Congestion Management in Deregulated Power System Using Lagrange Multiplier Method

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Abstract— The deregulation of the electricity industry in the word has made the problem of transmission congestion increasingly significant. It aggravates the smooth functioning of competitive markets. Also congestion problems are threatening to system securities. Therefore, investigation of techniques for congestion-free-wheeling of power is of paramount interest and necessary for the sake of system security. In this paper classical lagrange multiplier method is used to solved the congestion problem from the system. Here in this paper standard IEEE-30 System is used.

Key words: IEEE-30 System, OPF, Lagrange Algorithm

I. INTRODUCTION

The traditional electricity utility can be described as a vertically integrated company (VIC) where generation, transmission and distribution are under the umbrella of one management. The modern trend and practice is for open markets. This calls for separation (unbundling) of the generation, transmission and distribution functions.

The deregulation of power system has made intensive usage of transmission grids. Here most of the time the power system operates near its rated capacity as the market players have an intention of maximizing profit by utilizing as much as of the existing transmission resources

With increasing demand for electric power all around the globe, electric utilities have been forced to meet the same by increasing their generation. However, the electric power that can be transmitted between two locations on a transmission network is limited by several transfer limits such as thermal limits, voltage limits and stability limits with the most restrictive applying at a given time. When such a limit is reached, the system is said to be congested. Ensuring that the power system operates within its limits is vital to maintain power system security, failing which can result in widespread blackouts with potentially severe social and economic consequences. Congestion management, that is, controlling the transmission system so that transfer limits are observed, is perhaps the fundamental transmission management problem [1]. The methods generally adopted to manage congestion include rescheduling generator outputs, supplying reactive power support or physically curtail transactions. System operators generally use the first option as much as possible and the last one as the last resort.

Several techniques of congestion management have been reported in literature [2]. The form of deregulated electric power industry differs from country to country as well as between different regions of a country. Different models to deal the different transactions, interactions between properties and limitations of the transmission system and the economic efficiency of the energy market have been mentioned in [3]. Congestion management techniques applied to various kinds of electricity markets are presented in [4]. Prioritization of electricity transactions and related curtailment strategies in a system where pool and bilateral/ multilateral dispatches coexist is proposed in [5]. In [6].A corrective switching operations of transmission lines is used instead of generation rescheduling to alleviate congestion in this paper.

Literature on optimal power flow (OPF)-based congestion management schemes for multiple transaction systems are available. In [7], an OPF-based approach that minimizes cost of congestion and service costs has been proposed. A coordination mechanism between generating companies and system operator for congestion management using Benders cuts has been discussed in [8]. In [9], a technique has been proposed for alleviating congestions due to voltage instability and thermal overloads. This also uses OPF which is solved by standard solvers. In [10], a congestion clusters based method has been presented that groups the system users having similar effects on the transmission constraints of interest.

Here the main intend to present this paper is to remove the congestion from the system and bring back the system to normal operating state with all the constraints are in limit. Also cost of generator rescheduling is optimized here. In this paper algorithm is utilized which is based on Lagrange multiplier method is used to optimize the cost of congestion management and output of generators.

II. PROBLEM FORMULATION

The generators in the system under consideration have different sensitivities to the power flow on the congested line. A change in real power flow in a transmission line k connected between bus i and bus j due to change in power generation by generator g can be termed as generator sensitivity to congested line (GS)[10]. Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_{Gg}} \quad \ldots\ldots(1)$$

Where P_{ij} is the real power flow on congested line-k; is the real power generated by the generator. The basic power flow equation on congested line can be written as,

$$\boxed{\begin{aligned} P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij}\cos(\theta_i - \theta_j) \\ + V_i V_j B_{ij}\sin(\theta_i - \theta_j) \end{aligned}} \quad (2)$$

where $\boldsymbol{\theta}_i$ and V_i and are the voltage magnitude and phase angle respectively at the ith bus; G_{ij} and B_{ij} represent, respectively, the conductance and susceptance of the line connected between buses i and j; neglecting P-V coupling, (1) can be expressed as

$$G_{Sg} = \frac{\partial Pij}{\partial \theta i}\frac{\partial \theta i}{\partial P_{Gg}} + \frac{\partial Pij}{\partial \theta j}\frac{\partial \theta j}{\partial P_{Gg}} \quad \ldots\ldots.. (3)$$

The first terms of the two products in (3) are obtained by differentiating (2) as follows:

$$\boxed{\frac{\partial P_{ij}}{\partial \theta_i} = -V_iV_jG_{ij}\sin(\theta_i-\theta_j) + V_iV_jB_{ij}\cos(\theta_i-\theta_j)} \quad (4)$$

$$\boxed{\begin{aligned}\frac{\partial P_{ij}}{\partial \theta_j} &= +V_iV_jG_{ij}\sin(\theta_i-\theta_j) - V_iV_jB_{ij}\cos(\theta_i-\theta_j)\\ &= -\frac{\partial P_{ij}}{\partial \theta_i}.\end{aligned}} \quad (5)$$

The active power injected at a bus-s can be represented as,

$$\boxed{P_s = P_{G_s} - P_{D_s}} \quad (6)$$

Where P_{Ds} is the active load at bus-s. P_s can be expressed as,

$$\boxed{\begin{aligned}P_s &= |V_s \sum_{t=1}^{n}((G_{st}\cos(\theta_s-\theta_t)\\ &\quad + B_{st}\sin(\theta_s-\theta_t))|V_t|)\\ &= |V_s{}^2G_{ss} + |V_s \sum_{\substack{t=1\\t\neq s}}^{n}\{(G_{st}\cos(\theta_s-\theta_t)\\ &\quad + B_{st}\sin(\theta_s-\theta_t))|V_t|\}\end{aligned}} \quad (7)$$

Where is the number of buses in the system. Differentiating (10) w.r.t. and ,the following relations can be obtained:

$$\boxed{\begin{aligned}\frac{\partial P_s}{\partial \theta_t} &= V_s|\, V_t\,\{G_{st}\sin(\theta_s-\theta_t)\\ &\quad - B_{st}\cos(\theta_s-\theta_t)\}\\ \frac{\partial P_s}{\partial \theta_s} &= V_s|\sum_{\substack{t=1\\t\neq s}}^{n}\{(-G_{st}\sin(\theta_s-\theta_t)\\ &\quad + B_{st}\cos(\theta_s-\theta_t))\, V_t\,\}.\end{aligned}} \quad (8)$$

Neglecting P-V coupling, the relation between incremental change in active power at system buses and the phase angles of voltages can be written in matrix form as

$$[\Delta P]_{n\times 1} = [H]_{n\times n} * [\theta]_{n\times 1}$$

Where n is the number of buses,

$$[\boldsymbol{\theta}]_{n\times 1} = [H]^{-1}_{n\times n} * [\Delta P]_{n\times 1}$$
$$[\boldsymbol{\theta}]_{n\times 1} = [M]_{n\times n} * [\Delta P]_{n\times 1}$$

Therefore,

$$[H]^{-1}_{n\times n} = [M]_{n\times n}$$

Matrix M is solved to get the values of $\frac{\partial\theta i}{\partial P_{Gg}}$ and $\frac{\partial\theta j}{\partial P_{Gg}}$ And this values are put in equation (3) to find the value of G_{Sg} [10]

It is to be noted that the generator sensitivity values thus obtained are with respect to the slack bus as the reference. So the sensitivity of the slack bus generator to any congested line in the system is always zero.

G_{Sg} denotes how much active power flow over a transmission line connecting bus-i and bus-j would change due to active power injection by generator g. The system operator selects the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling their power outputs.

Optimization of generator output is require here to remove congestion from the system. GSg denotes how much active power flow over a transmission line connecting bus-i and bus-j would change due to active power injection by generator g. The system operator selects the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling their power outputs.

The amount of rescheduling required is computed by solving the following optimization problem [10]:

$$F(Cgi) = \sum_{g}^{Ng} Cg(\Delta Pg)\Delta Pg \quad (9)$$

Subject to Energy Balance equation

$\sum_{i=1}^{Ng} Pgi = Pd + Pl,$

Pmin<Pgi<Pmax

Qmin<Qgi<Qmax

Where, P_{gi}, Q_{gi} = Active and reactive power of generator i respectively,

P_{min}, Q_{min} = Lower limit of active and reactive power of the generators

P_{max}, Q_{max} = Upper limit of active and reactive power of the generators

III. LAGRANGE ALGORITHM

The above constrained optimization problem can be convert to unconstrained optimization problem using lagrange method. Lagrange multiplier method can be used to minimized or maximized the function with side conditions, Using lagrange method the function can be define as

$$L(Cgi,\lambda) = F(Cgi) + \lambda(Pd - \sum_{i=1}^{Ng} Pgi) \quad (11)$$

Where, λ is the lagrangian multiplier

Pgi is the real power generation

Pd is the real power demand

Ng is number of generator is the system

Optimal loading of generator correspond to equal incremental cost of all generators. Incremental cost of generator can be define as,

$$\frac{\partial F(Pgi)}{\partial Pgi} = 2ai\ Pgi + bi \quad (12)$$

Now differentiate lagrange equation with respect to Pgi we will get,

$$\lambda = 2ai\ Pgi + bi$$

Re-arranging the above equation to get new Pgi,

$$Pgi = \frac{\lambda - bi}{2ai} \qquad \text{For } i=1,2,3\ldots..Ng$$

Thus λ can be calculated using above equation and Pgi can be calculated as well. If a particular generator loading is reaches the limit Pgi min or Pgi max, Its loading is held fixed at this value and the balance load is shared between the remaining generators on equal incremental cost basis.

A. *Steps of Lagrange Algorithm:*

1) Step 1: Read cost coefficient ai, bi, ci; B-coefficient; convergence tolerance,ϵ; maximum iteration allowed etc.
2) Step 2: Compute initial values of Pgi and λ by assuming that the transmission losses Pl =0; then problem can be solved by eq. (1) and solution can be obtain by using

3) Step 3: Set iteration count= 1
4) Step 4: Compute Pgi (i=1,2,3…,Ng) and check necessary condition
$P_{giMin} \leq P_{gi} \leq P_{giMax}$
5) Step 5: Compute transmission Losses
6) Step 6: Compute the Function F(Cgi) for finding cost of rescheduling
7) Step 7: Compute power balance=Pd +Pl- $\sum_{i=1}^{Ng}$ Pgi.
8) Step 8: Check power balance $\leq \epsilon$,if yes go to Step 11.
9) Step 9: Update λ(new) = λ + a|ΔP|, where a is the step size used to increase the value of λ.
10) Step 10: Iteration = iteration +1, λ = λ new and go to Step 4 and repeat
11) Step 11: Compute optimal rescheduling cost and transmission loss.
12) Step 12: STOP

IV. RESULTS & DISCUSSION

IEEE-30 system is used here to solve the congestion management problem.IEEE-30 system has 24 load buses and 6 generator buses. System is made ill by gradually increasing the loading of the system.

Load increased by 25% more than the base case load so 3 lines of IEEE 30 system has overloaded. So because of this excessive loading system lines get overloaded and system get congested. Line 1-2, Line 3-4 and Line 4-6 get overloaded.

From Bus	To Bus	Line Flow	Line Limit (MW)	Power Violation (MW)
1	2	184.13	130	54.13
3	4	66.75	65	1.75
4	6	65.65	60	5.65
Total Power Violation = 61.53 MW				

Table 1:

Congested line data showed in table number-I, total violation of 61.53 MW are found in system. The values of generator sensitivities computed for the congested line 1-2 are presented in Table II.

Generator No.	Generator Sensitivity
1	Reference
2	0.883
3	0.855
4	0.734
5	0.724
6	0.684

Table 2:

Close values of sensitivities point out that the 30-bus system is practically a very small system compared to a realistic power network. All the generators show strong influence on the congested line flow. This is because a small system is generally very tightly connected electrically. Thus, all the generators are chosen to participate in congestion management and the next part of the algorithm.

Generator Number	Generator Rescheduling (MW)	Incremental Cost ($/MWH)
WITHOUT CONSIDERING GENERATOR SENSITIVITY INDEX		
1	-15.5316	38.63
2	+26.7192	40.65
3	+9.6835	41.55
4	+ 35.0000	19.00
5	+30.0000	30.04
6	+2.0000	43.23
Total Cost of Rescheduling = 211.770 $		
TOTAL RESCHEDULING = 87.85 MW		

Table 3:

Table-(III) is represent the value of generator rescheduling without utilizing the generator sensitivity index. Total cost of rescheduling is 211.770 $ and total rescheduling is 61.53 MW. Different Parameters post rescheduling and pre rescheduling is shown in Table-(IV).

Parameter	Pre-rescheduling	Post-rescheduling
P loss (MW)	16.6290	8.4720
Power Flow on Previously Congested Line(1-2)	184.13	103.86
Power Flow on Previously Congested Line(3-4)	66.75	36.37
Power Flow on Previously Congested Line(4-6)	65.65	31.89
Power Balance = 0.00007 ≈ 0.00		

Table 4:

Table (V) showed the results of generator rescheduling with considering the value of generator sensitivity.

Generator Number	Generator Rescheduling (MW)	Incremental Cost ($/MWH)
WITH CONSIDERING THE VALUE OF GENERATOR SENSITIVITY INDEX		
1	-8.9209	38.63
2	+20.1963	40.65
3	+ 6.2431	41.55
4	+25.7222	19.00
5	+21.7434	30.04
6	+1.3690	43.23
Total Cost of Rescheduling = 156.391 $		
TOTAL RESCHEDULING = 61.53 MW		

Table 6:

By utilizing the value of generator sensitivity index the amount of rescheduling is reduced and also the cost of rescheduling is reduced. Parameters post rescheduling and pre rescheduling is shown in Table-(VI).

Parameter	Pre-rescheduling	Post-rescheduling
P loss (MW)	16.6290	8.820
Power Flow on Previously Congested Line(1-2) in MW	184.13	109.23
Power Flow on Previously Congested Line(3-4) in MW	66.75	37.60

Power Flow on Previously Congested Line(4-6) in MW	65.65	32.89
Power Balance = 0.00008 ≈ 0.00		

Table 7:

So all the congested line is come into its thermal limit and congestion is removed from the system at minimum cost and all the constrained are in its prescribed limit.

V. CONCLUSION

The present paper focuses on demonstrating a technique for optimum selection of generators for congestion management and additionally lagrange multiplier algorithm is used to optimized the amount and the cost of rescheduling. Generators from the system are selected for congestion management based on their sensitivities to the power flow of the congested line followed by corrective rescheduling. The problem of congestion is modeled as an optimization problem and solved by Lagrange multiplier method. Problem is tested on IEEE-30 system and successfully remove the congestion from the system at minimum cost.

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