



Optimal Allocation of Distributed Energy Resource in Distribution System

Mahdi Mozaffari Legha¹, Mansour Shamsi Goshki²

¹Department of Power Engineering, Kahnooj Branch, Islamic Azad University, Kahnooj, Iran.

Email: mozaffarilegha.m@gmail.com

²Electricity Distribution Company, South of Kerman, Iran.

Email: mansourshamsi@yahoo.com

Abstract: Increasing application of distributed energy resource on distribution networks is the direct impact of development of technology and the energy disasters that the world is encountering. To obtain these goals the resources capacity and the installation place are of a crucial importance. The expected energy, economic, and environmental benefits may not be achieved and a deficit in energy supply may occur if the uncertainties are not handled properly.

In this paper a new method is proposed to find the optimal allocation of DER systems to losses reduce, improve voltage profile. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on 69-bus simulation results are presented and discussed.

Keyword: distributed energy resource, losses reduce, voltage profile.

INTRODUCTION

The Distributed generations (DGs) are small-scale power generation technologies of low voltage type that provide electrical power at a site closer to consumption centers than central station generation. It has many names like Distributed energy resources (DER), onsite generation, and decentralized energy. DGs are from renewable and artificial models. DGs are the energy resources which contain Renewable Energy Resources such as Wind, Solar and Fuel cell and some artificial models like Micro turbines, Gas turbines, Diesel engines, Sterling engines, Internal combustion reciprocating engines[1]. In the present vast load growing electrical system, usage of DG have more advantages like reduction of transmission and distribution cost, electricity price, saving of the fuel, reduction of sound pollution and greenhouse gases. Other benefits include line loss reduction, peak shaving, and better voltage profile, power quality improvement, relieving of transmission and distribution congestion then improved network capacity, protection selectivity, network robustness, and islanding operations [2-3]. The impact of DG on power losses is not only affected by DG location but also depends on the network topology as well as on DG size and type [1]. The electric power industries have witnessed many reforms in recent years. The present trend toward the deregulation in power sector is forcing distribution network operators (DNOs) to improve energy efficiencies for cost reduction whereas customers are becoming more sensitive to reliability and power quality. Distributed energy resources (DERs) such as shunt capacitors (SCs) and distributed generators (DGs) are some of the essential components for achieving higher energy efficiency in distribution system operation. Several successful attempts have been made in the recent past to solve the problem of optimal allocation of either SCs [4-10] or for DGs [11-16] separately. However, the simultaneous placement strategy of DERs is more practical and can independently set and control the real and reactive power flow in distribution network(DN) [12]. Some researchers [17-24] have attempted this simultaneous allocation strategy and have shown mutual impact of these devices on the performance of distribution network using analytical or/and heuristic technique. Zou et al. [17] proposed an analytical approach for the simultaneous placement of SCs and DGs for minimizing investment cost. They reduced the search space by identifying voltage support zones using analytical approach and solved the problem using particle swarm optimization (PSO.(Abu-Mouti and El-Hawary [18] employed artificial bee colony) ABC) algorithm to determine the optimal size of DGs' power factor, and location to minimize power losses while considering various scenarios. It has been shown that

there is a substantial enhancement in the results in terms of voltage profile improvement and loss reduction. A heuristic approach is suggested by Naik et al. [19] where a node sensitivity analysis is used to identify the optimal candidate locations, and then the optimal capacity of SCs/DGs are determined by suggesting heuristic curve fitting technique. The energy efficient grid requires integrated solutions to well-formulated problems that reflect facts on the ground where all such devices coexist to achieve smart grid goals of efficiency through loss minimization and high-quality power delivered to the ultimate user [1]. Optimal DER placement can improve network performance in terms of better node voltage profiles, reduced power flows, reduced feeder losses, improved power quality and reliability of electric supply, but inappropriate DER placement may increase system losses as well as network capital and operating costs [2]. Whatever be the particular driver for a DNO, e.g., to allow the connection of more DG capacity, to reduce energy losses, or to increase network reliability, the DG planning tools must take into account essential network constraints such as voltage and thermal limits [3].

Distributed energy resource (DER) systems refer to advanced energy supply systems located in or near end users. These systems can simultaneously provide electricity, cooling, and heating to meet the demands of local users [1]. They have the potential of high overall efficiency, excellent environmental performance, low transmission and distribution losses, and other benefits through the efficient use of exhaust heat and on-site generation. In maximizing the potential economic and energy-saving benefits, the rational design and operation of DER systems are vital issues [5]. The design of such a system requires the determination of its structure by selecting appropriate equipment from numerous alternatives as well as determining the capacities and numbers of each type of selected equipment to match the load demands of specific customers [5]. The operation problem requires determining the operating strategies, such as equipment operation status (on/off) and load allocation corresponding to the relative temporal variations in load demands [5]. However, most of these approaches are formulated as deterministic mathematical programming models without considering the uncertainties of parameters. Actually, many types of uncertainties exist in the optimal design of DER systems, for example, uncertainties in load demands and energy supplies, uncertainties in market data such as electricity price and fuel price, uncertainties in equipment technological and economic data such as efficiency and investment cost, and uncertainties in relevant policies such as taxes, incentives and emission limiting policies [31–34]. If the uncertainties of parameters are ignored, then the systems' economic and energy-saving benefits may not be attained. Even more serious is the deficit in energy supply that may occur if load demands at the operation stage are larger than those estimated at the design stage [33,35]. Therefore, identifying and handling the uncertainties are necessary in designing a DER system. Various efforts have been made to assess the uncertainties in the modeling of DER systems. Sensitivity analyses have been conducted about load demands, energy prices, equipment cost and efficiency, and other aspects [36,37]. The Monte Carlo simulation, which is a common method used to describe and simulate the uncertainties expressed in the form of probability distribution, has been widely applied. Marquez et al. [38] and Dialynas et al. [39]

Used this method to carry out DER systems' availability and reliability assessment under the uncertainties of the operation status of facilities. In our previous work, Monte Carlo simulation has been used to evaluate DER systems from the perspective of energy, economic, and environmental aspects under the uncertainties of load demands and energy prices [40]. Li et al. [41] proposed an uncertain programming model composed of MINLP model and Monte Carlo simulation to optimize a combined cooling heating and power (CCHP) system with consideration of the uncertainty of load demands. Mavrotas et al. [42] developed an energy planning framework combining the MILP model and Monte Carlo simulation for buildings of the tertiary sector considering the uncertainties in natural gas price, electricity purchase price, and interest rate for investment. Parameters sensitivity analysis and Monte Carlo simulation can be used to evaluate the portion of the variance of model outputs that is attributable to the parameters and to identify the parameters that contribute the most to the uncertainties of the outputs. However, they do not have the optimization capability and cannot provide a definite optimal solution for decision makers. Moradi et al. [46] developed a fuzzy programming model for CHP systems to determine the optimal equipment capacities, employing fuzzy set theory to account for the uncertainties associated with load demands and energy prices. Stochastic programming, where the uncertainties are represented in the form of probability distributions, is used to formulate and solve problems that involve uncertain parameters. Siddiqui et al. [47,48] demonstrated that a microgrid can proceed in a sequential manner with DER systems investment in order to reduce its exposure to risk from natural gas price volatility by means of stochastic programming. Rezvan et al. [49] presented an optimization method based on stochastic programming to determine the appropriate design of the hospital's DER system under uncertainties in load demands. Handschin et al. However, operating conditions significantly affect the performance characteristics of equipment. For instance, the equipment has a low energy generating efficiency at low partial load; for gas turbines, the increase in ambient air temperature degrades the electric and thermal performance and compromises its investment in some situations. One of

the major novel contributions of this paper is to overcome these two shortcomings. The purpose of this work is to develop a methodological framework based on a two-stage stochastic programming approach for the optimal design of DER systems under multiple uncertainties. With respect to the reference [34], the novelties of the current study mainly lie in three aspects. First, the model is built in consideration of the discreteness of equipment capacities, equipment partial load operation as well as of the influence of ambient temperature on gas turbine performance. Such measures improve the accuracy and precision of the model, thus greatly increasing the reliability of the optimization results. However, on the other hand, they also bring severe challenges to modeling and solution of the model. To overcome the challenges to modeling and solution of the model, we used a concise and efficient modeling method, and transformed the nonlinear model into a linear one through linearizing the nonlinear terms without any approximation. Second, the model solution method, which is different from the existing stochastic approximation approach, is simple and easy to implement on a computer. This paper a new method is proposed to find the optimal allocation of DER systems with consideration of the uncertainties to losses reduce, improve voltage profile.

II. Formulation for the optimal design of DER systems

A structure model is developed to optimally design a DER system at the building level under purely deterministic conditions. The structure of the DER system is shown in Fig. 1. The active and reactive losses are greatly depending on the proper location and size of the DGs. The indices are defined as

$$ILP = \left(\frac{TP_{loss}^{withDER}}{TP_{loss}^{withoutDER}} \right)$$

$$ILQ = \left(\frac{TQ_{loss}^{withDER}}{TQ_{loss}^{withoutDER}} \right)$$

Where, $TP_{loss}^{withDER}$ and $TQ_{loss}^{withDER}$ are the real and reactive power losses of the distribution system with DER. $TP_{loss}^{withoutDER}$ and $TQ_{loss}^{withoutDER}$ are the real and reactive power losses of the system without DER.

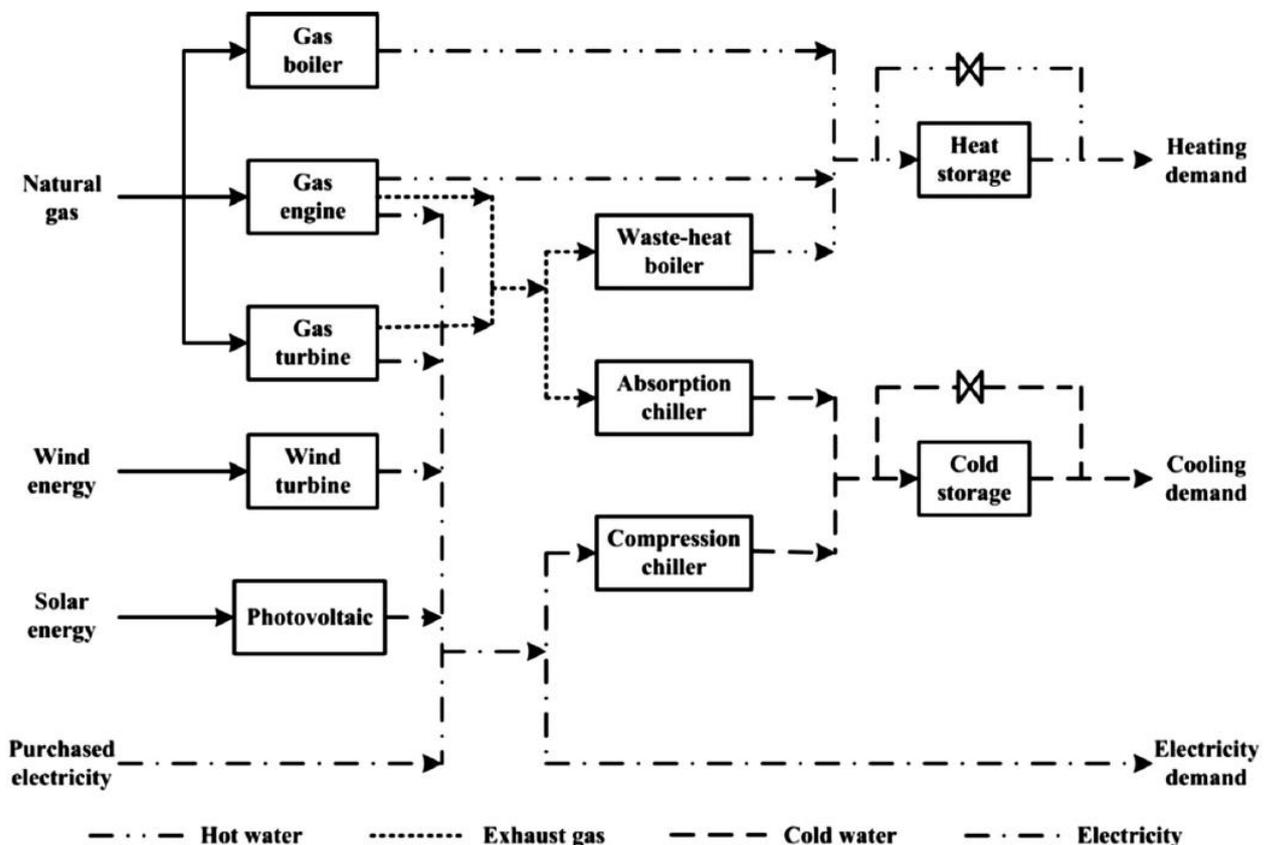


Fig. 1. Structure of the DER [4].

The design variables include the selection of the types and capacities of equipment, the number of equipment, and the capacities of the storages. The operation variables include the load allocation of equipment, the amount of energy stored or released by the storages, and the amount of electricity purchased from the external grid. The constraints can be grouped into three categories: selection and availability of equipment, performance characteristics of equipment, and energy balance and supply-demand relationships. Other constraints such as specific legislation constraints (e.g., special tariffs or tax abatements for fuel allocated to DER systems, operational restrictions, and other constraints are considered if they are necessary. The main objective of this paper is to study the effect of placing and sizing the DG in all system indices given previously. Also observe the study with renewable bus available limits. Multi objective optimization is formed by combining the all indices with appropriate weights. The multi objective function is defined as

$$\text{Objective Function} = (w_1 * ILP + w_2 * ILQ + w_3 * IVD)$$

In this paper the weight are considered as $W_1=0.4$, $W_2=0.2$, $W_3=0.25$ following the constraint

$$\sum_{k=1}^3 w_k = 1 \quad w_k \in [0,1]$$

The weights are indicated to give the corresponding importance to each impact indices for the penetration of DER s and depend on the required analysis. In this analysis, active power losses have higher weight (0.4), since the main importance is given to active power with integration of DER. Equality constraint is

$$p_{gs} + \sum_{DG=1}^m P_{DG} = p_{load} + p_{loss}$$

In equality constraint is

$$V_{imin} \leq V_i \leq V_{imax}$$

III. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods and Newton-Raphson (NR) methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [12].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [12]. Single line diagram of main feeder depicted in Fig 2.

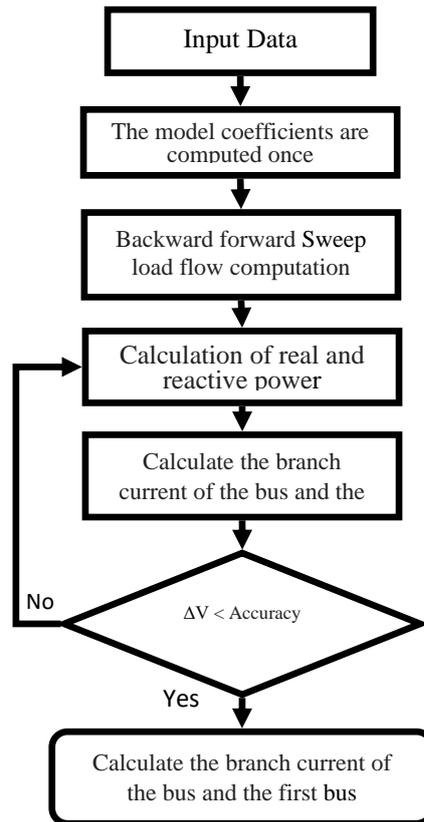


Fig 2. Single line diagram of main feeder

IV. Method

In the present paper, as mentioned, particle swarm optimization algorithm is the second EA which is used to solve the DG allocation problem. Its key concept is that potential solutions are flown through hyperspace and are accelerated towards better or more optimum solutions. It lies somewhere on between evolutionary programming and the genetic algorithms. Some of the features of PSO are adaptability, diverse response, proximity, quality, and stability (Clerk and Kennedy, 2002). There are three versions of PSO: real, binary and discrete codifications. As the decision variables of the present problem are of discrete type, hence, Discrete Particle Swarm Optimization (DPSO) method is used in this paper.

1. Produce an initial population P and create the empty external non-dominated set Q.
2. Paste non-dominated members of P into Q.
3. Remove all the solutions within Q, which are covered by any other members of Q. If the number of externally stored non-dominated solutions exceeds a given maximum N', prune Q by means of clustering.
4. Calculate the fitness of all individuals in P and Q.
5. Use binary tournament selection with replacement and select the individuals from P and Q until the mating pool is filled.
6. Apply crossover and mutation operators as usual.
7. If the maximum number of generations is reached, then stop, else go to step 2.

V. Tests and Results

Simulations are carried out on 69-bus radial distribution network using PSO approaches in order to show the accuracy as well as the efficiency of the proposed solution technique. The single line diagram for proposed radial distribution systems is shown in Fig 3. Length of all branches is considered to be equal to 60m. The properties of the three conductors used in the analysis of this system are given in Table 1.

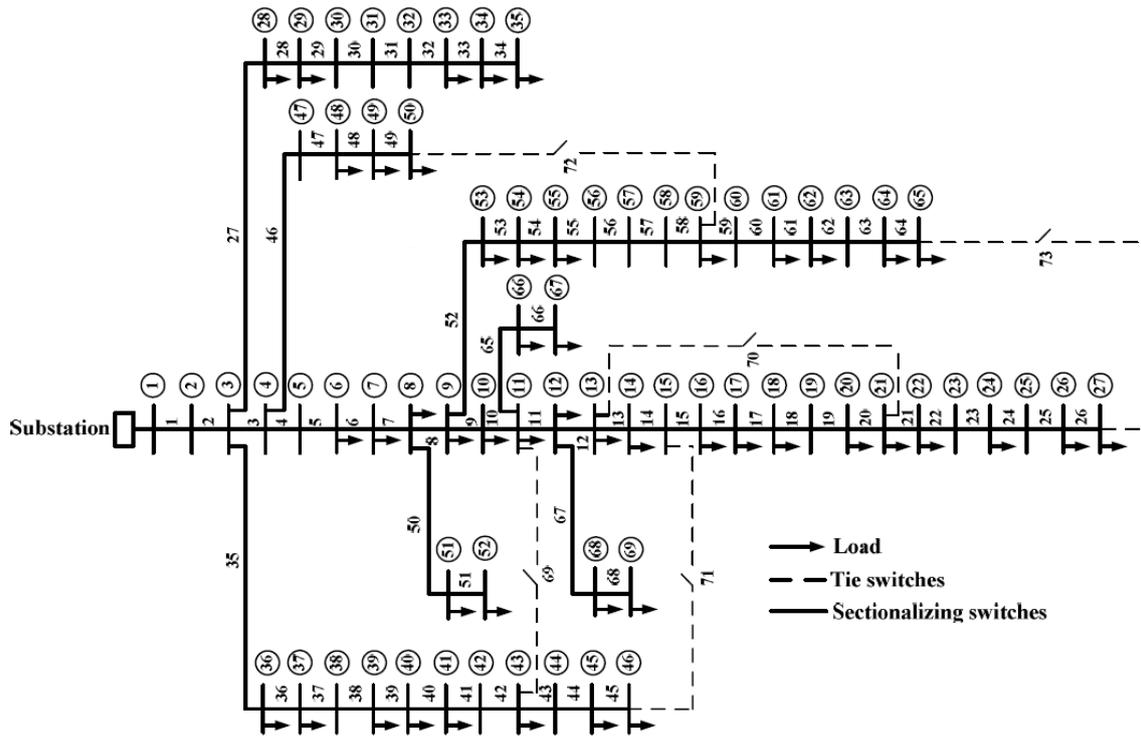


Fig 1. Single line diagram for a 69-bus radial distribution system

Table 1: Conductor properties

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm ²]	Cost [Toman/m]
Hyena	0.1576	0.2277	550	126	2075
Dog	0.2712	0.2464	440	120	3500
Mink	0.4545	0.2664	315	70	2075

The Table 2 shows the methods which are compared, location (bus number), DG capacity, and real power loss in fig 4 shows which are basic columns. After installing DG, the voltage level for that bus is improved. Furthermore, the voltage levels at all nodes for RDS have improved. It can be seen that the voltage profile achieved by PSO optimization algorithms are almost the same while having better improvement in compare with no DG state.

Table 2: Optimal Place and Size of the DG in 69 Bus systems

Bus Location	Capacity [MW]	type
3	0.47	wind
17	1.035	PV
26	1.52	PV
33	0.345	micro turbine
49	0.5	PV
64	1.5	PV

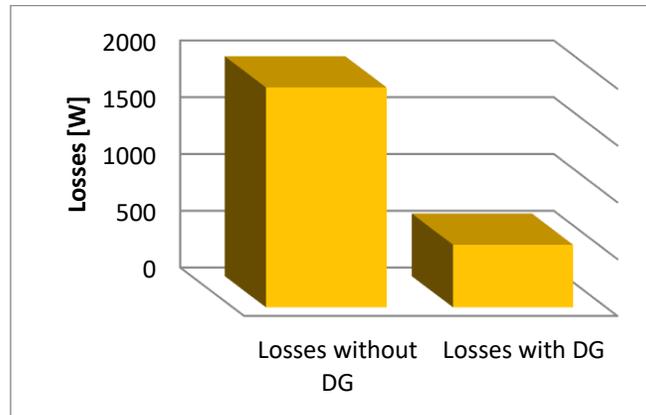


Fig 4. Bar Losses profile with & without DG in 69 bus system

VI. Conclusions

In this study, a new method is proposed to find the optimal allocation of DER systems to losses reduce, improve voltage profile. The optimization location of distribution generation in distribution must meet some objective functions in order to enhance the quality of network. The placement and capacity of the DGs in a 69 bus distribution system was presented. The objective function, which contains the different objectives combined with weights, is optimized with and without considering

the DG available bus limit constraints. The different impact indices, losses and voltages profile at all busses are studied at all cases. The total annual cost is underestimated if the DER system is designed without considering the uncertainties. The uncertainty in energy prices has the significant and greatest effect on the total annual cost, the next is the uncertainty in load demands, and the last is the uncertainty in renewable energy intensity which has little effect.

References

- [1] T. Ackermann, G. Andersson, L. Söder, Distributed generation: a definition, *Elect. Power Syst. Res.* 57 (3) (2001) 195–204.
- [2] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, W. D'haeseleer, Distributed generation: definition, benefits and issues, *Energy policy* 33 (6).798-787(2005)
- [3] K. Alanne, A. Saari, Distributed energy generation and sustainable development, *Renew. Sustain. Energy Rev.* 10 (6) (2006) 539–558.
- [4] Yun Yang, Shijie Zhang, Yunhan Xiao, Optimal design of distributed energy resource systems based on twostage stochastic programming, *Applied Thermal Engineering* 110 (2017) 1358–1370.
- [5] Andrew Keane and Mark O'Malley, "Optimal Allocation of Embedded Generation on Distribution Networks," *IEEE Transaction on Power System*, vol.20, pp. 1640-1646, 2005
- [6] Katsigiannis, Y.A., Georgilakis, P.S. "optimal sizing of small isolated hybrid power system using Tabu search", *J. Optoelectron. Adv. Mater.*, 2008, 10, (5), pp. 1241-1245
- [7] Gozel, T., Hocaoglu, M.H., "An analytical method for the sizing and siting of distributed generators in radial system", *Int. J. Electr. Power Syst. Res.*, 2009, 79, pp. 912-918
- [8] Lalitha, M.P., Reddy, V.C.V., Usha, V.: 'Optimal DG placement for minimum real power loss in radial distribution systems using PSO', *J. Theor. Appl. Inf. Technol.*, 2010, 13, (2), pp. 107-116
- [9] Jabr R.A., Pal B.C., " Ordinal optimisation approach for locating and sizing of distributed generation ", *IET Generation, Transmission and Distribution*, 2009 ; 3 (8), pp. 713-723
- [10] Deependra Singh, Devender Singh, and K. S. Verma, "Multiobjective Optimization for DG Planning With Load Models", *IEEE Transactions On Power Systems*, VOL. 24, NO. 1, Feb 2009
- [11] M. M. Elnashar, R. El-Shatshat and M. A. Salama, "Optimum Siting and Sizing of a Large Distributed Generators in a Mesh Connected System," *International Journal of Electric Power System Research*, Vol. 80, June 2010, pp. 690-697
- [12] Chandrasekhar Yammani, Naresh.s, Sydulu.M, and Sailaja Kumari M., " Optimal Placement and sizing of the DER in Distribution Systems using Shuffled Frog Leap Algorithm", *IEEE conference on Recent Advances in Intelligent Computational Systems (RAICS)*, pp. 62-67, Sep 2011
- [13] W. El-Khattam, Y. G. Hegazy and M. M. A. Salama, "An Integrated Distributed Generation Optimization Model for Distribution System Planning," *IEEE Transactions on Power Systems*, Vol. 20, No. 2, May 2005, pp. 1158-1165
- [14] R. K. Singh and S. K. Goswami, "Optimum Allocation of Distributed Generations Based on Nodal Pricing for Profit, Loss Reduction and Voltage Improvement Including Voltage Rise Issue," *International Journal of Electric Power and Energy Systems*, Vol. 32, No. 6, July 2010, pp. 637-644
- [15] A.M. El-Zonkoly, "Optimal Placement of multi-distributed generation units including different load models using particle swarm optimisation" *IET Gener. Transm. Distrib.*, 2011, Vol. 5, Iss. 7, pp. 760-771
- [16] J.-H.Teng, "Modelling distributed generations in three-phase distributed load flow," *IET Gener. Transm. Distrib.*, 2008, vol.2, No.3, pp.330-340
- [17] Feijoo A.E., Cidras J.: 'Modeling of wind farms in the load flow analysis', *IEEE Trans. Power Syst.*, 2000, 15,(1), pp. 110–115
- [18] Saber, A.Y, Venayagamoorthy, G.K.; "Plug-in Vehicle and Renewable Energy Sources for Cost and Emission Reductions," *IEEE Transaction on Industrial Electronics*, Vol. 58, No. 4, pp. 1229-1238, April 2011
- [19] Mesut E. Baran, Felix F. Wu, "Network Reconfiguration in Distribution Systems For Loss Reduction and Load Balancing," *IEEE Transactions on Power Delivery*, Vol. 4, No. 2, pp 1401-1407, April 1989
- [20] M. Mozaffari Legha, (2011) Determination of exhaustion and junction of in distribution network and its loss maximum, due to geographical condition, MS.c Thesis. Islamic Azad University, Saveh Branch, Markazi Province, Iran.
- [21] M.F. Akorede, H. Hizam, I. Aris and M.Z.A. Ab kadir, " A Review of Strategies for Optimal Placement of Distributed Generation in Power Distribution Systems," *Research Journal of Applied Sciences* 5(2):pp 137-145, 2011
- [22] M. Rastegar, M. Fotuhi-Firuzabad, H. Zareipour, Home energy management incorporating operational priority of appliances, *Int. J. Electr. Power Energy Syst.* 74 (2016) 286–292.
- [23] D. Chinese, Optimal size and layout planning for district heating and cooling networks with distributed generation options, *Int. J. Energy Sect. Manage.* 2 (3) (2008) 385–419.
- [24] D. Buoro, M. Casisi, P. Pinamonti, M. Reini, Optimal lay-out and operation of district heating and cooling distributed trigeneration systems. In: *ASME Turbo Expo 2010: Power for Land, Sea, and Air*, Glasgow, UK June 14–18, 2010.

- [25] E.D. Mehleri, H. Sarimveis, N.C. Markatos, L.G. Papageorgiou, Optimal design and operation of distributed energy systems: application to Greek residential sector, *Renew. Energy* 51 (2013) 331–342.
- [26] E.D. Mehleri, H. Sarimveis, N.C. Markatos, L.G. Papageorgiou, A mathematical programming approach for optimal design of distributed energy systems at the neighbourhood level, *Energy* 44 (1) (2012) 96–104.
- [27] A. Omu, R. Choudhary, A. Boies, Distributed energy resource system optimisation using mixed integer linear programming, *Energy Policy* 61 (2013) 249–266.
- [28] G.M. Kopanos, M.C. Georgiadis, E.N. Pistikopoulos, Energy production planning of a network of micro combined heat and power generators, *Appl. Energy* 102 (2013) 1522–1534.
- [29] Y. Yang, S. Zhang, Y. Xiao, Optimal design of distributed energy resource systems coupled with energy distribution networks, *Energy* 85 (2015) 433–448.
- [30] Y. Yang, S. Zhang, Y. Xiao, An MILP (mixed integer linear programming) model for optimal design of district-scale distributed energy resource systems, *Energy* 90 (2015) 1901–1915.