Electrical Power and Energy Systems 101 (2018) 356–370

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal sizing and location of renewable energy based DG units in distribution systems considering load growth

Hamid HassanzadehFard[a], Alireza Jalilian[a,b,*]

[a] School of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran
[b] Center of Excellence for Power Systems Automation and Operation, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Keywords:
Distribution system
Particle swarm optimization
Renewable energy resources
Total harmonic distortion
Uncertainty

ABSTRACT

In recent years, scientists have extensively focused on renewable energy resources such as wind power and solar units to reduce the consumption of fossil fuels as the main source of environmental pollutions. One of the main challenges for the production of wind and solar energies is that they often involve uncertainties due to the stochastic natures of wind speeds and solar radiation. Therefore, the existing uncertainties in the resources of wind and solar units must be considered in the planning procedure of distribution systems for having a reliable performance. To consider uncertainties in the output power of renewable energy resources, a new formulation is proposed to determine the optimal location and sizing of solar and wind units in the distribution system. To achieve this, Particle Swarm Optimization (PSO) algorithm as a robust technique is employed to find the best location and sizing of wind, solar and fuel cell units in the distribution system. The main objective of the present work is to minimize the Total Harmonic Distortion (THD), the total power losses, the total cost of DG units (including investments, replacement, operation and maintenance costs) and greenhouse gas emissions. Different types of loads such as linear and non-linear loads as well as load growth are also considered in the distribution system. To demonstrate the effectiveness of the proposed algorithm, 31-bus test system is considered as the case study. Our findings show that the use of renewable energy resources significantly reduces the greenhouse gas emissions in the mentioned system. Furthermore, the simulation results reveal that DG units must be added at some years to keep the voltage within its allowable limits.

1. Introduction

In recent years, the consumptions of electrical energy have extensively increased and this motivated the distribution system companies to supply the required power by proper design and utilization of networks. Hence, implementing the DG units in the distribution systems is one of the main solutions to provide loads of the consumers. Among various DG technologies, using of renewable energy resources such as solar, wind, and biomass has been widely considered because of their environmental benefits [1]. In fact, renewable energy resources generally require less maintenance expense than other DG technologies. The costs of their operations are also low since their fuel is derived from natural and available resources. Furthermore, the greenhouse gas emissions such as carbon dioxide or other chemical pollutants can be remarkably reduced by using renewable energy resources and consequently their detrimental effects on the environment would be minimized.

The installation of the DG units has a great role in the distribution system performance. The placement and sizing of the DG units are very crucial and challenging in the distribution system since the optimal and strategic placement of DG units reduces the system power losses and improves system voltage profile, reliability, voltage regulation, power quality issues, etc. [2,3]. The installation of DG units can have either positive or negative impacts [4]. Therefore, the installation of DG units in the proper size and location in the distribution systems is the most important problem.

Recently, many different algorithms have been widely implemented and proposed to solve the DG unit optimization problems in different systems. The main differences in these solutions are based on the formulation of problem, methodology, constraints and also assumptions being made. Some studies are based on the optimization of DG units in the hybrid systems and they only find the optimal sizing of DG units. In [5] PSO algorithm is implemented for the optimization of grid connected micro-grid consisting of photovoltaic, fuel cell and ultra capacitor considering frequency control. This algorithm is also used in [6] to optimize the reliable hybrid renewable energy system. In [7], the optimal sizing of hybrid grid-connected PV–Wind power systems is determined in order to minimize the life cycle cost of the proposed system.

* Corresponding author at: School of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran.
E-mail addresses: h_hassanzadehfard@iust.ac.ir (H. HassanzadehFard), jalilian@iust.ac.ir (A. Jalilian).

https://doi.org/10.1016/j.ijepes.2018.03.038
Received 9 January 2017; Received in revised form 24 February 2018; Accepted 28 March 2018
0142-0615/

Ref. [8] proposed a methodology for the optimization of a stand-alone hybrid PV-Wind-Hydrogen system supplying a desalination unit. In this research, the main purpose was to minimize the initial investment cost of the system. Determining the optimal size of the PV-diesel generator and the energy storage system in a stand-alone ship power system is done in [9]. Minimizing the investment and fuel cost and also the CO_2 emissions are the primary objectives of this paper. A method based on Hybrid Big Bang–Big Crunch (HBB–BC) algorithm is proposed in [10] for the optimization of a stand-alone PV, wind and battery bank hybrid power system. The objective of the paper is minimizing the total present cost of the hybrid system. In [11], Mine Blast Algorithm (MBA) is used to find the optimal sizing of a hybrid PV/WT/FC system for a remote area in Egypt to decline the annual cost of the hybrid system with load coverage. The main focus of the accessed papers is only based on finding the optimum sizing of the different DG technologies in hybrid systems.

Extensive optimization analyses were performed in the distribution systems by considering technical and economical constraints. In order to reduce power losses, Ref. [12] proposed a multi-objective shuffled bat algorithm for optimal placement and sizing of the DG units in radial distribution systems. In this work, minimizing the voltage deviation is also considered in its objective function. Ref. [13] used index vector method to find the optimum DG locations. In the mentioned paper, flower pollination algorithm is proposed to determine the optimal size of DG units. A novel method for optimization of DG units is presented in [14]. Minimizing the total power losses of the radial distribution system was the main objective of this paper. The loss sensitivity factor was used to find the optimal location of DG units. Also, intelligent water drop algorithm is used for the optimal sizing of the DG units. Bacterial foraging optimization algorithm is proposed in [15] for optimal location and sizing of DG unit in the radial distribution system. Reducing the total power losses and improving the voltage profile were the primary objectives of this study.

A hybrid method based on improved particle swarm optimization algorithm and Monte Carlo simulation is proposed in [16] for optimal DG placement and sizing in distribution networks in order to minimize the costs of total power losses and improve the voltage profile and reliability of the distribution networks. Ref. [17] used PSO algorithm to obtain the optimal location of DG units in the radial distribution systems and reduce the power losses. A Modified Teaching–Learning Based Optimization (MTLBO) algorithm is proposed in [18] for the optimization of DG units in distribution systems. Ref. [19] applied meta-heuristic algorithms including PSO, GA and Imperialist Competitive Algorithm (ICA) to determine the optimal location and size of DG units in a distribution system.

Ref. [20] proposed a problem formulation of renewable energy DG unit location and size planning that considers various constraints, relevant uncertainties, and load variations aiming at maximizing benefits of the distribution company. The main objective of [21] was to optimize the size of DG units in a hybrid power system with wind and energy storage units considering uncertainties. Ref. [22] introduced a new application of multi objective particle swarm optimization with the aim of determining optimal location and size of DG units and shunt capacitor banks simultaneously with considering load uncertainty in distribution systems.

Some studies also used mathematic programming such as Mixed Integer Linear Programming (MILP) and Mixed Integer Quadratic Programming (MIQP) to allocate DG units. Ref. [23] presented an optimization model formulated as a MILP, which determines the optimal technology portfolio, the optimal technology placement, and the associated optimal dispatch, in a micro-grid with multiple energy types. In [24], a MILP approach is also implemented to solve the problem of optimal type, size and allocation of DG units in radial distribution systems. A method based on MIQP with quadratic constraints is proposed in [25] to determine the optimal number, locations and sizes of multiple types of DG units simultaneously for power loss minimization.

Besides the abovementioned objectives, some studies have also considered power quality issues such as voltage sag, total harmonic distortion in their objective functions. In [26], PSO algorithm is used to find the optimal placement and sizing of DG units in distribution systems considering harmonic and protection coordination limits. Maximizing DG penetration level was the main objective of the mentioned paper. In this work, the main constraints were bus voltage limits, total and individual harmonic distortion limits, etc. Ref. [27] applied genetic algorithm for the optimization of DG units in distribution systems. The main constraints of this paper were voltage limits, feeder capacity, THD limits and maximum penetration limit of DG units. In [28], Improved Gravitational Search Algorithm (IGSA) is proposed to find the optimal sizing and location of DG units in a distribution system. In this work, the authors tried to minimize the total power losses, average total voltage harmonic distortion, and voltage deviation in the distribution system. In [29,30], the voltage sag is considered as another power quality index. They used genetic algorithm to find the optimal allocation of DG units.

In most of previous works, the authors did not consider the uncertainty of the output power of DG units and required loads in distribution systems. In addition, the load growth for different types of loads was not considered in their optimization procedure. Furthermore, loads did not vary with time and were assumed to be constant in previous studies. To incorporate the uncertainty and load growth, a new methodology is presented for optimal sizing and placement of renewable energy resources in the distribution system. Therefore, the innovations of our paper based on literature reviews can be listed as follows: (i) incorporating different types of loads such as linear and non-linear loads in distribution system (ii) considering the time-varying loads in the distribution system (iii) considering load growth for the available loads in the mentioned system (iv) considering the uncertainty of wind and solar power and load demand in the simulation procedure.

In this paper, the optimization of distribution system based on wind, solar and fuel cell is carried out via PSO algorithm. The backward/forward sweep technique and harmonic power flow algorithm are implemented for power flow simulation. The optimization objectives are considered as follows: (i) the reduction of the system power losses, (ii) the reduction of total costs of capital, operation, maintenance and replacement of DG units, (iii) the reduction of total harmonic distortion, (iv) the improvement of voltage profile, and (v) the decrease of greenhouse gas emissions in the radial distribution system.

The rest of this paper is outlined as follows: the components used in the distribution system are stated in Section 2. Section 3 presents uncertainty calculation. The problem formulation is described in Section 4. The PSO-based approach for solving the optimization problem with harmonic consideration is given in Section 5. The simulation procedure and results are given in Section 6, and finally, the conclusion is presented in Section 7.

2. Components used in distribution system

2.1. Renewable energy resources

Since the early 1970s, the exploitation of renewable energy resources such as wind and solar power has become increasingly attractive and cost effective due to oil crisis [31]. Several environmental and economical benefits made them very popular as alternative resources for energy production in distribution networks. In fact, the main advantages of these resources are that they have minimum environmental impacts and also low greenhouse gas emissions. To take full advantages of these resources in the present study, renewable energy resources including wind and solar power are used to install in the distribution system. These units are briefly expressed in below.

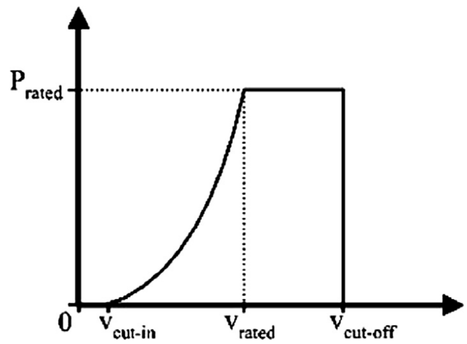

Fig. 1. Wind turbine power versus wind speed characteristic.

2.1.1. Wind generation

Excessive heat produced by the burning of fossil fuels in conventional power plants has forced companies to generate alternative power through renewable energy resources due to global warming problem. Wind energy, which is also based on renewable resources, is a proper choice since it is widely available throughout the world. Therefore, a wind generator is used as a clean technology to produce electrical energy in this paper.

In this paper, different power-speed curves are used to calculate the output power of wind turbines. The applied diagram of wind turbine power versus wind speed characteristic is shown in Fig. 1.

The power of the wind turbine is described in terms of the wind speed by the following equation [32]:

$$\begin{cases} 0 & V < V_{cut-in},\ V > V_{cut-off} \\ P_{WG-\max} \times ((V - V_{cut-in})/(V_{rated} - V_{cut-in}))^3 & V_{cut-in} \leqslant V < V_{rated} \\ P_{rated} & V_{rated} \leqslant V \leqslant V_{cut-off} \end{cases} \quad (1)$$

in which V_{cut-in} cut in wind speed [m/s], $V_{cut-off}$ cut out wind speed [m/s], V wind speed [m/s], V_{rated} nominal wind speed [m/s], $P_{WG-\max}$ maximum power of wind turbine [kW].

2.1.2. Photovoltaic

Photovoltaic is also a renewable energy that is applied to produce electricity directly from sunlight. Since the cost of the PV arrays declines, these technologies now become more affordable than ever. Therefore, in this paper, PV arrays are also chosen to generate electricity in the distribution system. Output power of PV arrays depends on the solar radiation and can be calculated according to the following equation:

$$P_{PV} = N * P_{mpv} * G_t / 1000 \quad (2)$$

where P_{PV} is the output power of PV arrays (W), P_{mpv} is the rated power of each array under the condition $G_t = 1000$, G_t is the global irradiance incident on the titled plane (W/m^2) and N is the number of modules [33].

2.1.3. Fuel cell

The other DG units used to produce electricity in this study are fuel cells. The main benefits of fuel cells in comparison with other DG technologies are their high efficiency and also environment-friendly [19]. The most commonly used fuel cell technologies are Proton Exchange Membrane fuel cells (PEM). In this paper, natural gas is used to produce the required hydrogen for FC units. Therefore, it is important to calculate the amount of electrical energy extracted from the FC units.

Generally, the 95% of Natural gas is composed of methane. Each cubic meter of methane is equivalent with 1.29 cubic meter of hydrogen gas. The equivalent heating value of hydrogen is 3.4 kWh/m^3 in the standard conditions. Therefore, by considering 50% efficiency for fuel cell, each cubic meter of hydrogen gas produces 2.083 kWh according to the following equation [19]:

Table 1
The harmonic spectrum of the available non-linear loads.

Harmonic order	Load type: Six-pulse type-1	Six-pulse type-2	Six-pulse type-3	PWM ASD 1	PWM ASD 2	Six-pulse VFD
1	1	1	1	1	1	1
5	0.2	0.191	0.42	0.02	0.828	0.235
7	0.143	0.131	0.143	0.012	0.775	0.061
11	0.091	0.072	0.079	0.055	0.463	0.046
13	0.077	0.056	0.032	0.037	0.412	0.042
17	0.059	0.033	0.037	0.002	0.142	0.018
19	0.053	0.024	0.023	0	0.097	0.014
23	0.043	0.012	0.023	0.002	0.015	0.007
25	0.004	0.008	0.014	0.004	0.025	0.006
29	0.034	0.002	0	0	0	0.005
31	0.032	0.002	0	0	0	0.005

$$1.29(\mathrm{m}^3) * 3.4\frac{\mathrm{kWh}}{\mathrm{m}^3} * 0.95 * \eta_{fc} = 2.083(\mathrm{kWh}) \quad (3)$$

Therefore, the required amount of fuel for producing 1 kWh of energy by the FC units is obtained as follows:

$$E\left(\frac{\mathrm{m}^3}{\mathrm{kWh}}\right) = \frac{1}{2.083} = 0.48 \quad (4)$$

2.2. Loads

The loads in the distribution system are composed of linear and non-linear loads. The linear loads are modeled as a constant power while non-linear loads are applied as harmonic current sources. The non-linear loads contain two types of load including adjustable speed drive (ASD) and variable frequency drive (VFD). Table 1 presents the harmonic spectrum of the available non-linear loads in the distribution system [27].

2.2.1. Load growth modeling

Many factors such as population growth, the construction of new industrial plants would increase the electricity demands in networks. Therefore, it is more important to consider the load growth factor at the beginning of the network planning. To achieve this goal, we consider load growth for available loads in the distribution system. Consequently, new DG units should be considered to supply the growth of loads. Added DG units in ith year would produce power for (R − i + 1) years in the mentioned distribution system (R is the lifetime of the project). In addition, these units impose costs in each year to the network. For considering these costs, net present cost of added units should be calculated.

The load curve for each year is obtained by multiplying the initial load curve by the load growth coefficient for each type of load in the mentioned year as follows:

$$P_{Load}^{i} = C_i * P_{Load}^{initial} \quad (5)$$

where P_{Load}^{i} is the load curve at i th year, C_i is the load growth coefficient for each type of load, and $P_{Load}^{initial}$ is the initial load curve.

3. Calculation of uncertainty

There are different uncertainties in forecasting the output power of wind turbine and PV arrays due to the stochastic natures of the renewable energy sources such as wind speed and solar radiation. Therefore, for accurate planning and optimum using of renewable energy resources, the uncertainties should be considered in the forecasting process.

To calculate the uncertainty, the profiles of solar radiation, wind speed and load demand should be forecasted in the first stage. Then, the output power of wind and PV units can be calculated according to Eqs. (1) and (2). It should be noted that there always exist some deviations between the forecasted values and the actual ones. To consider these deviations, the following formulations suggested by [34] are employed in the present study as follows:

$$dP_{Wind} = 0.8*\sqrt{P_{Wind}} \tag{6}$$

$$dP_{PV} = 0.7*\sqrt{P_{PV}} \tag{7}$$

$$dP_{Load} = 0.6*\sqrt{P_{load}} \tag{8}$$

where dP_{Wind}, dP_{PV} and dP_{Load} are the deviations for wind power, solar power and load demand, respectively. These deviations have random natures in reality. To consider this feature, dP_{Wind}, dP_{PV}, and dP_{Load} are multiplied by random variables (*noise*) derived from the white noise block in MATLAB/SIMULINK. The white noise block generates random variables to consider the uncertainty for wind power, solar power and load demand (hourly throughout one year). In fact, 8760 scenarios are considered to represent the uncertainties in the simulation procedure. At final step, the mentioned random deviations are added to the forecasted values as follows:

$$P_{Wind\,un} = dP_{Wind}*noise + P_{Wind} \tag{9}$$

$$P_{PV\,un} = dP_{PV}*noise + P_{PV} \tag{10}$$

$$P_{Load\,un} = dP_{Load}*noise + P_{Load} \tag{11}$$

where $P_{PV\,un}$, $P_{Wind\,un}$ and $P_{Load\,un}$ are the final output power of PV and wind units and load demand, respectively.

4. The problem formulation

In this paper, the main problem is finding the optimal size and placement of renewable energy resources in the distribution system to minimize the total cost of the system and satisfy the constraints. The minimization of the total power losses of the distribution system, the total cost of the DG units, and penalty for greenhouse gas emissions are considered as the economical factors. Load balance constraint, voltage and power flow limits, total harmonic distortion limit, and output power of DG units are also considered as the main technical constraints. These factors are determined as follows:

4.1. Cost of distributed generation units

Net Present Cost (NPC), which is known as one of the most important calculations in the projects, is a capital budgeting formula that calculates the difference between the present cost of the cash inflows and outflows of a project. NPC is a method of determining the current cost of all future cash flows generated by a project after accounting for the initial capital investment [35,36]. In this paper, NPC is used to calculate the total cost of the renewable energy resources used in distribution system. The cost of each DG unit consists of capital, operation and maintenance, and replacement costs. The NPC of each DG is defined as follows:

$$NPC = N_{RE} \times \left(CC_{RE} + RC_{RE} \times K + OM_{RE} \times \frac{1}{CRF(ir,R)}\right) \tag{12}$$

$$CRF(ir,R) = \frac{ir*(1+ir)^R}{(1+ir)^R - 1} \tag{13}$$

$$K = \sum_{n=1}^{y} \frac{1}{(1+ir)^{L*n}} \tag{14}$$

$$\text{Y} = \left[\frac{R}{L}\right] - 1 \text{ if R is dividable to L} \tag{15}$$

$$\text{Y} = \left[\frac{R}{L}\right] \text{ if R is not dividable to L} \tag{16}$$

where CC_{RE}, RC_{RE}, and OM_{RE} are capital, replacement and operation and maintenance cost of DG units. R is the lifetime of the project, N_{RE} is the optimal number and L is the lifetime of each component. Capital Recovery Factor (CRF) is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time [37].

4.2. Cost of total power losses

Another significant factor considered in the objective function is the real power loss of the distribution system. The net present cost of active power loss (NPC_{Loss}) is defined by the following equation:

$$NPC_{Loss} = P_{Loss}*C_{Loss}*(1/CRF(ir,R)) \tag{17}$$

where C_{Loss} is constant penalty for power losses. The real power losses of distribution system (P_{Loss}) is defined by the following equation:

$$P_{Loss} = \sum_{i=1}^{nb} P_{Loss_i}^{(1)} + \sum_{i=1}^{nb} \sum_{h=h_0}^{h=h_{\max}} P_{Loss_i}^{(h)} \tag{18}$$

where n_b is number of branches and $h_{\max}$ is upper limit of the considered harmonic orders.

4.3. Cost of greenhouse gas emissions

In this paper, the penalty for greenhouse gas emissions is considered in the mentioned distribution system. The cost of greenhouse gas emissions ($NPC_{Pollution}$) is considered in the objective function. In this study, $C_{Pollution}$ indicates the penalty coefficient ($/kg) for emission of different greenhouse gases. This penalty factor is considered in the following equation for calculating the $NPC_{Pollution}$:

$$NPC_{Pollution} = Pollution*C_{Pollution}*(1/CRF(ir,R)) \tag{19}$$

4.4. Cost of fuel

In this paper, natural gas was used to produce the required hydrogen for the fuel cells to provide electricity. The net present cost of the purchased natural gas from grid (NPC_{fuel}) is described as:

$$NPC_{fuel} = \sum_{t=1}^{8760} [P_{fc}(t) \times C_{fuel} \times E] \times \frac{1}{CRF(ir,R)} \tag{20}$$

where E is the amount of fuel that is needed to produce 1 kWh of energy by the fuel cell.

4.5. Constraints

The constraints are significant parts of optimization process that should be defined. The constraints considered in this paper consist of two types such as equality and inequality. These constraints are briefly described as follows:

4.5.1. Equality constraints

The produced power of renewable energy resources and input power of the main bus should satisfy the required loads and power losses in the distribution system; therefore, the load balance constraint was formulated as follows:

$$P_{RE}(t) + P_{Dis}(t) = P_{Load}(t) + P_{Loss}(t) \tag{21}$$

where $P_{RE}(t)$ is the total produced power of DG units, $P_{Dis}(t)$ is the input power of the main bus, $P_{Load}(t)$ is the required electrical loads in the distribution system and $P_{Loss}(t)$ is the total power losses in the distribution system.

The injected reactive power from main bus ($Q_{Dis}(t)$) should satisfy both the required reactive loads ($Q_{Load}(t)$) and reactive power losses

($Q_{Loss}(t)$) in the distribution system. Therefore, the reactive load balance constraint was formulated as follows [38]:

$$Q_{Dis}(t) = Q_{Load}(t) + Q_{Loss}(t) \tag{22}$$

4.5.2. Inequality constraints

The inequality constraints considered in this paper are as follows:

4.5.2.1. Voltage limits. At normal conditions, the voltage of each bus must be kept within standard limits according to the following equation:

$$V_{\min} \leqslant |V_i| \leqslant V_{\max} \tag{23}$$

where, $V_{\min}$ and $V_{\max}$ are the lowest and highest allowable values of voltage. $|V_i|$ is the rms value of the i 'th bus voltage defined by following equation:

$$|V_i| = \sqrt{|V_i^1|^2 + \sum_{h=2}^{h_{\max}} |V_i^h|^2} \tag{24}$$

4.5.2.2. Total harmonic distortion limits. The total harmonic distortion at each bus must be kept less or equal to the maximum acceptable harmonic distortion level ($THD_{\max}$) described as follows:

$$THD_i\% \leqslant THD_{\max} \tag{25}$$

It should be mentioned that the amount of $THD_{\max}$ is considered 5% according to [39]. Total harmonic distortion at each bus is calculated by following equation:

$$THD_i\% = \frac{\sqrt{\sum_{h=2}^{h_{\max}} |V_i^h|^2}}{|V_i^1|} \times 100 \tag{26}$$

4.5.2.3. DG constraints. Each DG unit produces the power between the maximum and the minimum of its levels in the mentioned distribution system:

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \tag{27}$$

4.5.2.4. Power flow limits. For safe operation of the system, the transmitted apparent power through each branch must not exceed the thermal limit of the line in steady state operation as follow:

$$S_i \leqslant S_i^{\max} \tag{28}$$

4.6. Objective function

The objective function is considered to minimize total net present costs as follow:

$$ObjectiveFunction = NPC_{PV} + NPC_{Wind} + NPC_{FC} + NPC_{Fuel} + NPC_{Pollution} + NPC_{Loss} \tag{29}$$

5. Solution method

5.1. Harmonic power flow algorithm

To solve the optimization problem of DG units with harmonic distortion consideration in the distribution system, it is essential to perform harmonic power flow calculations for different harmonic orders [40]. In this paper, the forward/backward sweep technique [41] is used for harmonic power flow calculation. This technique can be divided into two parts including backward current sweep and forward voltage sweep [42,43].

Non-linear loads in the distribution system are modeled as current sources that inject harmonic currents into the system. The fundamental

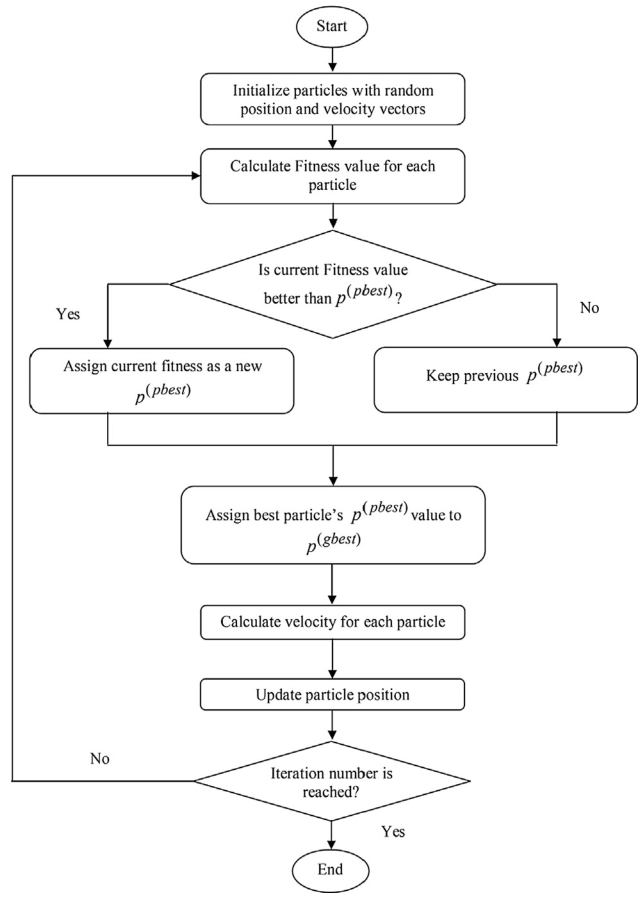

Fig. 2. Flowchart of the PSO algorithm.

and the hth harmonic current of the non-linear loads with real power P and reactive power Q are modeled as follows:

$$I_i^{(1)} = \left[\frac{P_i + jQ_i}{V_i^{(1)}}\right]^* \tag{30}$$

$$I^h = C(h) I_i^{(1)} \tag{31}$$

where $C(h)$ is the ratio of the hth harmonic current to its fundamental one. The current of each branch, can be calculated by following equation:

$$B_{i,j}^{(h)} = [A_{i,j}^{(h)}][I^{(h)}]] \tag{32}$$

$I^{(h)}$ is the system harmonic currents and $A_{i,j}^{(h)}$ is the coefficient vector of harmonic currents between buses i and j. The backward current sweep can be used to build the coefficient vectors ($A_{i,j}^{(h)}$). For example, if a bus harmonic current flows through the branch, then the corresponding position in the coefficient vector will be 1. Therefore, the coefficient vector will only consist of 0 and 1 [41].

The branch voltage drop resulting from system harmonic vector can be calculated by multiplying the branch impedance ($Z_{i,j}^{(h)}$) and the current of each branch:

$$\Delta V_{i,j}^{(h)} = Z_{i,j}^{(h)} B_{i,j}^{(h)} \tag{33}$$

After calculating the voltage drops, the bus voltage can be calculated by the forward voltage sweep as follow:

$$[V^{(h)}] = [HA_{i,j}^{(h)}][I^{(h)}] \tag{34}$$

where $HA_{i,j}^{(h)}$ is the relationship matrix between bus voltage vector and system harmonic current vector. Finally, the relationship between voltage and power can be expressed as follows:

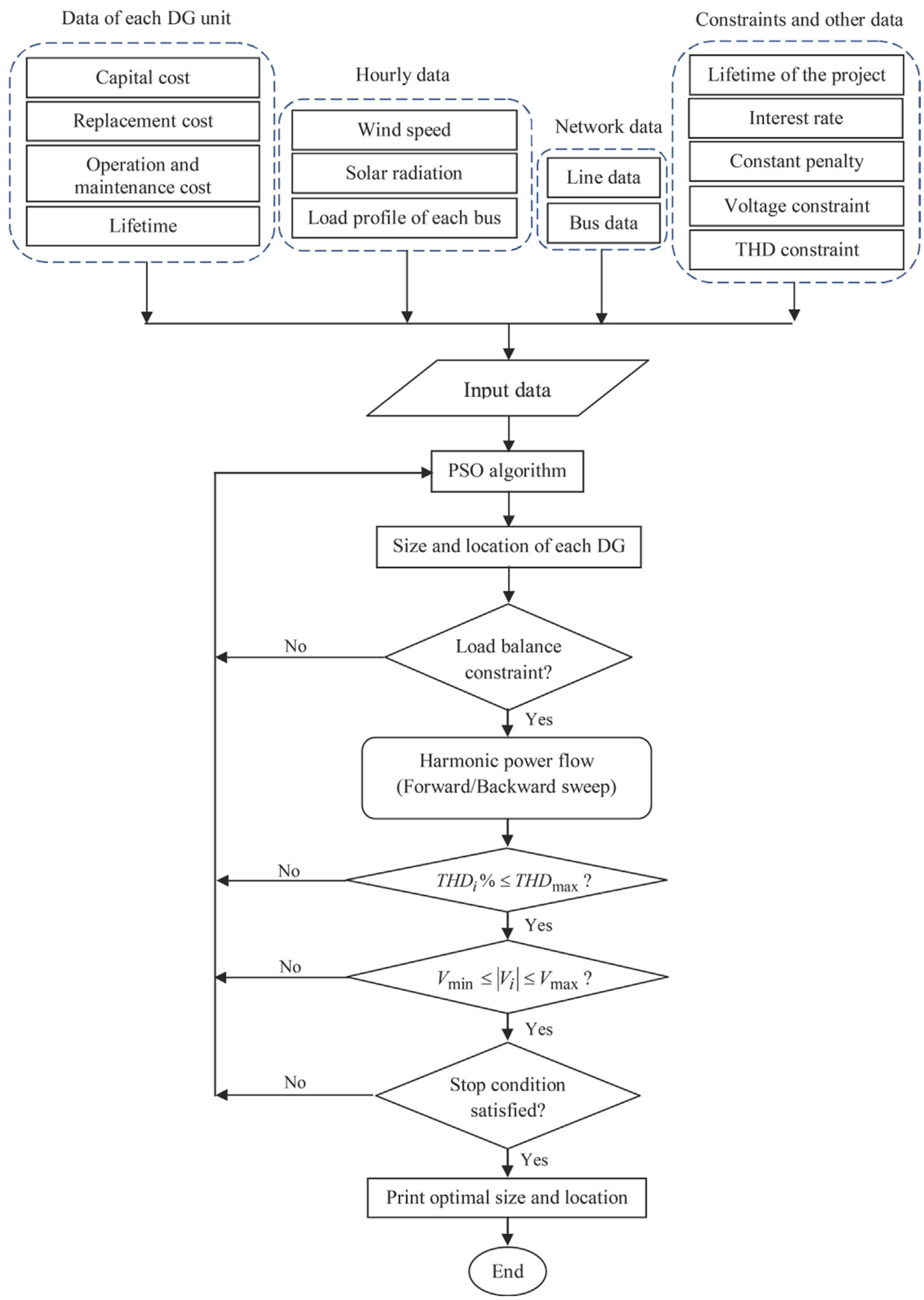

Fig. 3. Flowchart of the proposed algorithm.

$$[V^{(h)}] = [HA_{i,j}^{(h)}][C(h)]\left[\left[\frac{P_i + jQ_i}{V_i^{(1)}}\right]^*\right] \tag{35}$$

5.2. Particle swarm optimization

PSO algorithm is a population based stochastic optimization technique which was first introduced by Dr. Eberhart and Dr. Kennedy in 1995 [44]. This algorithm is based on a simple concept and can be easily implemented with computer codes [45,46]. So, in recent years, many researchers have used this algorithm for optimization problem.

In PSO algorithm, each particle represents a candidate solution for the optimization problem. Their positions are changed with time based on their present velocity, previous experience and the experience of their neighbors.

The updated velocity and position of each particle in the $(k + 1)$th iteration are calculated using the following equations:

$$v_{t+1} = w*v_t + c_1*(p^{(pbest)}-x_t) + c_2*(p^{(gbest)}-x_t) \tag{36}$$

$$x_{t+1} = x_t + v_{t+1} \tag{37}$$

where v_t is the particle velocity at the t th iteration, x_t is the particle position at the t th iteration, $p^{(pbest)}$ is the personal best position or the particle's best position thus far, $p^{(gbest)}$ is the best global position or the best solution among all particles, w is the inertia factor, and c_1 and c_2 control coefficient. The flowchart of the PSO algorithm is shown in Fig. 2.

The advantages of PSO algorithm in comparison with other optimization algorithms are as follows [19]:

- PSO is a simple algorithm and users could easily develop this

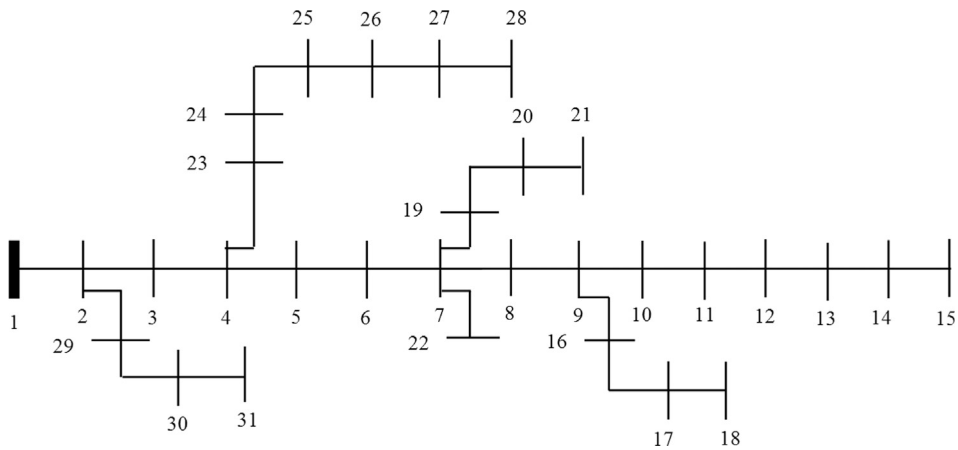

Fig. 4. 31-bus radial distribution system.

Table 2
The costs for the system components.

Type of DG unit	Capital cost ($/kW)	Replacement cost ($/kW)	O&M cost ($/kW)
PV	2500	2500	65
Wind	3500	2800	95
FC	2500	2500	70

Table 3
The peak of loads (p.u.) for each bus.

Bus number	Type of load	Peak of load	Bus number	Type of load	Peak of load
1	–	–	17	PWM-ASD 2	0.025
2	Constant	0.032	18	Constant	0.026
3	Constant	0.026	19	Constant	0.028
4	Constant	0.079	20	Constant	0.042
5	Constant	0.038	21	Six-pulse type 3	0.014
6	PWM-ASD 2	0.046	22	Constant	0.016
7	Constant	0.052	23	Constant	0.018
8	PWM-ASD 1	0.034	24	Constant	0.018
9	Constant	0.056	25	Six-pulse VFD	0.022
10	Constant	0.066	26	Constant	0.024
11	Constant	0.042	27	Constant	0.025
12	Six-pulse type 1	0.024	28	Constant	0.022
13	Constant	0.038	29	Constant	0.038
14	Constant	0.021	30	Six-pulse type 2	0.033
15	Constant	0.035	31	Constant	0.015
16	Constant	0.045			

Table 4
Power factor of each type of load.

Type of load	Cos φ
Constant	0.8
PWM-ASD 1	0.88
PWM-ASD 2	0.5
Six-pulse type 1	0.9
Six-pulse type 2	0.75
Six-pulse type 3	0.88
Six-pulse VFD	0.9

algorithm with basic mathematical and logic operations.
- It does not require the good initial solution to start its iteration process.
- PSO is much faster for power system optimization.

According to the abovementioned advantages of PSO algorithm, we implemented PSO as a powerful algorithm to determine the optimal location and size of DG units in the mentioned radial distribution system.

5.3. Solution of the proposed objective function

In this paper, PSO algorithm is used to find the optimal location and size of PV, wind and fuel cell units in the radial distribution system. This algorithm is combined with a harmonic power flow algorithm. To achieve the objectives of the paper, the initial population is generated by PSO algorithm, as representatives of DG sizes and locations. Then the given sizes with input power from main bus must provide required power and power losses in the distribution system. The harmonic power flow was done to compute the power losses, total harmonic distortion and voltage of each bus in the mentioned distribution system. If the THD and also voltage of each bus at each hour are not in their acceptable ranges, PSO generates other sizes and locations for DG units. If the produced power satisfies the required loads in the distribution system, total harmonic distortion at each bus and voltages are within their acceptable limits, the size and location are considered as the optimum. For more illustration, the flowchart of proposed algorithm is shown in Fig. 3.

To validate the proposed algorithm, the existing 34-bus electrical system from [29] is selected as a comparative case study. In the mention paper, GA algorithm has been used to find the optimal allocation of DG units in distribution system. The objective function and all constraints employed in [29] are also implemented in our proposed algorithm. Simulation results confirmed that the proposed algorithm is robust and effective for this case.

6. Simulation procedure

The developed methodology is applied to a 31-bus radial distribution system as presented in Fig. 4.

To optimize the size and location of DG units, the PSO algorithm is implemented in MATLAB software. Lifetime of the project and interest rate are chosen 20 years and 8%, respectively. The cost of each DG unit consists of capital, operation and maintenance, and replacement costs. The economic data are taken from [47–49] and are summarized in Table 2.

It should be noted that the penalty for emission of different gases and power losses are assumed to be 0.107$/kg and 0.06$/kWh, respectively [50,51]. The line data of the mentioned radial distribution system can be found in [52]. In this paper, different types of loads such

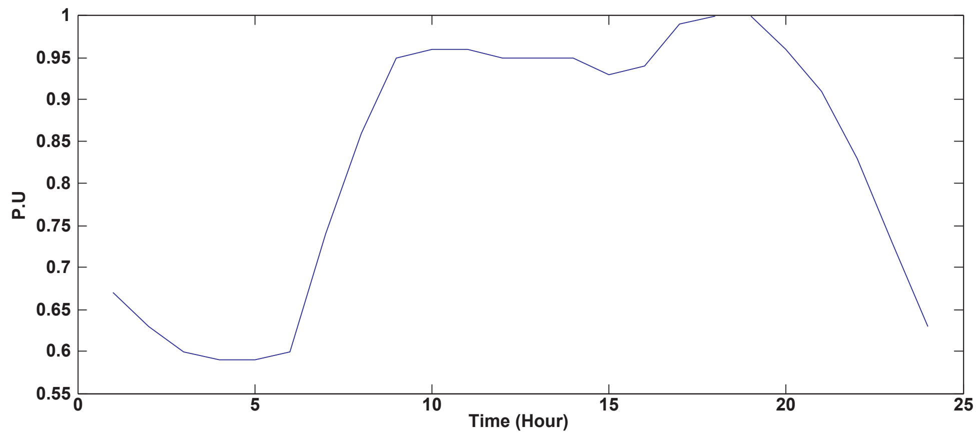

Fig. 5. The daily load profile.

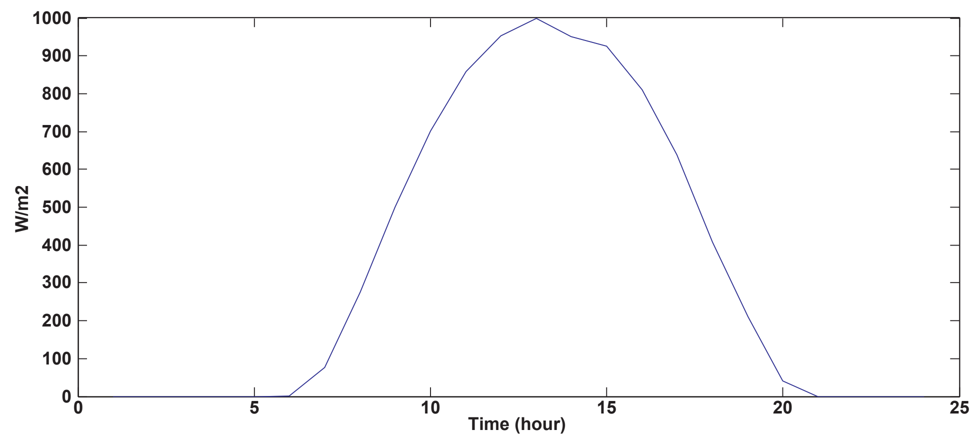

Fig. 6. Daily curve of solar radiation.

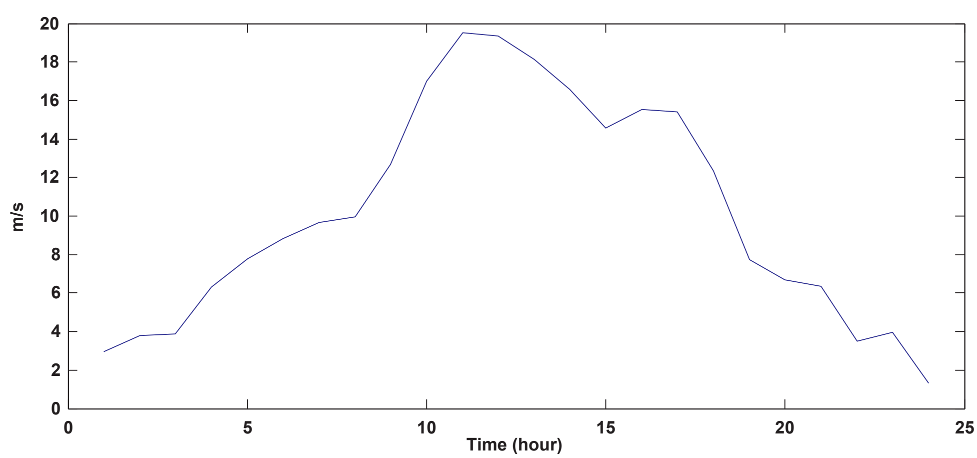

Fig. 7. Daily curve of wind speed.

as linear and non-linear loads are applied in the mentioned distribution system. The type of loads and their peaks for each bus are illustrated in Table 3.

It should be also mentioned that the total loads were considered 15 MW in the mentioned distribution system. Table 4 depicts the power factor of each type of load in the distribution system. It is assumed that all load patterns vary with time. The annual load profile is also used in the simulation procedure. However, for more illustration, daily typical load profile is shown in Fig. 5.

The yearly wind speed and solar radiation information were also considered. To more visualization, the daily curves of wind speed and solar radiation are depicted in Figs. 6 and 7.

6.1. Determining the optimal location and size for DG units

The PSO algorithm is applied to find the optimal sizing and location of DG units including PV systems, wind turbines and fuel cells in the radial distribution system. The mentioned DG units are examples of inverter-based DG units. The inverter-based DG units would act as the harmonic producing device in the distribution system. The typical

Table 5
Harmonic spectrum of inverter-based DG units.

Harmonic order	Inverter based DG
1	1
5	0.1941
7	0.1309
11	0.0758
13	0.0586
17	0.0379
19	0.0329
23	0.0226
25	0.0241
29	0.0193
31	0.0181

Table 6
Optimal size and location of DG units.

	PV	Wind	Fuel cell	Cost
Size (MW)	2.2	2	7.7	$8.15 * 10^7$
Location	17	18	15	

harmonic spectrum of inverter-based DG units is shown in Table 5 [53].

The optimal size and location of DG units are shown in Table 6.

The objective function versus the number of iterations is shown in Fig. 8.

The amounts of the produced power of each DG unit and input power from main bus for providing the available loads are shown in Fig. 9. The mentioned figure shows the percentage of total required power in the distribution system provided by each component at each hour.

Fig. 9 clearly shows that PV arrays and wind turbines produce power between 7:00 AM–20:00 PM and 4:00 AM–21:00 PM respectively. At the other times, fuel cells and input power from main bus provide the available loads in the mentioned distribution system.

The voltage profile for the peak load condition after optimal sizing and placement of DG units is shown in Fig. 10. From this figure, it is obvious that the voltage profile was improved to a standard range by optimal installation of DG units.

To show the efficiency of the proposed optimization procedure, some buses are chosen to be analyzed with more details. Therefore, the voltage variations of bus 2 in the day before and after DG installation are shown in Fig. 11. Bus 2 is at the head of the mentioned radial distribution system, and its voltage is mainly dominated by the main bus. Therefore, its voltage is nearly maintained at 1 p.u. in all hours in the day.

Fig. 12 depicts the voltage profile of bus 11 after optimal installation of DG units at each hour. It is clear that the voltage profile was improved and kept within its acceptable limit in the condition in which loads were varied all the day. Furthermore, the voltage variations were within a safe interval ((0.95, 1.05)) at all hours for this bus.

The voltage variations of bus 17, in which the PV arrays were optimally installed, are shown in Fig. 13. Since PV arrays initiate to produce power at 7:00 AM, its voltage greatly increases. Even though there are voltage variations at each hour in the day, the voltage of each bus is within the safe interval.

Fig. 14 shows the variations of the total power losses in the mentioned distribution system at each hour after and before the installation of DG units. The figure clearly shows that total power losses have decreased during times between 00:00 and 6:00. In fact, available electrical demands are supplied by the main bus and fuel cells during this period. Consequently, the output power of PV arrays was equal to zero and also the produced power by wind turbine was negligible. As shown in Fig. 14, the power losses were remarkably reduced from 8:00 since the PV arrays and wind turbines were capable to produce power after this time.

The total harmonic distortion of the bus 17 at each hour is shown in Fig. 15. As mentioned, PV arrays start to produce electrical power from 7:00. So, the harmonic currents are injected to the distribution system at this time by PV systems. Since PV arrays produce power, THD of the related bus is increased. According to results of this figure, it can be concluded that the amount of THD is within the acceptable range when the loads varied during the day.

Fig. 16 shows the THD of the buses at the peak load condition. From this figure, it is obvious that the THD of the buses is within the standard limit.

Different greenhouse gas emissions are shown in Table 7. As shown in this table, the most portion of contamination is related to the produced carbon and carbon dioxide emissions due to the use of fossil fuels in power plants. After installing of DGs, the emission of CO_2 and C and other greenhouse gases has dropped about 80%. Therefore, it can be concluded that the emissions of greenhouse gases would be remarkably reduced by applying renewable energy units in the distribution system and reducing in the use of fossil fuels in power plants.

6.2. Considering the load growth

In this paper, load growth is considered for each type of available loads in the distribution system. The peak of the available loads in each year is shown in Fig. 17. It should be noted that the load growth will be saturated after 10 years.

According to the load growth, new DG units must be considered to

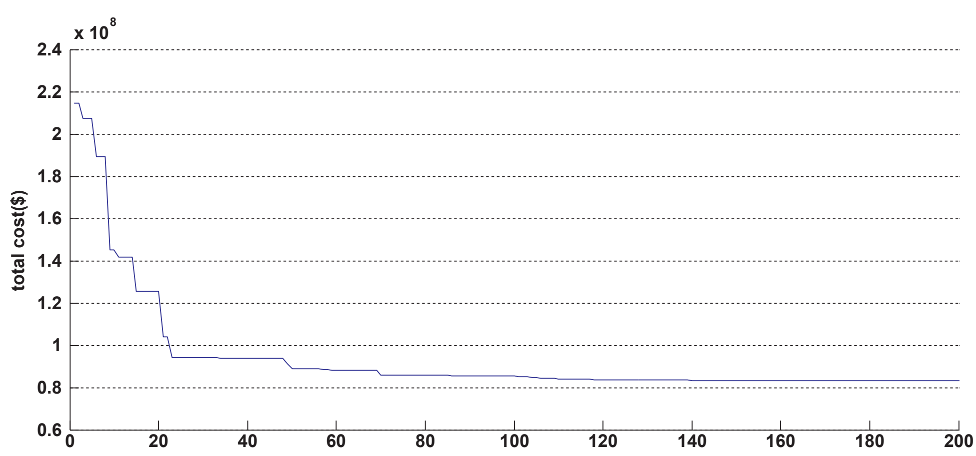

Fig. 8. Objective function in terms of iterations.

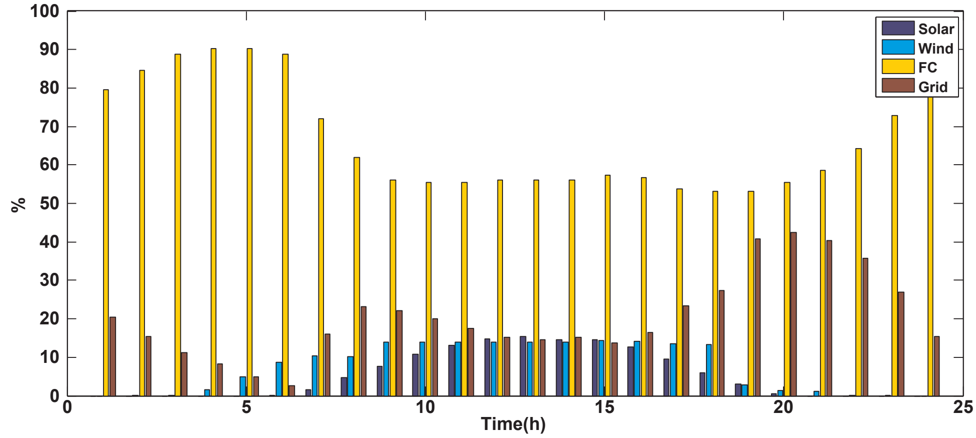

Fig. 9. The amount of the produced power of each DG unit and input power from main bus.

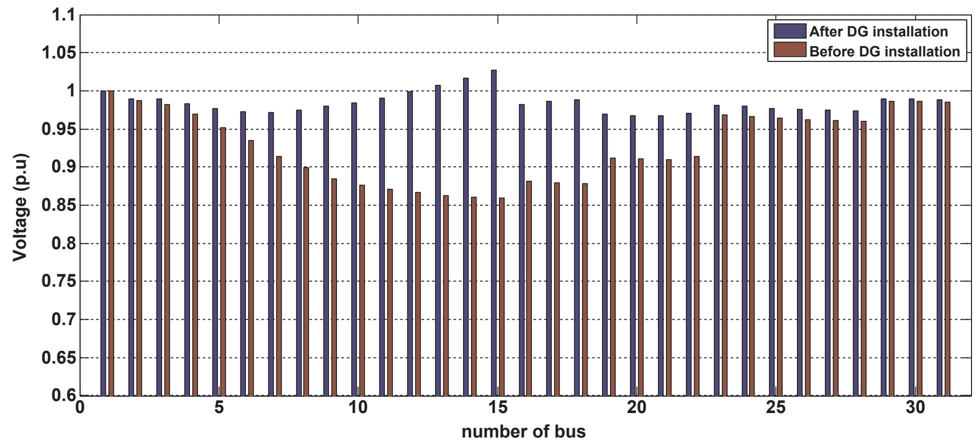

Fig. 10. The voltage profile after the optimal sizing and sitting of DG units.

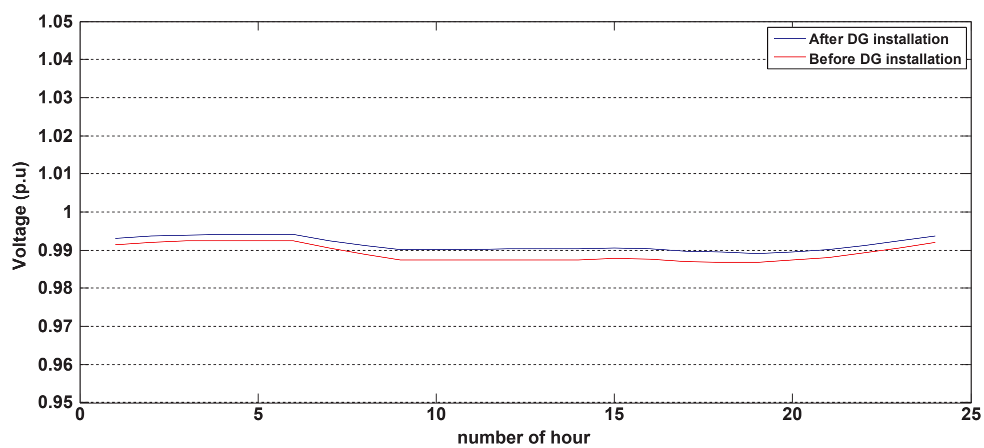

Fig. 11. Voltage profile of bus 2 at each hour.

install in the mentioned distribution system for supplying the added loads in each year. The location and size of these DG units should be optimized by considering the technical constraints. The simulation results are presented in Table 8.

According to this table, it is clear that DG units must be added at some years to keep the voltage within its allowable limit. To investigate the performance of the system, three scenarios are studied as follows:

(1) DG units are installed only at the beginning of the project at the optimum location and size.
(2) New DG units are installed at 5th year according to Table 8.
(3) New DG units are installed at 5th and 9th year.

For demonstrating the performance of the mentioned scenarios, the minimum magnitude of voltage occurred at each year is depicted in Fig. 18.

It can be concluded from Fig. 18 that the voltage magnitude decreases to lower value than its minimum allowable limit at 5th year. Therefore, new DG units must be optimally added in the system according to the 2nd scenario to keep the voltages at their acceptable

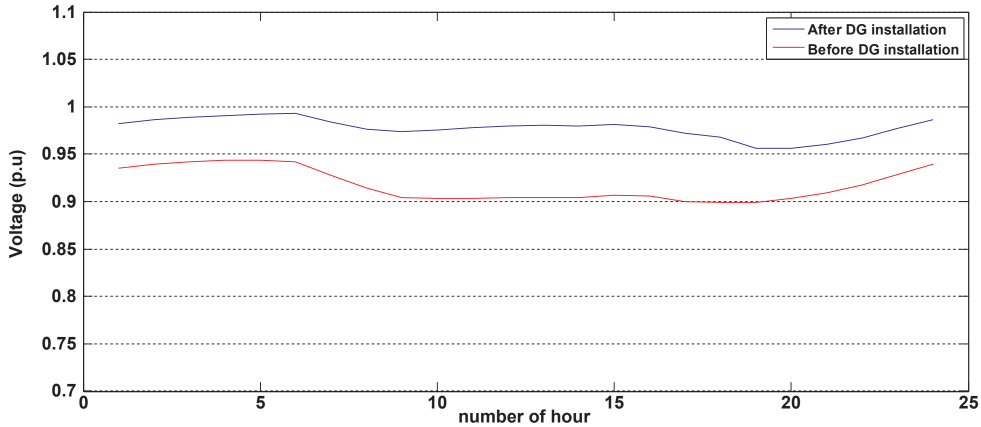

Fig. 12. Voltage profile of bus 11 at each hour.

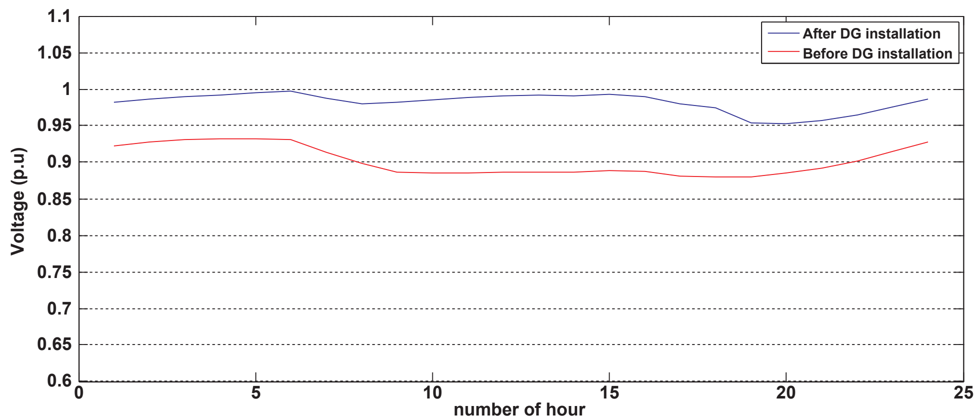

Fig. 13. Voltage profile of bus 17 at each hour.

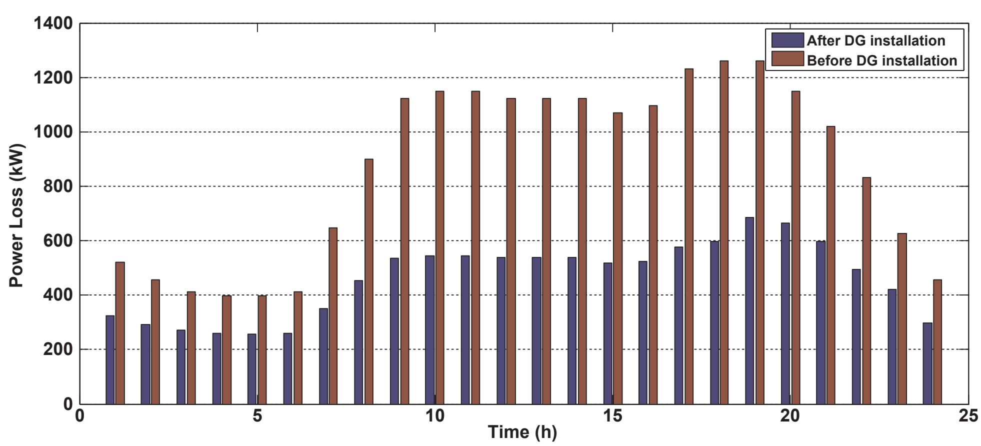

Fig. 14. Total power losses in the distribution system at each hour.

limits. It is also observed that the voltage magnitude is improved after installing the DG units until 9th year. However, the voltage magnitudes have not been at the allowable limits from 9th year to the year which the load growth still existed (10th year in this case). Therefore, in the 9th year, the other new DG units are considered to install in the system according to the 3rd scenario. As shown in Fig. 18, the magnitude of the voltage is at the acceptable limits in 9th and 10th years by implementing the 3rd scenario. Therefore, these results confirm the effectiveness of the proposed method in the condition of the load growth for the mentioned distribution system. Maximum amount of THD in 20th year is shown in Fig. 19. As shown, the THD is kept within its standard limit by installing the DG units in their optimal sizes and locations.

In addition, the voltage profile at 20th year is shown in Fig. 20. The figure shows that the voltage of each bus is within a safe interval (i.e. (0.95–1.05)).

Fig. 21 illustrates the total power losses at 20th year. It can be concluded from this figure that the installation of the DG units at their optimal sizes and locations also reduces the total power losses when the load growth exists.

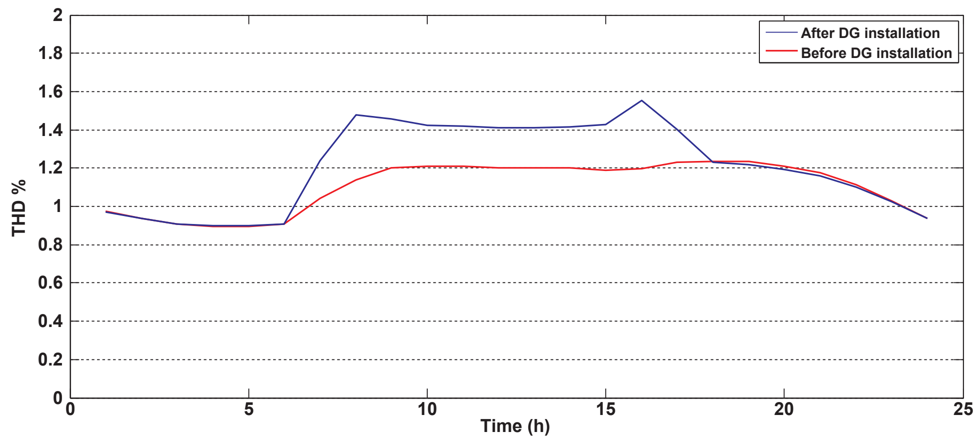

Fig. 15. THD of bus 17 at each hour.

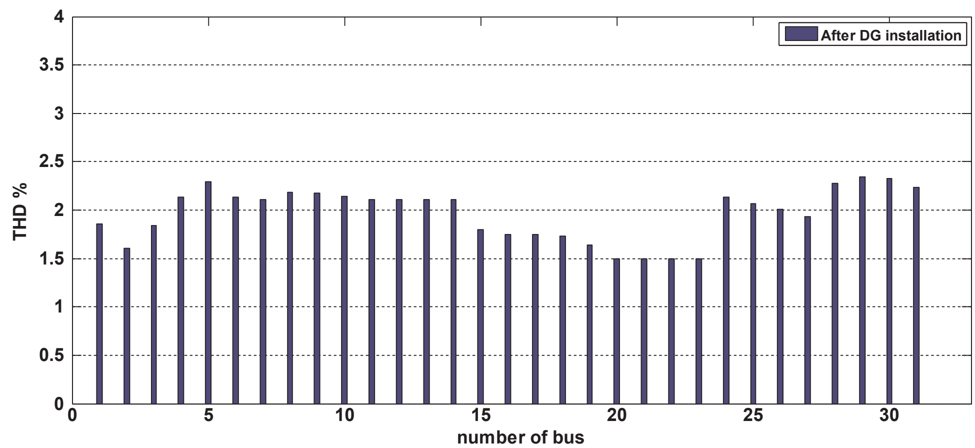

Fig. 16. THD of each bus.

Table 7
Greenhouse gas emissions.

Scenario	C	SPM	CH	CO	SO_3	CO_2	SO_2	NO_x
Without DG	18,690	13.7418	4.7987	0.109	2.1812	68528.7	141.7806	106.1173
With DG	4041	2.9712	1.0376	0.02358	0.4716	14,817	30.65	22.95

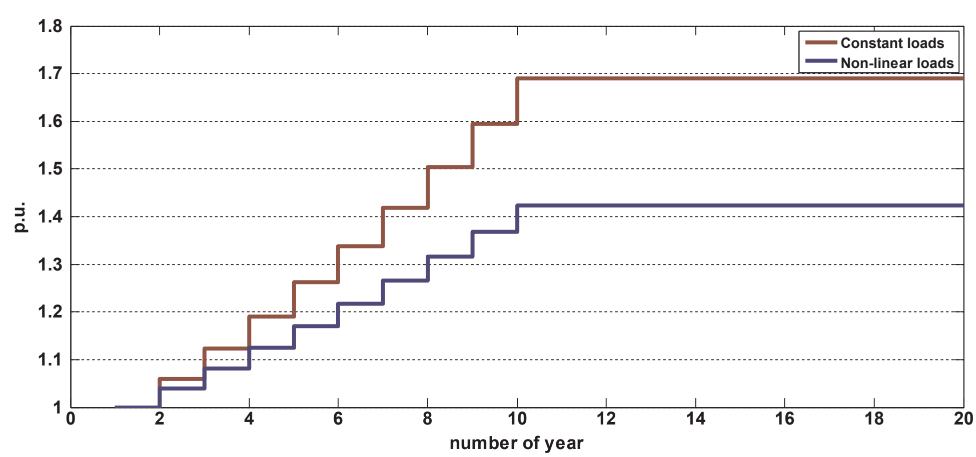

Fig. 17. Peak load at each year.

Table 8
Simulation results.

Year	PV		Wind		FC		Vmin	Vmax
	Size (MW)	Location	Size (MW)	Location	Size (MW)	Location		
1	2.2	17	2	18	7.7	15	0.9673	1.026
2	–	–	–	–	–	–	0.9548	1.005
3	–	–	–	–	–	–	0.9520	1.000
4	–	–	–	–	–	–	0.9502	1.000
5	2.9	17	2.7	18	9	15	0.9570	1.000
6	–	–	–	–	–	–	0.9544	1.000
7	–	–	–	–	–	–	0.9519	1.000
8	–	–	–	–	–	–	0.9501	1.000
9	3.4	17	3.2	18	9.5	15	0.9540	1.000
10	–	–	–	–	–	–	0.9521	1.000

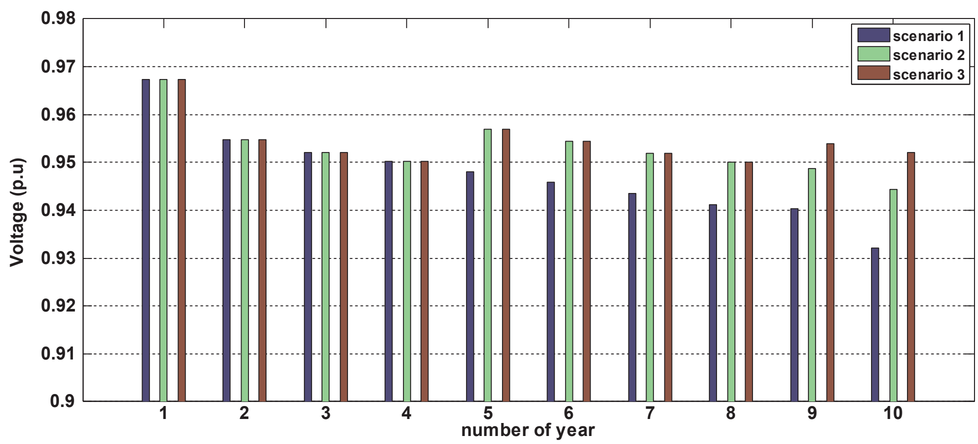

Fig. 18. Minimum magnitude of voltage occurred at each year.

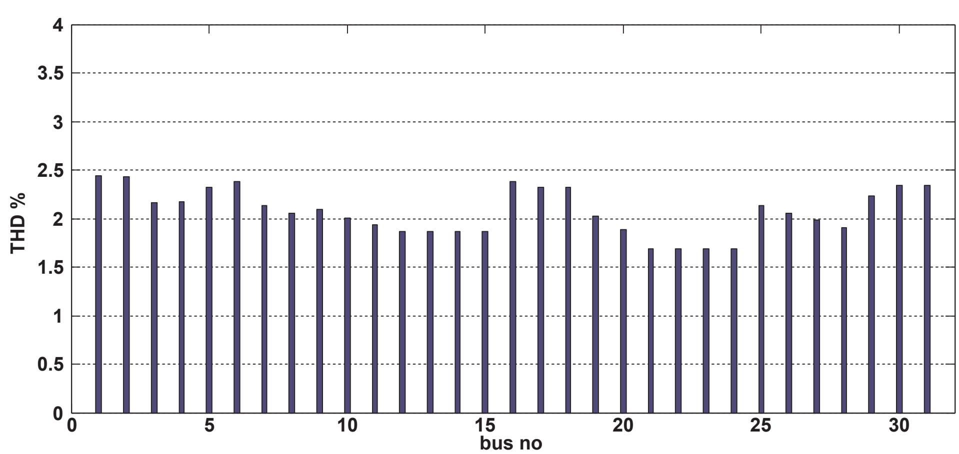

Fig. 19. Amount of THD.

7. Conclusion

In this paper, PSO algorithm was used to find the optimal location and size of renewable energy based DG units such as PV arrays, wind turbines and fuel cells in the distribution system. Due to the stochastic nature of wind speeds and solar radiation, the uncertainty in the resources of wind and solar units were considered in the planning procedure of the distribution system to obtain a reliable performance. Different types of loads such as linear and non-linear loads were considered in the system. These loads have been considered to vary with time during a day. The proposed method was tested on 31-bus radial distribution system to minimize the total power losses, total cost of DG units, greenhouse gas emissions, and improve the voltage profile. The results showed that voltages profile at each hour improved and total power loss reduced by installing the optimum DG units. After installation of renewable energy resources, greenhouse gas emissions remarkably reduced more than 80%. Furthermore, the load growth was considered for each type of available loads in the distribution system. In this case, with the increase of the demand in the distribution system at each year, the voltage at some buses decreased to lower value than its minimum allowable limit. Therefore, DG units were added to the system at the optimal locations and sizes to keep the voltage at its standard limit. Our findings showed that THD and voltage profile were kept within their standard limit at each year when the DG units are installed in their optimal sizes and locations. Furthermore, optimization results indicated that total losses in the distribution system can be

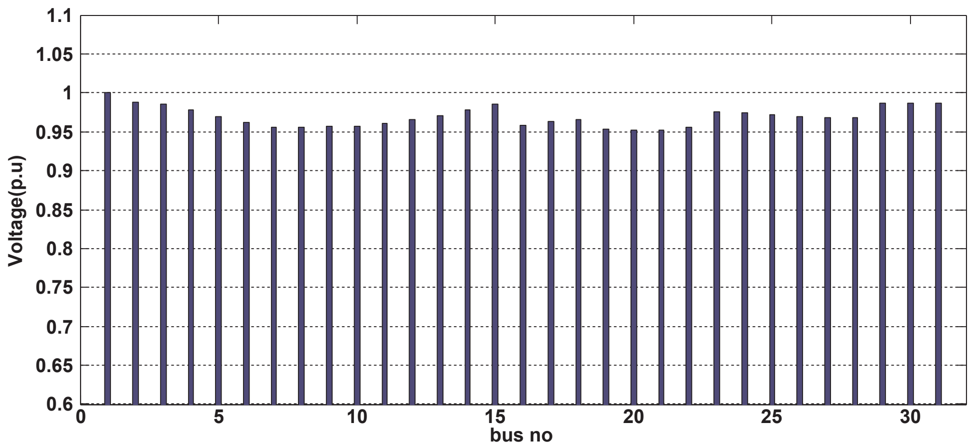

Fig. 20. Voltage profile at 20th year.

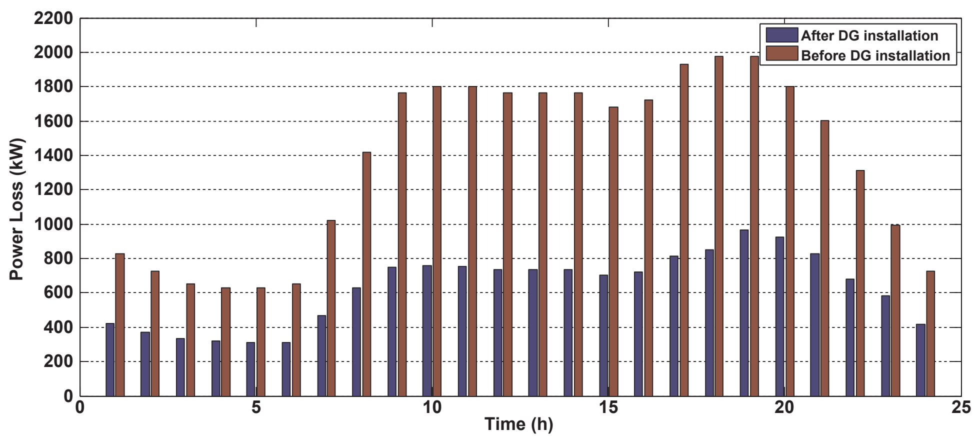

Fig. 21. Total power losses in the distribution system at 20th year.

reduced substantially by optimizing the sizes and placements of DG units in the condition of the load growth.

References

[1] Panwar NL, Kaushik SC, Kothari S. Role of renewable energy sources in environmental protection: a review. Renew Sustain Energy Rev 2011;15(3):1513–24.

[2] Walling R, Saint R, Dugan RC, Burke J, Kojovic LA. Summary of distributed resources impact on power delivery systems. IEEE Trans Power Delivery 2008;23(3):1636–44.

[3] Prakash P, Khatod DK. Optimal sizing and siting techniques for distributed generation in distribution systems: a review". Renew Sustain Energy Rev 2016;57:111–30.

[4] Milanovic JV, Ali H, Aung MT. Influence of distributed wind generation and load composition on voltage sags. IET Gener Transm Distrib 2007;1(1):13–22.

[5] HassanzadehFard H, Moghaddas-Tafreshi SM, Hakimi SM. Optimization of grid-connected microgrid consisting of PV/FC/UC with considered frequency control. Turk J Electrical Eng Comput Sci 2015;23:1–16.

[6] Hakimi SM, Moghaddas-Tafreshi SM, HassanzadehFard H. Optimal sizing of reliable hybrid renewable energy system considered various load types. J Renew Sustain Energy 2011;3(6):1–18. 062701.

[7] González A, Riba JR, Rius A, Puig R. Optimal sizing of a hybrid grid-connected photovoltaic and wind power system. Appl Energy 2015;154:752–62.

[8] Smaoui M, Abdelkafi A, Krichen L. Optimal sizing of stand-alone photovoltaic/wind/hydrogen hybrid system supplying a desalination unit. Sol Energy 2015;120:263–76.

[9] Lan H, Wen Sh, Hong YY, Yu DC, Zhang L. Optimal sizing of hybrid PV/diesel/battery in ship power system. Appl Energy 2015;158:26–34.

[10] Ahmadi S, Abdi Sh. Application of the Hybrid Big Bang-Big Crunch algorithm for optimal sizing of a stand-alone hybrid PV/wind/battery system. Sol Energy 2016;134:366–74.

[11] Fathy A. A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt. Renew Energy 2016;95:367–80.

[12] Yammani Ch, Maheswarapu S, Matam SK. A Multi-objective Shuffled Bat algorithm for optimal placement and sizing of multi distributed generations with different load models. Int J Electr Power Energy Syst 2016;79:120–31.

[13] Reddy PDP, Reddy VCV, Manohar TG. Application of flower pollination algorithm for optimal placement and sizing of distributed generation in distribution systems. J Electr Syst Inf Technol 2016;3(1):14–22.

[14] Prabha DR, Jayabarathi T, Umamageswari R, Saranya S. Optimal location and sizing of distributed generation unit using intelligent water drop algorithm. Sustain Energy Technol Assess 2015;11:106–13.

[15] Devi S, Geethanjali M. Application of modified bacterial foraging optimization algorithm for optimal placement and sizing of distributed generation. Expert Syst Appl 2014;41(6):2772–81.

[16] Abdi Sh, Afshar K. Application of IPSO-Monte Carlo for optimal distributed generation allocation and sizing. Int J Electr Power Energy Syst 2013;44(1):786–97.

[17] Bhumkittipich K, Phuangpornpitak W. Optimal placement and sizing of distributed generation for power loss reduction using particle swarm optimization. Energy Proc 2013;34:307–17.

[18] García JAM, Mena AJG. Optimal distributed generation location and size using a modified teaching–learning based optimization algorithm. Int J Electr Power Energy Syst 2013;50:65–75.

[19] HassanzadehFard H, Jalilian A. A novel objective function for optimal DG allocation in distribution systems using meta-heuristic algorithms. Int J Green Energy 2016;13(15):1624–34.

[20] Rasid M Md, Murata J, Takano H. Fossil fuel cost saving maximization: optimal allocation and sizing of renewable-energy distributed generation units considering uncertainty via clonal differential evolution. Appl Therm Eng 2017;114:1424–32.

[21] Abd-el-Motaleb AM, Bekdach SK. Optimal sizing of distributed generation considering uncertainties in a hybrid power system. Int J Electr Power Energy Syst 2016;82:179–88.

[22] Zeinalzadeh A, Mohammadi Y, Moradi MH. Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach. Int J Electr Power Energy Syst 2015;67:336–49.

[23] Mashayekh S, Stadler M, Cardoso G, Heleno M. A mixed integer linear programming approach for optimal DER portfolio, sizing, and placement in multi-energy microgrids. Appl Energy 2017;187:154–68.

[24] Rueda-Medina AC, Franco JF, Rider MJ, Padilha-Feltrin A, Romero R. A mixed-integer linear programming approach for optimal type, size and allocation of distributed generation in radial distribution systems. Electr Power Syst Res 2013;97:133–43.

[25] Chang RW, Mithulananthan N, Saha TK. Novel mixed-integer method to optimize distributed generation mix in primary distribution systems. In: 21st Australasian universities power engineering conference (AUPEC), Brisbane, Australia; 2011.
[26] Pandi VR, Zeineldin HH, Xiao W. Determining optimal location and size of distributed generation resources considering harmonic and protection coordination limits. IEEE Trans Power Syst 2013;28(2):1245–54.
[27] Abdelsalam AA, El-Saadany EF. Probabilistic approach for optimal planning of distributed generators with controlling harmonic distortions. IET Gener Transm Distrib 2013;7(10):1105–15.
[28] Kadir AFA, Mohamed A, Shareef H, Ibrahim AA, Khatib T, Elmenreich W. An improved gravitational search algorithm for optimal placement and sizing of renewable distributed generation units in a distribution system for power quality enhancement. J Renew Sustain Energy 2014;6(3).
[29] Biswas S, Goswami SK, Chatterjee A. Optimum distributed generation placement with voltage sag effect minimization. Energy Convers Manage 2012;53(1):163–74.
[30] Jahromi MJ, Faraji E, Zolghadri M. Mitigating voltage sag by optimal allocation of distributed generation using genetic algorithm. In: 9th International conference on electrical power quality and utilisation; 2007.
[31] Diaf S, Diaf D, Belhamel M, Haddadi M, Louche A. A methodology for optimal sizing of autonomous hybrid PV/wind system. Energy Policy 2007;35(11):5708–18.
[32] Hassanzadehfard H, Moghaddas-Tafreshi SM, Hakimi SM. Optimal sizing of grid connected micro-grid using particle swarm optimization considering interruptible loads. Electrimacs; 2011.
[33] Markvard T. Solar electricity. 2nd ed. USA: Willey; 2000.
[34] Li X, Song YJ, Han SB. Frequency control in micro-grid power system combined with electrolyzer system and fuzzy PI controller. J Power Sources 2008;180(1):468–75.
[35] Lin Grier CI, Nagalingam Sev V. CIM justification and optimization. London: Taylor & Francis; 2000.
[36] Berk J, DeMarzo P, Stangeland D. Corporate finance. 3rd Canadian ed. Toronto: Pearson Canada; 2015.
[37] Memon AG, Memon RA. Parametric based economic analysis of a trigeneration system proposed for residential buildings. Sustain Cities Soc 2017;34:144–58.
[38] Rasid MM, Murata J, Takano H. Fossil fuel cost saving maximization: optimal allocation and sizing of renewable-energy distributed generation units considering uncertainty via clonal differential evolution. Appl Therm Eng 2017;114:1424–32.
[39] IEEE Std 519-1992. IEEE recommended practices and requirements for harmonic control in electrical power systems; 1993.
[40] Yu XM, Xiong XY, Wu YW. A PSO-based approach to optimal capacitor placement with harmonic distortion consideration. Electr Power Syst Res 2004;71(1):27–33.
[41] Teng JH, Chang ChY. Backward/forward sweep-based harmonic analysis method for distribution systems. IEEE Trans Power Delivery 2007;22(3):1665–72.
[42] Shirmohammadi D, Hong HW, Semlyen A, Luo GX. A compensation-based power flow method for weakly meshed distribution and transmission networks. IEEE Trans Power Syst 1988;3(2):753–62.
[43] Cheng CS, Shirmohammadi D. A three-phase power flow method for real-time distribution system analysis. IEEE Trans Power Syst 1995;10(2):671–9.
[44] Kennedy J, Eberhart R. Particle swarm optimization. In: IEEE international conference on neural networks; 1995.
[45] Hassanzadehfard H, Moghaddas-Tafreshi SM, Hakimi SM. Effect of energy storage systems on optimal sizing of islanded micro-grid considering interruptible loads. In: 3rd International youth conference on energetics, Leiria, Portugal; 2011.
[46] Ziari I, Jalilian A. Optimal placement and sizing of multiple APLCs using a modified discrete PSO. Int J Electr Power Energy Syst 2012;43(1):630–9.
[47] Doagou-Mojarrad H, Gharehpetian GB, Rastegar H, Olamaei J. Optimal placement and sizing of DG (distributed generation) units in distribution networks by novel hybrid evolutionary algorithm. Energy 2013;54:129–38.
[48] Kalinci Y, Hepbasli A, Dincer I. Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options. Int J Hydrogen Energy 2015;40(24):7652–64.
[49] Lipman TE, Edwards JL, Kammen DM. Fuel cell system economics: comparing the costs of generating power with stationary and motor vehicle PEM fuel cell systems. Energy Policy 2004;32(1):101–25.
[50] Karki Sh, Mann MD, Salehfar H. Substitution and price effects of carbon tax on CO_2 emissions reduction from distributed energy sources. In: Power systems conference: advanced metering, protection, control, communication, and distributed resources, Clemson, SC, USA; 2006.
[51] Devabalaji KR, Ravi K, Kothari DP. Optimal location and sizing of capacitor placement in radial distribution system using bacterial foraging optimization algorithm. Int J Electr Power Energy Syst 2015;71:383–90.
[52] Grainger JJ, Civanlar S. Volt/Var control on distribution systems with lateral branches using shunt capacitors and voltage regulators Part III: the numerical results. IEEE Trans Power Apparatus Syst 1985;104(11):3278–83.
[53] Chang CY, Teng JH. Three-phase harmonic load flow method. In: IEEE international conference on industrial technology (ICIT'02); 2002. p. 839–44.