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# Placement of Renewable Distributed Energy Resources in the Radial Distribution Network to Overcome the Losses and Air Pollution

**Amandeep Gill*, Himani Bali[1] and Abhilasha Choudhary[1]**
Department of EEE, Chandigarh University, Jaipur, India
[1]Department of ECE, JECRC University, Jaipur, India
✉ aamangill.87@gmail.com

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**Abstract:** Unplanned placement of the distributed energy resources in the existing network can cause severe problems like voltage instability, increase in power losses, system islanding, reverse power flows, air pollution, etc. Power losses and voltage profile maintenance are the most significant restrictions of the existing power system. Therefore, optimal placement of distributed energy resources is required to overcome the above problems and the use of renewable distributed energy resources is required for the reduction of air pollution. For optimal placement, many researchers have proposed various techniques but many of them have neglected the iteration convergence rate for the solution. Optimal placement of distributed energy resources has to deal with constraints like size, location, number, power factor and type. Enhanced particle swarm optimisation and genetic algorithm technique for optimal penetration and sizing of renewable distributed energy resources in the IEEE 33 bus radial distribution network has been applied. Enhanced particle swarm optimisation and genetic algorithm techniques have been applied for power loss reduction, enhancing voltage profile and minimising the iteration for the convergence rate of the solution.

**Key words:** Distributed energy resources, enhanced particle swarm optimisation technique, genetic algorithm, radial distribution network.

## Introduction

The demand for electrical energy is rising day by day, and due to inadequate investments in power systems, electrical energy sectors are dealing with various problems. The existing power systems setups are older and outdated. The current power system is unable to bear the load demand as well as supply the generated power from the central power plant to the customers, which might create high demand in the existing network. Moreover, significant amount of power losses in the existing network lowers its efficiency. A big part of generated power is lost in transmission and distribution losses. These losses have a direct influence on the network regarding economic outcomes and the efficiency of the network. Therefore, the main objective of this study is to effectively make use of the existing network by appropriate preparation of readily available sources and reliable usage of arising technologies. Deregulation of the power system network leads to particular distribution problems, such as reactive power monitoring. Also, most of the feeders run at crucial loading problems. So the power loss reduction of the distribution system is vital to improving systems efficiency, stability, reliability and voltage profile. To achieve all these, it is necessary to utilise new modern

*Corresponding Author

technologies to the optimum use of existing resources. In the last two decades, different approaches have been presented and carried out to resolve these problems like network reconfiguration, conductor grading, distribution transformer allotment and sizing, high voltage distribution system, automatic voltage booster, capacitor penetration and penetration of distributed energy resources (DER). All these discussed strategies can be utilised to minimise the losses successfully and increase the system's efficiency (Ma et al., 2018).

However, to meet the load demand, minimise the power losses, and enhance the voltage profile during peak time, the most commonly used approaches are capacitor placement and DER placement. According to the fuel used for the operation, DER is categorised into two types: non-renewable DER and renewable DER. Non-renewable DER units are based on combustion turbines, reciprocating engines, gas turbines, and microturbines. Renewable DER units are based on solar, wind, biomass, hydro, tidal and geothermal (Moghaddam et al., 2018). These types of power plants are the major reason behind air pollution. The major exhausts from thermal power plants that add to air pollution consist of sulphates, nitrates, mercury, as well as additional particle matter (which is mainly developed by SOX exhausts). Coal, fly ash, as well as additional particulates from the thermal power plant and industries in Delhi, add 35% of PM2.5 in the wintertime and 41% of PM2.5 in the summertime. Considering that Delhi has 13 thermal nuclear power plants with a capacity of over 11,000 MW within a 300-km span, these exhausts are commonly blown right into the NCR by the northwesterly winds. Beyond Delhi, in the Indo-Gangetic belt, satellite images reveal a straight boost in the particle matter around Delhi, which can be associated with the existence as well as the development of thermal power plants in the area. The majority of the present operational thermal power plants are located in 5 states: Maharashtra, Uttar Pradesh, Chhattisgarh, Madhya Pradesh, and also Gujarat. Furthermore, the Ministry of Power claims that 47,800 MW of thermal power plant construction is under progress. It is the right time to adopt renewable energy sources and replace conventional plants to save the planet. Nowadays, the placement level of renewable DER in the distribution network (DN) is increasing due to its advantages like technical, financial and ecological. Renewable DER unit placement's technical benefits enhance network reliability, and voltage profile, and minimise power losses. The financial benefits of renewable DER unit placement have less maintenance and operational costs, losses related costs reduced, renewable DER units are having no fuel costs, and the setup cost is reduced, preserving the constant running cost for a long time auxiliaries expenses are reduced. The ecological benefits of renewable DER unit placement are effects of land utilisation are reduced, and renewable DER units lessen the expenditures on health as they are eco-friendly and reduce the greenhouse gas discharge pollutants which reduce air pollution (Prabha and Jayabarathi, 2016). The placement of DER units in the DN is boosting swiftly due to a high rate of worldwide electrical energy consumption. The use of DER in a modern-day power system assists consumers to satisfy their needs for continuous and high-quality power. As a result, DER unit innovations are extra-effective and trusted. But if the DER units are not used optimally, it shows an unfavourable effect on the system efficiency like increased power losses and voltage instability. To obtain optimum advantages, the optimal placement of DER units in the DN plays an important function (Devabalaji et al., 2018). Here photovoltaic (PV) type renewable DER unit is selected at unity power factor (PF) for placement in the radial distribution network (RDN). Photovoltaic innovations transform solar radiation right into electron current utilising semiconductor tools. Whenever subjected to adequate light, solar cells generate direct current (DC) power of about 0.5 V. To get more power outcome, numerous solar cells are linked in series connection. Inverter circuits are made to convert the DC outcome acquired by the photovoltaic cell into an alternating current outcome. For DER, PV provides a distinctive benefit over various other kinds of generations. Regardless of the high expense of instalment at first, sunlight is free as well as it is likewise readily available in remote areas. They neither create noise nor produce any contamination in the atmosphere (Gupta et al., 2019).

Unplanned placement of the DER in the existing DN can cause severe problems like voltage instability, increase in power losses, system islanding, reverse power flows, environmental pollution, etc. Therefore, optimal penetration of DER is required for power loss minimisation and voltage profile enhancement. Optimal penetration of distributed generation has to deal with constraints like size, location, number, power factor and type. For optimal placement, many researchers have proposed various techniques, but many of them have neglected the iteration convergence rate for the solution. Therefore, for optimal placement of PV-type renewable DER units, a population-based search strategy is needed. In this study, enhanced particle swarm optimisation (EPSO) and genetic algorithm (GA) are applied for the optimal placement of PV-type renewable DER in the DN. EPSO and GA methods for sizing PV-type renewable DER units at a suitable location in the existing RDN have been applied. EPSO and GA have been applied for power loss reduction, enhancing voltage profile and minimising the iteration for solution convergence rate. The PV-type renewable DER is selected for placement for the reduction of air pollution.

## Objective Problem Formulation

Backward-Forward Load flow analysis is used to discover power loss and voltage representing each branch in an RDN.

### Power Loss Index (PLI)

Real Power Loss minimisation with DER placement is calculated by PLI, which is the proportion of total power loss of RDN with the placement of DER to the total amount of power loss of RDN without placement of DER can be created as:

$$\text{PLI} = \left(\frac{P_{DG,Tl}}{P_{Tl}}\right) \quad (1)$$

The overall quantity of power loss can be minimised with the optimal positioning of DER and can be improved by reducing PLI.

### Voltage Inconsistency Index (VII)

When the DER systems are placed optimally in the RDN, it improves the voltage profile of this network.

$$VII = \max\left(\frac{|V_1| - |V_j|}{|V_1|}\right) \quad \text{where } j = 1, 2, \ldots, n \quad (2)$$

where $V_1$ is the nominal voltage i.e. 1 per unit (p.u) and $V_j$ is the voltage at any node $j$ of RDN. Throughout the placement of DER in the RDN which gives greater voltage inconsistencies from the real value, the suggested method reduces the VII near to zero (Pandi et al., 2013).

### Problem Formulation

The multi-objective problem is developed to reduce the real power loss and voltage incontinency for enhancing the voltage profile of the RDN that is offered as:

$$\min(P_T) = \min(\beta_1 PLI + \beta_2\ VII) \quad (3)$$

where $\beta_1$ and $\beta_2$ are the weighing variables.

### Voltage Sensitivity Constraint (VSC)

To find the voltage sensitivity constraint of the nodes of RDN, DER at 30% loading was placed at each load node at a time. DER unit is placed at node $j$, and VSC for node $j$ is as follows:

$$VSC_j = \sqrt{\frac{\sum_{j=1}^{n}(1 - v_j)^2}{n}} \quad (4)$$

where $V_j$ is the voltage at node $j$ and $n$ is the number of nodes in RDN. The node with the lowest VSC will be the optimal location for DER placement.

### Optimal Sizing for DER

For finding the optimal sizing for DER, place the DER at the node having the lowest VSC. At constant PF, vary the size of DER from the minimum range to the range equal to the branch load capacity in steps until minimum power loss is attained. This is the optimal size for DER (Marchesan et al., 2016).

If all the constraints are satisfied, only then all the resultant service shall be approved or else it should be rejected. DER placement at an optimal location, type, PF and size is recommended and measured by the PSO and GA techniques.

## Particle Swarm Optimisation

The main idea behind composing the PSO algorithm is to mimic the search procedure of fragments for food far away during the migration. The placement of each fragment Y stands for the optimum remedy of the examined trouble which is taken into consideration as the outcome power of the DER in the network. The first populace is produced arbitrarily similar to various other transformative algorithms. Logically, each fragment should transfer to upgrade its placement. To upgrade the motion of each fragment, three keynotes are utilised: the inertia (I), the global ideal placement (Gi) as well as the fragment ideal placement (Pij).

The velocity of each fragment is in between a particular mentioned range as $S_{j,\,min} \leq S_j \leq S_{j,\,max}$. A high velocity for $S_{j,\,max}$ can misguide the fragments to rise past the optimum remedy when a reduced value of $S_{j,\,max}$ can reduce the ability of the PSO to get away from the local ideal placement (Basser et al., 2015).

### The Enhanced PSO (EPSO)

Here the procedure is modified for efficiency enhancement of PSO in both global and local searching approaches, this is done to lower the possibility of being caught in local ideal placement in addition to being reliable on the algorithm's first parameters. The performance of the modified procedure is boosting the capability of the PSO by improving its search capability. This suggested two-stage modified method discussed complies as follows: In the initial stage, the concept of the flying trip is a formula effective technique used to provide more effective local searching.

In the 2nd adjustment stage, the populace is approached with the most effective present fragment in every iteration. Initially, the average of the populace is determined (AP); thereafter the range between the most effective fragment and AP is calculated as well as included in the entire populace.

The motion discussed above will certainly compel the entire populace to alter its placement towards the most effective remedy, quickly. Finally, the variety of the populace can be raised, efficiently. Usage of these two basic modified procedures enhances the search capability and convergence rate of the PSO (Akbari et al., 2016).

## Genetic Algorithm

Here, a GA-based power loss minimisation and voltage profile enhancement method is recommended for locating the size and location for DER placement in the RDN. As a result assessment of the objective feature depends only on the size and location of DER devices.

The GA is utilised to assign an optimisation formula that executes a type of approx global searching. Searching depends on the details acquired by the analysis of numerous factors in the search area. Each present factor is called a people, and the collection of present factors is called the populace. The GA maintains this collection of present factors rather than maintaining a solitary present factor as would certainly hold in the majority of optimisation formulas. The populace is anticipated to protect near-optimal with consecutive applications, at every iteration, of GA operators.

Primary actions are the standard variation of GA programmes. The individual connects the top-level declaration of the trouble to the GA programmes by executing specific distinct primary actions. The primary actions are the individual-provided input to the GA programmes. The GA that produces excellent results in numerous useful troubles is made up of 3 operators:

- In the crossover, the people arbitrarily arranged set-wise, have their area incorporated as if each previous set of people generates a brand-new set.
- In mutation, some people are arbitrarily customised, to get to various other factors of the searching area.
- In selection, the people after a crossover as well as mutation, are assessed. They are selected or not selected for being placed in the brand-new populace with a probabilistic guideline that provides a higher possibility of choice to far better people.

The benefits of GA are that they need no expertise or slope details regarding the reaction surface area; they are immune to ending up being caught in local optimum as well as they can be utilised for a range of optimisation troubles. A GA search is done by analysing at the same time a collection of feasible remedies, rather than a solitary one. This method permits a much better expedition of the remedy area throughout the look for the global optima. Additionally, it decreases the possibility of being embedded in local optima. The optimisation procedure success relies on the suitable layout of a fitness feature for the trouble. The fitness values of people in an offered populace are used to drive the development procedure. These attributes allow the GAs to existing outcomes also when maximising complicated or alternate features. Most of the time, it is extremely challenging to attain an analytic connection between the sensitivity of the substitute power system as well as the values of the specifications to be enhanced. GA does not require this type of detail, thus it is appropriate for optimising the process.

An evolutionary approach requires embracing the process to produce people for the next step. The people are set up by their fitness as well as just the most effective of them are taking the same right into the next step. By this, excellent people are not shed throughout a race. Various other kids originate from crossover as well as mutation. The purpose of the fitness feature is to mathematically stand for the efficiency of a person (Singh et al., 2008).

## Results and Discussion

The EPSO and GA techniques have been applied for the optimal placement and sizing of DER. The EPSO and GA are tested on 12.66 kV, IEEE 33 node RDN. The total actual and reactive load is 2.8 MW as well as 1.4 MVAR. Line and bus data for the IEEE 33 node RDN are taken from the study of Sahoo and Prasad (2006). Backward forward sweep load flow analysis is done by considering base apparent power (Sb = 100 MVA) and base voltage (Vb =12.66 kV). One PV-type renewable DER at unity PF is placed in the IEEE 33-node RDN.

The power loss is 231.85 kW, and the minimum bus voltage is 0.9072 per unit (p.u) for this RDN.

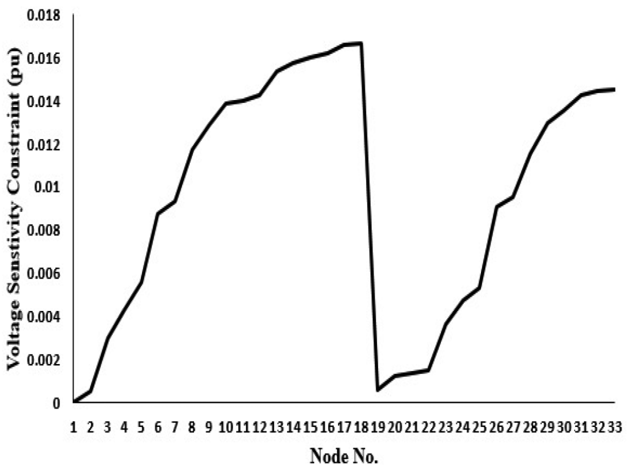


**Figure 1: VSC for DER penetration at the optimal location.**

The VSC for DER penetration at the optimal location is shown in Figure 1; nodes 19 to 22 have the lowest VSC. Therefore these are the best nodes for the optimal placement of DER. A PV-type renewable DER unit at unity PF is selected for placement in the IEEE 33 node RDN. Here, the DER unit's optimal placement with GA and EPSO techniques is shown at different nodes, which reduces the existing power loss and enhances the voltage profile.

Table 1 shows the GA technique and the EPSO technique results. The final optimised results obtained using GA and EPSO techniques are displayed in Table 2. These results are compared with no DER placement.

**Table 1: The GA technique results**

| *GA technique* | | | |
|---|---|---|---|
| *Voltage profile (p.u)* | *Power Loss (kW)* | *DER Capacity (kVA)* | *DER at Node No.* |
| 0.9398 | 210.628 | 46.14 | 24 |
| 0.9411 | 210.109 | 45.25 | 23 |
| 0.9571 | 200.352 | 40.74 | 19 |
| 0.9392 | 211.072 | 47.53 | 25 |
| 0.9469 | 206.258 | 43.68 | 21 |
| 0.9386 | 211.938 | 44.92 | 18 |
| 0.9531 | 203.646 | 41.84 | 20 |
| 0.9432 | 207.031 | 44.14 | 22 |

**Table 2: The EPSO technique results**

| *EPSO technique* | | | |
|---|---|---|---|
| *Voltage profile (p.u)* | *Power Loss (kW)* | *DER Capacity (kVA)* | *DER at Node No.* |
| 0.9495 | 194.659 | 43.24 | 24 |
| 0.9521 | 191.803 | 42.37 | 23 |
| 0.9631 | 190.164 | 39.14 | 21 |
| 0.9574 | 191.732 | 41.35 | 22 |
| 0.9465 | 198.889 | 43.93 | 25 |
| 0.9436 | 194.827 | 40.73 | 18 |
| 0.9731 | 190.152 | 38.42 | 19 |
| 0.9713 | 188.084 | 35.21 | 20 |

By the EPSO technique, the optimal sized 30.21 kVA DER unit is connected to the optimal bus 20. In the GA technique, the optimal sized 40.74 kVA DER unit is connected to the optimal bus 19. The EPSO technique reduced the DER size by 5.53 kVA compared to the GA technique DER unit size. The power loss obtained from the EPSO technique is 188.084 kW, 200.352 kW with the GA technique and 231.285 kW when there is no DER. The minimisation of power loss by the EPSO technique is 18.67% compared with 13.37% by the GA technique. The voltage profile enhances from 0.9084 p.u to 0.9713p.u from the RDN with no DER unit to the EPSO. (Figures 2 and 3 show the voltage profile and real power loss comparison due to the optimal placement and sizing of the DER unit with EPSO technique, with GA technique and RDN with no DER unit.

Figure 4 shows the convergence rate of the EPSO and GA techniques. The convergence rate of the EPSO technique is 72 iterations and for the GA technique is 83 iterations. EPSO technique has the best results w.r.t voltage profile enhancement, and real power loss minimisation, as shown in Table 3.

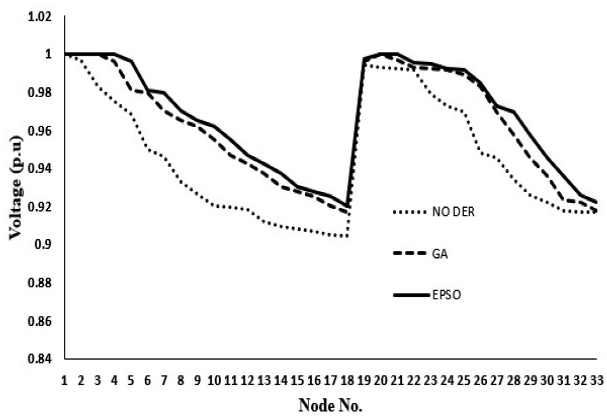


**Figure 2: Voltage profile (p.u) comparison.**

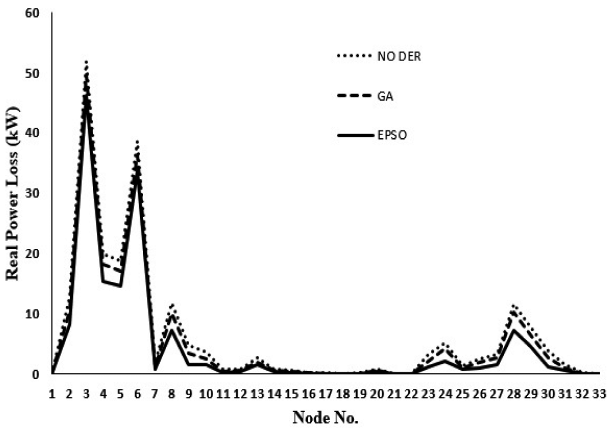


Figure 3: Power loss (kW) comparison.

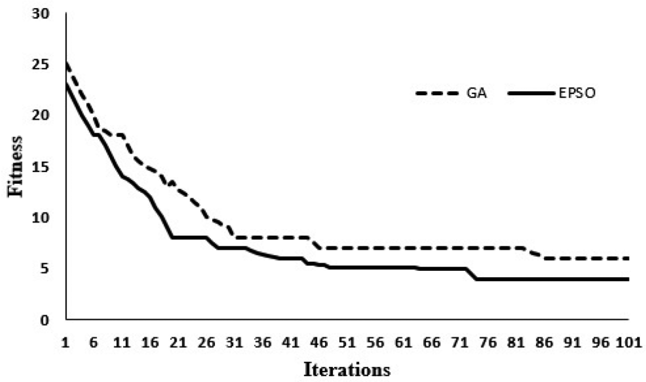


Figure 4: Convergence rate comparison.

**Table 3: Final optimised results**

| *IEEE 33 node RDN* | *Voltage profile (p.u)* | *Power loss (kW)* | *Power reduction (kW)* | *Power loss minimisation (%)* | *DER size (kVA)* | *DER placed at optimal Node No.* |
|---|---|---|---|---|---|---|
| No DER | 0.9084 | 231.285 | - | _ | _ | _ |
| GA | 0.9571 | 200.352 | 30.933 | 13.37 | 40.74 | 19 |
| EPSO | 0.9713 | 188.084 | 23.201 | 18.67 | 35.21 | 20 |

## Conclusion

All the constraints related to optimal penetration like size, location, type, and PF have been considered. PV-type renewable DER unit at unity PF is selected for reducing air pollution. The use of EPSO and GA techniques has reduced the size of DER units. The optimal placement and sizing of the DER unit have been successfully done by the EPSO and GA techniques for power loss reduction and enhancing the voltage profile at the optimal bus. The EPSO technique has better results than the GA technique and RDN with no DER unit, i.e. reduced real power losses, better voltage profile and convergence rate.

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