AHP based technical, economic and environmental impact analysis with optimal DG placement in radial distribution network

Surender Singh Tanwar[1], Ganesh Prasad Prajapat[1], Ravindra Rathod[2], Sanjay Kumar Bansal[3], Sukhlal Sisodia[4]
[1]Faculty of Electrical Engineering, Engineering College Bikaner, Rajasthan, India
[2]Faculty of Information Technology, Walchand College of Engineering, Maharashtra, India
[3]Faculty of Electrical Engineering, Bikaner Technical University, Rajasthan, India
[4]Faculty of Electrical Engineering, SGSITS Indore, Rajasthan, India

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ABSTRACT

This manuscript considers multi-criteria based multi-objective approach with technical, economic and environmental indices (TEE) for optimal placement and sizing of distributed generation (DG) units in the distribution network. Technical criteria include indices of active energy losses, voltage deviation; whereas economic criteria include the index of cost of DG installation, and environmental index considers the various greenhouse gas (GHG) emissions from generating unit's and biomass DG. Combined sensitivity analysis is applied for sorting the candidate nodes for DG placement and reducing the search space. Multi-criteria decision-making among TEE factors are addressed using a scientific approach named Analytic Hierarchy process (AHP) approach. The impact of prioritized solutions is analyzed in terms of three scenarios formed using AHP in the form of TEE criterion. The developed formulation is tested on IEEE 33-bus bus radial distribution system and is solved using hybrid optimization approach (hybrid GA-PSO) and AHP based scenarios performed better than base case scenario (non-prioritized scenario).

Corresponding Author:

Surender Singh Tanwar
Faculty of Electrical Engineering, Engineering College Bikaner
Bikaner, Rajasthan, India
Email: stanwar@ah.iitr.ac.in, sst.iitr@gmail.com

1. INTRODUCTION

In the present power scenario, the optimal penetration of distributed generation (DG) units for power generation has given multiple benefits in terms of technical economic and environmental (TEE) criterion. The most of the centralized power generators utilizes fossil fuels with transportation costs and high the greenhouse gas (GHG) emissions. The technical analysis of DG power generation includes power loss reduction, voltage profile improvement, and line loading capacity enhancement, network stability improvement and power quality improvement. The economic aspect included the cost factors covers the cost of power and energy losses, costs related to operation and maintenance of DG and distribution network expansion, DG installations, peak power losses etc. However, environmental indices focus on reduction in GHG emissions, penalty due to emissions and others keys points.

Recently, Prasad *et al.* [1] presented a techno-economic multi-objective whale optimization-based approach for placement and sizing of wind and solar based DGs for power loss reduction and voltage profile improvement in the distribution system. Annual economic losses are substantially reduced with reduction in annual energy losses. Ali *et al.* [2] exercised a genetic algorithm (GA) based approach for DG placement and sizing in the distribution network for improvement voltage profile, increasing spinning reserve and reduction in line power flows and losses. Raj and Saravanan [3] proposed ‘dwarf mongoose optimization technique’ for optimal placement and sizing of DG and STATCOM in the distribution network using loss sensitivity factors approach in the radial distribution network. It resulted in reduction of power losses, improvement in voltage profile, improvement in system operation cost along with environmental constraint. Sun *et al.* [4] developed a methodology to examine the impact of DG placement on the efficiency and reliability distribution network of with time varying load pattern. Switching operations of DG’s may affect the optimal operation of the distribution system. Yaldız *et al.* [5] developed a stochastic optimal power flow method for DG integration in an active distribution network for evaluation of different indices such as DG integration ratio, generation curtailment ratio and adjustable power factor. The impact of DG placement into the distribution system in terms of environmental impact assessment has been concluded in [6], [7]. Akella *et al.* [6] proposed social, economic, and environmental effects of renewable energy systems for the grid connected distribution systems. The reduction in CO_2 emission is determined for both baseline and plants cases is calculated. However, model considers only CO_2 emissions. Descateaux *et al.* [7] developed a methodology to assess the implications of introducing different carbon tax levels and to assess the greenhouse gas (GHG) abatement performance with DG penetration.

From the above literature, it may is observed that most of the literatures available on optimal sizing and placement of DG units considers non-prioritized indices in the formulations. Therefore, it is not possible to analyze the impact of different indices in the objective function and relevant results. Therefore, multi-objective problems are converted into single objective problem by giving equal weightage to all the objectives. A promising logical and scientific technique for weighing factor selection needs further study, as the selection of weighing factors decides the quality and optimality of the obtained solution. Further, the reduction of GHG emission due to DG placement is also an issue of concern around the globe. This issue has not given due consideration in the existing literature.

Hence, the proposed study aims to determine the optimal placement and sizing of renewable energy based DGs considering to technical, economic and environmental benefits by DG. An analytic hierarchy process (AHP) technique is used in this multi-objective problem for the selection of weighting factors using multiple criteria multi decision process. The weights are mathematically driven and varied by consistency ratio test. A hybrid GA-PSO optimization approach is applied to solve the developed formulation. The obtained results reveal the effectiveness of the proposed methodology.

2. PROPOSED METHODOLOGY AND PROBLEM FORMULATION

The developed mathematical formulation for optimal allocation of dispatchable DG namely micro-turbine (MT), gas-turbine (GT), and fuel-cell (FC) based DG types in a radial distribution network is multi-objective in nature. Weighting factor are multiplied in accordance to AHP and non-AHP scenarios. The objective function comprising of various technical, economic and environmental indices are discussed as follows:

2.1. Objective function

The objective function of proposed formulation for optimal allocation of dispatchable DG units in a radial distribution network comprises techno-economic criteria along with environmental benefits, which is to be minimized. The objective function includes the indices for network losses, voltage deviation, installation cost of DG units and GHG emission. The detailed formulation of each term is presented in the subsequent sections [8].

2.1.1. Index for active energy losses

Mathematically, the index of active energy losses can be expressed by (1) as [8], [9]:

$$IREL = \frac{E_{Loss}^{DG}}{E_{Loss}} \quad (1)$$

where, $IREL$ is the index of active energy losses; and E_{Loss}^{DG} and E_{Loss} are the total active energy losses of the network with DG integration and without DG integration, respectively (in kWh) and computed by (2) and (3).

$$E_{Loss}^{DG} = \sum_{d=1}^{N_{dl}} P_d^{LT2} \cdot TD_d \quad (2)$$

$$E_{Loss} = \sum_{d=1}^{N_{dl}} P_d^{LT1} \cdot TD_d \quad (3)$$

Where, P_d^{LT1} and P_d^{LT2} are the active power losses corresponding to d^{th} demand level before and after DG placement, respectively, in the network (in kW); N_{dl} is the number of load levels; and TD_d is the duration of occurrence of d^{th} load level in a year (in hours).

2.1.2. Index for voltage deviation

Mathematically, the index of voltage deviation can be expressed by (4) as [8], [9].

$$IVD = \frac{\sum_{i=2}^{N_{Bus}}\left\{\left(V_{i,1}^2 - V_{\min}\right)^2 + \left(V_{i,N_{dl}}^2 - V_{\max}\right)^2\right\}}{\sum_{i=2}^{N_{Bus}}\left\{\left(V_{i,1}^1 - V_{\min}\right)^2 + \left(V_{i,N_{dl}}^1 - V_{\max}\right)^2\right\}} \tag{4}$$

Where, IVD is the index of voltage deviation; $V_{i,d}^1$ and $V_{i,d}^2$ are the voltage magnitudes at i^{th} bus corresponding to d^{th} demand level before and after DG placement, respectively, in the network (in kV); and $V_{\min}$ and $V_{\max}$ are the minimum and maximum permissible limits, respectively, on voltage magnitude of the system (in kV).

2.1.3. Index for environmental impact

For better environmental impact, this index should be as minimum as possible. Mathematically, the index of environmental impact can be expressed by (5) as [10].

$$IEI = \frac{E_{GHG}^{DG}}{E_{GHG}} \tag{5}$$

Where, IEI is the index of environmental impact; and E_{GHG}^{DG} and E_{GHG} are the annual GHG emissions with DG integration and without DG integration, respectively (in kg) and are computed by (6) and (7).

$$E_{GHG}^{DG} = \sum_{d=1}^{N_{dl}}\left[P_d^{GD2} \cdot RE^{GD} + \sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot \left\{P_{j,d}^{GT} \cdot RE^{GT} + P_{j,d}^{MT} \cdot RE^{MT}\right\}\right] \cdot TD_d \tag{6}$$

$$E_{GHG} = \sum_{d=1}^{N_{dl}} P_d^{GD1} \cdot RE^{GD} \cdot TD_d \tag{7}$$

Where, P_d^{GD1} and P_d^{GD2} are the active power imported from the upper grid corresponding to d^{th} demand level before and after DG placement, respectively (in kW); RE^{GD} is the emission rate of the upper grid (in kg/kWh); x_j^{DG} is a binary variable indicating whether j^{th} bus is a candidate location or not; $P_{j,d}^{GT}$ and $P_{j,d}^{MT}$ are the active power generation from gas turbine and micro turbine based DG units, respectively, at j^{th} bus corresponding to d^{th} demand level (in kW); and RE^{GT} and RE^{MT} are the emission rates of gas turbine and micro turbine based DG units, respectively (in kg/kWh).

2.1.4. Index for installation cost of DG units

Mathematically, the index of installation cost of DG units can be expressed by (8) as [10].

$$IIC = \frac{\sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot \left\{IC^{GT} \cdot P_{j,1}^{GT} + IC^{MT} \cdot P_{j,1}^{MT} + IC^{FC} \cdot P_{j,1}^{FC}\right\}}{\sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot \left\{IC^{GT} \cdot P_{max}^{GT} + IC^{MT} \cdot P_{max}^{MT} + IC^{FC} \cdot P_{max}^{FC}\right\}} \tag{8}$$

Where, IIC is the index of installation cost of DG units; IC^{GT}, IC^{MT} and IC^{FC} are the installation cost of gas turbine, micro turbine and fuel cell based DG units, respectively (in \$/kW); $P_{j,1}^{GT}$, $P_{j,1}^{MT}$ and $P_{j,1}^{FC}$ are the sizes of gas turbine, micro turbine and fuel cell based DG units, respectively, at j^{th} candidate location (in kW); and P_{max}^{GT}, P_{max}^{MT} and P_{max}^{FC} are the maximum sizes of gas turbine, micro turbine and fuel cell based DG units, respectively (in kW). Finally, the objective function, C can be expressed by (9).

$$\min_{\left(P_{j,d}^{GT}, P_{j,d}^{MT}, P_{j,d}^{FC}, P_d^{GD2}, Q_d^{GD2}, P_d^{LT2}, Q_d^{LT2} : d=1 \text{ to } N_{dl}\right)} C \tag{9}$$

Where:

$$C = w_1 \times IREL + w_2 \times IVD + w_3 \times IEI + w_4 \times IIC \tag{10}$$

where, w_1, w_2, w_3, and w_4 are the weighing factors to the indices for active energy losses, voltage deviation, environmental impact and installation cost of DG units, respectively. The weighing factors are selected in such a manner so that the (11) is satisfied:

$$w_1 + w_2 + w_3 + w_4 = 1 \tag{11}$$

2.2. Constraints

The objective function with various indices needs to consider constraints too. The developed formulation includes constraint such as operating and planning restrictions to be followed during the allocation of DG units in a radial distribution network. Both equality and inequality type of bounds considered in the optimization are discussed as follows:

2.2.1. Thermal limit of feeder

Since each distribution feeder of a distribution network is designed to carry a certain amount of maximum current (referred to as 'Thermal Limit' of feeder), loading a feeder beyond its thermal limit can cause severe damage to it [10] which is governed by (12).

$$\sqrt{\left(P_{j,d}^{FS}\right)^2 + \left(Q_{j,d}^{FS}\right)^2} \leq FC_{j,0} \qquad \text{for } j = 1 \text{ to } N_{Bus} - 1, \text{ and } d = 1 \text{ to } N_{dl} \tag{12}$$

Where, $P_{j,d}^{FS}$ and $Q_{j,d}^{FS}$ are the active and reactive power flows, respectively, through sending end of j^{th} feeder corresponding to d^{th} demand level after DG placement in the network (in kW and kVAr, respectively); and $FC_{j,0}$ is the apparent power capacity of j^{th} feeder (in kVA).

2.2.2. System voltage profile

For a given demand level, the voltage magnitude at every bus should be maintained within its pre-specified limits after DG placement as [11] which is governed by (13).

$$V_{\min} \leq V_{i,d}^2 \leq V_{\max} \qquad \text{for } i = 2 \text{ to } N_{Bus}, \text{ and } d = 1 \text{ to } N_{dl} \tag{13}$$

Where, $V_{i,d}^2$ is the voltage magnitude at i^{th} bus corresponding to d^{th} demand level after DG placement in the network (in kV).

2.2.3. Size and operating limit on DGs

The optimal sizes of different types of DG units are computed by (14), (15), and (16) considering the peak load of the system and are restricted to certain fraction of total peak demand of the system as [11], [12].

$$P_{j,1}^{GT} \leq x_j^{DG} \cdot \alpha \cdot \sum_{i=1}^{N_{Bus}} P_{i,1}^{D} \qquad j = 1 \text{ to } N_{Bus} \tag{14}$$

$$P_{j,1}^{MT} \leq x_j^{DG} \cdot \alpha \cdot \sum_{i=1}^{N_{Bus}} P_{i,1}^{D} \qquad j = 1 \text{ to } N_{Bus} \tag{15}$$

$$P_{j,1}^{FC} \leq x_j^{DG} \cdot \alpha \cdot \sum_{i=1}^{N_{Bus}} P_{i,1}^{D} \qquad j = 1 \text{ to } N_{Bus} \tag{16}$$

Where, α is the fraction of total peak demand of the system.

For other than peak load operation, the optimal power generation from different types of DG units are restricted to their capacities are given by (17), (18), and (19)

$$P_{j,d}^{GT} \leq x_j^{DG} \cdot P_{j,1}^{GT} \qquad j = 1 \text{ to } N_{Bus} \text{ and } d = 2 \text{ to } N_{dl} \tag{17}$$

$$P_{j,d}^{MT} \leq x_j^{DG} \cdot P_{j,1}^{MT} \qquad j = 1 \text{ to } N_{Bus} \text{ and } d = 2 \text{ to } N_{dl} \tag{18}$$

$$P_{j,d}^{FC} \leq x_j^{DG} \cdot P_{j,1}^{FC} \qquad j = 1 \text{ to } N_{Bus} \text{ and } d = 2 \text{ to } N_{dl} \tag{19}$$

2.3. Analytic hierarchy process for selection of weighing factors

The final objective function given by (10) and (11) is obtained by taking the sum of indices for active energy losses, voltage deviation, environmental impact and installation cost of DG units, given by (1) to (10) respectively, after multiplying them with suitable weighing factors. Therefore, the selection of proper weightage to each index becomes very important to achieve an optimal solution, which results minimum investment cost of DG units and maximum technical and environmental benefits. This is because the optimal sizes of DG units are computed considering the peak load condition in the network. Mathematically, this is expressed by (20).

$$w_1 = w_2 = w_3 \text{ and } w_1, w_2, w_3 > w_4 \tag{20}$$

Since, the sum of all weighing factors is equal to unity; the following relations can also be given by (21).

$$w_1 = w_2 = w_3 = \frac{1-w_4}{3} \text{ and } \frac{1-w_4}{3} > w_4 \quad (21)$$

The above equation implies to (22).

$$w_4 < 0.25 \quad (22)$$

As the capacity of DG units is obtained for peak load condition, the installation cost of DG units is fixed at peak load condition. Therefore, for obtaining optimal DG operation at load levels less than peak load, the index for installation cost of DG units is not necessary and is set to zero to (23) as:

$$w_4 = 0 \quad (23)$$

the values of weighing factors w_1, w_2, and w_3 are computed by using analytic hierarchy process (AHP) technique [13], [14]. In the proposed formulation, three technical indices, i.e., real energy losses, voltage deviation, environmental impact, in the objective function is taken as the input criterion for decision-making. Once the comparison matrix is found to be consistent, the values of weights are computed and used to form scenario-2, 3 and 4 reflecting the priority to one out of three technical indices. Scenario-1 is a non-AHP scenario and reflects equal importance to all indices [15].

2.4. Net annual savings

The economic analysis of DG integration is calculated in terms of net annual savings (NAS). Where, NAS is the net annual saving to the distribution utilities (in $) [10]. It considers annual economic benefit with annual investment of distribution utilities. The net annual saving due to integration of DG units in the distribution system computed by (24).

$$NAS = AB - AI \quad (24)$$

2.4.1. Annual economic benefit to distribution utilities

DG provides active power support to the loads connected at nearby buses, and therefore, reduces the energy imported from the upper grid. After integration of DG units into the existing distribution system, the annual economic benefit to the distribution utilities due to the reduction of energy imported from the upper grid can be computed by (25).

$$AB = C_E \cdot \sum_{d=1}^{N_{dl}} (P_d^{GD2} - P_d^{GD1}) \cdot TD_d \quad (25)$$

Where, AB is the annual economic benefit to the distribution utilities (in $); and C_E is the price of energy imported from the upper grid (in $/kWh).

2.4.2. Annual investment from distribution utilities

With integration of DG units into the existing distribution system, the annual investment from the distribution utilities towards procurement, installation, operation and maintenance of DG units are computed by (26).

$$\begin{aligned} AI = {} & \sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot IC^{GT} \cdot P_{j,1}^{GT} \cdot \frac{r\cdot(1+r)^{T^{GT}}}{(1+r)^{T^{GT}}-1} + \sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot IC^{MT} \cdot P_{j,1}^{MT} \cdot \frac{r\cdot(1+r)^{T^{MT}}}{(1+r)^{T^{MT}}-1} \\ & + \sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot IC^{FC} \cdot P_{j,1}^{FC} \cdot \frac{r\cdot(1+r)^{T^{FC}}}{(1+r)^{T^{FC}}-1} \\ & + \sum_{j=1}^{N_{Bus}} x_j^{DG} \cdot \left\{ \sum_{d=1}^{N_{dl}} \left\{ P_{j,d}^{GT} \cdot OC^{GT} + P_{j,d}^{MT} \cdot OC^{MT} + P_{j,d}^{FC} \cdot OC^{FC} \right\} \cdot TD_d \right\} \end{aligned} \quad (26)$$

Where, AI is the annual investment from the distribution utilities (in $); r is the interest rate; T^{GT}, T^{MT} and T^{FC} are the life-times of gas turbine, micro turbine and fuel cell based DG units, respectively, (in year); and OC^{GT}, OC^{GT} and OC^{GT} are the operating and maintenance costs of gas turbine, micro turbine and fuel cell based DG units, respectively, (in $/kWh).

2.5. Methodology/solution procedure

The values of weighing factors for Prioritized scenarios, *i.e.*, w_1, w_2, and w_3 are computed using AHP technique. The overall four scenarios are formed including Scenario-1 as non-AHP and other AHP based scenarios are numbered 2 to 4 are given in:

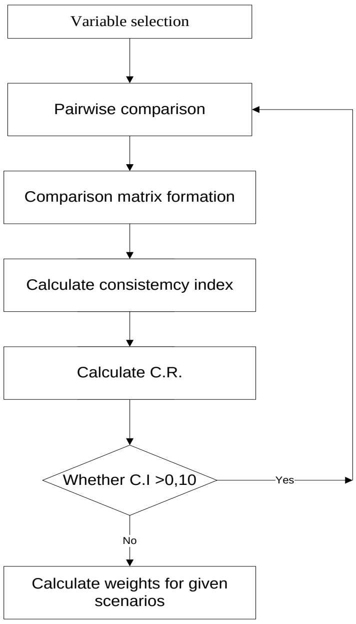
- Scenario-1: Equal weightage to all indices.

- Scenario-2: Prioritization to index of active energy losses.
- Scenario-3: Prioritization to index of voltage deviation.
- Scenario-4: Prioritization to index of environmental impact.

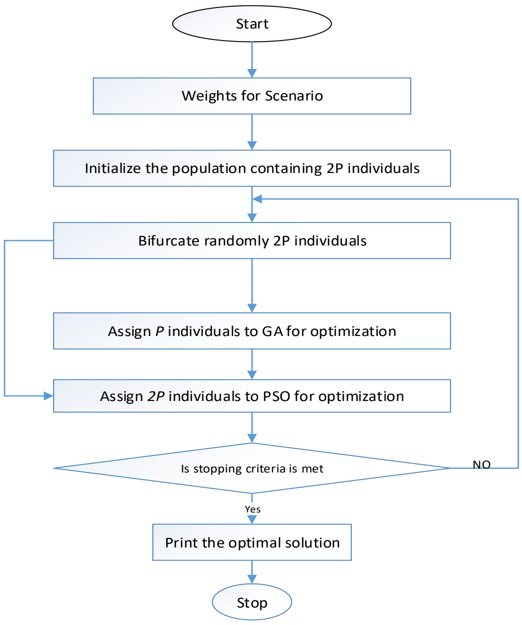
It has been observed from the various literature studies that equal weightage to all objectives are considered in most of the multi-objective formulations. Hence, scenario-1 has been considered in this work as base case scenario. Other scenarios have been also generated giving priority to one index over remaining two indices. For scenarios 2 to 4, the weights to the indices are being scientifically calculated using AHP [15]. In AHP, the comparison matrix has been computed from the input data from power system experts in terms of comparative importance based on respective knowledge and expertise. The comparison matrix is acceptable; only if the value of its consistency ratio (CR) is below 0.1 [16], [17]. Table 1 shows the values of weighting factors for scenarios. The solution procedure for getting optimal solution of the proposed formulation using Hybrid GA-PSO optimization technique and calculation of weighting factors for scenarios 2 to 4 using AHP are shown in Figures 1(a) and 1(b).

Table 1. Values of weighting factors and CR for scenarios 1-4 using AHP

Scenarios	Weighing factors	C.R.
Scenario-1	$w_1 = 1/3, w_2 = 1/3, w_3 = 1/3$	-
Scenario-2	$w_1 = 0.5934, w_2 = 0.1284, w_3 = 0.2764$	0.0053
Scenario-3	$w_1 = 0.1655, w_2 = 0.6098, w_3 = 0.2247$	0.0904
Scenario-4	$w_1 = 0.1488, w_2 = 0.1603, w_3 = 0.6908$	0.0053



(a)



(b)

Figure 1. Flow chart of proposed methodology (a) steps for AHP calculation and (b) solution procedure using hybrid GA-PSO optimization

3. RESULTS AND DISCUSSION

The developed methodology is implemented using MATLAB environment and tested on two test systems, namely IEEE 33-bus radial distribution systems to determine the optimal sizing and siting of dispatchable DG units. For both these test networks, the daily load duration curve is approximated by a piecewise linear function. The load levels and corresponding time durations are obtained from [18], [19].

In this study, micro-turbine, gas-turbine and fuel-cell based DG units are considered for possible integration in both the test distribution networks. The installation and size of different DG are considered from [20], [21]. In this study, Price of energy imported from the upper grid is 60 $/MWh, Emission rate of upper grid is 632 kg/MWh and interest rate is taken as 10%. For the peak load condition in the network, the weighing factors for active energy losses index (w_1), voltage deviation index (w_2) and environmental impact index (w_3) are considered to be equal and higher than the index for installation cost of DG units (w_4) satisfying (22). For other load levels, w_4 is set to zero as given in (23) as the optimal sizes of DG units are already computed considering the peak load condition in the network.

3.1. IEEE 33-bus radial distribution system

The 12.66 kV, 33-bus radial distribution system is used as test system for implementation of proposed topology. The GHG emission for base case is 14.17 kt per annum [7], [22], [23]. To identify the suitable buses for DG placement in 33-bus radial distribution network, a sensitivity index is computed using (27). Mathematically; the sensitivity of active power losses, P_L with respect to active power injection at i^{th} bus can be given as [13]. Where, P_i denotes the active power injection at i^{th} bus; ΔP_i is the incremental change in P_i; and $P_L(P_i + \Delta P_i)$ and $P_L(P_i)$ are the active power losses with injected power P_i and $P_i + \Delta P_i$, respectively. At each node; DG power injection of 10%, 20% and 30% of total active power demand (TAPD) of the system is made and the sensitivity indices are computed using (27).

$$\text{Sensitivity of } P_L = \frac{\partial P_L}{\partial P_i} = \frac{P_L(P_i+\Delta P_i)-P_L(P_i)}{\Delta P_i} \tag{27}$$

As seen in the Figure 2 among different buses, buses 18, 17, and 16 have the higher value of sensitivity index hence, these buses are identified as the candidate buses for DG placement for placement of micro-turbine (MT), gas-turbine (GT), and fuel-cell (FC) based DG units, respectively. The optimal sizes of different types of DG units are restricted to 25% of total peak demand of the system (*i.e.*, α = 0.25). This results the maximum penetration of each DG type as 900 kW. Considering the peak load condition in the network; firstly, an analysis of impact of installation cost of DG units on active energy losses, voltage deviation and environmental impact is analyzed. Since the weightage to the index of installation cost of DG units, w_4 is restricted by (20), its value is varied from 0.00 to 0.24 in a step of 0.03 and the impact of w_4 on other indices considered in the objective function are analyzed. For each value of w_4, other weighing factors, *i.e.*, w_1, w_2, and w_3 are computed using (21) and optimal sizes of DG units are determined using hybrid GA-PSO based approach. The final solution and the values of different indices are presented in Table 1. Since the behavior of different indices is not similar with the change in the value of w_4, the optimal sizes of DG units corresponding to w_4 = 0.12 is selected to ensure cost-effective penetration of DGs with reasonable technical and environmental benefits [10], [23]. Thus, the optimal sizes of micro-turbine, Gas-turbine and fuel-cell based DG units become 0.88 MW, 0.88 MW, and 0.11 MW, respectively.

In Table 2, Base case scenario reflects equal priority to all indices in the objective function whereas scenarios 2 to 4 are prioritized scenario with respect to the indices formulated in the problem [24], [25]. Further, all scenarios result in the positive value of net annual saving, therefore, all scenarios are economically viable alternatives for the operation of DG units. Among these four scenarios, scenario-4 results maximum net annual saving. Thus, it is beneficial to the system to operate the DG units according to the results of scenario-4. It also causes minimum losses in the network, higher economic savings and minimum GHG emission.

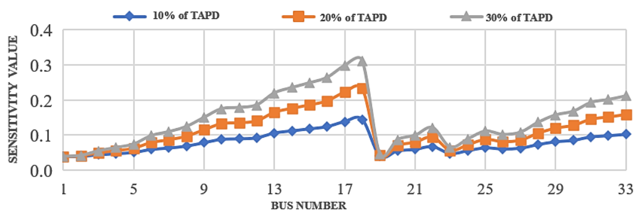


Figure 2. Sensitivity analysis of 33-bus distribution system

Table 2. Comparison of TEE performance of 33-bus distribution system under different scenarios

Scenario	Active energy losses (in MWh)	Active energy from grid (in GWh)	GHG emission (in kt)	Net annual saving (M$)
Base Case	827.99	22.42	14.17	-
Scenario-1	522.13	14.89	11.51	17.79
Scenario-2	523.54	15.10	11.59	17.72
Scenario-3	562.43	15.63	11.77	15.40
Scenario-4	487.37	14.54	11.38	19.87

4. CONCLUSION

In this study, TEE based analysis for optimal placement and sizing of dispatchable DG units has been carried out with mathematical multi-criterion decision making approach for selection of weighting factors *i.e.* AHP. Sensitivity analysis for selection of most sensitive nodes is performed which ultimately reduces the burden of iteration and optimization duration. All AHP based scenarios results in higher saving, better technical performance and lowering of the emissions as compared to base case. It gives a better sense to consider priority based optimal solutions rather than equal priority indices for DG placements and achieve results that are more efficient.

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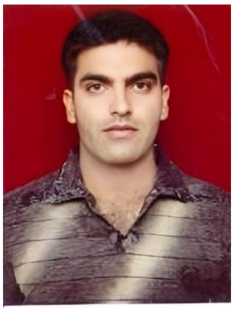
BIOGRAPHIES OF AUTHORS



Surender Singh Tanwar as born on August 15, 1980 in Rajasthan India. He received Master's degree in Electrical Engineering in 2011 and also received Ph.D. degree in 2021 from Indian Institute of Technology Roorkee, India. He is currently working as Assistant Professor in Department of Electrical Engineering at Engineering College Bikaner, Bikaner Technical University, India. His fields of interest are planning of distribution systems and DG integration. He can be contacted at email: stanwar@ah.iitr.ac.in.

Ganesh Prasad Prajapat has received his B.Tech. degree from M.B.M. Engineering College, Jodhpur, Rajasthan in 2005, M.E. degree from NITTTR, Chandigarh in 2011 with Gold-medal and Ph. D. degree from Indian Institute of Technology, Delhi in year 2018. He is working as an Assistant Professor in Electrical Engineering Department, Engineering College, Bikaner, India. His research interests include advanced control of renewable energy systems. He can be contacted at email: prajapat2008@gmail.com.

Ravindra Rathod as born on 7th August 1979 in Maharashtra, India. He received Ph.D. degree under QIP from Indian Institute of Technology Roorkee, India, in 2017. He is currently working as Assistant Professor in Information Technology Department at WCE, Sangli, Maharashtra. His fields of interest are data mining, artificial intelligence, and geographic information system. He can be contacted at email: rrr.wce@gmail.com.

Sanjay Kumar Bansal has 25 years of teaching, research and academic leadership experience. He received the M.Tech. and Ph.D. degrees from MNIT, Jaipur, Rajasthan, India. He is currently working as an Associate Professor in the Department of Electrical Engineering, BTU Rajasthan, India. He researches interests in the areas of renewable energy and smart grids. He can be contacted at email: skbansal30@gmail.com.

Sukhlal Sisodia as born at Dhar in Madhya Pradesh, India. He received Ph.D. degree in Electrical Engineering from Indian Institute of Technology Roorkee, India. He is currently working as Assistant Professor in Department of Electrical Engineering at SGSITS, Indore, India. His fields of interest are demand-side management, planning of distribution systems. He can be contacted at email: sukhlalsisodiya.iitr@gmail.com.