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Transmission Congestion Management in Restructured Power Systems

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ABSTRACT: In past few years electric supply industry undergoing restructuring around the world. Restructuring is one of the technical challenges in Power system. In this cut-throat power market surroundings all market participants try to get benefits of cheaper source accessible. An effort of archiving more profit margins tends to lead overloading in transmission line which may result congestion in certain transmission. On the one hand the network modifies the bulk prices of electrical energy due to the presence of network losses and congestions. On the other hand, the costs of investment and operation of the transmission network have to be allocated to its user according to some reasonable criterion.

KEYWORDS: Congestion management; Congestion management method; Calculation of Available transfer capacity(ATC); Non-market methods; Nodal pricing; Inter-zonal/Intra-zonal; Price Area Congestion Management; Capacity Allevation Method.

I.INTRODUCTION

Transmission congestion occurs in the system when there is insufficient transmission capacity to simultaneously accommodate all requests for transmission service within a region is called congestion. Congestion management is a multi-buyer/multi seller system in which most tasks are involved. In vertically integrated utilities managed this condition by constraining the economic dispatch of generators with the objective of ensuring security and reliability of their own systems. Vertically integrated system activates like Genco, Transco & Disco are fully control with central agency or government agency with the optimal dispatch solution and security and eliminating the possible congestion present [1]. In a restructured environment each buyer can buy the power from the cheapest generation existing, within geographical location of buyer and seller as well. Congestion occurs when system operator finds that all the transitions are not allowed due to overloading on the transmission networks. The scale of transmission congestion management in the deregulated environment involves defining a set of rules to ensure control over generators and loads in order to maintain acceptable level of system security and reliability. This rules should ensure market efficiency maximization with short term as well as long term horizons. In a restructured structure, the market must be modelled so that the market participants or (buyers and sellers of energy) hold freely transactions and play as per market forces but in a manner that does not threaten the security of the power systems [2]. Congestion management has across the world become an important activity of power system. The vital two aims of congestion management schemes are to minimize the interference of the transmission network in the market for electrical energy and at the same time ensure secure operation of the power system [3].

II. LITEARTURE SURVEY

Vora Animesh, " Congestion Management in Degulated Power System- A Review", International Journal of Science and Research vol.3 Issue 6, June 2014, pp 2237-2240.

This paper presents a new method to mitigate congestion in a restructured Power system. In this paper, different cost-free methodologies were used to manage the congestion in the transmission network. To relieve congestion in

transmission lines, there are two types of congestion management methodologies are discussed in this paper One is cost-free methods and another is non-cost free methods.
Elango.K, Panjothi.S.R, Sharmeela.C, "Congestion Management In Restructured Power System," International journal of applied enginnering reasearch, Dindigul Vol.2, No.2,2011.
In this paper author analyses the use of FACTS devices and Load Shedding for relieving congestion by Extended Quadratic Interior Point (EQIP) based OPF. The OPF problem is solved with the help of Evolutionary Programming (EP) approach and at major iteration, an approximation is made of the Hessian of the Lagrangian function using a Quasi Newton updating method so that the social welfare is maximized while satisfying the operation and security related constraints. The proposed algorithm has been analysed on IEEE 57 bus system. The reactive power rescheduling and FACTS devices causes lower cost of rescheduling and the better voltage profile. The amount of reactive power supplied by the capacitor is less when it is compared to the capacitor reactive support. The proposed method gives the better results compared to the other methods.

Antonio J.Conejio, Fellow, IEEE, Raqual Garcia-Bertrand, Manuel Diaz-Salazar, "Generation Maintenance Scheduling in Restructured Power Systems," IEEE Transactions on Power Systems, Vol. 20, NO. 2, May 2005.
This paper proposes an mathematical procedure to coordinate maintenance scheduling among the ISO and the appropriate degree of reliability is achieved throughout the week of the year in acceptable manner for every producer. This paper suggest the appropriate coordinating mechanism that allows to achieve generation maintenance plan that meet the expectation of maximum profit criteria. While achieving expectation level of reliability in every week of the year.

Uhlen, K, Warland, L, Grande, O.S, "Model for Area Price Determination and Congestion Management in Joint Power Markets," CIGRE/IEEE PES, 2005. International Symposium, vol., no., pp.100,109, 7-7 Oct. 2005.
The paper describes a simulation model where the flow based market coupling method is implemented and demonstrated. This method can be seen as a compromise between nodal pricing and market splitting (area pricing), where the criterion for congestion management is minimization of the socio-economic congestion cost.

III.TRANSMISSION CONGESTION METHODS

Different methods have been designed for congestion management is one of the reasons why a particular congestion management method is used in a system is that the desired method should solve the congestion problem in the short-term and also create the necessary encouragements for investing in transmission network development and new production capacities. The problem is to find a method that simultaneously creates a signal to all market participants including the Independent system operator (ISO), consumers, GENCOs & retailers [4]. Congestion management methods allow the market participants to make maximum use of the network so that the system security is not at risk the relation of congestion management issue to issues such as various energy markets, allocation of the transmission right, transmission tariff, accessory services market, transmission capacity evaluations, transmission development, the setting up location of new generators, the new connectivity point of loads, use of FACTS essentials power plants repair program and transmission lines and several other issues. A variety of methods have been developed around the world to address these issues which are currently used in different systems [5][6]. These methods can be divided with different criteria. Congestion management methods can also be divided in terms of time that are:

Non-Market Methods		Market Based Methods	
1	Type of contract	1	Explicit Auctioning
2	First come first serve	2	Coordinated Auctioning
3	Pro-rata Methods	3	Nodal pricing
4	Curtailment	4	Zonal pricing
		5	Price Area congestion management
		6	Re-dispatch
		7	Counter trace

Table 1. Non-Market/Market Methods

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IV.NON-MARKET/MARKET METHODS OF CONGESTION MANAGEMENT

The non-market methods of congestion management are essentially referred to network capacity allocation based on some pre-defined set of rules that neglect the ability or the willingness of a payer to pay for the transmission capability. For such schemes and also for explicit market based methods the system operator is required to know the capacity remaining with the grid after accommodating the transactions which is nothing but ATC[7].

- First Come First Serve
- Pro-rata Methods
- Type of Contract
- Curtailment

A. Types of contract: In this type of capacity allocation, network capacity is assigned to a specific type of transactions.

B. First come First serve: There are some systems in which the bilateral contracts are awarded for transmission network access on first come first served basis.

C. Pro-rata methods: Various norms can be set to assign network capacities on pro-rata basis. The capacities can be assigned on generation, average load, or percentage of long span transactions or utmost demand, etc.

D. Curtailment: Transaction-based curtailment approach is another methodology that is used for congestion management. This event is of violations occurring or being imminent, the TLR method of curtailing transactions is exercised.

Market Based Methods:

A. Explicit Auctioning: The principle of explicit auctioning is based on selling the available capacity of the tie line to the highest bidder through auction.

B. Coordinated Auctioning: The coordinated auctioning splits the markets into two market energy market and transmission capacity market.

C. Nodal Pricing: Nodal pricing is to model an electricity market with its various economical and technical specifications that includes generation limits, generators' cost functions, line power flow limits, demand elasticity and develop the system for improvising social welfare & development.

D. Price Area Congestion Management: These methods comprises of splitting a power exchange into geographical bid areas with limited capacities of exchange.

E. Re-dispatching: Re-dispatching is implemented as a command scheme and control scheme.

F. Counter trace Counter trading follows the same principles as re-dispatching, however, it may be considered market oriented. Rather than applying command and control.

V.AVAILABLE TRANSFER CAPACITY

The quick restructuring of electric power industry and mutual power transactions between the participating areas have necessitated the critical requirement of new methods for estimating and updating the available transfer capability (ATC) [8][9][10][11][12].

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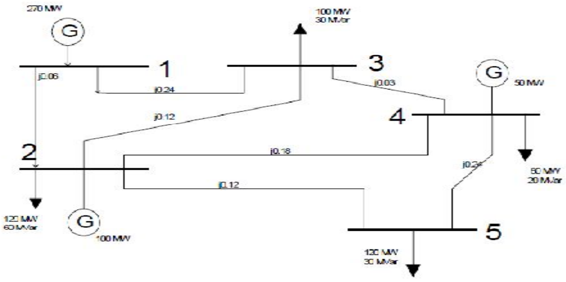

Fig 1. 5 Bus System

Bus	Load Mw	MVAr	Gen MW	Gen Min MW	Gen Max MW	Voltage Set point	Cost ($/MWhr)
1(slack)	1	1.05	0	0	0	0	-1
2	2	1.05	0.20	10	1.25	0	-1
3	0	1.05	0.45	15	0	0	-1
4	0	1	0.40	5	0	0	0
5	0	1	0.60	10	0	0	0

Table 2. Bus data for 5-bus system

In the bus data table the type column is represented by the bus type means here 1 is represented by slack bus, 2 is represented by p-v bus and 3 is represented by p-q bus.

From bus	To bus	P.U. Impedance	MVA rating	Base case power flow (MW)
1	2	j0.06	150	197.27
1	3	j0.24	100	72.72
2	3	j0.12	50	46.39
2	4	j0.18	100	34.29
2	5	j0.12	120	96.60
3	4	j0.03	100	19.12
4	5	j0.24	100	23.40

Table 3. Line data for 5-bus system

0	0	0	0	0
0	0.0511	0.0383	0.0410	0.0478
0	0.0383	0.0902	0.0799	0.0524
0	0.0410	0.0799	0.0963	0.0596
0	0.0478	0.0524	0.0596	0.1322

Table 4. X-matrix for 5-bus system

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The X- matrix is obtained by when the element of the susceptance matrix are the function of line reactance. One node is assigned as a reference node by making its angle zero and deleting corresponding row and column in [Bx] matrix and then takes the inverse of that matrix.

Lines	**PTDF in (p.u)**			
	T1	**T2**	**T3**	**T4**
1-2	0.8509	0.6390	-0.2118	-0.1683
1-3	0.1598	0.3757	0.2159	0.1732
2-3	-0.0706	0.2879	0.3585	0.2871
2-4	-0.0561	0.2310	0.2871	0.3634
2-5	-0.0268	0.1169	0.1437	0.1820
3-4	0.0870	-0.3414	-0.4284	0.4580
4-5	0.0287	-0.1148	-0.1435	-0.1816

Table 5. PTDF for line difference transactions

We have determined the PTDF for different transaction of the lines. First we are determined the PTDF for transactionT1 at lines 1-2,1-3,2-3,2-4,2-5,3-4 and 4-5. In this way we have seen that the PTDF values varied from positive to negative. The same procedure is done for transactions T2, T3 and T4. When the transaction T1 is applied then we see the effect of transaction T1 on the lines with respect to buses.

VI. NODAL PRICING

The general idea of nodal pricing is to model an electricity market with its various economical and technical specifications such as generator cost functions, elasticity, generation limits line power flow restrictions and optimize the system for maximizing social benefit. This problem represents one of the commonly employed formulations of Optimal Power Flow (OPF) [13][14][15].

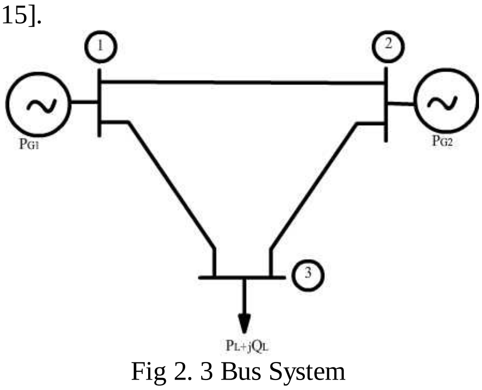

Fig 2. 3 Bus System

The cost for generators at bus 1 and 2 are given as:

$$CC_1 = 9.6 + 4.1P_{G_1} + 2.4P_{G_1}^2$$

$$CC_2 = 7.6 + 3.1P_{G_2} + 1.6P_{G_2}^2$$

In addition, following inequalities are imposed:

$$0 \leq P_{G_1} \leq 400$$

$$0 \leq P_{G_2} \leq 600$$

$$0.9 \leq V_i \leq 1.1$$

The above mentioned constraints with the objective of generation cost minimization. The results are shown in Table below.

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Bus No.	V	Δ	PG	PD	λ(INR / MWh)
1	1.099	0	359.87	-	1731.5
2	1.100	10.041	540.13	100	1731.5
3	1.099	-0.893	-	800	1731.5

Table 6. Results of OPF without line limits

VII. INTER-ZONAL/INTRA-ZONAL CONGESTION MANAGEMENT

Intra-zonal congestion most frequently occurs in load pockets or areas where load is intense. Where transmission within the zone is not sufficient to allow access to competitively-priced energy [16]. In a few cases, the CAISO must also decrement generation outside the load pocket to balance the incremental generation dispatched within it. Intra-zonal congestion can also occur due to pockets in which generation is clustered together, without the transmission necessary for the energy to flow out of that pocket to load. In both cases, the absence of sufficient transmission access to an area means that the CAISO has to resolve the problem nearby, either by incrementing generation within a load pocket or by decrementing it in a generation load pocket. Such congestion is inefficient if over the course of congestion in that area, the market costs due to the transmission congestion [17][18].

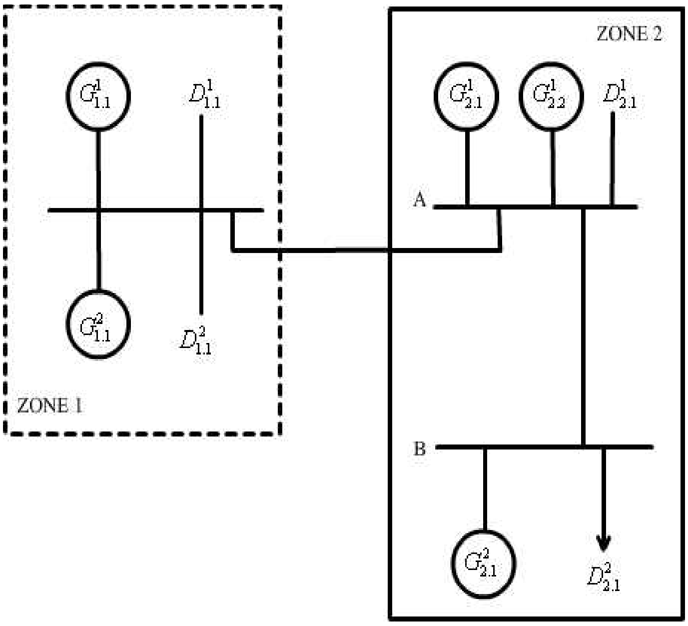

Fig 3. Two zone example

$$G_{1,1}^{1} + G_{2,1}^{1} + G_{2,2}^{1} = D_{1,1}^{1} + D_{2,1}^{1}$$

$$G_{1,1}^{2} + G_{2,1}^{2} = D_{1,1}^{2} + D_{2,1}^{2}$$

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QSE	Variable	Pref. Schedule	Inc/Dec Bid
QSE 1	$G^1_{1,1}$	500	1000
	$G^1_{2,1}$	0	2000
	$G^1_{2,2}$	100	4000
	$D^1_{1,1}$	200	-
	$D^1_{2,1}$	400	-
QSE 2	$G^2_{1,1}$	400	3000
	$G^2_{2,1}$	0	5000
	$D^2_{1,1}$	100	-
	$D^2_{2,1}$	300	-

Table 7. Preferred initial schedules and Inc/Dec bids

Congestion Charges: Zone 2 LMP is set by and it is equal to INR 2000/MWh. Similarly for Zone 1 LMP is set by and equals INR 1000/MWh. Hence Congestion charges for QSE 1 are calculated as follows::

$$(400\times2000-400\times1000)+(-200\times2000+200\times1000)=20\times10^4 \text{ ₹}$$

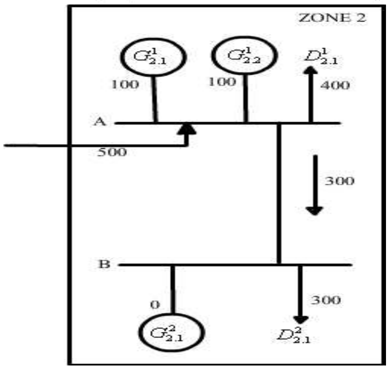

Fig 4. Intra-zonal congestion management

Generator $G^1_{2,2}$ belonging to QSE 1 decreased its output by 50 MW. Therefore, payment by QSE 1 to ISO is

$$50\times4000=20\times10^4 \text{ ₹}$$

VIII. PRICE AREA CONGESTION MANAGEMENT

This is a simplified version of the inter-zonal and intra-zonal congestion management schemes. This method consists of splitting a power exchange into geographical bid areas with limited capacities of exchange. At what time when congestion is predicted the system operator declares that the system is split into areas at predicted congestion traffic flow. Spot market bidders must submit separate bids for each price area in which they have generation or load. The market will settle at lone price, if no congestion occurs all through market settlements ,which will be the same as if no price areas existed. If congestion occurs then price areas are separately settled at prices that satisfy transmission constraints [19].

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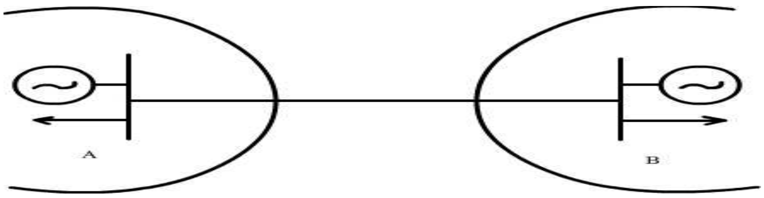

Fig 5. Two area system

$$P_{G_A} + P_{G_B} = P_{D_A} + P_{D_B}$$

Consider a two area system as shown in Figure 5. Suppose the capacity of line between the system A and B assumed as 100MW. The Power exchange will be receiving buying and selling bids from both areas A and B [20][21]. These bids present power as a function of price, which are represented as:

$$P_{D_i}(\text{price}) = a_i \times \text{price} - b_i$$

$$P_{G_i}(\text{price}) = c_i \times \text{price} - d_i$$

Area	Sell Bid		Buy Bid	
	C	D	A	B
A	15	120	-4	-350
B	8	160	-6	-525

Table 8. Bid data

The bid constants are given in Table 8

IX.CONCLUSION

In this paper, different method for congestion management of transmission lines has been presented based on this method. Various market and Non market methods have been studied.

In this scheme, the ISO schedules generators and loads based on their bid data such that social welfare is kept a major concern. At same instance, network constraints are added to the optimization problem so that the most economic nodal injection pattern is obtained without creating congestion. The inter-zonal/ intra-zonal scheme tries to strike a balance between the complexity and economic significance. The core idea in this approach is to partition the grid into few predefined congestion zones, which have individual markets whose respective market clearing prices set the uniform price within the zone. Price areas are defined rationally, based on practice and engineering judgment. Some additional criterion for analytical determination of price areas is required if the system is not radial inter-connected.

The method has been tested on IEEE 5-bus system successfully. Test results on the IEEE 5-bus system prove the efficacy of the proposed approach in managing transmission congestion in a restructured power system.

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