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CONGESTION MANAGEMENT IN POWER SYSTEM USING OPTIMAL POWER FLOW TOPOLOGY

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ABSTRACT

Due to the increasing demand, transmission line outage and generator outage factor etc., the power system becomes congested or deregulated. Congestion is condition of the power systems when it reaches at or beyond the transfer capability limit of the transmission system. The transfer capability limit of the transmission lines are line voltage limit, thermal limit, stability limit etc. The congestion of the line will cause huge power losses, poor voltage regulation, high temperature rise etc. So relieving congestion system is the most important task for the efficient power transfer capability. For keeping the network out of congestion

KEYWORDS: Congestion Management in Power System

I. INTRODUCTION

The recent development of the electric power industry has involved paradigm shifts in the real time controls activities of the power grids. Managing load dispatch is one of the important control activities in a economic power system. Optimal power flow (OPF) has perhaps been the most significant technique for obtaining minimum cost generation patterns in a power system area with existing transmission and operational constraints. The role of an independent load system operator in a competitive market environment would be to facilitate the complete dispatch of the power that gets contracted among the market players. With the recent trends of an increasing number of bilateral contracts being signed for electricity market trades, the possibility of insufficient resources leading to network congestion management may be unavoidable. In this deregulated environment, congestion management (within an OPF framework) becomes an important issue. Real-time congestion system can be defined as the operating condition for which there is not enough transmission capability to implement all the traded transactions simultaneously due to some unexpected contingencies. It may be alleviated by incorporating transmission line capacity constraints in the dispatch and scheduling process.

This may involve redistribution of generation or load curtailment. Other possible means for relieving congestion system are operation of phase-shifters or FACTS devices. In this report we look at a modified OPF whose objective is to minimize the absolute MW of rescheduling loads. In this case, we consider dispatching the bilateral contracts too in case of serious congestion, the any change in a bilateral contract is equivalent to modifying the power injections at both the buyer and the seller buses. This highlights of the fact that, in a restructured scenario, contracts between trading entities must be considered as system decision factors (in addition to the usual generation, loads and flows). Figure 1.1 shows a transaction network [1] in a typical deregulated electricity market. It displays key role in links of data and cash flow between various market players. In the figure, G stands for generator-serving entities (or gencos), D for demand-serving entities (LSEs or discos), E for marketers, and ISO for the independent system operator.

The load dispatch problem has been formulated with two different objective: cost minimization and minimization of transaction deviations. Congestion charges can be calculated in both the cases. In a pool market mode, the sellers (competitive generators) may submit their incremental and decremental bidding prices in a real-time market. These can then be incorporated in the OPF problem to yield the incremental/decremental changes for the generator outputs. Similarly, in case bilateral market mode, every transaction contract may include a compensation price that the buyer-seller pairs are willing to audies should its transaction be curtailed. This can then be modified as a prioritization of the transactions based on the latter's sensitivities to the violated constraint in case congestion occurs. In this case studies, we also seek to develops an OPF solution incorporating FACTS devices in a given market mode (pool or bilateral dispatch). FACTS devices assume importance in the context of power system restructuring since they can expand the usage potential of transmission systems by controlling power flows in the network. FACTS devices are operated in a manner so as to ensure that the contractual requirements are fulfilled by minimizing line congestion. Various optimization techniques have been used to solve Optimal Power Flow problems. These may be classified as sequential, quadratic, linear, nonlinear, integer and dynamic programming G D ISO E 3 methods, Newton-based methods, interior point techniques etc. Nonlinear programming methods are involve nonlinear objective and constraint equations. These improve the earliest category of OPF techniques as they can closely model electric power systems. The benchmark paper by Dommel and Tinney [2] discusses a methods to minimize fuel costs and active power

losses using the penalty function optimization approach. Divi and Kesavan [3] use an adapted Fletcher's quasi-Newton technique for optimization of shifted penalty functions. Linear programming deals with problems with constraints and objective function formulated in linear systems. Sterling and Irving [4] solved an economic dispatch of active power with constraints relaxation using a linear programming methodology. Chen et al. [5] developed a successive linear programming (SLP) based method for a loss minimization objective for ac-dc system. In the SLP approach, the nonlinear OPF problem is approximated to a linear programming problems by linearizing both the objective function as well as the constraints about an operating states. At every iteration, a suboptimal solution is found and the variables are updated to get new operating state. The process is repeated until the objective function converges to an optimal level. Megahed et al. [6] have discussed the treatment of the nonlinearly constrains dispatch problem to a series of constrained linear programming problems. Similarly, Waight et al. [7] have used the Dantzig-Wolfe decomposition method to break the dispatch problems into one master problem and several smaller linear programming sub-problems. Combinations of linear programming methods with the Newton approach have been discussed in the literature survey [8]. In [9], Burchett and Happ apply an optimization method based on transforming the original problem into that of solving a series of linearly constrained sub-problems using an augmented Lagrangian type objective function. The sub-problems are optimized by using quasi-Newton, conjugate directions, and steepest descent methods. Quadratic programming is another form of nonlinear programming where the objective functions are approximated by a quadratic function and the constraints are linearized. Nanda et al. [10] discussed an OPF algorithm developed using the Fletcher's quadratic programming method. Burchett et al. [11] discussed a successive quadratic programming (SQP) method where the approximation-solution-update process is repeated to convergence as in the SLP method. In this method, a sequence of quadratic programs are created from the exact analytical first and second derivatives of the 4 power flow equations and nonlinear objective function. Interior point methods are fairly new entrants in the field of power system optimization issues. Vargas et al. [12] discussed an interior point method for a security-constrained economic dispatch issues. In [13], Momoh et al. present a quadratic interior point method for OPF problems, economic load dispatch, and reactive power planning. The report is organized as follows:

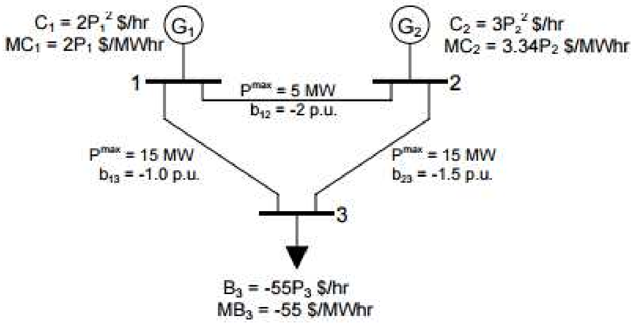


Figure 1: Sample Power System

In Chapter 2 We studied congestion management methodologies and how they get modified in the new competitive framework of electricity power markets. A simple example is given for the computation of congestion charges in a scenario where the objective of optimization is to maximize societal benefit. In Chapter 3, we work out different OPF problem formulations. Objective functions that are treated include cost minimization and transaction curtailment minimizations. Market models involving pool and bilateral dispatches are considered for experimental cases. The possibility of using these formulations in an open access system dispatch models and in real-time balancing markets is discussed. In Chapter 4, we treat the subject of including FACTS devices in the OPF problems. Various FACTS device models are considered and then applied in the problem formulation. The impact of these devices on minimizing congestion and transaction deviations is studied. In Chapter 5, the OPF results are displayed on two test systems and inferences are drawn from the same results. Further areas of research in this field are then explained in the concluding chapter.

II. CONGESTION MANAGEMENT METHODOLOGIES

We studied Vertically Integrated Operation the unbundling of the electric power system has led to the evolution of new organizational structures. Unbundling implies opening of competition those tasks that are, in a vertically integrated structure, coordinated jointly with the objective of minimizing the total costs of operating system the utility. In such a traditional organizational structure, all the control system functions, like automatic generation control (AGC), state estimation, generation dispatch, unit commitment system, etc., are carried out by energy management systems. Generation is dispatched in a manner that realizes the most economic overall performance. In such an environment, an optimal power flow can perform the dual function of minimizing generation costs and of avoiding congestion in a least-cost manner. Congestion management thus involves determining a generation pattern that does not violate the line operating flow limits. Line flow capacity constraints, when incorporated with scheduling program, lead to increase in marginal costs. This may used as an economic signal for rescheduling generation or, in case of recurring congestion for installation of new generation/transmission facilities.

2.3 Unbundled Operation In a competitive power market, besides production, loads, and line flows, contracts between trading entities also comprise the system decision factors. The following pool and bilateral competitive structures for the electricity market have involved 6 (1) Single auction power pools, where whole-sale sellers (competitive generators) bids to supply power into a single pool system. Load serving entities (LSEs or buyers) then buy wholesale power in units from that pool at a regulated price and resell it to the retail loads. (2) Double auction power pools, where the sellers put their bids in a single pool and the buyers compete with their offers to buy wholesale power from the pools and then resell it to the retailer loads. (3) In addition to the combinations of (1) and (2), bilateral wholesale contracts between the wholesale generators in MW and the LSEs without third-party intervention. (4) Multilateral contracts, i.e., purchase and sale agreements between several sellers and customers, possibly with the intervention of third parties such as forward contractors. In both (3) and (4) the price-quantities trades are up to the market participants to decide and not the ISO standard. The role of the ISO in such a scenario is to maintain power system security and carry out congestion management problem. The contracts, thus determined by the market conditions are the system inputs that drive the power system. The transactions resulting may be treated as sets of power injections and extractions at the seller and buyer buses, respectively. For example, in a system of n buses, with the generator buses numbered from 1 to m numbered , the nodal active powers may be represented as [14] = + ∑ + k∈K i po i T i K P P, P and loss compensation, i =1, 2, …m (2.1) ∑∈ = + k K j po j T j K D D , D , , j= m+1, …n (2.2) where Pi = active injected power at generator bus and i Dj = active extracted power from load bus j K = set of bilateral / multilateral transactions system Ppo,I = pool power injected at bus i Dpo,j = pool power extracted at bus j PTk,I = power injected at bus i with transaction TK DTk,j = power extracted at bus j in accordance with transaction TK Loss compensation = power supplied at bus i by all transaction participants to make good the transmission system losses.

2.4 Congestion Management Methodologies

There are two broad methods that may be employed for congestion management. These are the cost-free means and the not-cost-free means systems [15]. The former include actions like outages of congested lines or operation of transformer taps, phase shifters, online tap changing transformers or FACTS devices. These means are termed as cost-free only because the marginal costs of the system involved in their usage are nominal. The not-cost-free means include: (i) Rescheduling generation. This leads to generation operation at an equilibrium point away from the one determined by equal area criteria or equal incremental costs. Mathematical models of costing 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 loads participants to rearrange their power injections / extractions such that congestion is avoided or eliminated to some extent. (ii) Prioritization and curtailments of loads/transactions. A parameter termed as willingness-to-pay-to-avoid-curtailments was introduced in [14]. This can be an effective instrument in setting the transaction curtailments strategies which may be incorporated in the optimal power flow frameworks. In the next chapters we look at OPF formulations incorporating both (1) and (2) above methods. These models can be used as part of a real-time systems open access system dispatch models [16]. The function of this module is to modify system dispatch to ensure secure and efficient power system operation based on the existing operating condition. It would use the dispatchable resources and controls the required curtailment of transactions to ensure uncongested operation of the power system.

2.5 Example of Congestion Management in an Economic Dispatch Framework We now look at an example of computing optimal bus prices and congestion costs for a power system, where in an independent company (ISO) controls the transmission system and sets nodal prices that are computed as part of a centralized load dispatch. A simple power system is considered here for the calculation of congestion charges and load dispatch. A three-bus system is shown in Figure 2.1 with generator costs/marginal costs and load benefits/marginal benefits functions as shown. Also in the figure are the maximum line flow limits and line susceptances.

Figure 2.1 Sample power system is considered with the following approximations:

- Each transmission line is represented by its base susceptance bij.
- A lossless DC power flow line model is assumed; i.e., the bus voltage angular differences are assumed to be small and the voltages magnitudes approximately 1.00 p.u.
- As mentioned above, we resolve this problems in a centralized dispatch framework where the objective is to maximize social benefit. This optimization problems thus seeks to minimize the system operating costs minus the consumer benefit (costs), subject to the binding G1, G2, 1 2 3 B3 = -55P3 $/hr MB3 = -55 $/MWhr C.

III. CONGESTION MANAGEMENT PROBLEM

Optimization Problem Building

The costs function of rescheduled active and reactive powers are f_1 and f_2, the objective function is formulated as optimization problem which has to be minimized is as follows:

Minimize $Z = f_1 + f_2$

Mathematically, an optimal power flow for minimization of the total operating cost can be formulated as follows:

Objective:

$$\text{Min } f(x) = \sum_{i}^{Ng}(\alpha_i * Pg_i^2 + \beta_i * Pg_i + \gamma_i) + C_{TCSC} \quad (1.1)$$

Based on following constraints:

1. Non linear equality constraints or variable

(load flow equations)

$$g(x)=0 \quad (23)$$

Where g(x) represents equality constraints including system bus power flow equations. i.e.,

$$Pg_i - Pd_i - P_i(V, \theta, T) = 0$$

$$Qg_i - Qd_i - Q_i(V, \theta, T) = 0$$

$i = 1, 2, \ldots N$

2. Non linear inequality constraints are such as line flow constraints, interface flow constraints and simple inequality constraints of variables such as voltage magnitudes, generator active powers, generator reactive powers, transformer tap ratios

$$h_j^{min} \le h_j(P_g, Q_g, V, \theta, T) \le h_j^{max} \quad (24)$$

$j = 1, 2, \ldots, N_h$

where $x = [V, \theta, T, Pg, Qg]^T$, $\alpha_i, \beta_i, \gamma_i$ are the coefficients of quadratic production cost functions at bus i, Pg is the bus active generation, Qg is the bus reactive generation and Pd is the bus active load, Q_d is bus reactive load, V is the bus voltage magnitude, θ is the bus angle vector, T is the transformer Tap ratio vector, h^{min}, h^{max} are lower bound and upper bound vectors, respectively, for inequality constraints, *Ng* is the total number of generators and *N* is total number of buses, and *Nh* is the total number of double-side inequality constraints.

For stability system operation the region of feasible solutions may not be able to converge whilst satisfying all constraints simultaneously. A robust non linear OPF formulation which introduces reactive slack bus variables and load-shedding variable in the problem shown in equations 1-4 is proposed to handle the infeasibility of a solution. It is formulated as objective:

By applying Fiacco and McCormick's barrier method, we transform the OPF problem (1) into the following equivalent OPF problem,

Objective:

$$Min\{f(x) - \mu \textstyle\sum_{i}^{Nh} \ln(sl_i) - \mu \sum_{i}^{Nh} \ln(su_i)\} \quad (22.1)$$

Based on the following constraints

$$g(x)=0 \quad (22.2)$$

$$h(x)- sl- h^{min} =0 \quad (22.3)$$

$$h(x)+ su- h^{max} =0 \quad (22.4)$$

where, $\mu > 0$.

The Lagrangian function for equalities optimization for problem (4) is

$$L = f(x) - \mu \sum \ln(sl) - \mu \sum \ln(su) - \lambda^T g(x)$$

$$-\pi l^T (h(x) - sl - h^{min}) - \pi u^T (h(x) + sl - h^{max}) \quad (23)$$

Where λ, пl, пu are Lagrangian multiples for constraints (2.2), (2.3), (2.4), respectively as follows.

The Karush-Kuhn-Tucker (KKT) first order filter conditions for the Lagrangian function of (3) are,

$$\nabla_x L_\mu = \nabla f(x) - \nabla g(x)^T \lambda - \nabla h(x)^T \pi l - \nabla h^T \pi u = 0 \quad (24.1)$$

$$\nabla_\lambda L_\mu = -g(x) = 0 \quad (24.2)$$

$$\nabla_{\pi l} L_\mu = -(h(x) - sl - h^{min}) = 0 \quad (24.3)$$

$$\nabla_{\pi u} L_\mu = -(h(x) + su - h^{max}) = 0 \quad (24.4)$$

$$\nabla_{sl} L_\mu = \mu e + Sl * \pi l = 0 \quad (24.5)$$

$$\nabla_{su} L_\mu = \mu e - Su * \pi u = 0 \quad (24.6)$$

where, Sl=diag(sl_j),

Su=diag(su_j),

Пl= diag(sl_j),

Пu= diag(su_j).

The Newton equation for the nonlinear interior point Optimal power flow algorithm derived above may be expressed as the following compact form,

$$\begin{bmatrix} -nl^{-1}Sl & 0 & -\nabla h & 0 \\ 0 & -nl^{-1}Sl & -\nabla h & 0 \\ -\nabla h^T & -\nabla h^T & H & -J^T \\ 0 & 0 & -J & 0 \end{bmatrix} \begin{bmatrix} \Delta nl \\ \Delta nu \\ \Delta x \\ \Delta \lambda \end{bmatrix} = \begin{bmatrix} -\nabla_{nl} L_\mu + nl^{-1} \nabla_{Sl} L_\mu \\ -\nabla_{nu} L_\mu + nu^{-1} \nabla_{Su} L_\mu \\ -\nabla_x L_\mu \\ g(x) \end{bmatrix} \tag{25.1}$$

$$\Delta sl = nl^{-1}(-\nabla_{sl} \mathrm{L}_\mu - \mathrm{Sl}\Delta \mathrm{nl}) \tag{25.2}$$

$$\Delta su = nu^{-1}(-\nabla_{su} \mathrm{L}_\mu - \mathrm{Su}\Delta \mathrm{nu}) \tag{25.3}$$

where,

$$H(x, \lambda, \pi l, \pi u) = \nabla^2 f(x) - \lambda \nabla^2 g(x) - (\pi l + \pi u) \nabla^2 h(x),$$

$$J(x) = \frac{\partial g(x)}{\partial x}$$

By resolving the Newton equation based on above derivatives equation (7),Δnl, Δnu, Δx, $\Delta \lambda$, Δsl, Δsu can be obtained. Then the Newton solution can be updated as follows,

$$sl = sl + \sigma \alpha_p \Delta sl \tag{26.1}$$

$$su = su + \sigma \alpha_p \Delta su \tag{26.2}$$

$$x = x + \sigma \alpha_p \Delta x \tag{26.3}$$

$$\pi l = nl + \sigma \alpha_d \Delta nl \tag{26.4}$$

$$\pi u = nu + \sigma \alpha_d \Delta nu \tag{26.5}$$

$$\lambda = \lambda + \sigma \alpha_d \Delta \lambda \tag{26.6}$$

Where σ =0.995~0.999 95. $\alpha_{p,}$ α_d are primal and dual step length respectively and they can be determined by

$$\alpha_p = min\left\{min\left(\frac{sl}{-\Delta sl}\right), min\left(\frac{su}{-\Delta su}\right), 1.0\right\} \tag{27.1}$$

$$\alpha_d = min\left\{min\left(\frac{-nl}{-\Delta nl}\right), min\left(\frac{nu}{-\Delta nu}\right), 1.0\right\} \tag{27.2}$$

The complementary gap of the nonlinear interior point Optimal power flow is,

$$C_{gap} = su^T nu - sl^T nl \tag{28}$$

The barrier parameters can be determined by,

$$\mu = \frac{\beta * C_{gap}}{2 * m} \tag{29}$$

where β=0.01~0.2, m is the number of inequality constraints in (21.3)

3.2 Algorithm

This solution procedure for the nonlinear interior point OPF is summarized as the following:

Step 0) set iterations count k=0,$\mu = \mu 0$, and initialize the Optimal power flow solution

Step 1) if KKT conditions are satisfactory and complementary gap is less than a tolerance, output results. Otherwise go to step 2)

Step 2) solve Newton equation in (25.1), then (25.2) and (25.3)

Step 3) Update Newton solution by equation (26)

Step 4) Compute complementary gap by (28)

Step 5) k=k+1 go to step 1).

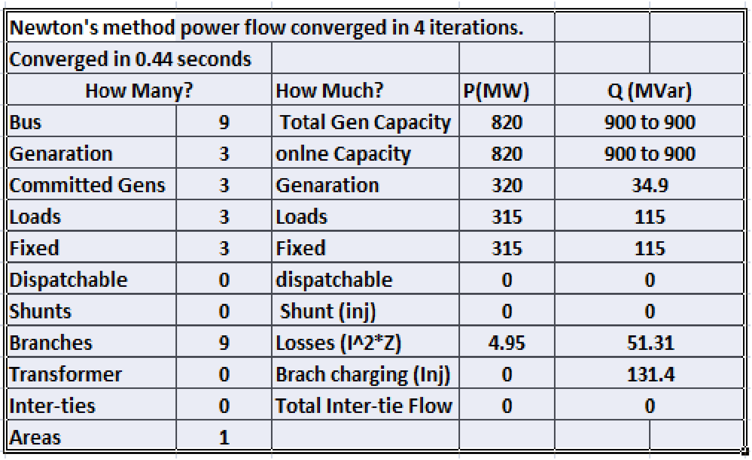
A. Solution by descent gradient method

IV. RESULTS AND DISCUSSIONS

Matlab is the software used for implementing and Programming language and is written for OPF has had a long history of development. Now optimal power flow has become a successful algorithm which could be applied on an everyday basis, in different kind of power market. The optimal power flow is use for a wide range of task from calculating the minimum cost generation dispatch to setting generation voltage, transformer taps MATPOWER is a package of MATLAB M-file for solving power flow studies and optimal power flow problems. It is used as a simulation tool for researchers and education, which is easy to use and modify MATPOWER is designed to give the best performance possible while keeping the code simple to understand and modify. It was initially developed as part of the power Web Project. It also solves the congestion of initial dispatch and provides good offers to re-dispatch for load dispatch problems

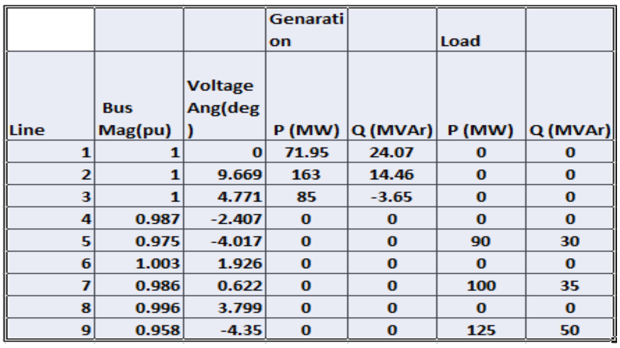
The 9 bus IEEE of bus test cases represents a portion of the American Electric Power System. The data was kindly provided by author Joe H.Chow's Book page No.70. The one line diagram of an IEEE-9 bus system is as shown in the Figure. The line data, bus data and load are as shown in table 1 and 2. Single line diagram of IEEE 9 bus test system and results. The system consists of 3 synchronous generators for production and the system had 3 load points. Associated flow results are shown in the Figure below. The data is on 100MVA base

Table 1: Generator Capacity, Active and Reactive Power for 9 Bus System Using NR Method



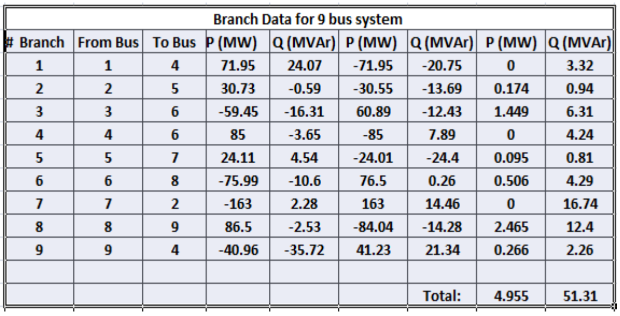
Newton's method power flow converged in 4 iterations.				
Converged in 0.44 seconds				
How Many?		How Much?	P(MW)	Q (MVar)
Bus	9	Total Gen Capacity	820	900 to 900
Genaration	3	onlne Capacity	820	900 to 900
Committed Gens	3	Genaration	320	34.9
Loads	3	Loads	315	115
Fixed	3	Fixed	315	115
Dispatchable	0	dispatchable	0	0
Shunts	0	Shunt (inj)	0	0
Branches	9	Losses (I^2*Z)	4.95	51.31
Transformer	0	Brach charging (Inj)	0	131.4
Inter-ties	0	Total Inter-tie Flow	0	0
Areas	1			

Table 2: Line to Line Power Flow Limits



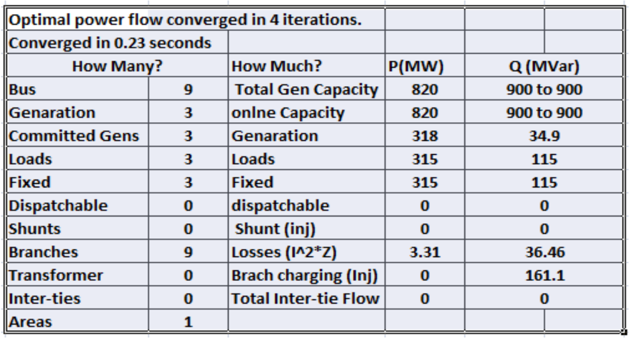
			Genaration		Load	
Line	Bus Mag(pu)	Voltage Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	0	71.95	24.07	0	0
2	1	9.669	163	14.46	0	0
3	1	4.771	85	-3.65	0	0
4	0.987	-2.407	0	0	0	0
5	0.975	-4.017	0	0	90	30
6	1.003	1.926	0	0	0	0
7	0.986	0.622	0	0	100	35
8	0.996	3.799	0	0	0	0
9	0.958	-4.35	0	0	125	50

Table 3: Branch Flow Limits



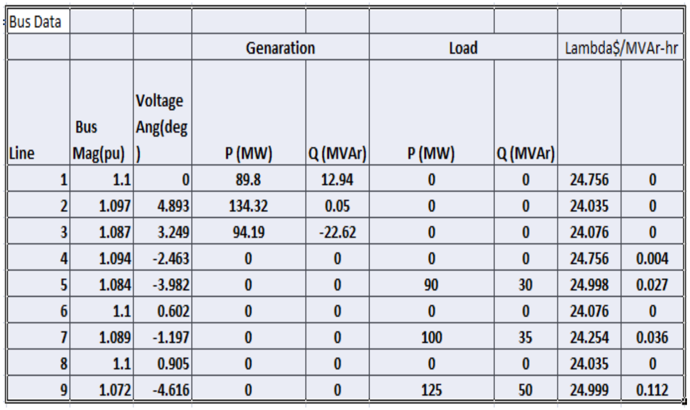
Branch Data for 9 bus system								
# Branch	From Bus	To Bus	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	4	71.95	24.07	-71.95	-20.75	0	3.32
2	2	5	30.73	-0.59	-30.55	-13.69	0.174	0.94
3	3	6	-59.45	-16.31	60.89	-12.43	1.449	6.31
4	4	6	85	-3.65	-85	7.89	0	4.24
5	5	7	24.11	4.54	-24.01	-24.4	0.095	0.81
6	6	8	-75.99	-10.6	76.5	0.26	0.506	4.29
7	7	2	-163	2.28	163	14.46	0	16.74
8	8	9	86.5	-2.53	-84.04	-14.28	2.465	12.4
9	9	4	-40.96	-35.72	41.23	21.34	0.266	2.26
						Total:	4.955	51.31

Table 4: Generator Capacity, Active and Reactive Power for 9 Bus System using Optimal Power Flow Method



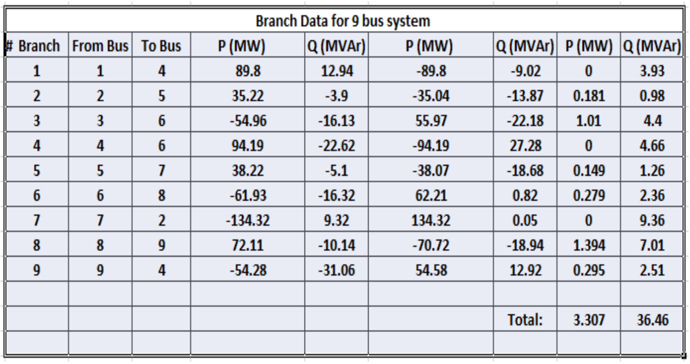
Optimal power flow converged in 4 iterations.				
Converged in 0.23 seconds				
How Many?		How Much?	P(MW)	Q (MVar)
Bus	9	Total Gen Capacity	820	900 to 900
Genaration	3	onlne Capacity	820	900 to 900
Committed Gens	3	Genaration	318	34.9
Loads	3	Loads	315	115
Fixed	3	Fixed	315	115
Dispatchable	0	dispatchable	0	0
Shunts	0	Shunt (inj)	0	0
Branches	9	Losses (I^2*Z)	3.31	36.46
Transformer	0	Brach charging (Inj)	0	161.1
Inter-ties	0	Total Inter-tie Flow	0	0
Areas	1			

Table 5: Line to Line Power Flow Limits



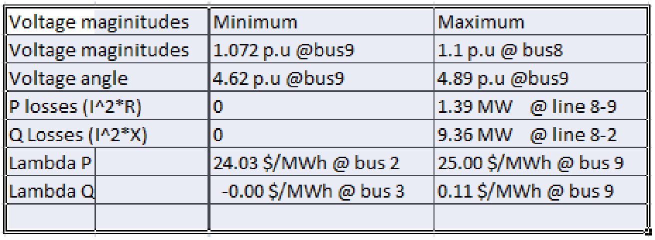
Bus Data								
			Genaration		Load		Lambda$/MVAr-hr	
Line	Bus Mag(pu)	Voltage Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)		
1	1.1	0	89.8	12.94	0	0	24.756	0
2	1.097	4.893	134.32	0.05	0	0	24.035	0
3	1.087	3.249	94.19	-22.62	0	0	24.076	0
4	1.094	-2.463	0	0	0	0	24.756	0.004
5	1.084	-3.982	0	0	90	30	24.998	0.027
6	1.1	0.602	0	0	0	0	24.076	0
7	1.089	-1.197	0	0	100	35	24.254	0.036
8	1.1	0.905	0	0	0	0	24.035	0
9	1.072	-4.616	0	0	125	50	24.999	0.112

Table 6: Branch Flow Limits



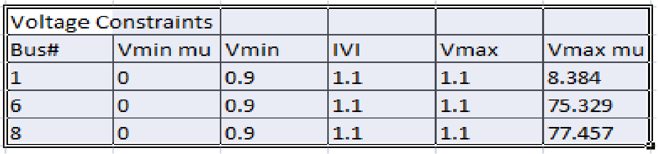
Branch Data for 9 bus system								
# Branch	From Bus	To Bus	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	4	89.8	12.94	-89.8	-9.02	0	3.93
2	2	5	35.22	-3.9	-35.04	-13.87	0.181	0.98
3	3	6	-54.96	-16.13	55.97	-22.18	1.01	4.4
4	4	6	94.19	-22.62	-94.19	27.28	0	4.66
5	5	7	38.22	-5.1	-38.07	-18.68	0.149	1.26
6	6	8	-61.93	-16.32	62.21	0.82	0.279	2.36
7	7	2	-134.32	9.32	134.32	0.05	0	9.36
8	8	9	72.11	-10.14	-70.72	-18.94	1.394	7.01
9	9	4	-54.28	-31.06	54.58	12.92	0.295	2.51
						Total:	3.307	36.46

Table 7: System Parameters



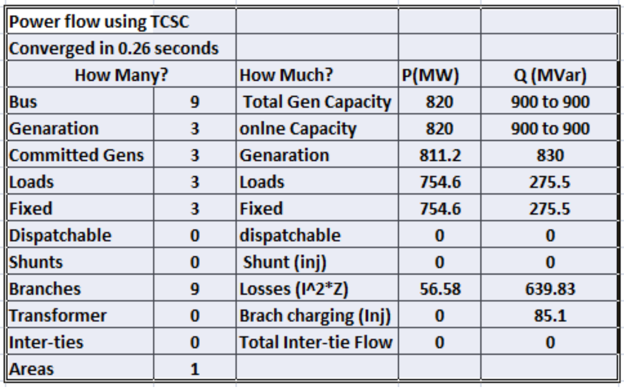
Voltage maginitudes	Minimum	Maximum
Voltage maginitudes	1.072 p.u @bus9	1.1 p.u @ bus8
Voltage angle	4.62 p.u @bus9	4.89 p.u @bus9
P losses (I^2*R)	0	1.39 MW @ line 8-9
Q Losses (I^2*X)	0	9.36 MW @ line 8-2
Lambda P	24.03 $/MWh @ bus 2	25.00 $/MWh @ bus 9
Lambda Q	-0.00 $/MWh @ bus 3	0.11 $/MWh @ bus 9

Table 8: Voltage Constraints



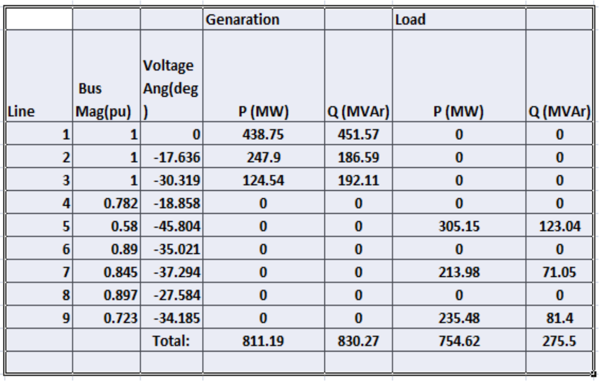
Voltage Constraints					
Bus#	Vmin mu	Vmin	IVI	Vmax	Vmax mu
1	0	0.9	1.1	1.1	8.384
6	0	0.9	1.1	1.1	75.329
8	0	0.9	1.1	1.1	77.457

Table 9: Generator Capacity, Active and Reactive Power for 9 Bus System using TCSC



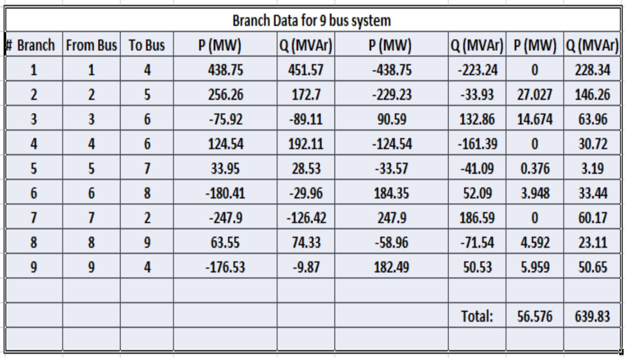
Power flow using TCSC				
Converged in 0.26 seconds				
How Many?		How Much?	P(MW)	Q (MVar)
Bus	9	Total Gen Capacity	820	900 to 900
Genaration	3	onlne Capacity	820	900 to 900
Committed Gens	3	Genaration	811.2	830
Loads	3	Loads	754.6	275.5
Fixed	3	Fixed	754.6	275.5
Dispatchable	0	dispatchable	0	0
Shunts	0	Shunt (inj)	0	0
Branches	9	Losses (I^2*Z)	56.58	639.83
Transformer	0	Brach charging (Inj)	0	85.1
Inter-ties	0	Total Inter-tie Flow	0	0
Areas	1			

Table 10: Line to Line Power Flow Limits Using TCSC



			Genaration		Load	
Line	Bus Mag(pu)	Voltage Ang(deg)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	0	438.75	451.57	0	0
2	1	-17.636	247.9	186.59	0	0
3	1	-30.319	124.54	192.11	0	0
4	0.782	-18.858	0	0	0	0
5	0.58	-45.804	0	0	305.15	123.04
6	0.89	-35.021	0	0	0	0
7	0.845	-37.294	0	0	213.98	71.05
8	0.897	-27.584	0	0	0	0
9	0.723	-34.185	0	0	235.48	81.4
		Total:	811.19	830.27	754.62	275.5

Table 11: Branch Flow Limits using TCSC



Branch Data for 9 bus system								
# Branch	From Bus	To Bus	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	4	438.75	451.57	-438.75	-223.24	0	228.34
2	2	5	256.26	172.7	-229.23	-33.93	27.027	146.26
3	3	6	-75.92	-89.11	90.59	132.86	14.674	63.96
4	4	6	124.54	192.11	-124.54	-161.39	0	30.72
5	5	7	33.95	28.53	-33.57	-41.09	0.376	3.19
6	6	8	-180.41	-29.96	184.35	52.09	3.948	33.44
7	7	2	-247.9	-126.42	247.9	186.59	0	60.17
8	8	9	63.55	74.33	-58.96	-71.54	4.592	23.11
9	9	4	-176.53	-9.87	182.49	50.53	5.959	50.65
						Total:	56.576	639.83

V. CONCLUSIONS

The operational aspects of power systems of the most challenging problems encountered in restructuring of the electric power industry. In this report we looked at one such problem. This work focuses on congestion management within an optimal power flow framework in a deregulated electricity market scenario. The conventional OPF problem is modified to create a mechanism that enables the market factors to compete and trade and simultaneously ensures that the system operation stays within security constraints. The pool and bilateral load dispatch functions of an ISO are dealt with. The approach is validated through numerical examples and tested in simulation tool. OPF is increasingly being used for transmission costing and transaction evaluation in open access transmission systems. From the case studies carried out in this report, it was apparent that the interactions between the market players are complex. Future work in this fie

It may focus on quantifying the economic risk faced by market factors due to differences in their willingness to pay to avoid curtailment. Research may also be carried out on designing different dispatch and curtailment strategies. The sensitivity approach for determining optimal locations of FACTS devices can at best of approximate idea about the optimal location for those devices in a deregulated environment. More reliable methods need to be developed for optimal power flow in a deregulated market environment. That would facilitate the development of simpler and robost OPF packages.

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