A Multi Objective PSO Algorithm for Sizing and Allocation of DG’s
From DG’s Owners and Disco’s View Points

L. Siva Prasad¹ V. E. Sowjanya²
¹P.G Scholar ²Assistant Professor
1,2Department of Electronics & Electrical Engineering
1,2Annamacharya Institute of Tech & sciences Tirupati, India

Abstract— This novel presents multi objective approach for calculating the DG optimum allocation, sizing and contract price simultaneously. DG’s (distributed generation) have significant benefits in the electric power industry, such as improvement of voltage profile in distribution feeders, amending voltage stability heavy load levels, enhancement of reliability and power quality, as well as securing power market. Despite the numerous advantages of DG’s technologies, weak capability in dispatching and managing of DG’s is a major challenge for distribution system operators. This novel presents a application of multi objective particle swarm optimization with the aim of determining the optimal DG allocation and sizes and their generated power contract price. The proposed multi objective optimization algorithm determines, not only the operational aspects (such as improving voltage profile and stability, power loss reduction) and also reliability enhancement taken into account and an economic analysis is performed based on distribution companies and DG’s owners viewpoints. This paper explained IEEE 33 bus distribution test system and the consequent discussions prove the effectiveness of the proposed approach.

Keywords: DG’s (distributed generation), combined heat and power units (CHP), photovoltaic cells (PV)

I. INTRODUCTION

Traditionally, utilities have served load demand by utilizing central generation, transmission, and distribution systems. However, in recent decades, utilities tend to deploy small-to-medium size distributed-generation (DG) units scattered across a power system. DGs can either be treated like additional renewable sources of energy, such as combined heat and power units (CHP), photovoltaic cells (PV), small wind turbines, or like the traditional ones such as gas turbines (3). Power-loss reduction, voltage profile improvement, reliability enhancement, power-quality (PQ) improvement, lower greenhouse gas emissions, and shorter construction schedules are mentioned in different papers as advantages of using DGs in power systems. However, with inappropriate design and planning of high penetration of DGs, power systems will face some problems. Including: decreasing reliability, increasing power losses, reducing voltage stability, and other safety issues (4). In order to maximize the benefits of using DGs in power systems, it is crucial to find the best location and size of DGs simultaneously to improve the voltage stability and reliability of the grid (5). In addition, in the deregulated markets, the DG owner’s and the DISCO’s economic objectives should be considered. Generally, cost minimization and technical improvement of the network are the main goals of the DISCO while the DG owner’s main aim is to maximize his or her revenue as much as possible by selling electricity to the distribution network.

A diversity of different objectives has been defined and considered in DG placement problems in papers. These objectives can be categorized into two major groups: (1) operational objectives and (2) economic objectives. Generally, the operational constraints consist of voltage stability improvement, active power loss reduction, reactive loss reduction, reliability of supply, emission reduction, and voltage profile improvement. Costs and benefits associated with the deployment of the DGs in the network for the DISCO and/or the DG owner(s) are the main parts of the economic objective function.

This paper presents a novel multi objective approach for calculating the DG optimum placement, sizing, and contract price simultaneously. It is assumed that the DG owner wants to install three dispatch able units and synchronous DG units in the network. The proposed method is based on economic and operational objectives from the DG owner’s and the DISCO’s points of view. The multi objective particle swarm optimization (MOPSO) method has been used to solve this problem subject to appropriate operational constraints. The proposed method benefits over most of the earlier surveys are: a) dynamic daily load modeling with an annual increase rate for all buses; b) both the DISCO’s and the DG owner’s economic objective consideration; and c) taking various operational issues of the power grid into consideration, such as power loss, voltage profile, stability, and reliability of the system; and d) planning incentive strategies with the aim of encouraging the development of DGs in the power grid.

II. PROPOSED METHOD

This section introduces the proposed approach for the DG planning problem. The optimization problem is based on maximizing the DG owner’s profit and minimizing the DISCO’s cost simultaneously. In addition to modeling cost and profit functions, multi objective optimization methods must be applied to find the optimum value of the planning parameters which are the DG’s size, location, and the electricity contract price between the DG owner and the DISCO. Regarding the number of variables as well as their range of variation, solving this problem using mathematical or classical methods is neither efficient nor possible. Moreover, these methods have very low convergence speed. Hence, heuristic methods have a special preference for solving this problem. The heuristic algorithms can be classified into two main categories: (1) single objectives and (2) multi objectives. Using the former one, one possible solution is summing all of the objective functions by appropriate coefficients. In the other words, the multi objective problem is converted to a single objective one. This method is called the weighted sum method. But this technique is not appropriate for solving this problem too, because there is a strong interconnection between the
DISCO’s and the DG owner’s economic equations in a way that optimizing one of the objective functions outweighs the other one and, in the final solution, one of the objective functions is optimized while the other one is not. Moreover, high sensitivity of economic equations to the variation in size, location, and contract price of DGs makes classical and single objective heuristic optimization methods inefficient.

Therefore, multi objective methods are better choices; they consider two distinct objective functions instead of one objective function, and they consider the domination of each one through another. Consequently, in this paper, the multi objective version of PSO or MOPSO is chosen to solve the DG placement problem. The following assumptions should be made before the formulation of the problem:

- There are no geographic or primary resource limitations to install various DG technologies within the distribution system.
- Connection between the DG unit and a bus is modeled as a negative PQ load in load-flow analysis (2), (21).
- The proposed DG placement model is presented from the perspectives of the DISCO and the DGs owners in an energy market environment.
- To exploit the advantages of using DG units for reducing the energy not served (ENS) index, the islanding operation of DG technologies is permitted (22).

In the following part, different functions related to the main problem are introduced

A. DG Owner’s Cost and Profit Functions

As an investor, the DG owner’s main purpose is to gain profit as much as possible without serious considerations about power grid operational conditions. According to this fact, the following cost and profit functions can be defined for the DG owner as follows.

1) Investment Cost
This cost contains the different initial costs, such as the amount of money spent on unit construction, installation, and essential equipment. For each unit of generation. This cost can be formulated as the following equation

\[ C_{\text{investment}} = \sum_{i=1}^{N_{\text{DG}}} P_{DG,i} \times Cost_{\text{investment}} \]  

(1)

Where denotes the distributed generation index. That is, \( P_{DG,i} \) denotes the active power generated by the “i”th unit.

2) Operational Cost
Costs of fuel, generation, and other similar ones can be combined together as the operational cost. The equation for modeling the present worth of this cost is as follows:

\[ C_{\text{operational}} = \sum_{j=1}^{N_{\text{Y}}} \sum_{i=1}^{N_{\text{DG}}} P_{DG,i} \times CF_{i} \times T_{h} \times Cost_{\text{oper}} \times \left(\frac{1+INF_{R}}{1+INF_{R}}\right)^{j} \]  

(2)

Where denotes the year index.

3) Maintenance Cost
This term includes costs of renewing, repairing, and restoring unit equipment in case of necessity. The present worth of this cost can be formulated as follows:

\[ C_{\text{maintenance}} = \sum_{j=1}^{N_{\text{Y}}} \sum_{i=1}^{N_{\text{DG}}} P_{DG,i} \times CF_{i} \times T_{h} \times Cost_{\text{maint}} \times \left(\frac{1+INF_{R}}{1+INF_{R}}\right)^{j} \]  

(3)

4) DG Owner’s Income
The DG owner gains profit from selling generated power to the DISCO based on the contract price. The present worth of the DG owner’s income is

\[ IN_{DG} = \sum_{j=1}^{N_{\text{Y}}} \sum_{i=1}^{N_{\text{DG}}} P_{DG,i} \times CF_{i} \times T_{h} \times CP_{DG} \times \left(\frac{1+INF_{R}}{1+INF_{R}}\right)^{j} \]  

(4)

B. DISCO’s Costs
The DISCO not only considers his or her own profit, but also takes into account the operational conditions of the power grid, such as voltage profile and stability, branch current limits, customer security, and reliability. Consequently, the DGs’ locations, sizes, and the contract prices are the vital factors for the DISCO. The DISCO’s costs are defined with the following functions

1) Cost of Purchasing Power From the DG Owner
The DISCO buys all of the power generated by DGs from the DG owner based on the contract price. This DISCO’s cost has already been formulated as the DG owner’s income in (4). In fact, the DISCO profits the DG owner by purchasing powers from humor her. This is the so-called strong interconnection between the DISCO and the DG owner from economic standpoints.

2) Cost of Buying Power from the Substation
The power, which is beyond the DG units capacities, should be bought by the DISCO from the substation. This power is computed by the following equation:

\[ P_{\text{sub,t,j}} = \sum_{n=1}^{N_{\text{bus}}} P_{\text{bus},n,t,j} + P_{\text{loss,t,j}} - \sum_{i=1}^{N_{\text{DG}}} P_{DG,i,j} \]  

(5)

Where

\[ P_{\text{loss,t,j}} = \sum_{b=1}^{N_{\text{b}}} r_{b} \times I_{t,b,j}^{2} \]  

(6)

In (5) and (6), and refer to the bus and branch indices, respectively. Furthermore, is the time index referring to each hour of the day. Buying power from the substation is another cost that the DISCO should spend. The present value of this cost is

\[ C_{\text{sub}} = \sum_{j=1}^{N_{\text{Y}}} \sum_{n=1}^{N_{\text{bus}}} P_{\text{sub},n,t,j} \times T_{d} \times C_{\text{MWh,p}} \times \left(\frac{1+INF_{R}}{1+INF_{R}}\right)^{j} \]  

(7)

It is obvious that the proper location and size of DGs can decrease power losses in the system and, consequently, it can impact the mentioned cost.

3) Customer Interruption Cost
Customer satisfaction and welfare in case of a failure in the power grid are imperative. Therefore, the cost associated with the interruptions and failures in supplying customers’ loads is the DISCO’s responsibility. On account of this fact, the customer interruption cost (CIC) in (8) is utilized to evaluate the present worth of this expense

\[ C_{\text{IC}} = \sum_{i=1}^{N_{\text{bus}}} L_{b} \times \lambda_{b} \times \sum_{k=1}^{N_{\text{NS}}} P_{k,i,j} \times C_{\text{int}} \times L_{b} \times \lambda_{b} \times \sum_{k=1}^{N_{\text{NS}}} P_{k,i,j} \times \left(\frac{1+INF_{R}}{1+INF_{R}}\right)^{j} \]  

(8)

Where denotes the not-supplied loads index. According to (8), CIC is a term which calculates the interruption cost based on the amount of energy which is not supplied (ENS) for all customers, \( C_{\text{int}} \) is the price of interruption in supplying each load during repair time and depends on the type of loads (residential, commercial, or industrial).

C. Objective Functions and Constraints
In this section, the objective functions and their related constraints for solving this optimization problem are introduced.
1) **Objective Functions**

According to the above formulations for the DG owner’s and the DISCO’s costs and profits, the objective functions for finding the appropriate locations, sizes, and contract price, which simultaneously maximize the DG owner’s profit and minimize the DISCO’s cost, results in the following equations. In these equations, \( F_1 \) is the difference between the DG owner’s profits and cost functions which are introduced in Sections II-A-1to A-4. Furthermore, \( F_2 \) is the summation of the DISCO’s costs which are introduced in Sections II-B-1–B-3.

\[
\begin{align*}
F_1 &= \max (IN_{DG} - C_{inv} - C_{main} - C_{operate}) \\
F_2 &= \min (C_{sub} - C_{DG} - CIC)
\end{align*}
\]  

(9)

2) **Constraints and Limitations**

This optimization problem is subjected to various constraints as follows.

a) **Bus Voltages and Branch Currents Limits**

In this optimization problem, DGs’ locations and sizes should be determined in such a way that bus voltages and branch currents remain in standard intervals during the planning period. These limitations are defined as follows:

\[
I_{b,l,n} \leq I_{b}^{max} \quad V_{n}^{min} \leq V_{n,t} \leq V_{n}^{max}
\]

Where \( V_{n}^{min} \) and \( V_{n}^{max} \) are the minimum and maximum allowed amounts of voltage in each bus, respectively. \( I_{b}^{max} \) also denotes the maximum amount of current that can flow in each line according to the lines thermal limitations.

b) **DG Capacity Limit**

It should be assumed that the active and reactive capacity of each DG is limited to a specific interval as follows:

\[
P_{DG,i}^{min} \leq P_{DG,i} \leq P_{DG,i}^{max} \quad Q_{DG,i}^{min} \leq Q_{DG,i} \leq Q_{DG,i}^{max}
\]

In these inequalities, \( P_{DG,i}^{min} \), \( P_{DG,i}^{max} \), \( Q_{DG,i}^{min} \), and \( Q_{DG,i}^{max} \) are the minimum and maximum amounts of active and reactive powers that can be generated by the \( i \)th DG unit.

c) **Contract Price Limits**

It is logical to say that the contract price between the DG owner and the DISCO is limited according to the electricity market conditions and this inequality can be formulated as follows:

\[
C_{DG}^{pmin} \leq C_{DG} \leq C_{DG}^{pmax}
\]

where \( C_{DG}^{pmin} \) and \( C_{DG}^{pmax} \) are the minimum and maximum amounts of the contract price that can be determined according to the market electricity price and other economic considerations.

d) **Power-Flow Constraints**

It is obligatory for active and reactive power injections to satisfy the power-flow equations

\[
P_n = \sum_{m=1}^{N} V_m g_{mn} \cos(\theta_{mn}) + b_{mn} \sin(\theta_{mn})
\]

\[
Q_n = \sum_{m=1}^{N} V_m g_{mn} \sin(\theta_{mn}) - b_{mn} \cos(\theta_{mn})
\]

(15)

(16)

e) **DG Owner Capitalization Constraint**

The amount of capitalization that the DG owner can afford is limited and is described by the following inequality:

\[
C_{investment} \leq C_{investment}^{max}
\]

Where \( C_{investment}^{max} \) denotes the maximum affordable amount of capitalization from the DG owner’s point of view.

D. **Operational and Economic Indices**

In this section, in order to have a better evaluation of the operational condition of the power grid and the profitability of the contract between the DG owner and the DISCO from their own viewpoints, some operational and economic indices are introduced as follows.

\[
TVPI_{p,u} = \sum_{j=1}^{N} \sum_{t=1}^{24} \sum_{n=1}^{N_{bus}} \left[ V_{rated} - V_{n,j,t} \right]
\]

(18)

\[
V_{n,j,t} = V_{n,j,t}^{max} \quad P_{DG,i}^{min} \leq P_{DG,i} \leq P_{DG,i}^{max} \quad Q_{DG,i}^{min} \leq Q_{DG,i} \leq Q_{DG,i}^{max}
\]

(19)

**Fig. 1: Representative Branch of a Radial Distribution System**

1) **Operational Indices**

In order to judge the operational state of the grid, some indices are introduced in the following sections. For better evaluation, per-unit (p.u.) values of these indices are also calculated. The nominators and denominators of these P.U. indices are, respectively, the related values of the defined indices in the presence and absence of DGs in the grid.

a) **Total Voltage Profile Index (TVPI)**

This index measures the variation of all bus voltages from \( V_{rated} \) (1 p.u.). Since the flatter voltage profile is more appropriate, the total voltage profile index (TVPI) is considered as follows [4]:

\[
TVPI = \sum_{j=1}^{N} \sum_{t=1}^{24} \sum_{n=1}^{N_{bus}} \left| V_{rated} - V_{n,j,t} \right|
\]

(20)

b) **Total Voltage Stability Index (TVSI)**

In radial distribution networks where each receiving node is fed by only one sending node, this index can be a good measure for evaluating voltage stability. According to Fig. 1, for all buses from two to \( N \), the stability index (SI) is calculated as follows [27]:

\[
SVI_{j,t,n} = \left[ V_{j,t,n}^{max} \right]_{t} - 4 \times (P_{p,j,t,n} X_{b} - Q_{p,j,t,n} X_{b}) \quad (21)
\]

\[
TVSI_{p,u} = \frac{TVSI_{with\ DG}}{TVSI_{with\ out\ DG}}
\]

(22)

c) **Total Power-Loss Index (TPLI)**

As the lower active power loss is more appropriate in case of power grid operation, therefore, the total power loss index (TPLI) and its per-unit value are defined as follows (4):

\[
TPLI_{p,u} = \frac{TVPLI_{with\ DG}}{TVPLI_{with\ out\ DG}}
\]

(24)
d) Energy not Supplied Index (ENSI)
The energy not supplied index (ENSI) provides comprehensive information about the amount of loads that will not be supplied in case of failure [26]. This index depends on the failure rate of branches and the amount of interrupted loads in the case of each branch failure. If this index becomes lower, the grid will have better conditions in case of accruing faults. Hence, the total ENSI and its per-nit value are stated as follows:

\[
ENSI = \sum_{j=1}^{N_{j}} \sum_{n=1}^{N_{n}} \text{Vert}_{fault} \times \lambda_{j} \times L_{j} \times \sum_{k=1}^{N_{k}} P_{l,k,j}
\]

\[
ENSI_{p,n} = \frac{ENSI_{with\ DG}}{ENSI_{with\ out\ DG}}
\]

Where \( \text{Vert}_{fault} \) is the average time that the corresponding load is out of service during the fault occurrence.

2) Economic Indices
In this section, in order to evaluate the economic condition of the contract between the DG owner and the DISCO from their viewpoints, three important economic indices are introduced as follows.

a) Payback Period (PP)
In capital budgeting, the payback period refers to the length of time required to recover the cost of an investment. This factor determines whether to undertake the project or not. Given a list of different investments equal to each other, the one with the shorter payback period is the best according to the economic standpoint (28). The following index is calculated by solving:

\[
Investment\ cost - \sum_{i=1}^{PP} (\text{cash\ inflows\ in\ } i\text{th\ year}) = 0
\]

b) Expected Rate of Return (ERR).
The expected rate of return is the return which an investor expects his or her investment to generate over a certain period. The expected rate of return on a single asset is equal to the sum of all possible rates of return multiplied by the respective probabilities of earning on each return. Since this term is dependent on the market risk of assets, it is variable according to different circumstances (28).

c) Internal Rate of Return (IRR)
IRR is the rate of return at which the net present value (NPV) of a flow of payments/incomes is equal to zero. In other words, the rate of return that would make the present value of future cash flows plus the final market value of an investment equal to the present market price. In order to judge whether an investment is worthwhile, this term is calculated. A greater value of this term compared to a return on a single asset is equal to the sum of all possible rates of return multiplied by the respective probabilities of earning on each return. This term is dependent on the market risk of assets, it is variable according to different circumstances (28).

E. Selecting the Optimal Solution in Accordance with the DISCO’s and DG Owner’s Viewpoints
As discussed earlier, this problem should be solved using multi objective methods, such as the MOPSO technique. Therefore, the final result of this optimization method is a Pareto optimal set of non dominated solutions (23). To extract the best compromise solution, various methods have been implemented in the literature, such as a fuzzy-based mechanism called a fuzzy decision-making method which presents a solution to the decision maker (25). In this paper, a new technique based on economic and operational indices is presented that satisfies both sides of the contract standpoints. To choose an optimal solution, including DGs’ size, location, and the contract price, two important issues should be considered: First, in the optimal solution, the profit of the DISCO and the DG owner should be provided adequately (based on the DG owner’s and DISCO’s viewpoints). Second, the operational condition of the grid, based on the optimal solution, should be at acceptable levels (based on just the DISCO’s viewpoints). It is worthy to note that the operational issues are not directly used in the proposed multi objective algorithm. Hence, another way must be contrived to include the operational factors in our selection procedure. According to the defined indices in Section II-D, it will be assumed that the ERR and PP are specified. These values are in accordance with the DG owner’s agreement; therefore, the values of IRR which are more than the ERR and lower PP will also be accepted by the DG owner. To motivate the DG owner, it is reasonable to eliminate the Pareto answers with lower values of IRR or higher values of PP indices from the Pareto set. In this case, the remaining points will be agreeable by the DG owner and could be selected from his or her viewpoints. After that, the DISCO’s viewpoints should be taken into consideration in order to have better operational condition for the grid besides gaining more profit. In the next step, the introduced operational indices will be calculated for each remaining point. In order to have all of the indices in an appropriate condition, for each index, the first half of points having better conditions are selected. Among the intersection of obtained points for all indices, the point with the lowest DISCO’s cost will be chosen ultimately. Consequently, the DG owner and the DISCO will be satisfied because the DG owner will receive adequate profit, and the DISCO’s cost will decrease in comparison to the case without using DGs. Furthermore, the operational conditions of the grid will be improved significantly. The flowchart of the algorithm

III. MULTIOBJECTIVE PSO
The multi objective (MO) format of PSO called MOPSO is suitable in case of minimizing multiple objective functions simultaneously. If \( f(x) \) consists of \( \eta \) objective functions, then the multi objective problem can be defined as finding the vector \( x^* = [x_1^*, x_2^*, ..., x_m^*] \) in order to minimize \( F(x) = \min f(x) = (f_1(x), f_2(x), ..., f_\eta(x)) \) subject to \( a^*x \leq b^* \). Generally, multi objective optimization technique results in a set of optimal solutions, instead of one solution. The reason is that none of the solutions can be considered to be better than any other with regard to all objective functions. Consequently, in the MOPSO method, there is not generally one global optimum, but a set of so-called Pareto-optimal solutions (23). A decision vector \( X_1 \) is called Pareto-optimal if there is no other decision vector \( X_2 \) that dominates it. In the minimization problem, the solution \( X_1 \) dominates \( X_2 \) if

1) \( \forall i \in \{1, 2, 3, ..., N_{obj}\}: f_i(x_1) \leq f_i(x_2) \) (29)
2) \( \exists i \in \{1, 2, 3, ..., N_{obj}\}: f_i(x_1) < f_i(x_2) \) (30)
IV. CASE STUDY, RESULTS, AND DISCUSSION

A. Case Study

For demonstrating the efficiency of the proposed method, simulations have been performed on the 12.66-kV IEEE 33-bus distribution test system (15) which is shown in Fig. 3. It is assumed that the average load of each bus varies with a pattern. The price of the electricity supplied by the substation varies in favor of different amounts of power bought during the day. For simplification, it is assumed that there are three price levels for low, medium, and peak load levels during a day. Moreover, the contract price between the DG owner and the DisCo are considered to be between U.S.$35/MWh and U.S.$50/MWh. It is assumed that there are three DG units with active power generation within 0.2 and 1 MW with a 0.9 lagging power factor.

B. Results and Discussion

The proposed multi objective optimization has been solved using the MOPSO algorithm in MATLAB to obtain the optimum solution that maximizes the DG owner’s profit and minimizes the DISCO’s cost. As mentioned before, these two objective functions are dependent of each other seriously in a way that the reduction of one of them results in decreasing the other one. Hence, there is more than one optimal point, and it is imperatives apply a proper methodology to choose the best solution. The Pareto optimal set attained from MOPSO is shown in Fig. 2.

In order to find the optimum solution, different values of the ERR are considered and the optimum solution for each respective ERR is calculated according to the flowchart. The data associated with each solution are given in Table 1. In this table, for each ERR, the value of operational indices, economic indices, the DG owner’s profit, and the DISCO’s cost and revenue are brought. Furthermore, the size of DGs, their optimal locations (buses’ number where DGs should be constructed), and the amount of the contract prices are shown. Since the interest rate is supposed to be 12.5%, clearly the ERR should be higher than this value to be rational. Besides, the maximum ERR that can be achieved for all points in the Pareto set is 50%.

After using DG units, the amount of the TVPI, TPLI, and ENSI indices has been decreased by about 80% in comparison with the case without deploying DGs, and the voltage stability of the grid (the TVSI index) has been increased by about 20%. As an example, the voltage profiles...
for the first year in light load and for the twentieth year in peak load conditions with an ERR of 25% are shown in Fig. 3, after installing DG units, bus voltages vary from 0.99 to 1.04 p.u., and it was in the range of 0.92 to 1 before installing DGs. In addition, in Fig. 3, the bus voltage variations were within 0.85 to 1, and reduce to the range of 0.96 to 1 after installing DG units. On account of the aforementioned facts, by using the proposed method not only does the DG owner receive desired profits, but he is also motivated due to the mentioned incentive policy of the proposed strategy. Furthermore, the DISCO’s cost decreases compared to the case without using DGs, and the operational conditions of the grid improve considerably.

V. Conclusion

In this paper, the MOPSO algorithm has been used to find the optimal solution of DGs sizing and locating problems, in addition to determining their optimal-generated electricity prices in a competitive market. The goal of this optimization was minimizing the DISCO’s cost and maximizing the DG owner’s benefit simultaneously. Moreover, a novel approach is proposed to obtain the best solution considering power-loss reduction, voltage profile and stability enhancement, and reliability improvement in the grid. The proposed algorithm results show that in addition to gaining sufficient profit and payback period for the DG owner, the electric utility’s cost decreases significantly compared with case of not deploying DGs. Furthermore, simulation results verified the potential of the proposed method in improving operational conditions of the power grid. Finally, it is shown that the introduced approach can be used as a proper incentive energy policy by system operators or utilities to encourage DG investors. Although the positive effects of DGs in distribution networks’ side effects were investigated in this paper, there are some negative impacts on protection, security, system stability, etc. In future works, these negative impacts, as well as implementing renewable DGs with uncertain output power, such as PV panels or wind turbines, will be considered in the modeling and formulations. Moreover, the DG allocation problem in future studies in this field.

REFERENCE