LMP Difference Approach for Management of Transmission Congestion

Divya Asija, K.M. Soni, S.K. Sinha and Vinod Kumar Yadav

Abstract This paper deals with new methodology for optimal placement of Distributed Generator (DG) to improve congestion in the transmission system. The proposed approach is based on LMP and LMP difference method to formulate priority list of buses. Based on priority list congested zones are formed and Distributed Generators are placed at potential location to analyze the status of the system. Loading condition is also studied. In this work, the simulation studies on IEEE 14 bus system is found to be competent to find the best location of DG for management of transmission system congestion.

Keywords Distributed generator · Locational marginal price · Congestion
Social welfare · Weighting factors

1 Introduction

In this new era, power system has been restructured from vertically integrated system to unbundled electric system. Restructuring brings the several changes by introducing electricity as commodity and deregulated power supply. Competitive market has participation from several buyers for low cost generators thereby creating intensified congestion in the linked corridors. Congestion in the system results in unrestricted loss of load which has to be avoided for reliability and security.

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Congestion management is done to decide the priority based transactions providing acceptable level of reliability and system security. In the current state of deregulated power system reliability and security of the network is of major concern which eventually enforce for the congestion management.

Literature Review

For mitigating congestion, Independent System Operator (ISO) mainly focuses on two major techniques non charge-free technique and charge-free technique [1]. Non charge-free technique involves generation re-dispatch and load curtailment. Charge-free technique is under the control of transmission system operator not involving Generation and Distribution Company. It includes network reconfiguration, installation of phase shifter, transformer taps, and utilization of series flexible AC transmission system devices. The above mentioned congestion management techniques exploit diverse techniques such as generation rescheduling [2], line flow sensitivity [3], voltage stability [4], installation of facts devices [5–7], network reconfiguration [8], relative electrical distance [9], expert system approach [7, 8, 10, 11], usage of Sen Transformer [12], zones and clustering [15, 16], power loss improvement [12, 13] and location of dispersed generator [10, 13, 14, 15].

In the proposed system the DGs have been used at the load side. DGs are small scale generators installed at consumer end for incrementing power system generating capacity. DG is considered as a good alternative for improving congestion in view of the fact that it itself acts as negative load thus reducing the higher payoff due to excess load [8]. Congestion cost diminishes with the installation of DG as it limits the expansion of transmission and high consumer demand by providing highly secure and reliable electricity. DGs supply the local load and remove the congestion from the transmission corridors thereby lowering the location marginal price (LMP) and nodal congestion price (NCP) for optimal power flow. The location of DG should be done with due consideration to provide maximum benefit. Improper placement may sometimes result in jeopardizing the system reliability and efficiency by augmenting the network congestion.

This paper is planned in the following manner: Sect. 2 presents the formulation of problem for congestion management. Section 3 deals with LMP and LMP difference method. Section 4 presents the simulation studies and result. Section 5 explains the conclusion related with the proposed system.

2 Problem Formulation

In these section nodal prices of electricity has been evaluated by optimal power flow (OPF) formulation to evaluate the price energy (NCP or LMP) with the objectives of social welfare maximization and network security. Optimal power flow (OPF) algorithm uses interior point nonlinear method to simultaneously optimize the multiple objectives. Social welfare is basically the benefit to the negotiator and it is the difference of total cost incurred by the consumer minus the total cost of supplier. The inputs to the OPF routine are generation and demand offers. At the base level OPF routine evaluates the generation dispatch, load demand, and nodal prices. The placement of DG is optimal when it meets the load demand at a lesser price by redistributing the power flow over the transmission lines. DG owner will place the DG in the network to achieve maximum revenue. Maximum revenue is generated when the location of DG is optimum to have lower LMP and NCP. DG is situated at a place to conciliate both objectives having different weightage level.

The main contribution of this paper is removal of congestion from the transmission network with the enhancement of social benefit factor and security of the system. LMP difference method is used to find the priority ranking based congestion zones. The DG will be placed at higher priority location in the transmission network which meets the load demand at lesser price thereby reducing the congestion in the network.

2.1 Optimal Power Flow Formulation

The objective function without DG comprises of quadratic profit curve submitted by consumer or distributed company, DISCO minus the quadratic offer curve of the supplier or generation company, GENCO. The ultimate goal is to minimize the function F having weighting factors as wt_1 for social welfare and wt_2 for network security.

$$\text{Min.}F = -wt_1\left[\sum_{i=1}^{n}\left(C_{\text{d}i}P_{\text{d}i} - C_{\text{s}i}P_{\text{s}i}\right)\right] - wt_2\lambda_{\text{c}} \tag{1}$$

(Objective function without the installation of DG)

$$\left.\begin{aligned} &0 < wt_1 < 1, \\ &0 < wt_2 < 1 \\ &wt_1 = 1 - wt_2 \end{aligned}\right\} \tag{2}$$

(wt_1 is weight factor for social welfare and wt_2 is for network security)

$$C_{\text{d}i}P_{\text{d}i} = x_{\text{d}i} + y_{\text{d}i}P_{\text{d}i} - z_{\text{d}i}\left(P_{\text{d}i}^2\right) \tag{3}$$

(Consumer benefit function)

$$C_{\text{s}i}P_{\text{s}i} = x_{\text{s}i} + y_{\text{s}i}P_{\text{s}i} + z_{\text{s}i}\left(P_{\text{s}i}^2\right) \tag{4}$$

(Supplier offer function)

$$\text{s.t.} \quad f(P_{\text{S}}, P_{\text{D}}, Q_{\text{G}}, \theta, V) = 0 \tag{5}$$

(Power flow equation)

$$f(P_{\text{s}}, P_{\text{d}}, Q_{\text{gc}}, \theta_{\text{c}}, V_{\text{c}}, \lambda_{\text{c}}) = 0 \tag{6}$$

(Power flow equation for max. load)

$$\lambda_{\text{cmin}} \le \lambda_{\text{c}} \le \lambda_{\text{cmax}} \tag{7}$$

(Loading Range)

$$0 \le P_{\text{S}} \le P_{\text{Smax}} \tag{8}$$

(Generator supply bid)

$$0 \le P_{\text{D}} \le P_{\text{Dmax}} \tag{9}$$

(Consumer demand bid)

$$\left.\begin{aligned} I_{ab}(\theta, V) &\le I_{ab\text{max}} \\ I_{ba}(\theta, V) &\le I_{ba\text{max}} \\ I_{ab}(\theta_{\text{c}}, V_{\text{c}}) &\le I_{ab\text{max}} \\ I_{ba}(\theta_{c}, V_{\text{c}}) &\le I_{ba\text{max}} \end{aligned}\right\} \tag{10}$$

(Thermal limits)

$$\left.\begin{aligned} Q_{\text{g min}} &\le Q_{\text{g}} \le Q_{\text{g max}} \\ Q_{\text{g min}} &\le Q_{\text{gc}} \le Q_{\text{g max}} \end{aligned}\right\} \tag{11}$$

(Generator Q limits)

$$\left.\begin{aligned} V_{\text{lower}} &\le V \le V_{\text{higher}} \\ V_{\text{lower}} &\le V_{\text{c}} \le V_{\text{higher}} \end{aligned}\right\} \tag{12}$$

(Voltage security limits)
The objective function with inclusion of DG is as follows:

$$\text{Min.}F = -wt_1 \left[\sum_{i=1}^{n} \left(C_{\text{d}i} P_{\text{d}i} - C_{\text{s}i} P_{\text{s}i} - C_{\text{dg}_i} P_{\text{dg}_i} \right) \right] - wt_2 \lambda_{\text{c}} \tag{13}$$

DG offer function is represented as

$$C_{\mathrm{dg}_i} P_{\mathrm{dg}_i} = x_{\mathrm{dg}_i} + y_{\mathrm{dg}_i} P_{\mathrm{dg}_i} + z_{\mathrm{dg}_i} \left(P_{\mathrm{dg}_i}^2 \right) \tag{14}$$

where

C_{s} is the supply cost ($/MWh)
C_{d} is the demand cost ($/MWh) minimum
$C_{\mathrm{dg}i}$ is the supply cost of distributed generator ($/MWh)
$P_{\mathrm{s}i}$ is the generated output power of unit i (MW)
$P_{\mathrm{d}i}$ is the power demand by consumer of unit i (MW)
$P_{\mathrm{dg}i}$ is the generated output power form distributed generator for unit i (MW)
Q_{g} is the reactive power output of unit i (MVar)
λ_{c} is the critical loading parameter
I is the total generating units
J is the total consumer units
N is the total transmission lines
μ_i is 1 for online unit i

In the above problem formulation, the congestion management problem has been resolved by installation of DG at optimum location thereby maximizing objectives of social welfare and network security.

3 LMP Difference Method

3.1 Locational Marginal Price

Location Marginal Price imitates the true marginal cost of production taking into account all operational and physical constraints of the system. It is calculated as the cost of allocating the subsequent increment of load at every location. Under normal operating conditions the value of LMP is same at all locations but when congestion occurs in the transmission network it differs. In a bilateral market, higher LMP gives the indication that demand is higher than the generation at that node. Injection of active power at the node having higher LMP will further accomplish the objective of social welfare maximization. DG is the source of active power and best suited to improve the system performance.

3.2 LMP Difference

LMP difference method finds the difference of LMPs of two nodes where transmission line is connected. The value of LMP difference is highest in case of congested line as compared to other lines. Therefore it directly indicates the prioritized location for placement of DG. LMP difference method is more reliable as compared to highest LMP method which sometimes leads to further increment in congestion.

LMP difference equation:

$$\Delta\mathrm{LMP}_{x\rightarrow y} = \mathrm{LMP}_x - \mathrm{LMP}_y; \quad x \text{ and } y = 1, 2\ldots N \tag{15}$$

where $\Delta\mathrm{LMP}_{x\rightarrow y}$ is the LMPs difference of transmission line from bus x to bus y and N is the total number of buses. Equation (15) will deliver the optimum location for placement of DG. The placement of DG at optimum location would improve the LMP difference.

4 Simulation and Results

System performance is analyzed and discussed after DG installation for two distinct objectives of social welfare and network security maximization with different weighting factors. The proposed design is tested on IEEE 14 bus system. It is modified by installation of DG at the high priority location. In the proposed modified IEEE 14 bus system the DG is located at bus 14 with higher LMP method (Fig. 1).

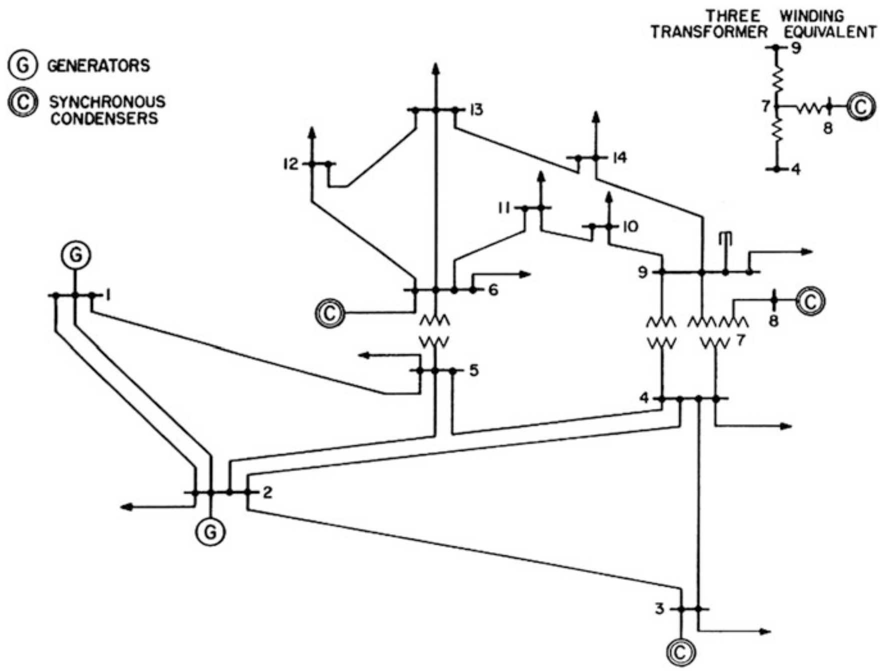

Fig. 1 Single line diagram of IEEE 14 bus system

Supplier and consumer bids data entered into the system to find the optimum power flow as shown by Table 1.

Table 1 shows the cost parameters having quadratic coefficients for the conventional generator connected in the base system and the distributed generator whose incremental cost is comparable to conventional generator in the modified system. In the modified system distributed generator will supply only the real power.

In order to have optimal placement of DG, the congestion management problem is first considered for IEEE 14 bus standard system using optimal power flow which comprises of both genco and disco functions. Results obtained are shown in Fig. 2. It is clear from the figure that bus no. 14 is having the highest NCP of 0.9631512 $/MWh and LMP of 8.8082221 $/MWh. contrary to load which is highest at node 3 having 0.9420 p.u. load. Therefore congestion is not load dependent it is directly related to the transmission capacity of the line. Consequently, bus no. 14 is considered as the desired location for placement of DG as per highest LMP. DG placement will further mitigate congestion from the transmission line.

Table 1 Cost parameters of conventional and distributed generators

Generator type	Bus number	*x* ($/h)	*y* ($/MWh)	*z* ($/MW^{2}h)
Conventional	1	0	20	0.0430293
Conventional	2	0	20	0.25
Conventional	3	0	40	0.01
Conventional	6	0	40	0.01
Conventional	8	0	40	0.01
Distributed	14	0	20	0.25

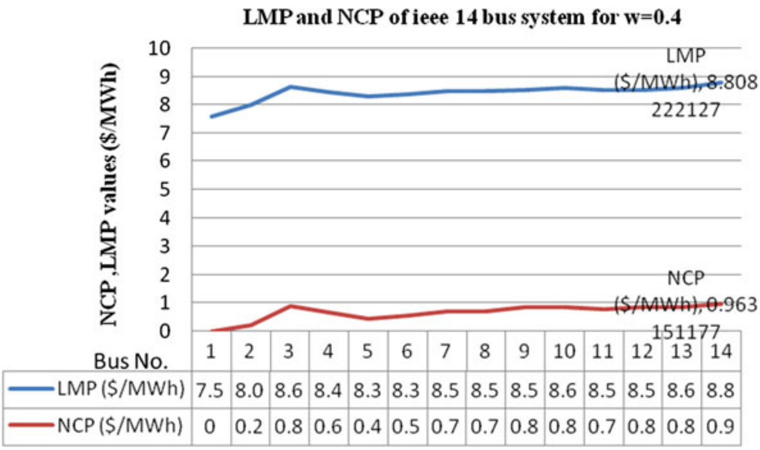

Fig. 2 LMP and NCP for IEEE 14 bus standard system

Table 2 Priority ranking for DG placement

Priority ranking	Transmission line No.	Transmission line from x to y bus	LMP difference
1	6	3 to 4	0.18
2	7	4 to 5	0.15
3	15	10 to 11	0.07
4	14	7 to 8	−8.52E−12
5	16	7 to 9	−0.0321

Table 3 Loading condition after DG placement

Maximum loading condition at optimum DG locations			
DG at bus no. 14 with LMP method		DG at bus no. 4 with LMP difference method	
Lambda (p.u.)	0.18732	Lambda (p.u.)	0.23643
Max. loading condition (MW)	307.9734	Max. loading condition (MW)	422.5383
Min. loading condition (MW)	48.588	Min. loading condition (MW)	80.7987

Table 2 shows the priority ranking for DG placement based on highest LMP difference technique. The transmission line having higher LMP difference has been placed on top. Table shows that line no. 6 is having highest LMP difference which is connected between bus 3 and 4. Since bus 3 is the generator bus, it is not considered as potential location for placement of DG. At generator bus the load demand should be greater then only it can be considered as one of the optimal location for placement of DG otherwise next sub-optimal location is considered. Bus 4 is considered as next possible location for placement of DG to relieve congestion. Bus 14 has been considered as optimal location for DG placement as per highest LMP method but it has got very less LMP difference as per Table 2.

Table 3 shows the effect of placement of DG in accordance with the two techniques of LMP and LMP difference on the loading condition of the system. The loading factor lambda increased from 0.18732 to 0.23463 p.u. resulting in increment of maximum loading condition by 114.5649 MW. Thus LMP difference technique gives better optimum location.

5 Conclusion

Results obtained from LMP and LMP difference techniques with different weighting factors are exploited to find the candidate node for installation of DG at most favorable location. DG having incremental cost equivalent to conventional generator cost is installed. Comparative analysis after DG placement in accordance with LMP and LMP difference techniques shows that loading factor has been increased when DG is placed at bus 4. Therefore it is concluded that LMP difference technique is best suited to find the optimum location of DG for congestion management and higher system efficiency.

References

1. Pillay, A., Karthikeyan, S.P., Kothari, D.P..: Congestion management in power systems—a review. Int. J. Electr. Power Energy Syst. **70**, 83–90 (2015)
2. Dutta, S., Singh, S.P.: Optimal rescheduling of generators for congestion management based on particle swarm optimization. IEEE Trans. Power Syst. **23**(4), 1560–1569 (2008)
3. Jibiki, T., Sakakibara, E., Iwamoto, S.: Line flow sensitivities of line reactances for congestion management. IEEE Power Eng. Soc. Gen. Meet. **1**, 1–6 (2007)
4. Conejo, A.J., Milano, F., García-Bertrand, R.: Congestion management ensuring voltage stability. IEEE Trans. Power Syst. **21**(1), 357–364 (2006)
5. Saravanan, M., Slochanal, S.M.R., Venkatesh, P., Abraham, J.P.S.: Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system loadability. Electr. Power Syst. Res. **77**(3–4), 276–283 (2007)
6. Acharya, N., Mithulananthan, N.: Locating series FACTS devices for congestion management in deregulated electricity markets. Electr. Power Syst. Res. **77**(3–4), 352–360 (2007)
7. Bhattacharyya, B., Gupta, V.K.: Fuzzy based evolutionary algorithm for reactive power optimization with FACTS devices. Int. J. Electr. Power Energy Syst. **61**, 39–47 (2014)
8. Granelli, G., Montagna, M., Zanellini, F., Bresesti, P., Vailati, R., Innorta, M.: Optimal network reconfiguration for congestion management by deterministic and genetic algorithms. Electr. Power Syst. Res. **76**(6–7), 549–556 (2006)
9. Yesuratnam, G., Thukaram, D.: Congestion management in open access based on relative electrical distances using voltage stability criteria. Electr. Power Syst. Res. **77**(12), 1608–1618 (2007)
10. Mithulananthan, N., Oo, T., Van Phu, L.: Distributed generator placement in power distribution system using genetic algorithm to reduce losses. Thammasat Int. J. Sci. Technol. **9**(3), 55–62 (2004)
11. Muneender, E., Vinod Kumar, D.M.: Optimal real and reactive power dispatch for zonal congestion management problem for multi congestion case using adaptive fuzzy PSO. In: IEEE Region 10 Annual International Conference, Proceedings/TENCON (2009)
12. Sen, K.K., Sen, M.L.: Comparison of the 'Sen' transformer with the unified power flow controller. IEEE Trans. Power Delivery. **18**(4), 1523–1533 (2013)
13. Dulau, L.I., Abrudean, M., Bica, D.: Optimal location of a distributed generator for power losses improvement. Procedia Technol. **22**, 734–739 (2016)
14. Gautam, D., Nadarajah, M.: Influence of distributed generation on congestion and LMP in competitive electricity market. World Acad. Sci. Eng. Technol. **39**(3), 822–829 (2009)
15. Sultana, S., Roy, P.K.: Krill herd algorithm for optimal location of distributed generator in radial distribution system. Appl. Soft Comput. J. **40**, 391–404 (2016)
16. Daganzo, C.F., Lehe, L.J.: Distance-dependent congestion pricing for downtown zones. Transport. Res. Part B: Met. **75**, 89–99 (2015)