Research Article

Multi objective optimal location and sizing of Distributed Generation unit using PSO

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Abstract

In this paper, multi objective approach used for Optimal Location and Sizing (OPS) of Distributed Generation (DG) unit using Particle Swarm Optimization (PSO) algorithm. The objectives used are Voltage Profile Improvement Index (VPII) and Locational Marginal Price (LMP). In order to improve the voltage profile and to lessen the congestion above two objectives are combined and formulate the multi objective optimization (MOO) problem. To solve the MOO problem metaheuristic optimization technique called PSO has been used. It is verified on IEEE 14-bus system to illustrate the effectiveness of the PSO.

Keywords: Multi objective optimization; PSO; distributed generation; VPII; LMP;

Introduction

The applications of DG are extremely increasing in recent years with special parameters, ratings and objectives to improve the efficiency of power systems. This is mainly due to growing attention in efficient performance of power networks and requirement in advancement of existing power plants. DG is a non-conventional energy source & these are usually placed near to load centers. Incorporation of power system with DG causes to voltage profile enhancement, lessening in Total Harmonic Distortion (THD), loss reduction & power quality improvement [1, 2].
DGs can be efficiently used for the recovery of distributed networks under unusual conditions by providing the minimum power requirements. By considering the equipment and operational constraints, DG unit installation is able to postpone an expensive system upgrades. In such cases, the abosolute conclusion will depend on DG units predictable cost which contains the capital costs corresponding to operation and utilization. To correctly decide about the OPS of DG units the result will be based on operating cost of DG, VP and congestion of the system are important for the independent system operator (ISO). There are numerous documents and literature about OPS of DG units for decline of system losses, improvement of social welfare, and enhancement of voltage profile, mitigating THD and fortification of system reliability [3]. Though, the congestion management in deregulated environment has not been considered in the DG problem and requires more attention and focus.
In conventional power plants generation, transmission, distribution and utilization are in a sequence to supply power to customers. The system of centralized power plant is shown in Fig. 1 and it has many disadvantages. Conventional power plants has the power loss in long transmission lines, the creation of nuclear waste, greenhouse gas production, inefficiencies in transmission lines, environmental distribution where the power lines are constructed and security associated issues [4]. These systems suffer with the transmission distance issues also. These issues can be reduced through DG units.

By placing the source near the end-user or at the end-user locality the transmission line matters are reduced. DG units are often generated by many renewable energy sources as shown in Fig. 2. Latest innovations permit the power to be produced in diminutive measured stations [5]. Also, the expanding utilization of conventional sources so as to decrease the natural brunt of power generation leads to the improvement and function of latest power stations [6, 7]. With this new commencement, the generation is not limited to phase1. For this reason a quantity of power demand is delivered by central generation and an additional division is created by dispersed generation, with this the electrical energy is to be delivered nearer to clients as shown in Fig. 3.

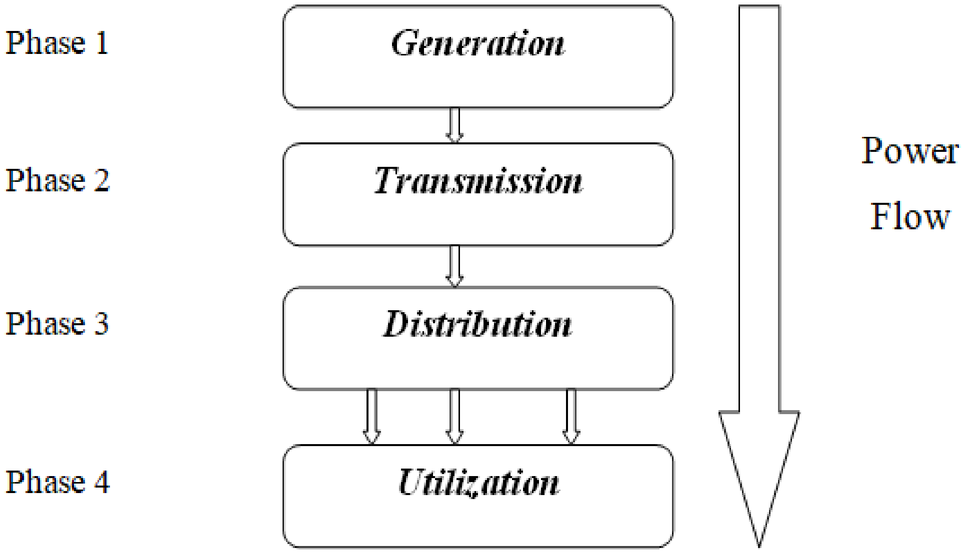

Fig. 1: Conventional industrial formation of the electrical power supply

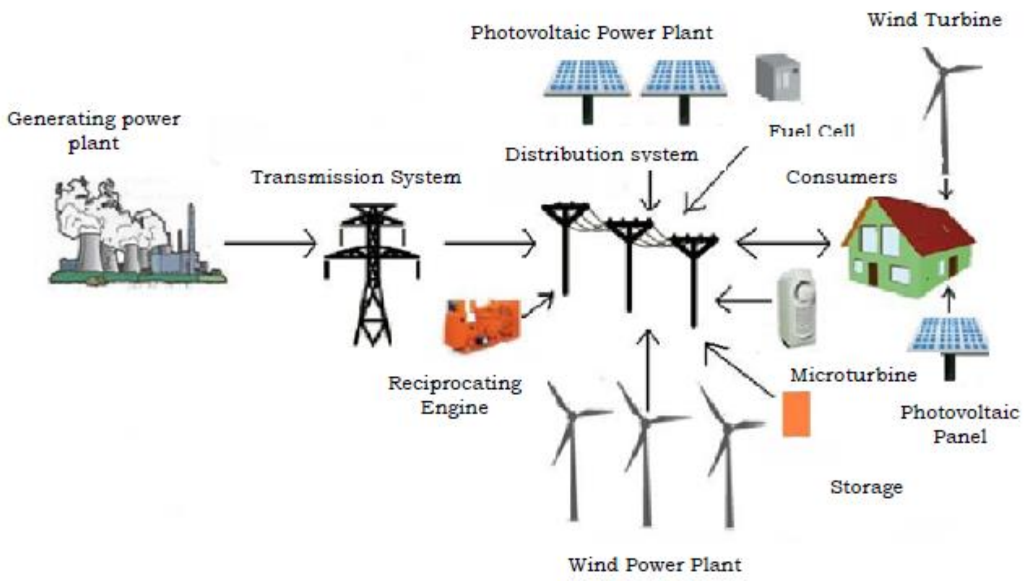

Fig. 2: DG Electricity Paradigm

Mohammad A.S. Masoum (2011)-[8]: This paper presents the algorithm PSO to find out the optimum place to insert the DG and optimum size of the DG. The objectives in this paper are congestion management in order to reduce the LMP differences in between various buses. VP improvement and minimization of cost of investment and operating cost Mithulananthan.D.G.N.(2007)-[9]: This paper presents two new methodologies for the optimum place to insert the DG and optimum size of the DG in a wholesale electricity market in an optimal power flow. The problem is stated for optimal place, with the optimal size. Two objectives are social welfare maximization and profit maximization.

Carpinelli, G.C. (2007)-[10]: This paper presents the optimal place of DG and optimal size of DG by connecting the DG to the distribution system using electronic devices. Performing by using multi-objective approach and a constarined technique is taken to solve the problem Harrison; L.F.O.A.P.-F. G. P. (2006)-[11]: This paper uses the multiobjective approach to solve the problem of where DG should be connected to the distributed system by giving priority to the technical problems.Quezada, V.H.M.A., J.R.; Roman, T.G.S.; (2006)-[12]: This paper deals with computation of annual energy losses differentiations when diverse concentration levels and penetration levels of DG are attached to a distribution system.

Alinejad-Beromi, Y.S., M.; Sadigshi, M.; (2008)-[13]: The main aim of this paper would be DG OPS for VP improvement, THD reduction and loss diminution in distribution systems using PSO.Hermann W. Dommel (1968): A realistic technique is proposed to automatically reduce the instant loss and costs by taking control variables as reactive power, transmission ratios and real power to solve the power flow problem. S.A. Hosseini, S.H.H. Sadeghi, A. Askarian-Abyaneh (2014)-[14]: This paper deals with the existing distribution system to improve the system parameters like VP, short circuit levels and power losses by using GA and this method is using to find OPS of DG sources by keeping the protective system unaffected.

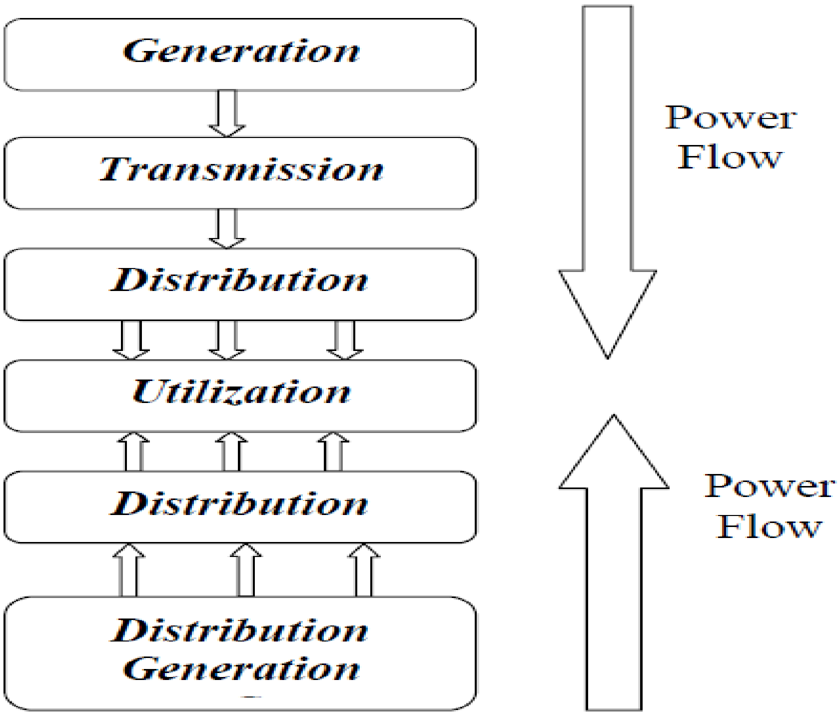

Fig. 3: New industrial formation of the electrical power supply

The main objective of this paper is OPS of DG units [15] for VP improvement and congestion management. IEEE 14 bus system is taken to show the use of the projected PSO. Multi objective function considered to improve VP is taken as VPII and for congestion management is LMP based method. Using multi-objective optimization method combining the two objectives using weighted sum method, one OPS of DG unit is found using PSO algorithm.

Problem Formulation

To determine the OPS of DG units for voltage profile enhancement, the subsequent voltage-based criteria can be taken [16]. The voltage profile VP_j of the j^{th} bus of the system is determined as

$$VP_j = \frac{(V_j - V_{minimum})(V_{maximum} - V_j)}{(V_{nominal} - V_{minimum})(V_{maximum} - V_{nominal})} \quad (1)$$

Where $V_{minimum}$, $V_{maximum}$ and $V_{nominal}$ are the minimum, maximum and nominal voltage values respectively, the whole network voltage profile index VP_{avg} of the system is indicated.

$$VP_{avg} = \frac{1}{m}\sum_{j=1}^{m} VP_j \quad (2)$$

Where m is the number of buses in the power system. The VP improvement index (VPII) for the system is defined as

$$VPII = \frac{VP_{avg\ withDG}}{VP_{avg\ withoutDG}} \quad (3)$$

The optimization problem can be stated as

$$max(VPII) \quad (4)$$

When the transmission lines are overloaded and/or large differences in the LMP values convey that there is congestion in the system.

$$LMP_B = \lambda^e + \lambda^c + \lambda^l \tag{5}$$

The objective function becomes

$$\text{Y = difference (LMP)} \tag{6}$$

$$\text{Objective = (minimum(Y)-maximum(Y))} \tag{7}$$

$$\text{F= Max (objective)} \tag{8}$$

Here IEEE 14 bus system is considering by assuming that it is a lossless system. Each bus of the system having LMP value [17], Y is the differences of the LMP values which are differentiated from the subsequent LMP value. So there will be 13 values to the variable Y. The value of the objective will be negative. So maximizing the objective means to take the LMP difference to zero by including the DG using PSO algorithm.

MULTI-OBJECTIVE OPTIMIZATION

A multi-objective optimization is a combination of more than one objective function which is to be maximised or minimised. There are several ways to solve multi-objective optimization (MOO) problem, among them weighted sum method is the simplest way to solve by creating a single meta-objective function [18]. The most common approach to solve multi-objective optimization problem is weighted sum method which is presented by Ramanathan. This technique forms two or more objectives into a single-objective by pre multiplying every one objective with a user supplied weight. After formulating the objective functions, a merged objective function is formed by summing the weight multiplied objective functions the multi objective optimization problem becomes to the single objective optimization. Optimization problem can be stated as

$$\text{Max ((} W_1 \text{ *first objective) + (} W_2 \text{ *second objective))} \tag{9}$$

W_1, W_2 are the weights using in multi-objective optimization. By giving weights to each objective, MOO is performed.

PSO Algorithm

The algorithm for optimal power flow using PSO is described in the following steps

1. Read data
2. After reading the data of particles the maximum and minimum velocities of the particles are calculated using the limits of the particle as
$$v_M = (x_M - x_m)/r \tag{10}$$
$$v_m = -v_M \tag{11}$$
3. Using the maximum and minimum velocities, random velocities of the particles are generated as
$$vel = v_m + (v_M - v_m) * rand \tag{12}$$
4. A set of particles are generated randomly by using the formula
$$D = x_m + (x_M - x_m) * rand \tag{13}$$
5. The particles are grouped into population.
6. For each set of randomly generated particles the load flow solution is obtained.
7. Objective function value is calculated at the end of each load flow for all the randomly generated populations and is stored as local best particles. The best particles among the local best particles are identified and are stored as global best particles.
8. The velocities of the particles randomly generated are updated using the formula
$$\Delta vel = \omega \times vel + \left(c_1 \times rand_1 \times local_{best} - D\right) + \left(c_2 \times rand_1 \times gloal_{best} - D\right) \tag{14}$$
$$D = D + \Delta vel \tag{15}$$
9. After checking the limit of the velocities generated the updated particles are assigned to respective particles and the load flow is performed for all the populations.
10. Objective function is calculated at the end of each load flow for every updated population and is compared with the local best particles. If the particles obtained are best when compared with previous local best, then the local best values are updated.

11. The global best values and particles are updated based on the updated local best values and particles. If the new global best obtained is comparatively best than the previous best value, the old particles are updated with the next best one.
12. Repeat the process until reach the maximum number of iterations
13. End

When the algorithm is executed, the position and velocity of each particle gets updated and settles at a best identified position in the problem space and it is known as best position to particle. For every position update, the fitness function is sampled [19, 20].

The social behavior of the flying birds is the motivation for this optimization method when searching for the food. Each bird called as particle and their group is called swarm. They search for the food in optimization problem hyperspace to find the optimal food location. The velocity and position of the particle gets updated each time using the equations (14) and (15) respectively. They get updated and change according to the supportive communication between the particles and by their individual particle at the same time. Each particle changes its place by matching the social and individual experience. Every particle is assigned a position as well as velocity vector.

The updated velocity vector for particle i is

$$v_i^{(k+1)} = wv_i^{(k)} + c_1 r_1 \left(p_{besti}^{(k)} - s_i^{(k)}\right) + c_2 r_2 \left(g_{best}^{(k)} - s_i^{(k)}\right) \quad (16)$$

Where

$v_i^{(k)}$: Particle i previous velocity

w : Inertia weight

c_1, c_2 : Individual & Social acceleration positive constants.

r_1, r_2: In the range of [0, 1]

p_{besti} : Personal best position

g_{besti}: Global best position

The informed velocity has 3 components containing of the following:

The first term indicates the last obtained velocity with two variables in it. First one being previous obtained velocity $v_i^{(k)}$along with the second variable inertia weight w.

The second component shows the personal experience of the individual known as cognitive component. The final component is called as social component as it includes the sharing of information between groups of particles. By removing second and third component the final solution can never be obtained since particles fly in the same direction. Hence the addition of 2 components aids in change of direction which helps to bring out the best possible solution which proves that combination of three components responsible for optimal value.

Results and discussion

DG unit's presence can characterize a significant effect on the distribution networks. Most of the electrical equipment's run near to the rated voltage, so the VP is the basic demand for the equipment. DG is able to supply voltage support to lift the low voltage at the end of the feeder. The VP of IEEE 14 bus system is shown in Table 1. First column, second column and third column represents the bus numbers, VP of the system before integration of DG and after integration of DG using PSO respectively. V_{nom}, V_{max} and $V_{\min}$ of the system are taken as 1 P.U., 1.1 P.U. and 0.9 P.U. respectively. VP_{avg} of the system before optimization is 0.989 and after optimization using PSO with DG is 0.995. Simulation is carried out for OPS of DG using MATLAB software. Optimal place (bus) to employ the DG is 13th bus and the optimal size is 9.118 MW. Voltage profile of IEEE 14 bus system is shown in Table 1. It is improved after multi-objective optimization by inclusion of DG at 13th bus. First column shows the bus number, second column shows the VP of the system before optimization and third column shows the VP of the system after optimization by adding DG to the system.

Table 1: Voltage Magnitude of IEEE 14 bus system

Bus. No	Voltage Magnitude before optimization (without DG)	Voltage Magnitude after multi-objective optimization (with DG)
1	1.06	1.06

2	1.035	1.035
3	1.00	1.00
4	0.985	0.99
5	0.99	0.9947
6	1.00	1.00
7	0.98	0.9919
8	0.98	1.00
9	0.967	0.9766
10	0.964	0.9728
11	0.978	0.9825
12	0.98	0.9846
13	0.976	0.9813
14	0.951	0.9722

The VP of the system is graphically shown in Fig. 4. Orange line represents the VP of the system before optimization and green dotted line represents the VP of the system after optimization by addition of DG using PSO.

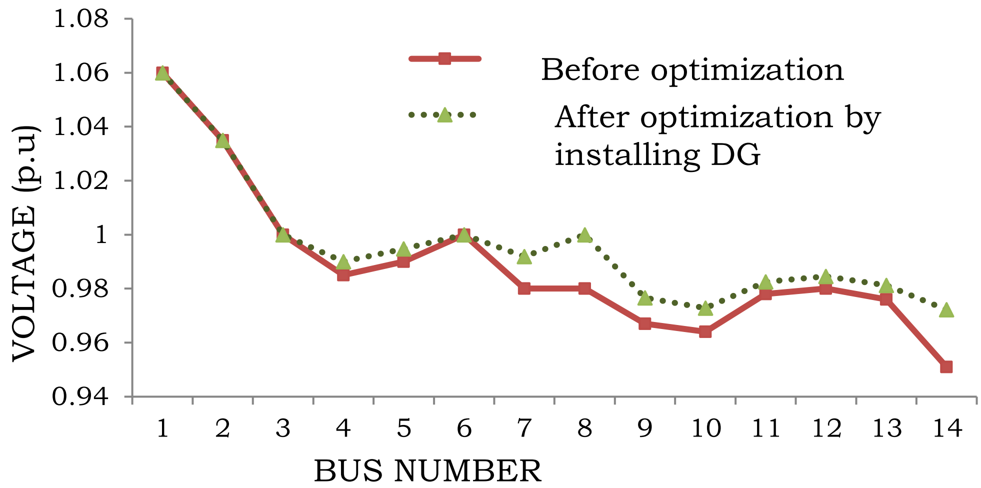

Fig. 4: Voltage Magnitudes of IEEE 14 bus system

Table 2 shows the LMP of the system before congestion and after congestion. LMP of the total system is 3.51 $/MWh before congestion which says that next increment of load at any bus can be supplied by G_2. Different LMP values say that the system is congested. When the system is congested different buses LMP values are different hence next increment of load at different buses has to supply by different generators.

Table 2: LMP of IEEE 14 bus system

Bus number	LMP before congestion $/MWh	LMP after congestion $/MWh
I	3.51	3.3673
II	3.51	3.2119
III	3.51	3.51
IV	3.51	3.7675
V	3.51	3.9531
VI	3.51	3.89
VII	3.51	3.8008
VIII	3.51	3.8008

IX	3.51	3.8183
X	3.51	3.8311
XI	3.51	3.86
XII	3.51	3.8843
XIII	3.51	3.8799
XIV	3.51	3.8452

Line flows of the system are shown in Table 3. Line flows of the system before congestion are within the thermal limits it says that there is no congestion. After making the load at bus 10 from 9 MW to 12 MW increasing by 3 MW line flows reached to the thermal limit which says that the system is congested. DG is added to the congested system using PSO to reduce the congestion. Line flows of the system after minimization of the congestion are within the thermal limits. So the congestion is minimized using PSO by adding DG to the system. LMP of each bus became to 3.51 ($/MWh) at each bus after placement of DG in a system at the optimal place. The differences of LMP values became to zero.

Table 3: Line flows of IEEE 14 bus system

Line	Line flow limit (MW)	Line flows (MW) before congestion	Line flows (MW) after congestion	Line flows (MW) after minimization of congestion using multi-objective approach
1-2	60	-24.2918	-22.2745	-21.7573
1-5	50	24.2918	25.2745	25.0573
2-3	70	28.7880	29.4518	30.7765
2-4	80	45.7942	46.5737	46.2209
2-5	40	39.4260	40	39.5454
3-4	30	13.888	13.9232	12.0262
4-5	30	-28.9487	-29.8426	-29.2428
4-7	40	25.9443	27.03	26.8548
4-9	20	14.8866	15.5095	14.8352
5-6	50	27.1691	27.8139	26.7598
6-11	30	9.2119	10.2016	10.0698
6-12	20	8.0294	8.0965	7.7477
6-13	20	18.7278	18.9623	17.7423
7-8	20	0	0	0
7-9	30	26.9443	27.03	25.8548
9-10	20	4.2881	5.2984	5.7302
9-14	20	8.0428	7.7412	5.4597
10-11	20	-5.7119	-6.7016	-6.5698
12-13	20	1.9294	1.9965	1.6477
13-14	20	6.8572	7.1588	5.59

Line flows of the system are within the limits after placement of DG using PSO. DG properties are shown in Table 4.

Table 4: DG properties

DG limit	0-10 MW
DG size	9.1182 MW

DG place (bus)	13
LMP value of all buses after congestion management using MOOP approach ($/MWh)	3.51

Convergence characteristics of multi-objective approach are shown in Fig.5. By giving weights equally to each objective MOO is carried out.

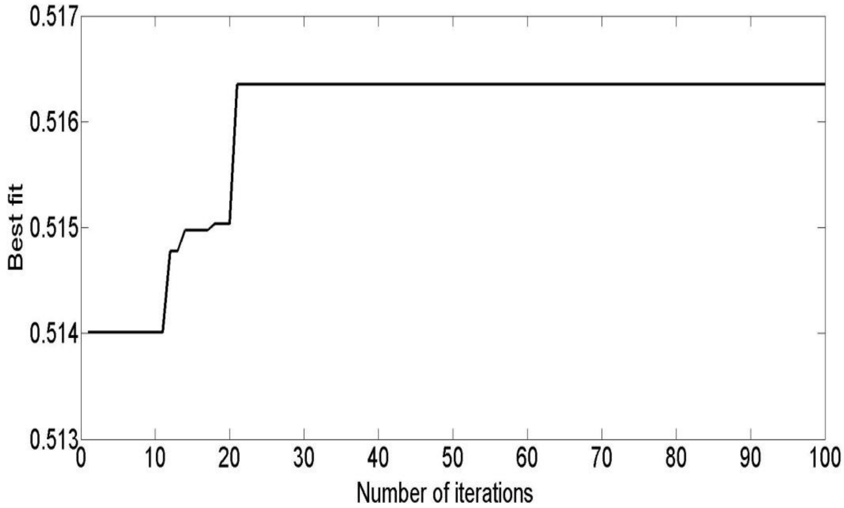

Fig. 5: Convergence characteristics of multi-objective function

Conclusions

In this paper, a PSO based algorithm for OPS of DG unit is proposed. OPS of DG unit to improve voltage profile using voltage profile improvement index (VPII) are carried out using PSO. OPS of DG unit for congestion management using LMP based criteria are carried out using PSO. OPS of DG unit using multi-objective approach are carried out using PSO algorithm. In this paper, a PSO based algorithm for optimal position & sizing of distributed generation units is suggested. The LMP established principles used to reduce the congestion on the power systems. The objective function is well-defined to advance the voltage profile & lessen investment as well as operating costs. The obtained results show that optimal position & sizing of DG units will condense the LMP differences between buses & relieves network congestion. Additionally, it will also increase the voltage profiles. This work can be further carried out by including the DG cost characteristics and different types of DG technologies. The proposed methodology can also be extended to improve the power quality issues in the system by changing the fitness function and by extending constraints.

References

[1] Le, A.D.T.K., M.A., Negnevitsky, M., Ledwich, G.: Maximising Voltage Support in Distribution Systems by Distributed Generation. IEEE Region 10 Conference TENCON 2005, Melbourne, pp. 1-6 (2005).

[2] D.T.Le., Kashem, M.A.: Optimal Distributed Generation Parameters for Reducing Losses with economic Consideration. IEEE Power Engineering Society General Meeting 2007, Tampa, pp. 1-8 (2007).

[3] Vani Bhargava.: Voltage Stability Enhancement of Primary Distribution System by Optimal DG Placement. In: H Malik.,S Srivastava., Y Sood. (eds) Applications of Artificial Intelligence Techniques in Engineering. Advances in Intelligent Systems and Computing 2016, vol. 697, pp. 65-78Springer, Singapore (2018).

[4] Srinivasa Rao, G.: Voltage Profile Improvement of Distribution System using Distributed Generating Units. International Journal of Electrical and Computer Engineering 3(3), 337-343 (2013).

[5] Srinivasa Rao, G.: Optimal Location of DG for Maintaining Distribution System Stability: A Hybrid Technique. International Journal of Electrical Power and Energy Conversion 4(4), 387-403 (2013).

[6] Kashyap, M., Mittal, A.: Optimal Placement of Distributed Generation Using Genetic Algorithm Approach. In: Nath V., Mandal J. (eds.) Proceeding of the Second International Conference on Microelectronics, Computing & Communication Systems 2017, vol 476, pp. 587-597. Springer, Singapore (2017).

[7] Mithulananthan, N.: Distributed generator placement technique in power system distribution system using genetic algorithm to reduce losses. The Thammasat International Journal of Science and Technology 9. 56-62 (2004).

[8] Mohammad A.S. Masoum.: Placement and Sizing of Distributed Generation Units for Congestion Management and Improvement of Voltage Profile using Particle Swarm Optimization. IEEE PES Innovative Smart Grid Technologies 2011, pp. 1-6. IEEE, Australia (2011).

[9] Mithulananthan, D.G.N.: Optimal DG placement in deregulated electricity market. Electric Power Systems Research 77(12), 1627-1636 (2007).

[10] Carpinelli, G.C., G.; Mocci, S.; Pilo, F.; Proto, D.; Russo, A. (2007). "Multiobjective Programming for the Optimal Sizing and Sitting of Power-Electronic Interfaced Dispersed Generators." IEEE Lausanne on Power Tech (1-5 July), pp. 443 - 448.

[11] Harrison;, L.F.O.A.P.-F. G. P. (2006). "Evaluating distributed generation impacts with a multiobjective index." IEEE Transactions on Power Delivery 21(3), pp. 1452-1458.

[12] Quezada, V.H.M.A., J.R.; Roman, T.G.S.; (2006). "Assessment of energy distribution losses for increasing penetration of distributed generation." IEEE Transactions on Power Systems 21(2), pp. 533-540.

[13] Alinejad-Beromi, Y.S., Sadighi, M.; (2008). "A particle swarm optimization for sitting and sizing of Distributed Generation in distribution network to improve voltage profile and reduce THD and losses." 43th International Universities Power Engineering Conference, UPEC (Sep. 1-4), pp. 1-5.

[14] S.A. Hosseini, S.H.H. Sadeghi, A. Askarian-Abyaneh.(2014). "Optimal Placement and Sizing of Distributed Generation Sources Considering Network Parameters and Protection Issues" 3rd International Conference on Renewable Energy Research and Applications.

[15] Gummadi Srinivasa Rao, Y. P. Obulesh, B. Venkateswara Rao, "Enrichment of Distribution System Stability Through Artificial Bee Colony Algorithm and Artificial Neural Network" In. Handbook of Research on Smart Power System Operation and Control, March, 2019, pp. 35-55, ISBN13: 9781522580300|ISBN10: 1522580301|EISBN13: 9781522580317, IGI Global, DOI: 10.4018/978-1-5225-8030-0.ch002

[16] Iyer, H., Ray. S.: Voltage Profile Improvement with Distributed Generation. IEEE Power Engineering Society General Meeting 2005, Vol. 3, pp. 2977-2984 (2005).

[17] James A. Momoh., Boswell, D.: Locational Marginal Pricing for Real and Reactive Power. IEEE power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh, PA, 2008, pp. 1-6. (2008).

[18] Luis F. Ochoa, Antonio Padilha-Feltrin.: Evaluating Distributed Generation Impacts With a Multiobjective Index. IEEE Transactions on Power Delivery, Vol. 21, No. 3, pp. 1452-1458 (2006).

[19] Kunapareddy M., Rao B.V. (2020) Hybridization of Particle Swarm Optimization with Firefly Algorithm for Multi-objective Optimal Reactive Power Dispatch. In: Deepak B., Parhi D., Jena P. (eds) Innovative Product Design and Intelligent Manufacturing Systems, pp 673-682. Lecture Notes in Mechanical Engineering book series (LNME). Springer, Singapore, 14 March 2020, DOI https://doi.org/10.1007/978-981-15-2696-1_64.

[20] Manasvi K., Venkateswararao B., Devarapalli R., Prasad U, "PSO Based Optimal Reactive Power Dispatch for the Enrichment of Power System Performance". In: Gupta O.H., Sood V.K. (eds) Recent Advances in Power Systems. Lecture Notes in Electrical Engineering, vol 699. Springer, Singapore. https://doi.org/10.1007/978-981-15-7994-3_24.