Comparing Two Ways of Congestion Management in Bilateral Based Power Market

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***ABSTRACT* — The restructuring of the electric power industry has involved paradigm shifts in the real time control activities of the power grids. Managing dispatch is one of the important control activities in a power system.**

With the trend of an increasing number of bilateral contracts being signed for electricity market trades, the possibility of insufficient resources leading to network congestion may be unavoidable. In this scenario, congestion management becomes an important issue. Real-time transmission congestion can be defined as the operating condition in which there is not enough transmission capability to implement all the traded transactions.

It may be alleviated by incorporating line capacity constraints in the dispatch and scheduling process. This may involve redispatch of generation or load curtailment. Other possible means for relieving congestion are operation of FACTS devices (TCSC) ,these two ways are compared in this paper.

***Index Terms* — Congestion Management, Deregulation ,Bilateral Power Market, FACTS devices, TCSC, ISO.**

I. INTRODUCTION

The changing nature of electricity supply industry is introducing many new subjects into power system operation related to trading in a deregulated , competitive market .Commercial pressures on obtaining greater returns from existing asset suggests an increasingly important role for dynamic network management using FACTS devices[1] . In this situation, congestion management becomes an important issue because it can make a penalty for market players. The congestion management in deregulated power system can be solved by load curtailment and using extra devices such as FACTS devices or phase shifters. These solutions will be discussed in forward.[2]

FACTS devices offer a fast series and parallels compensation and offer flexible power system control [6]-[9]-[12]-[14]-[15], therefore, it can be utilized to control line active and reactive power, achieve more power transfer capability, and to significantly improve power system reliability.In a competitive power market scenario, besides generation, loads, and line flows, contracts between trading entities also comprise the system decision variables. The following pool and bilateral competitive structures for the electricity market have evolved:

1) Single auction power pools, where wholesale sellers (competitive generators) bid to supply power in to a single pool. Load serving entities (LSEs or buyers) then buy wholesale power from that pool at a regulated price and resell it to the retail loads.

2) Double auction power pools, where the sellers put in their bids in a single pool and the buyers then compete with their offers to buy wholesale power from the pool and then resell it to the retail loads.

3) In addition to combinations of (1) and (2), bilateral wholesale contracts between the wholesale generators and the LSEs without third-party intervention.

4) Multilateral contracts, i.e., purchase and sale agreements between several sellers and buyers, possibly with the intervention of third parties such as forward contractors or brokers [2]-[4].

In both (3) and (4) the price-quantity trades are up to the market participants to decide, and not the ISO. The role of the ISO in such a scenario is to maintain system security and carry out congestion management. The contracts, thus determined by the market conditions, are among the system inputs that drive the power system. The transactions resulting from such contracts may be treated as sets of power injections and extractions at the seller and buyer buses, respectively.

In this paper , at first , the two different structures of restructured power system has been mentioned such as pool structure and bilateral structure then the bilateral structure has been chosen for further research. The two distinct ways for solving the congestion problem has been declared. At the end these solution have been examined and compared by curtailment and using FACTS devices.

II.TWO MODELS OF DEREGULATED POWER SYSTEM

Two different way of power system operation in

Restructured power system is mentioned below:

A. *Pool Structure*

Interconnected system operation becomes significant in a deregulated environment. This is because the market players are expected to treat power transactions as commercial business instruments and seek to maximize their economic profits. Now when several gencos decide to interchange power, complications may arise. An economic dispatch of the interconnected system can be obtained only if all the relevant information, viz., generator curves, cost curves, generator limits, commitment status, etc., is exchanged among all the gencos. To overcome this complex data exchange and the resulting nonoptimality, the gencos may form a power pool regulated by a central dispatcher. The latter sets up the interchange schedules based on the information submitted to it by the gencos. While this arrangement minimizes operating costs and facilitates system-wide unit commitment, it also leads to several complexities and costs involved in the interaction with the central dispatcher [2]. Conventionally, the optimal operation of a power system has been based on the economic criterion of loss minimization, i.e., maximization of societal benefit. Pool dispatch follows the same criterion but with certain modifications necessitated by the coexistence of the pool market with a short-term electricity spot market. Namely, these effects are demand elasticities and the variation in the spot price with the purchaser's location on the grid. The existence of the spot market or bilateral market behind the scene does not explicitly affect the operation of the ISO.[3]

B. *Bilateral Structure*

The conceptual model of a bilateral market structure is that gencos and discos enter into transaction contracts where the quantities traded and the prices are at their own discretion and not a matter for the ISO; i.e., a bilateral transaction is made between a genco and a disco without third party intervention. These transactions are then submitted to the ISO.

In the absence of any congestion on the system, the ISO simply dispatches all the transactions that are requested, making an impartial charge for the service.The bilateral structure has been selected in this paper for research.[3]

III. TWO METHODS FOR CONGESTION MANAGEMENT

There are two broad paradigms that may be employed for congestion management. These are the *cost-free* means and the *not-cost-free* means [5]. The former include actions like outaging of congested lines or operation of transformer taps, phase shifters, or FACTS devices. These means are termed as *cost-free* only because the marginal costs (and not the capital costs) involved in their usage are nominal. The *not-cost-free* means include:

1) Rescheduling generation. This leads to generation operation at an equilibrium point away from the one determined by equal incremental costs. Mathematical models of pricing tools may be incorporated in the dispatch framework and the corresponding cost signals obtained. These cost signals may be used for congestion pricing and as indicators to the market participants to rearrange their power injections/extractions such that congestion is avoided.

2) Prioritization and curtailment of loads/transactions. A parameter termed as *willingness-to-pay-to-avoid-curtailment* was introduced in [4]. This can be an effective instrument in setting the transaction curtailment strategies which may then be incorporated in the optimal power flow framework.

IV. DISPATCH FORMULATION WITH CUTAILMENT STRATEGY AND USING FACTS

A. *Bilateral dispatch formulation with Curtailment Strategy*

In a bilateral market mode, the purpose of the optimal transmission dispatch problem is to minimize deviations from transaction requests made by the market players. The goal is to make possible all transactions without curtailments arising from operating constraints.

The new set of rescheduled transactions thus obtained will be closest to the set of desired transactions, while simultaneously satisfying the power flow equations and operating constraints. One of the most logical ways of rescheduling transactions is to do it on the basis of rationing of transmission access. This may be modeled as a user-pay scheme with "willingness-to-pay" surcharges to avoid transmission curtailment. The mathematical formulation of the dispatch problem may then be given as:

$$Min\ f(x,u)$$

where

$$f(u,x)=\left[\left(u-u^{0}\right)^{T}.A\right]W.\left[\left(u-u^{0}\right)^{T}.A\right]^{T} \quad (1)$$

subject to:

$$g(x,u)=0$$
$$h(x,u)\leq 0$$

where

W is a diagonal matrix with the surcharges as elements

A is a constant matrix reflecting the curtailment strategies of the market participants

u and u^o are the set of control variables, actual and desired

x is the set of dependent variables

g is the set of equality constraints, viz., the power flow equations and the contracted transaction relationships.
h is the set of system operating constraints including transmission capacity limits.

The bilateral case can be modeled in detail. We consider transactions in the form of individual contracts where a seller i injects an amount of power Tij at one generator bus and the buyer j extracts the same amount at a load bus. Let the power system consist of n uses with the first m assumed to be seller buses and the remaining n-m as buyer buses. One particular bus (bus 1) may be designated as the slack to take into account transmission losses. The total power injected/extracted at every bus may be given by the summation of all individual transactions carried out at those buses, thus:

$$\text{For } i=2 \text{ to } m,\ P_i=\sum Tij$$
$$\text{For } j=m+1 \text{ to } n,\ P_j=\sum Tij \quad (2)$$

The transactions Tij also appear in the power flow equality constraints since they act as the control variables along with the usual generator bus voltages. The set of control variables can thus be represented as $u=\{\sum Tij, V\}^T$, where V is the vector of generator bus voltages.

The real and reactive power flow equations can be written in the usual form represented by g(x,u).

The transaction curtailment strategy is implemented by the ISO in collaboration with the market participants. In the case of bilateral dispatch, this strategy concerns the individual power contracts. One such strategy is such that, in case of an individual contract, the curtailment of the transacted power injected at the genco bus must equal the curtailment of the transacted power extracted at the disco bus.

In this case, we may rewrite the dispatch formulation as

$$\mathit{Min}\ f(x,u)$$

where

$$f(x,u)=\sum_{i=2}^{m}\ \sum_{j=m+1}^{n} w_{ij}.\left(T_{ij}-T_{ij}^{0}\right)^2 \quad (3)$$

w_{ij} = the willingness to pay factor to avoid curtailment of transaction
T_{ij}^{0} = the desired value of transaction T_{ij}.

B. Bilateral Dispatch Formulation with FACTS Devices

In this part we look at treating congestion management with the help of flexible AC transmission (FACTS) devices. We consider an integrated approach to incorporate the power flow control needs of FACTS in the OPF problem for alleviating congestion. The concept of flexible AC transmission systems (FACTS) was first proposed by Hingorani [9]. FACTS devices have the ability to allow power systems to operate in a more flexible, secure, economic, and sophisticated way. Generation patterns that lead to heavy line flows result in higher losses, and weakened security and stability. Such patterns are economically undesirable. So many FACTS devices have been mentioned in many papers such as TCSC , TCPAR, UPFC, SVC, STATCOM ,…[1]-[9]. In this paper Thyristor-controlled series compensators (TCSC) was selected for evaluation. Combinations of generation and demand unviable due to the potential of outages. In such situations, FACTS devices may be used to improve system performance by controlling the power flows in the grid. Studies on FACTS so far have mainly focused on device developments and their impacts on the power system aspects such as control, transient and small signal stability enhancement, and damping of oscillations [10]-[13]. With the increased presence of independent gencos in the deregulated scenario, the operation of power systems would require more sophisticated means of power control. FACTS devices can meet that need.

For the optimal power dispatch formulation using FACTS controllers, only the static models of these controllers have been considered here [4]. It is assumed that the time constants in FACTS devices are very small and hence this approximation is justified.

Thyristor-controlled series compensators (TCSC) are connected in series with the lines. The effect of a TCSC on the network can be seen as a controllable reactance inserted in the related transmission line that compensates for the inductive reactance of the line. This reduces the transfer reactance between the buses to which the line is connected. This leads to an increase in the maximum power that can be transferred on that line in addition to a reduction in the effective reactive power losses. The series capacitors also contribute to an improvement in the voltage profiles.Fig.1. shows a model of a transmission line with a TCSC connected between buses i and j. The transmission line is represented by its lumped π-equivalent parameters connected between the two buses. During the steady state, the TCSC can be considered as a static reactance $-jx_c$. This controllable reactance, x_c, is directly used as the control variable to be implemented in the power flow equation.

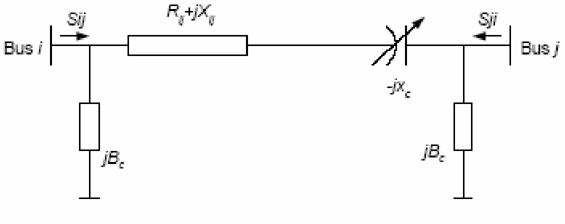

Fig.1. Model of a TCSC

Let the complex voltages at bus *i* and bus *j* be denoted as *Vi* <δ*i* and *Vj* <δ*j*, respectively.
The complex power flowing from bus *i* to bus *j* can be expressed as

$$S_{ij}^{*} = P_{ij} - jQ_{ij} = V_{ij}^{*} I_{ij}$$
$$= V_i^{*}\left[\left(V_i - V_j\right) Y_{ij} + V_i\left(jB_c\right)\right]$$
$$= V_i^{2}\left[G_{ij} + j\left(B_{ij} + B_c\right)\right] - V_i^{*} V_j\left(G_{ij} + jB_{ij}\right) \quad (4)$$

Where

$$G_{ij} + jB_{ij} = 1/\left(R_L + jX_L - jX_C\right) \qquad (5)$$

Equating the real and imaginary parts of the above equations, the expressions for real and reactive power :

$$P_{ij} = V_i^{2} G_{ij} - V_i V_j G_{ij} \cos\left(d_i - d_j\right) - V_i V_j B_{ij} \sin\left(d_i - d_j\right)$$
$$Q_{ij} = -V_i^{2}\left(B_{ij} + B_c\right) - V_i V_j G_{ij} \sin\left(d_i - d_j\right) + V_i V_j B_{ij} \cos\left(d_i - d_j\right) \quad (6)$$

Similarly, the real and reactive power flows from bus *j* to bus *i* will be reversed in notation. The active and reactive power loss in the line can be calculated as

$$P_L = P_{ij} + P_{ji}$$
$$= V_i^{2} G_{ij} + V_j^{2} G_{ij} - 2V_i V_j G_{ij} \cos\left(d_i - d_j\right)$$
$$Q_L = Q_{ij} + Q_{ji}$$
$$= -V_i^{2}\left(B_{ij} + B_c\right) - V_j^{2}\left(B_{ij} + B_c\right) + 2V_i V_j B_{ij} \cos\left(d_i - d_j\right) \quad (7)$$

These equations are used to model the TCSC in the OPF formulations.The optimal dispatch is comprised of complete delivery of all the transactions and the fulfillment of pool demand at least cost subject to nonviolation of any security constraint. It may be assumed that the ISO provides for all loss compensation services and dispatches the pool power to compensate for the transmission losses, including those associated with the delivery of contracted transactions. The normal dispatch problem is rewritten here as

$$Min_{\{Pgi,\ Pdj\}} \sum C_i(P_{gi}) - \sum B_j(P_{dj}) \quad (8)$$

subject to:

$$g(P_G, P_D, T_K, Q, V, \delta, F) = 0$$
$$h(P_G, P_D, T_K, Q, V, \delta, F) \leq 0$$

where P_{Gi} and P_{Dj} are the active powers of pool generator *i* with bid price *Ci* and pool
load *j* with offer price *Bj*, respectively.
If only bilateral transactions are considered, we may rewrite the dispatch formulation as

$$Min\ f(x, u)$$

Where :

$$f(x,u) = \sum_{i=2}^{m} \sum_{j=m+1}^{n} w_{ij} \cdot \left(T_{ij} - T_{ij}^{0}\right)^2 \quad (9)$$

subject to the real and reactive power balance equations

$$P_{G_i} + P_{i(inj)}^{F} + \left(P_{C_i} - P_{D_i}\right) - P_i = 0$$
$$Q_{G_i} + Q_{i(inj)}^{F} + \left(Q_{C_i} - Q_{D_i}\right) - Q_i = 0 \quad (10)$$

where
n number of buses in the power system, with the first *m* buses being gencos
and the rest, discos
wij the willingness to pay factor to avoid curtailment of transaction
T_{ij}^{0} the desired value of transaction T_{ij}
P_{G_i}, Q_{G_i} are the real and reactive power generation at genco *i*.
P_{D_i}, Q_{D_i} are the real and reactive load demand at disco *i*.
P_{C_i}, Q_{C_i} are the real and reactive load curtailment at disco *i*.
P_i, Q_i are the real and reactive power injection at bus *i*.
$P_{i(inj)}^{F}$, $Q_{i(inj)}^{F}$ are the real and reactive power injection at bus *i*, with the installation of FACTS device.

We look at static considerations here for the placement of FACTS devices in the power system,and our method based on the sensitivity of the total system reactive power loss (*QL*) with respect to the control variables of the FACTS devices. we consider the following control parameters: net line series reactance (*Xij*) for a TCSC placed between buses *i* and *j*. The reactive power loss sensitivity factors with respect to this control variables may be given as follows:

$$a_{ij} = \frac{\partial Q_L}{\partial X_{ij}} \quad (11)$$

Loss sensitivity with respect to control parameter *Xij* of TCSC placed between buses *i* and *j*.This factor can be computed for a base case power flow solution. Consider a line connected between buses *i* and *j* and having a net series impedance of *Xij*, that includes the reactance of a TCSC, was written in below:

$$\frac{\partial Q_L}{\partial X_{ij}} = \left[V_i^{2} + V_j^{2} - 2V_i V_j \cos\left(d_i - d_j\right)\right] \cdot \frac{R_{ij}^{2} - X_{ij}^{2}}{\left(R_{ij}^{2} + X_{ij}^{2}\right)^{2}} \quad (12)$$

V. TEST RESULTS

We consider a six-bus system representing a deregulated market with bilateral transactions. An OPF will be solved for this system to determine the optimal generation schedule that satisfies the objective of minimizing deviations from the desired transactions.

Fig.2. shows the system network configuration. Buses 1 and 2 are genco buses and, being PV buses, the voltages here are specified exactly. At the other buses, the allowable upper and lower limits of voltage are specified. The losses are assumed to be supplied only by the generator at bus 1. Table I. provides the system data pertaining to generation and load. In appendix provides the system network data.

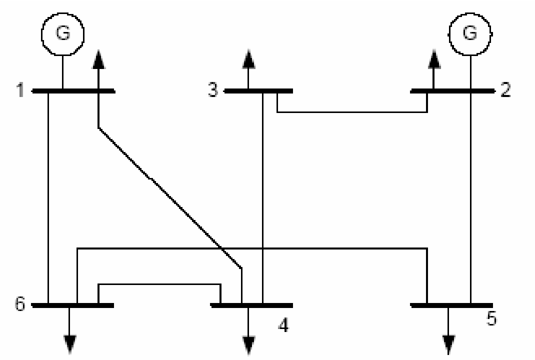

Fig. 2. Six bus system configuration

TABLE I
SYSTEM DATA

Bus	Generation Capacity, MW	Generator Cost Characteristic, \$/hr	Voltage p.u.
1	$100 \le P1 \le 400$	$P_1^2+8.5P_1+5$	1.05
2	$50 \le P2 \le 200$	$3.4P_2^2+25.5P_2+9$	1.06
3	-	-	$0.9 \le V \le 1.1$
4	-	-	$0.9 \le V \le 1.1$
5	-	-	$0.9 \le V \le 1.1$
6	-	-	$0.9 \le V \le 1.1$

A. Test Results with Curtailment Strategy

In this case, bilateral contracts have been considered between each genco and each disco.Table II shows the desired power transactions.

Three strategies for the curtailment of transactions are adopted for congestion management:

1) The curtailment on the disco loads is assumed to be linear. In this case, all the willingness to pay factors are taken to be equal.

2) Same as case (1), except that the willingness to pay price premium of loads on buses 1 to 3 is assumed to be twice that of loads on buses 4 to 6.

3) In this case, the price premium of loads on buses 4 to 6 is assumed to be twice that of loads on buses 1 to 3.

Power flow solution was done by PSAT. Table III shows the constrained generation and load data obtained from the OPF solution. It can be seen that the willingness to pay and the participants' curtailment strategy are two factors that significantly affect the constrained dispatch. The higher the willingness to pay, the less is the curtailment of that particular transaction. The curtailment strategies implemented have complex effects. These factors not only affect the curtailment of its own transaction, but will also impact that of other transactions

TABLE II.
DESIRED TRANSACTIONS BEFORE CURTAILMENT

Bus #	Desired transactions, MW
1	20.0
2	30.0
3	35.0
4	50.0
5	42.0
6	55.0

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TABLE III.
CONSTRAINED GENERATION AND LOAD DATA AFTER RUNNING POWER FLOW

Bus #	Constrained generation and load, MW		
	Case (1)	Case (2)	Case (3)
1	109.63	109.62	109.68
2	124.24	124.41	123.60
3	34.72	34.93	33.95
4	48.87	48.86	48.94
5	40.74	40.72	40.81
6	53.99	53.97	54.05

B. Test results with FACTS devices

The criteria for deciding device location might be stated as follows that TCSC must be placed in the line having the most positive loss sensitivity index *aij*. The lines having the most positive loss sensitivity index must be chosen for placement of the TCSC devices. For this we select lines 5 and 6 from Table IV.

When TCSC devices in the inductive mode of operation are connected in series with these two lines, with inductive reactances of 53.6% and 48.2% of the line reactances, espectively, it is seen that the line overloads are removed. The effect of optimal power dispatch with the TCSC devices installed on the line flows is shown in Table V.

The constrained generation and load data may be obtained after running the OPF with the TCSC installed. Table VI shows a comparison between the data obtained with and without FACTS devices in the system for one particular curtailment strategy employed by the ISO (Case (1)).

TABLE IV
VAR LOSS SENSITIVITY INDEXES

Line	From bus	To bus	Sensitivity index
1	1	4	a_{14} = -0.179
2	1	6	a_{16} = -0.123
3	2	3	a_{23} = -0.23
4	2	5	a_{25} = -0.15
5	3	4	a_{34} = -0.0189
6	4	6	a_{46} = -0.0184
7	5	6	a_{56} = -0.044

TABLE V
LINE FLOWS

Line	From bus	To bus	Line flow (in p.u.)		
			Rated	Without TCSC	With TCSC
1	1	4	0.50	0.138	0.176
2	1	6	0.50	0.383	0.386
3	2	3	0.50	0.480	0.494
4	2	5	0.80	0.132	0.162
5	3	4	0.57	0.62	0.483
6	4	6	0.55	0.562	0.418
7	5	6	0.30	0.025	0.027

TABLE VI
OPF RESULTES WITH OR WITHOUT TCSC

Bus #	Constrained generation and load, MW, Case (1) of 3.3.3	
	Without TCSC	With TCSC
1	109.63	109.72
2	124.24	124.41
3	34.72	34.96
4	48.87	49.14
5	40.74	41.32
6	53.99	53.99

This integrated framework covers the scenario where, even after putting the FACTS devices into operation, there is a need for the ISO to curtail the initial power transactions in order to maintain the system operation within security limits.

The OPF result shows that the individual power transactions suffer less curtailment when FACTS devices are included in the system.

VII. CONCLUSION

The operational aspects of power systems pose some of the most challenging problems encountered in the restructuring of the electric power industry. In this paper was looked at one such problem as congestion management becomes an important issue because it can make a penalty for market players. Congestion management can be solved by curtailment loads or using FACTS devices. Comparative case studies with and without FACTS devices show the efficacy of FACTS devices in alleviating congestion. Optimal placement of these devices leads to improved congestion reduction and less curtailment in the desired power transactions. The bilateral dispatch functions of an ISO are dealt with. This paper then focused on the use of FACTS devices (TCSC) to alleviate congestion. From the case studies carried out in this report, it was apparent that the interactions between market players are complex. An integrated approach that includes FACTS devices in a bilateral dispatch framework to maintain system security and to minimize deviations from contractual requirements is then proposed. The approach is validated through numerical examples.

APPENDIXE

SYSTEM NETWORK DATA

From bus – to bus	Resistance, pu	Reactance, pu	Line charging admittance, pu
1-4	0.0662	0.1804	0.003
1-6	0.0945	0.2987	0.005
2-3	0.0210	0.1097	0.004
2-5	0.0824	0.2732	0.004
3-4	0.1070	0.3185	0.005
4-6	0.0639	0.1792	0.001
5-6	0.0340	0.0980	0.004

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