregulated power system has been divided into three sub sections; the prevailing frequencies in these areas can be assumed by trend of the unscheduled interchange of power in these areas with the help of equation. Then corresponding unscheduled interchange (UI) prices are calculated at each bus with the help of equation (1). First of all, run optimal power flow in matpower software for scheduled power flow in the system for optimal generation and demand at generator and load buses and Locational Marginal Price (LMP) at each bus of the system, then calculate UI price at each bus of competitive electricity market. Now due to Unscheduled Interchange of power at various buses of the system, there will be corresponding increase in generation at various buses of the system; these optimal values of generations can be found out by running the optimal power flow again. Unscheduled Interchange payment paid by load bus and received at every generator is calculated on the basis of prevailing frequency in that section of the power sector by equation (3). Net Profit or loss in the system comprising of pool, bilateral and multilateral transactions can be calculated by equation (4). Difference between payment received from load buses and payment paid to generator bus of the system.

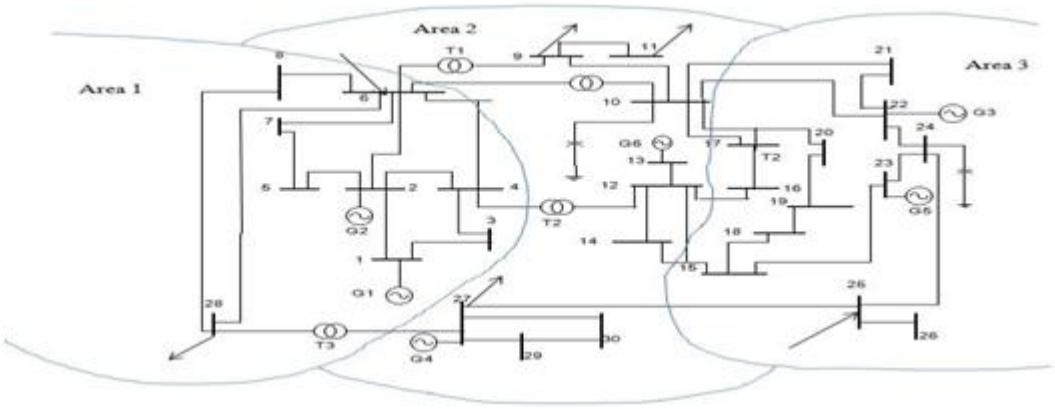


Figure 3: Single Line Diagram of Modified IEEE-30 Bus System with Bilateral and Multilateral Transactions

Table 1 show UI Revenue received from load buses of the pool as well as transaction for unscheduled power interchange by them. The unscheduled interchange payment paid by each demand bus is calculated by multiplying the difference between UI Price and LMP price with unscheduled power of at that particular demand bus. The overall unscheduled interchange payment paid by all such participants are calculated by taking summation of payment paid by each individual demand bus. Fixed power demands are also penalized on the same basis, because these entities are not bidding.

Table 1: UI Revenue received from load buses of the pool as well as transaction

Area 1, f=49.86 Hz, Deviation Ratio=1.68								
Sr. No.	Bus No.	Demand Bid (MW)	Sch. Demand P_{sch} (MW)	Actual Demand P_{act} (MW)	UI Demand ΔP (MW)	LMP ($/MWh)	UI Price ($/MWh)	UI amount received from load buses ($/h)
1	2	31.7	22.36	23.86	1.50	3.8794	6.517	3.957
2	3	31.4	31.40	33.2	1.80	3.9769	6.681	4.868
3	4	41.6	6.58	7.08	0.50	3.9775	6.682	1.352
4	7	32.8	0.00	0.00	0.00	3.9497	6.635	0.000
5	8	40	4.12	4.62	0.50	3.9709	6.671	1.350
6	28	Multi-lateral	3.0	3.3	0.30	3.9531	6.641	0.806
UI Revenue received from load buses of Area 1 = 12.33($/h)								

Area 2, f=49.82 Hz, Deviation Ratio=1.92								
1	9	Bilateral	2.00	2.20	0.20	3.9958	7.672	0.74
2	10	25.8	25.80	27.80	2.00	4.0087	7.697	7.38
3	11	Multi-lateral	3.00	3.30	0.30	3.996	7.672	1.10
4	12	51.2	11.98	13.48	1.50	3.9993	7.679	5.52
5	14	36.2	13.70	15.20	1.50	4.0997	7.871	5.66
6	27	Multi-lateral	4.00	4.40	0.40	3.8496	7.391	1.42
7	29	22.4	0.00	0.00	0.00	3.9884	7.658	0.00
8	30	30.6	19.70	21.2	1.50	4.1476	7.963	5.72
UI Revenue received from load buses of Area 2 = 27.53($/h)								

Area 3, f= 49.85 Hz, Deviation Ratio=1.75								
1	15	38.2	0.00	0.00	0.00	4.0263	7.046	0.00
2	16	33.5	22.40	23.9	1.50	4.0893	7.156	4.60
3	17	29.0	0.00	0.00	0.00	4.0308	7.054	0.00
4	18	33.2	23.05	24.05	1.00	4.1495	7.262	3.11
5	19	29.5	0.00	0.00	0.00	4.106	7.186	0.00
6	20	32.2	1.51	1.71	0.20	4.0841	7.147	0.61
7	21	27.5	11.16	12.66	1.50	3.987	6.977	4.49
8	23	23.2	0.00	0.00	0.00	3.8755	6.782	0.00
9	24	28.7	7.22	7.92	0.70	3.9219	6.863	2.06
10	25	Multi-lateral	0.00	0.00	0.00	3.8116	6.670	0.00
11	26	23.5	0.00	0.00	0.00	3.8089	6.666	0.00
UI Revenue received from load buses of Area 3 =14.87($/h)								

Net Unscheduled Interchange received from all defaulters load buses of area 1, area 2 and area 3 of the pool =54.73 ($/h)

Table 2 shows UI Revenue paid to generator buses of the pool as well as transaction for balancing the system. The unscheduled interchange payment received by each generator bus is calculated by multiplying the difference between UI Price and LMP price with unscheduled power at that particular generator bus. The overall unscheduled interchange payment paid to all generators is calculated by taking the summation of payment received by each individual generator.

Table 2: UI Revenue paid to generator buses of the pool as well as transaction

Gen. Buses of All areas of pool and transaction								
Sr. No.	Bus No.	Sch. Gen. P_{sch} (MW)	Actual Gen. P_{act} (MW)	UI Gen. ΔP (MW)	Frequency Deviation Ratio	LMP ($/MWh)	UI Rate ($/MWh)	UI amount paid to gen.buses ($/h)
1	1 (A1)	46.45	50.33	3.89	1.68	3.8579	6.481	10.20
2	2(A1)	60.84	65.40	4.56	1.68	3.8794	6.517	12.03
3	13(A2)	19.99	22.64	2.66	1.92	3.9993	7.679	9.79
4	22(A3)	23.77	25.55	1.77	1.75	3.9713	6.950	5.27
5	23(A3)	17.51	16.43	-1.08	1.75	3.8755	6.782	-3.14
6	27(A2)	35.95	40.42	4.47	1.92	3.8496	7.391	15.83
7	6(A1)	2.0	2.2	0.2	1.68	3.9712	6.672	0.54
8	25(A3)	10	11	1.0	1.75	3.8116	6.670	2.86
UI Revenue paid to Gen. buses = 53.38($/h)								

Net Unscheduled Interchange Amount paid to all generator buses of area 1, area 2 and area 3 of the Pool and transaction = 53.38($/h). Net Profit to ISO due to implementation of Unscheduled Interchange in deregulated system=1.35 ($/h).

5. Conclusions

Impact: This paper presents an approach for determination of unscheduled interchange revenue at various generator and load buses in the competitive electricity market model consisting of pool, bilateral and multilateral transactions. In this paper a double auction competitive electricity market model has been analyzed with modified IEEE-30 bus test system. Frequency has been assumed in each region by trend of the unscheduled interchange of power in pool, bilateral and multilateral transactions. Frequency linked tariff has been applied for unscheduled variation of power in pool, bilateral and multilateral transactions. Impact of unscheduled interchange of power based upon the frequency variation has been analyzed on this bus system. In this method, those defaulters load market participants have paid huge amount who are diverting from their schedule entitlement in the market and creating the disturbance in the system by varying the frequency of the system as well as those generator participants are rewarded who maintains the frequency of the system in the nominal range by providing extra power in the competitive market other than their committed entitlements.

Significance: The UI mechanism has been a good course correction for the Indian power market and therefore we need to take further steps to reinforce the gains. It is time we started planning for the next step in this initiative. There are other difficult jigsaw pieces that have to be placed rightly before we can entirely solve the Indian power sector puzzle. We need to revisit and probably redesign the transmission pricing and hydro tariff to make it more scientific and effective. Intra state ABT and open access are essential for getting a stronger demand side response. With the interconnection of the Northern and Central grid in near future we would need to reconsider the reactive tariff to suit the new circumstances.

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Author Profile

Umashankar Vishnoi, B.Tech. In Elecrical and Electronics Communication and M.Tech Pursuing at present. His interested field is Power System Stability.

Vikas Dadheech, B.Tech. in Electrical Engineering and at present M.Tech. Pursuing. He have 2 years teaching experience. His interested field is Power System Analysis, Circuit Theory, Power system Engineering, etc.