Congestion Management with Feasible Placing of Distributed Generators

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***Abstract*—To meet the increasing demand for electricity around the world, transmission systems must drive beyond or close to their stability, thermal and voltage limits, and so on, putting transmission system security at risk. Some transmission lines may become overwhelmed if power exchanges through them are not managed, which is known as congestion. There are many congestion management methodologies. In this research article the optimal placement of Distributed Generators to mitigate congestion has been employed using LMP based methods.**

Keywords: Locational Marginal Pricing, DC Optimal Power Flow, Lagrangian Function, Restructuring.

I. Introduction

In a monopoly market there is a direct control of a single utility on generation, transmission, and distribution. To achieve the system's lowest cost operation, generation is dispatched. This effectively means that generations are dispatched in such a way that the transmission lines' power flow restrictions are not exceeded. In a deregulated system, every buyer seeks to buy power from the cheapest generator available, regardless of the buyer's and seller's relative geographic locations. If all such transactions are allowed, the transmission channels removing the power of cheaper plants will become overburdened. When the system operator discovers that all the transactions are unable to be processed due to transmission network overload, congestion is said to have occurred [1-3]. Congestion management is a system for prioritizing transactions and sticking to a schedule that does not overburden the network [4]. Despite these precautions, real-time congestion can emerge because of a transmission line interruption [5]. The system operator then uses real-time congestion management to deal with the situation. Distributed generators also play a vital role in microgrids planning in rural and remote communities. The author in reference [6-8] reported the functioning and optimal planning of microgrid system in rural areas. There are different methodologies for congestion management like reactive power control, voltage stability etc. but all these controls the congestion from generation side.

In this paper LMP based methods have been used to relieve congestion i.e Highest LMP method and LMP Difference method. Both these methods are very useful for congestion management because they control the congestion from load side which is very beneficial from the system point of view.

II. Problem Formulation

The problem is formulated on optimal power flow (OPF) formulation with the objective function of minimization of cost of generations subject to various constraints such as power balance equality constraint and generator operating limit, line flow limit and bus voltage limit inequality constraints.

$$Minimize \sum_{z=1}^{NL} c_z\,(p_z)$$

Where NL is total number of generating units and c_z (p_z) is the cost for the generation of z[th] generating unit. The above cost function is given as quadratic cost function as:

$$C_z(P_z) \ = a_z.(P_z)^2 + b_z.(P_z) + c_z$$

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Where a_z, b_z, c_z are the coefficients of cost

Subject to multiple constraints:

A. Power Balance Equality Constraint

$P_{Gi} - P_{Di} = P_i$ For i = 1, 2, 3……. NB

$Q_{Gi} - Q_{Di} = Q_i$ For i = 1, 2, 3…..…NB

Where, NB = total number of buses

P_{Gi} = real power generation at ith bus

P_{Di} = real power demand at ith bus

P_i = real power flow from bus I

Q_{Gi} = reactive power generation at ith bus

Q_{Di} = reactive power demand at ith bus.

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B. Generator Operating Limit Constraint

$$P_{G_j}^{min} \le P_{G_j} \le P_{G_j}^{max} \quad \text{For j = 1, 2, 3….NG}$$

$$Q_{G_j}^{min} \le Q_{G_j} \le Q_{G_j}^{max} \quad \text{For j = 1, 2, 3….NG}$$

Where, $P_{G_j}^{min}$ = minimum real power output limit of j^{th} generator

$P_{G_j}^{max}$ = maximum real power output limit of j^{th} generator

$Q_{G_j}^{min}$ = minimum reactive power output limit of j^{th} generator

$Q_{G_j}^{max}$ = maximum reactive power output limit of j^{th} generator.

C. Bus Voltage Limit Constraint

$$V_i^{min} \le V_i \le V_i^{max} \quad \text{For i =1, 2, 3...NB}$$

Where, V_i^{min} = minimum voltage limit at bus i

V_i^{max} =maximum voltage limit at bus i

D. Line Flow Limit Constraint

$$L_{mn}^{min} \le L_{mn} \le L_{mn}^{max}$$

For mn = 1,2, 3…NL

Where, L_{mn}^{min} = minimum line flow between bus m and bus n

L_{mn}^{max} = maximum line flow between bus m and bus n

Lagrangian method can be used for the optimization of the above objective function subject to all constraints. It can be written as:

$$\mathcal{L} = \sum_{j=1}^{NG} C_j(P_j) + \sum_{i=1}^{NB} \lambda_{p_i}(P_i - P_{G_i} + P_{D_i}) + \sum_{i=1}^{NB} \lambda_{Q_i}(Q_i - Q_{G_i} + Q_{D_i}) + \sum_{mn=1}^{NL} \mu_l (L_{mn} - L_{mn}{}^{max}) + \sum_{j=1}^{NG} \mu_{G_j}^{-}\left(P_{G_j}^{min} - P_{G_j}\right) + \sum_{j=1}^{NG} \mu_{G_j}^{+}\left(P_{G_j} - P_{G_j}^{max}\right) + \sum_{j=1}^{NG} \mu_{G_j}^{-}\left(Q_{G_j}^{min} - Q_{G_j}\right) + \sum_{j=1}^{NG} \mu_{G_j}^{+}\left(Q_{G_j} - Q_{G_j}^{max}\right) + \sum_{i=1}^{NB} \mu_{v_i}^{-}\left(v_i^{min} - v_i\right) + \sum_{i=1}^{NB} \mu_{v_i}^{+}\left(v_i - v_i^{max}\right)$$

In the above equation λ and μ are the lagrangian multipliers associated with the power balance equality constraint and generator limit, bus voltage limit and line flow limit inequality constraints.

III. Locational Marginal Pricing (LMP)

In the deregulation system LMP is a tool or instrument used for market clearance [9]. Because of per unit rise of load or power drawn at similar bus, there will increase cost a same bus obtained, and it represented by LMP [10-12]. It is equal to congestion component, energy component plus loss component.

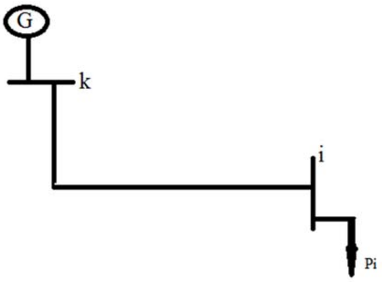

Fig. 1: Simple 2 Bus System

Where, *k* and *i* are the buses, G= generation at bus *k*, *Pi*= power drawn at bus *i*

Mathematically LMP is defined as: $\lambda_i = \dfrac{\Delta C_i}{\Delta P_i}$

$\lambda_i = \lambda_e + \lambda_{loss} + \lambda_{cong}$

Where, λ_i= LMP at bus I,

ΔC_i = incremental cost at bus I,

ΔP_i = incremental power at bus I,

λ_e = energy component,

λ_{loss} = loss component,

λ_{cong} = congestion component.

To find LMPs for base case without congestion a nonlinear programming solver has been used in MATLAB environment. This nonlinear programming solver is called as fmincon function in matlab environment, fmincon stands for finding minimum of constrained nonlinear multivariable function. Fmincon function minimize the cost function (F) given above [13-15]

Subject to equality constraint i.e.

$A_{eq}.X = B_{eq}$

Where A_{eq} = it is a matrix of the order 14 × 19 where 14 rows and 14 coulmns represents susceptance matrix and other represents decision variables i.e (P_{G1}, P_{G2}, P_{G3}, P_{G6}, P_{G8})

X= it ia vector of order 19 × 1 that represents decision variables i.e.

(δ_1, δ_2,… δ_{14} P_{G1}, P_{G2}, P_{G3}, P_{G6}, P_{G8})

B_{eq}= is also a vector of order 14 × 1 that represents load at each bus i.e. (P_{D1}, P_{D2}, ……… P_{D14})

As the LMPs obtained by the lossless DCOPF model for base case without congestion has come same at every bus therefore market operator can clear the market at single price.

Optimal Placement of DG Method: The optimal placement of Distributed Generators depends on the LMP values at each bus. There are two methods Highest LMP method and LMP difference method. When there is no

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congestion in the system then LMP at each bus is same and there is no need of DG to mitigate congestion but when there is congestion in transmission lines then LMP at each bus is not same, here we need the DG for congestion mitigation. In Highest LMP method we have found the LMP at each bus and placed the DG at highest LMP bus and so on. This method is not very accurate because there are minor variations in LMP [16-17]. In LMP Difference method the difference of LMP between two buses has been taken and then the variations in LMP is seen. This is a better method for accurate DG placement.

Algorithm Steps:- The procedure for finding the optimal placement of Distributed Generators and LMP calculation at each bus includes following steps:

Step 1: Obtain the Generator data, line data, bus data, generator cost data and other power flow data of the utility test system.

Step 2: Run optimal power flow and obtain LMP values.

Step 3: Check whether LMP values are in limit or not.

Step 4: If the LMP is not within limit then check abnormal condition of load increased.

Step 5: When the LMP is not same for all buses then there is congestion and check the buses for highest LMP.

Step 6: Place the DG at highest LMP bus and manage the congestion.

Step 7: Take the LMP difference between two buses and then put the DG at highest LMP difference buses.

Step 8: Obtain the LMP values again after optimal power flow and check the system for congestion.

Step 9: Stop.

IV. Result and Discussion

For IEEE 14 bus system when there is no congestion then obtain the DC optimal power flow and get the LMP values. As there is no congestion in the system then LMP values are same for all buses.

Table 1: LMP Values When No Congestion

S. NO.	BUS NO	LMP($/MWH)
1	1	39.02
2	2	39.02
3	3	39.02
4	4	39.02
5	5	39.02
6	6	39.02
7	7	39.02
8	8	39.02
9	9	39.02
10	10	39.02
11	11	39.02
12	12	39.02
13	13	39.02
14	14	39.02

Now we have considered three cases when there is congestion in the system. First case we consider congestion between line 1-5, second case we consider congestion between line 7-8 and third case we consider congestion between line 1-2.

Table 2: Comparison Between LMP in Different Congestion Cases

S. NO.	NO CONGESTION (LMP) ($/MWH)	CONGESTION 1-5 (LMP) ($/MWH)	CONGESTION 7-8 (LMP) ($/MWH)	CONGESTION 1-2 (LMP) ($/MWH)
1	39.02	31.833	34.106	28.629
2	39.02	35.947	37.059	43.538
3	39.02	38.272	38.727	41.910
4	39.02	40.280	40.168	40.504
5	39.02	41.725	41.204	39.492
6	39.02	41.253	40.866	39.822
7	39.02	40.539	40.354	40.323
8	39.02	40.539	40.354	40.323
9	39.02	40.678	40.454	40.225
10	39.02	40.781	40.527	40.153
11	39.02	41.013	40.693	39.991
12	39.02	41.208	40.833	39.854
13	39.02	41.172	40.808	39.879
14	39.02	40.894	40.608	40.074

According to highest LMP method in first case highest LMP is at bus 5 so the DG is placed here and so on. Similarly in second case DG is placed at bus 5 because LMP has highest value. This method is not very accurate

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because there is low difference between LMP of two buses. We also see the graphical comparison when there is no congestion and when there is congestion between 1-5.

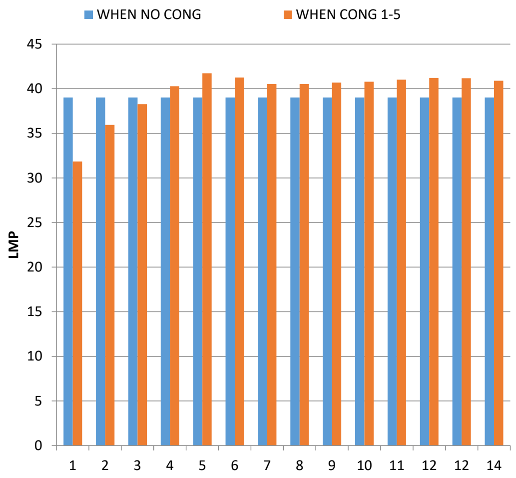

Fig.2: Comparison in LMP Values when there is Congestion and when no Congestion

Now we see in table 3 comparison in LMP values when we use LMP difference method. It is easy to place DG in LMP difference method because here more precise result is obtained as compare to Highest LMP method.

Table 3: LMP Comparison with LMP Difference Method

S. NO.	BUS NO	CONG 1-5 LMP DIFFERENCE	CONG 7-8 LMP DIFFERENCE	CONG 1-2 LMP DIFFERENCE
1	1-2	4.114	2.953	14.904
2	3-4	2.008	1.441	1.406
3	5-6	0.472	0.338	0.33
4	7-8	0	0	0
5	9-10	0.103	0.073	0.072
6	11-12	0.195	0.14	0.137
7	13-14	0.278	0.2	0.195

We take the first case when congestion between 1-5 and obtain the LMP value.

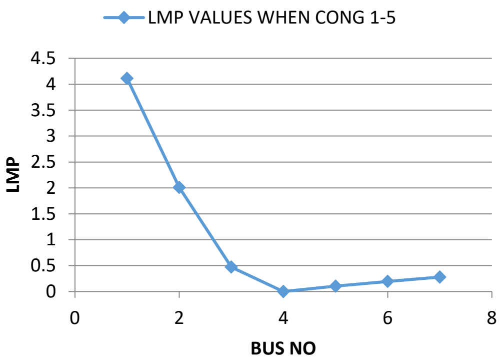

Fig. 3: Representation of Congestion at Bus 1-5

Here it is seen clearly that in this method LMP difference is highest in bus no 1-2 so the DG is placed here and it is accurate method for finding the optimal placement of distributed generators. Table 4 shows that placement of DG with Highest LMP method.

Table 4: Placement of DG According to Highest LMP Method

S. NO.	BUS NO	LMP ($/MWH)
1	5	41.725
2	6	41.253
3	12	41.208
4	13	41.172
5	11	41.013

V. Conclusion

In this paper we have found out DC OPF on IEEE 14 bus system and have applied LMP based methods for relieving congestion on the effected transmission lines. Here two methods for congestion management are proposed which are Highest LMP method and LMP difference method, both these methods are used for optimal placement of Distributed Generators so that we mitigate the congestion. LMP Difference method has been found to be very accurate and precise.

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