# Optimal Allocation of Distributed Generation for Performance Enhancement of Distribution System Using Particle Swarm Optimization

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**Abstract.** The rapid growth of power demand and urbanization needs a quality and reliable power supply system. On the other hand, the existing passive distribution network and high cost of power transmission from generation can't meet the fast-growing power demand. The weak performance of the utility like high power interruption and poor voltage profile affect the living standard of individual consumers which are the most serious problems of Ethiopian power distribution system. This type of problem can be minimized by integrating optimally allocated renewable distributed generations with the existing distribution system which are environmentally friend. Optimal sizing and siting of DG done by applying PSO for multi-objective function using MATLAB software. The significant process is how to minimize the power loss, reduce power interruption and improve the voltage profile of distribution systems. The voltage profile and power loss evaluation are done using a power flow method of forward-backward for radial networks. The reliability indices of the network like SAIDI, SAIFI, and EENS are evaluated using ETAP software. The proposed method is tested at Gihon 25-bus feeder of Bahir Dar distribution system. The simulation result indicates appropriate sizing and placement of solar based DG improves the performance of the distribution system.

**Keywords:** Distributed generation · Reliability indices · Power losses · Particle swarm optimization · Voltage profile

## 1 Introduction

The electric power produced from generation can be delivered to end-users through transmission and distribution systems. Utilities contain a complex structure of power system consisting of transmission lines, generating plants, substations, distribution systems, and the load. The fundamental purpose of the power system is to give an economic and reliable channel for electrical energy to transfer from points of generation to customer locations. The complex structure of the power system challenges the quality and reliability of power supply system [1]. Distribution systems directly connected to end


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users. The responsibility of electric power distribution systems are to deliver the electrical energy from the complex power systems to the consumers with the desired quality and reliability but the imbalance between power demand and supply, inaccurate design and operation practices, aging infrastructures, radial type network and high exposure to external environment are the main agents for reliability problems in distribution system [2]. In radial distribution network, there is high power loss which diminishes the quality of power supply. The power loss affects the voltage profile of the system which results in loads not to get the nameplate value.

The existing power distribution systems are not flexible to handle the power demand [2]. This problem diverts the idea of power engineers to change the existing passive distribution systems to active distribution systems. The passive distribution system cannot satisfy the interest of consumers in terms of quality and reliable power supply system. The installation of new generation power plants and transmission lines needs high capital and long time. This problem reduced by using renewable distributed energy sources. The renewable energy sources like wind and PV take the attention of power world to minimize the impact of other energy sources on the environment [3]. Ethiopia which is the country near to the equator that has a good solar irradiance for solar power installation. Due to high solar irradiance available in the country using solar power based DG is preferable. The main performances that determine the efficiency of the distribution system are high reliability, minimum power loss, and desired voltage profile. There are different economical and technical contributions that can be obtained from the integration of renewable based DG such as [4],

- Voltage profile improvement
- Reduction of reserve requirements
- Improved power quality
- Energy loss reduction
- Reliability enhancement
- Increased energy security
- Emissions reduction

On the other hand, improper installation of renewable based DG in the distribution system may reduce the system performance like the voltage profile to be under voltage or overvoltage, decrease system overall efficiency and enable system feeders to be overloaded. Consequently, DG units' placement and sizing into an existing distribution system must be designed and planned precisely.

### 1.1 Renewable Energy Resource Assessment of Bahir Dar City Ethiopia

Ethiopia is located near the equator and has abundant renewable energy resources. Even though, the available resources are not used sufficiently to the manner that eliminates the problem of power demand. So, before integrating renewable DG to the system the first task is identifying the feasible type of source in the site. From the Table 1 below the solar irradiance of the country is from 4–6 Kwh/m$^2$/day [5]. This shows Ethiopia has high renewable energy resource as compared to other countries. Bahir Dar is the capital city of the Amhara region which has solar irradiance of 4.0 to 5.5 Kwh/m$^2$/day throughout the year [6].

**Table 1.** Ethiopian energy resource potential [5]

| Type of resource | Unit | Maximum capacity | Used |
|---|---|---|---|
| Solar irradiance/day | KWh/m$^2$ | 4–6 | <0.01 |
| Wind: power speed | GW m/s | 100 > 7 | <0.01 |
| Hydropower | MW | 45,000 | <0.05 |
| Geothermal | MW | <10,000 | <0.01 |
| Wood | Million tons | 1120 | 0.5 |
| Agricultural waste | Million tons | 15–20 | 0.3 |
| Coal | Million tons | 300 | 0 |
| Natural gas | Billion m3 | 113 | 0 |
| Oil shale | Million tons | 253 | 0 |

The insolation of Bahir Dar city is more than enough because the solar irradiance that reaches the surface of Bahir Dar city is from 4.0 to 5.5 Kwh/m$^2$/day [6]. As compared to developed countries like Germany which uses 40% of renewable distributed generation the renewable energy resource of Ethiopia is untouched. Ethiopia has much enough resource to shift towards solar based distributed generation but still, it is less than 1%.

The average wind speed of the country at 50 m height is around 6 m/s. Bahir Dar which is more suitable for solar power as compared to wind power from the resource availability. But the other part of Ethiopia like Adama and Mekele are also suitable for wind power. For Bahir Dar city solar based DG is preferable since the solar irradiance throughout the year is 4.0–5.5 Kwh/m$^2$/day as shown in Fig. 1 above. The output of wind power depends on different factors in addition to wind speed. In large cities like Bahir Dar which have large buildings and trees installing wind power faces some challenges. Lower places have higher obstructions from the surrounding and this reduces the wind speed of the area. The monthly average wind speed at 40 m is shown in Fig. 2 below and indicates the wind speed of Bahir Dar city is not enough to generate high power.

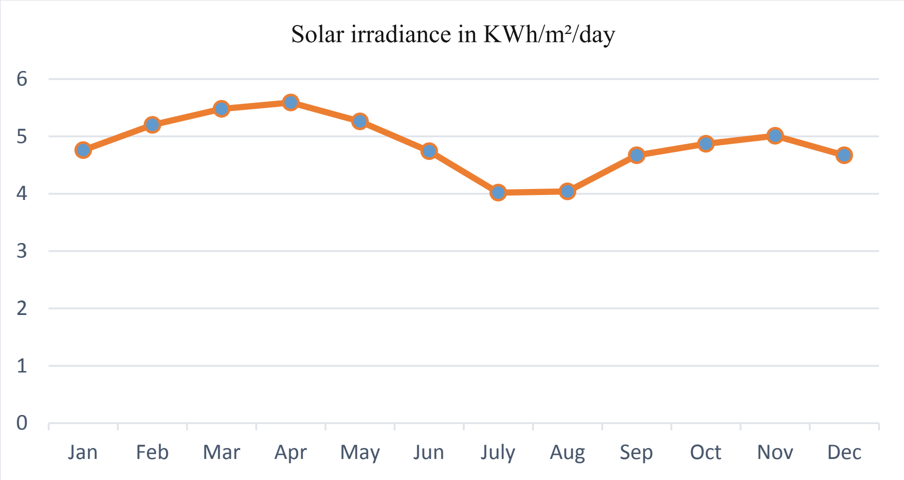



**Fig. 1.** Average monthly insolation of Bahir Dar city

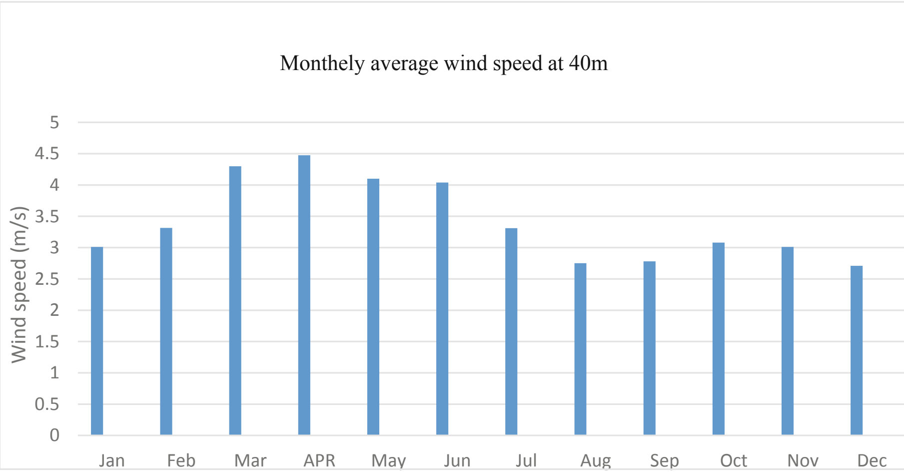



**Fig. 2.** Average monthly wind speed of Bahir Dar city at 40 m height

## 2 Related Works

There have been numerous studies on DG optimal sizing and placement techniques. The power loss and voltage deviation index minimization are one of the objectives to be achieved. Particle Swarm Optimization (PSO) and Genetic algorithm (GA) were used to place and size DG. PSO is preferred due to its fast convergence and its flexibility to handle multi-objective function. PSO is used to size and place DG so as to satisfy a multi-objective function with different constraints. Solar based DG injects real power to the system so that the voltage profile should be in the limit by minimizing the loss.

Arazghlich Igderi et al. [7] suggested on the problem of sizing and allocating of DG. Proper allocating and sizing of DG improves several parameters of the network like power loss, voltage profile, and total harmonic distortion. PSO algorithm is used to place and size DG by considering different constraints. The objective function is formulated by combining different single objective functions using weighting factors. The proposed system is implemented on Tehran 12 bus radial distribution network. The result indicates the optimal placing and sizing of DG improves several parameters. The installation and operating cost of DG are reduced without affecting the power loss and voltage profile of the network. PSO method is preferable than the genetic algorithm interims of fast convergence and low iteration. The contribution of DG on the reliability of the distribution system was not studied.

Raji Rahul [8] done on optimal sizing and placement of DG using PSO to improve the voltage profile of the distribution system with the objective function of voltage stability index. The connection of DG with Grid is in parallel, and the placement depends on the resource availability. Installing DG units may have a negative effect on performances of distribution system like reliability, power quality and voltage profile of the system. The proposed method is simulated in MATLAB software by implementing on IEEE 33 and 69 bus distribution systems. This research addresses only on voltage profile improvement. It did not address power loss minimization and reliability indices enhancement.

Musa and Adamu [9] done on performance enhancement of the distribution network by minimizing the power loss and improving the voltage profile. The optimal place of DG installation is found using the objective function. A combination of evolutionary programming and PSO is used to place and size DG by searching the minimum voltage stability index. The method was developed on IEEE 33 bus system. The result indicates the method used improves the voltage profile by minimizing the power loss. It did not say about the effect of DG on other performance parameters like reliability, protection, operation and installation cost of DG.

Prasanna et al. [10] proposed on reduction of power loss and improvement of voltage profile by optimal allocating and sizing of distributed generation using a genetic algorithm. A multi-objective function is make up by combining the tail-end node voltage deviation index and power loss reduction index using weighting factors. The method was implemented on standard IEEE 69 and 33 bus radial distribution network. The result indicates that the method brings good result on reduction of power loss and improvement of voltage profile. Even if the result on improvement of voltage profile and power loss reduction is good but the research did not address the outcome of DG on reactive power loss and reliability. And also it did not consider the environmental impact and stochastic nature of DG. Economic feasibility and protection problem of integrating DG is not studied.

Ajay Bansal et al. [11] done on voltage profile and efficiency improvement of the distribution system by minimizing real power loss. Selective PSO technique is used to allocate and size DG by considering distributed generation capacity and voltage limit. The objective function is to minimize the active power loss by obtaining the appropriate size and location of DG. The proposed method was tested on IEEE 33 and 69 bus radial distribution network which brings a better performance improvement when compared to genetic algorithm technique. This technique reduces the number of distributed generation by allocating optimally and meets the objective. The objective function did not include reactive power loss. Reliability of the network is not considered when distributed generation installed. Cost analysis and a payback period of the DG is not analyzed. Renewable energy sources are motivated to install as distributed generation. It did not suggest the significance of renewable energy on the environment.

Tiwari et al. [12] done on distribution system performance enhancement using the optimal allocation of DG and DSTATCOM in order to minimize branch losses with the improvement of voltage profiles. The weak bus was identified by fast voltage stability index to size and place DG with the power loss minimization and voltage profile enhancement of the system as the objective function. The method was implemented on IEEE 33 bus radial distribution network and the result compares the voltage profile and power loss of the system with the base case. This research did not address the effect of DG on the reliability of a radial distribution network.

Mohamed et al. [3] suggested to minimize operating cost and power loss by keeping the voltage profile in the desired value. A hybrid PSO is used to allocate DG effectively by combining loss sensitive factor, operating cost of installing DG and VSI. The weighting factors were used to form objective functions. Power flow analysis is done using the forward-backward method due to the special feature of radial network. The method was tested by IEEE 33 and 69 bus radial distribution network. The convergence of HPSO technique is fast when compared to the GA and PSO. This method achieves the objective with better output relatively to the previous techniques. Reactive power loss and environmental problems were not studied. The effect of integrating DG on the short circuit current level of protection devices were not evaluated in this research. Only the operating cost of distributed generation is considered related to reliability evaluation.

Laksmi Kumari et al. [13] done on efficiency enhancement of distribution network by optimally sizing DG. PSO was used for DG optimization. Finding the optimal size and location of DG plays a very important and effective role in the distribution system to improve the overall efficiency by reducing the active power loss. The developed method was tested on IEEE 33 Bus and IEEE 15 Bus radial distribution systems. The obtained result shows the NPSO optimized system is more effective than the PSO optimized and the non-optimized system for voltage profile improvement and system loss reduction. This research did not suggest the contribution of renewable DG on system reliability of the network.

Hussein Abdel-mawgoud et al. [14] done on optimal DG allocation in radial distribution networks using the loss sensitivity factor and moth-flame optimization algorithm. The objective of the study was to reduce the power loss, to improve the voltage profile and the voltage stability of the system by optimally sizing and siting of wind and PV-based DG. The method was implemented on standard IEEE 33 and 69 bus system. The result shows wind and PV-based DG enhances system performance. The stochastic nature of solar irradiance and wind speed were not studied in this research. The impact of PV and wind-based DG on the reliability of the system was not studied.

From previous related works they mostly study on voltage profile improvement and real power loss minimization by optimally placing and sizing of DG. This research addresses placing and sizing of renewable DG by minimizing active power loss, reactive power loss and voltage deviation index by considering as multi-objective function using weighting factors. The particle swarm algorithm has been coded as well as the power flow forward-backward method using MATLAB. The effect of DG on reliability studied before and after DG placement using ETAP software. Feasibility of wind and solar power resource also studied on Bahir Dar city.

## 3 Proposed System Model

A standard and efficient power flow technique is required for real-time applications such as planning, switching, optimization of network, load shading, and so on. Load flow analysis of radial distribution system is done using the Backward/Forward Sweep(BFS) algorithm since it is fast, flexible, simple to implement, powerful in convergence and the high ratio of R/X nature of radial distribution system [3].

A. Power flow analysis

The power flow analysis is done using a load flow method of BFS. A simple radial distribution system which connects bus "i" and "k" through a line "M" in Fig. 3 is used for modeling of radial network.

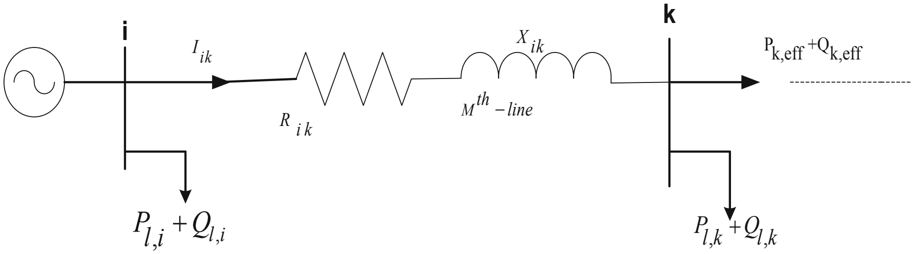



**Fig. 3.** Single line diagram for simple radial distribution system

Kirchhoff's current and voltage law (KCL and KVL respectively) are used to implement BFS. The real ($P_{ik}$) and reactive ($Q_{ik}$) power that flows through line 'M' from bus 'i' to bus 'k' can be calculated (i) Backward direction from the end node to first node and are given as [3],

$$P_{ik} = P_k^{'} + R_{ik}\frac{(P_k^{'2} + Q_k^{'2})}{V_k^2} \tag{1}$$

$$Q_{ik} = Q_k^{'} + X_{ik}\frac{(P_k^{'2} + Q_k^{'2})}{V_k^2} \tag{2}$$

Where, $P_k^{'} = P_k + P_{l,k}$ and $Q_j^{'} = Q_k + Q_{l,k}$

$P_{l,k}$ and $Q_{l,k}$ are loads connected at bus k. Pk, eff and Qk, eff are the effective real and reactive power flows out of bus "k".

The angle and voltage magnitude at each node are calculated (ii) Forward direction. Assume a voltage $V_i < \delta i$ at bus 'i' and $V_k < \delta_k$ at bus 'k', then the current flowing through the line 'M' having an impedance, $Z_{ik} = R_{ik} + X_{ik}$ between bus 'i' and 'k' can be obtained as,

$$I_{ik} = \frac{(V_i < \delta_i - V_k < \delta_k)}{R_{ik} + jX_{ik}} \tag{3}$$

and,

$$I_{ik} = \frac{(P_i - Q_k)}{V_i < -\delta_i} \tag{4}$$

The voltage at bus 'k' is obtained by evaluating Eqs. (3) and (4) as,

$$V_k = [V_i^2 - 2 * (P_i R_{ik} + jQ_i X_{ik}) + (R_{ik}^2 + X_{ik}^2) * (\frac{P_i^2 + Q_i^2}{V_i^2})]^{0.5} \tag{5}$$

The power losses of the branch 'M' between nodes "i" and "k" can be found as,

$$P_{loss(ik)} = R_{ik} \frac{(P_{ik}^2 + Q_{ik}^2)}{V_i^2} \tag{6}$$

$$Q_{loss(ik)} = X_{ik} \frac{(P_{ik}^2 + Q_{ik}^2)}{V_i^2} \tag{7}$$

The total losses of the distribution system like active and reactive power can be obtained as,

$$f_1 = P_{Loss(ik)} = \sum_{k=1}^{N} P_{Loss(ik)} \tag{8}$$

$$f_2 = Q_{Loss(ik)} = \sum_{k=1}^{N} Q_{Loss(ik)} \tag{9}$$

Where, "N" is the number of branches, N = nb − 1, i = 1: nb, and "nb" is the number of buses.

B. Voltage deviation index: The deviation of voltage from the terminal value can be calculated as,

$$f_3 = VDI = \sum_{i=1}^{nb} (1 - V_i)^2 \tag{10}$$

Where, $V_i$ is the voltage at bus i and nb is the number of buses.

C. Formulation of optimized function

The multi-objective function of this research is considered to minimize the real power loss, reactive power loss, and VDI.

$$\text{Minimize}(f) = \min(w_1 * f_1 + w_2 * f_2 + w_3 * f_3) \tag{11}$$

Where, $\sum_{k=1}^{3} w_k = 1$, $w_k$ are weighting factors used to form the objective function and depend on the focus of the research.

The constraints to be satisfied when minimizing the objective function are:

- Power balance

$$\sum P_{DG} + P_{grid} = \sum P_{loss} + P_d \tag{12}$$

- Voltage limits

$$0.95 \le V_i \le 1.0 \tag{13}$$

- DG capacity limit

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{14}$$

D. Sensitivity factors analysis

The Voltage Sensitivity Factor (VSF) is obtained by the ratio of the base case voltage magnitudes at buses V(i) to the minimum limit of voltage (0.95 p.u). The buses with the smallest value of VSF (i.e. VSF < 1.0) are candidate buses for placement of DG. PSO uses VSF to identify the most critical bus to install DG and to size its proper capacity.

$$VSF = \frac{V_{(i)}}{0.95} \tag{15}$$

## 4 Particle Swarm Optimization Technique

Particle Swarm Optimization (PSO) proposed by Kennedy and Eberhart in 1995 which is one of the evolutionary algorithms [15]. The competition and cooperation among individuals through iterations helps to develop population of individuals in PSO. A potential solution to a problem is obtained from swarm of particles which is from individual particles. The position "Xi" and velocity "Vi" of the particle changes its movement and neighbors' movement experience, towards a better position for itself. The optimization problem of any engineering problem can be expressed as Minimize (f) (As fitness function). Changing and updating the position and velocity of the particle using Eqs. (17) and (16), respectively [3].

$$v_i^{1+t} = w * v_i^t + c_1 * r_1[pbest_i^t - x_i^t] + c_2 * r_2[gbest_i^t - x_i^t] \tag{16}$$

$$x_i^{1+t} = x_i^t + \Delta t * v_i^{t+1} \tag{17}$$

Where, c1 and c2 are acceleration constants, whereas r1 and r2 are two random values between 0 and 1.

## 5 Optimal Sizing and Siting of DG Using PSO and Voltage Sensitivity Factor

The procedures used to site and size DG using PSO and VSF is implemented in the following steps:

Step 1: Read load and line data of radial distribution system including base MVA and base KV.
Step 2: Run the power flow algorithm BFS to evaluate voltage profile, the real and reactive power loss including VSF to select the most critical buses for DG placement.
Step 3: Randomly initialize the PSO parameters like population of the swarm.
Step 4: Identify optimal location of DG based on VSF i.e. (VSF $< 1$), can be considered as candidate bus for DG placement.
Step 5: Update the particle position and velocity according to Eqs. (16, 17) by considering constraint limits in Eqs. (12–14).
Step 6: Run the load flow analysis method of BFS for each particle of PSO to acquire the data that are in step 1.
Step 7: Evaluate the objective function (f) in Eq. (11) for all condition.
Step 8: Do again from step 4 to step 7 until the constraints are satisfied and the objective function is minimized.
Step 9: Print results like voltage profile at each bus, DG location and size, real and reactive power loss of the system.

The flow chart below in Fig. 4 shows the procedure of how DG sizing and placement is done using particle swarm optimization in combination with load flow method of BFS.

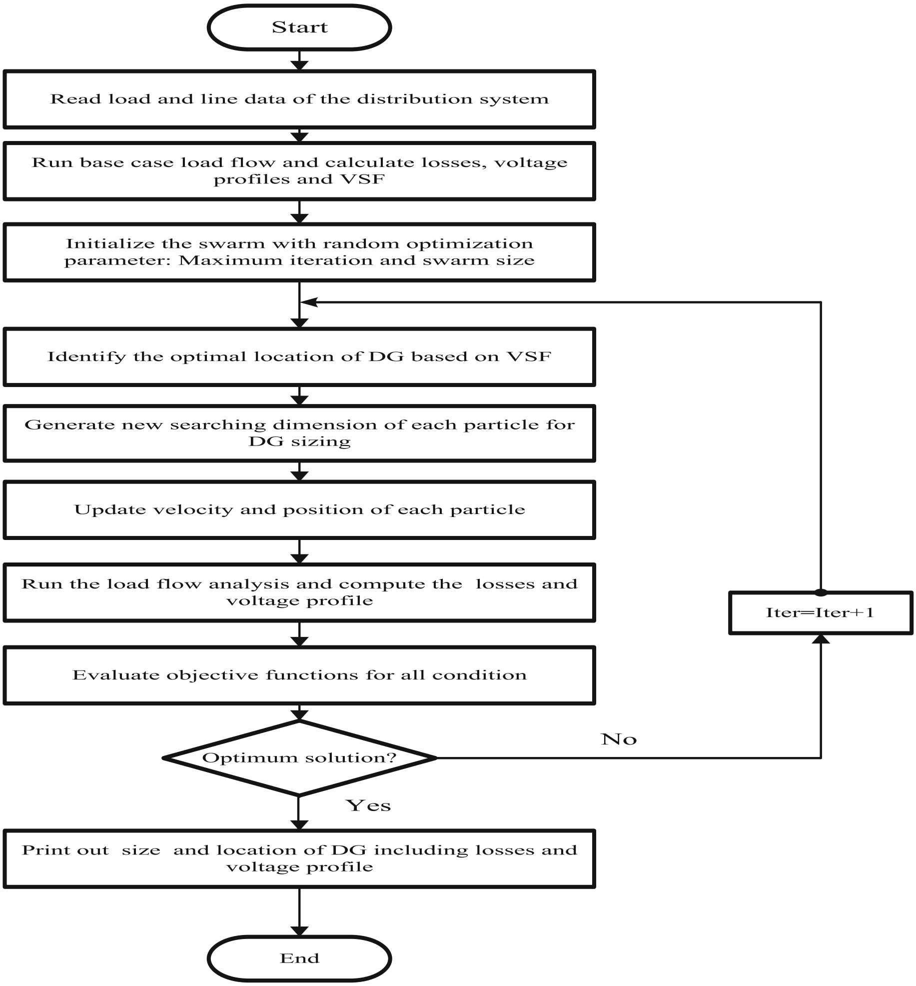



**Fig. 4.** Particle swarm optimization computational procedure

## 6 Reliability Analysis of the Radial Distribution System

Distribution system reliability indices are functions of repairs, restoration times and component failures which are unplanned in nature. The reliability assessment of distribution system needs the evaluation of system reliability and load point indices [4]. The load point indices used to determine system reliability indices are the average load point outage rate (r hr/failure), the average load point failure rate (λ failures/year), and the average annual load point outage time or average annual unavailability (U hr/year) [16]. The basic reliability indices which determine system reliability are SAIFI, SAIDI, and EENS.

**System Average Interruption Frequency Index (SAIFI):** It is the measure of a number of times a system customer faces failure over a period of time and can be calculated as,

$$SAIFI = \frac{\sum \lambda_i N_i}{N_T} \tag{18}$$

Where, Ni is a total number of customer interruption at load point i, $\lambda_i$ is the average failure rate of load point i. $N_T$ is the total number of customers served for the area.

**System Average Interruption Duration Index (SAIDI):** It is the measurement of the total duration of an interruption in a system with a given time interval.

$$\text{SAIDI} = \frac{\sum U_{ai} N_i}{N_T} \tag{19}$$

**Electrical Energy Not Supplied (EENS):** It is the total energy not supplied due to power outage.

$$\text{EENS} = \sum U_{ai} L_{ai} \tag{20}$$

Where, Uai and ai are respectively the average annual outage time and the average connected load at load point i.

## 7 Discussions on Results

The proposed method is implemented on the 25-bus 15 kV Ethiopian power distribution at Bahir Dar city. Figure 5 shows the structure of the radial distribution system under study.

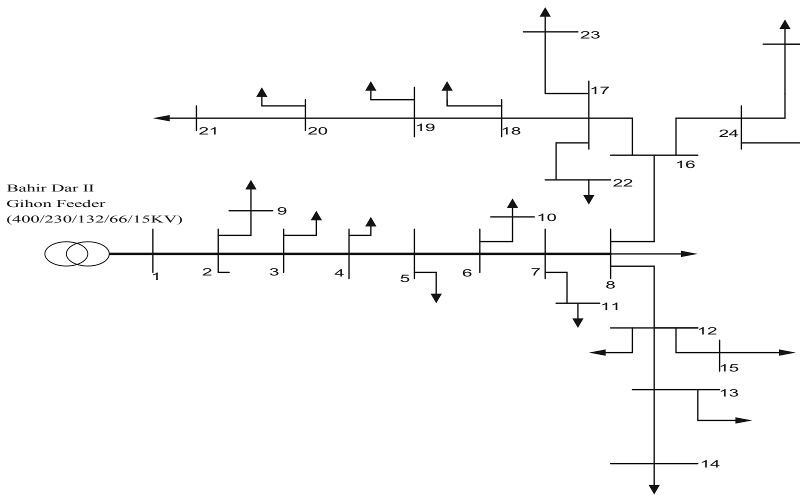



**Fig. 5.** The 25-bus radial distribution system

The total active and reactive loads of the 25-bus radial distribution system are 1.423 MW and 1.11 MVar respectively. The real power loss of the system is 87.0145 KW whereas its reactive power loss is 17.4197 KVar at the base case. Solar based DG is selected to improve voltage profile as well as to reduce the power loss because of the resource availability. The average solar irradiance of Bahir Dar city is from 4.0 to 5.5 kwh/m$^2$/day throughout the year which is a more abundant resource of energy as compared to wind resource of the city. Single DG unit is installed in the system to analyze the performance of the network. For PSO parameters, maximum number of iteration = 100, the size of the population = 100, c1 = c2 = 2, and w2 = 0.2, w1 = 0.6, w3 = 0.2. The system input data like base MVA = 100 and base KV = 15 which are used to change the base value in to per unit value.

The optimal location of solar based DG is bus 21 with the size of 0.710668 MW obtained by PSO. The voltage sensitivity factor of the candidate buses which have (VSF $< 1.0$) is shown in Table 2 below.

**Table 2.** Candidate bus for optimal allocation of DG based on VSF

| Candidate buses | VSF | Candidate buses | VSF |
|---|---|---|---|
| 13 | 0.9797 | 21 | 0.9744 |
| 14 | 0.9792 | 22 | 0.9770 |
| 15 | 0.9790 | 23 | 0.9768 |
| 16 | 0.9787 | 24 | 0.9781 |
| 17 | 0.9773 | 25 | 0.9780 |
| 18 | 0.9765 | 8 | 0.9867 |
| 19 | 0.9753 | 11 | 0.9925 |
| 20 | 0.9748 | 7 | 0.9927 |

The minimum voltage before DG installation was 0.9256 p.u whereas after DG installation all the voltage values are in the given limit between 0.95 and 1.0 p.u as shown in Fig. 6 below. The minimum voltage after DG integration is 0.955 p.u. The system voltage profile is improved when DG installed at bus 21 with a capacity of 710.668 kw.

From Table 3 shown below the real power loss decreases from 87.0145 kw to 14.0946 kw due to the installation of solar based DG at bus 21 with 710.668 kw capacity. This enables to save 72.9199 kw and it is 83.8% of the power loss. The reactive power loss also decreases from 17.4197 Kvar to 7.0785 Kvar which saves 10.3405 Kvar and this is 59.36% of the reactive power loss. The reduction of power loss helps to maintain the system voltage profile to be in the desired value.

For reliability analysis of the network, the failure rate of the distribution line is 1.49 f/yr.km whereas the repair time is 6 h according to the data obtained from Ethiopian Electric Power (EEP). The failure rate of transformers is 0.14 f/yr and its maintenance time is 6 h. Based on those data ETAP software is used to analyze the reliability indexes of

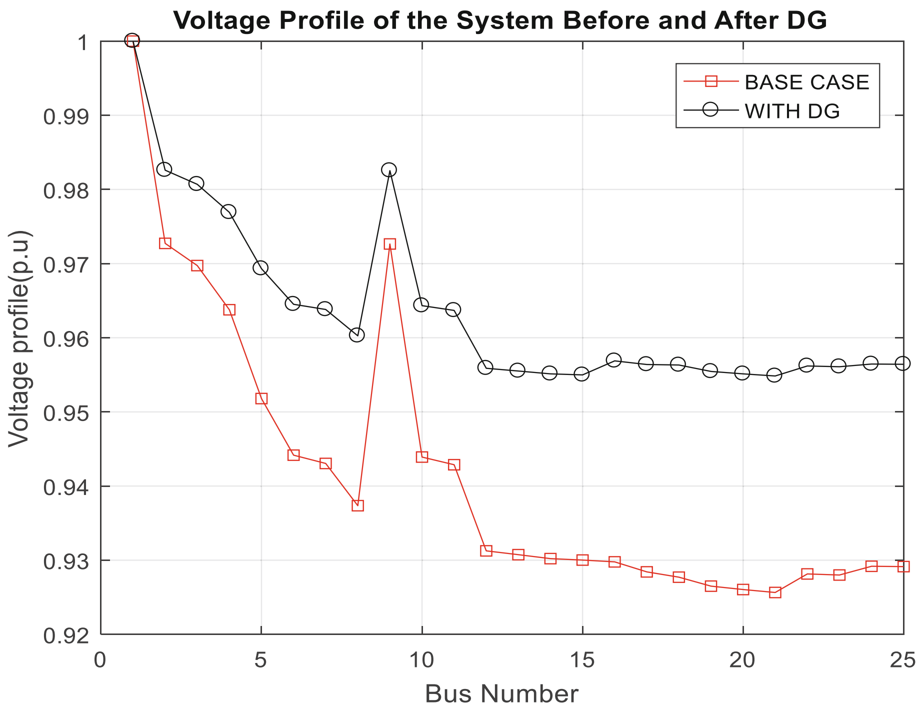



**Fig. 6.** The studied system voltage profile base case and with DG

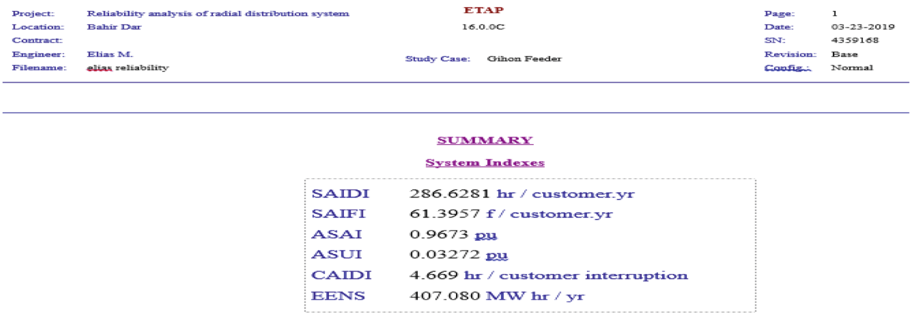
**Table 3.** Comparing results of the system with and without DG

| Parameters | Without DG | With DG |
|---|---|---|
| Power loss (KW), and loss reduction % | 87.0145,0 | 14.0946,83.8 |
| Reactive power loss (KVar) and loss reduction % | 17.4197,0 | 7.0785,59.36 |
| Minimum voltage (p.u), bus | 0.9256,21 | 0.955,15 |
| Optimal location and size of DG(KW) | – | 21(710.668) |
| DGs power factor | – | 0.85 |
| SAIDI (hr/customer.yr) | 286.7879 | 81.1748 |
| SAIFI (f/customer.yr) | 61.4003 | 18.1410 |
| EENS (MWhr/yr) | 407.3 | 110.232 |
| Loss of energy due to power loss (MWhr/yr), and energy loss reduction % | 762.247,0 | 123.468,83.8 |

the system. The reliability of the system improved by 70.45% due to the integration of DG at the optimal place with the desired size. The SAIDI decreases from 286.7879 h/cus.yr to 81.1748 h/cus.yr and enables to save the cost of energy losses due to power interruption. The SAIFI decreases from 61.4 f/customer.yr to 18.14 f/customer.yr and this determines the reliability of the system that gives continuous service for its end-users which is

70.46% reliability improvement. The reliability result of the system using ETAP software is shown in Figs. 7 and 8 below.

The EENS decreases from 407.3 MWhr/yr to 110.232 MWhr/yr this indicates that the objective of the utility achieved and the satisfaction of customers increase implies that the duration of power interruption and the frequency of power interruption also reduced. The lower value of SAIDI, SAIFI, EENS, and CAIDI indicates better reliability of the system.



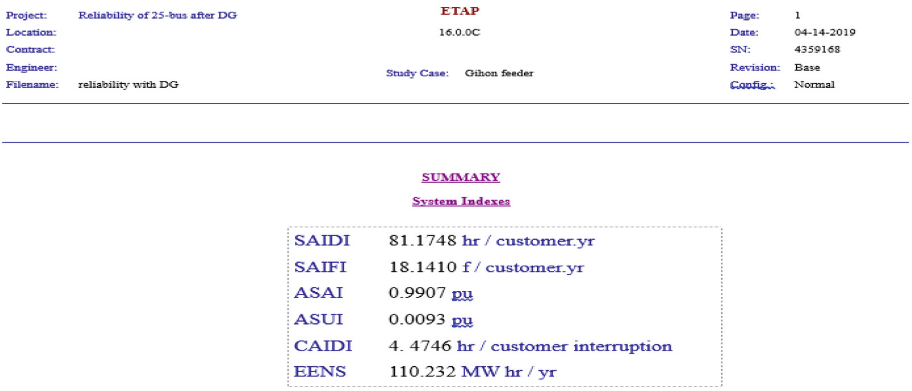
| | | | | | |
|---|---|---|---|---|---|
| Project: | Reliability analysis of radial distribution system | ETAP | | Page: | 1 |
| Location: | Bahir Dar | 16.0.0C | | Date: | 03-23-2019 |
| Contract: | | | | SN: | 4359168 |
| Engineer: | Elias M. | Study Case: | Gihon Feeder | Revision: | Base |
| Filename: | elias reliability | | | Config.: | Normal |

SUMMARY

System Indexes

| | |
|---|---|
| SAIDI | 286.6281 hr / customer.yr |
| SAIFI | 61.3957 f / customer.yr |
| ASAI | 0.9673 pu |
| ASUI | 0.03272 pu |
| CAIDI | 4.669 hr / customer interruption |
| EENS | 407.080 MW hr / yr |

**Fig. 7.** Reliability index result of 25-bus Gihon feeder base case



| | | | | | |
|---|---|---|---|---|---|
| Project: | Reliability of 25-bus after DG | ETAP | | Page: | 1 |
| Location: | | 16.0.0C | | Date: | 04-14-2019 |
| Contract: | | | | SN: | 4359168 |
| Engineer: | | Study Case: | Gihon feeder | Revision: | Base |
| Filename: | reliability with DG | | | Config.: | Normal |

SUMMARY

System Indexes

| | |
|---|---|
| SAIDI | 81.1748 hr / customer.yr |
| SAIFI | 18.1410 f / customer.yr |
| ASAI | 0.9907 pu |
| ASUI | 0.0093 pu |
| CAIDI | 4. 4746 hr / customer interruption |
| EENS | 110.232 MW hr / yr |

**Fig. 8.** Reliability index result of Gihon feeder after DG Integration

Generally integrating solar based DG brings the better result in power loss reduction as well as reliability index minimization. Installation of DG increases the reliability of the system by supporting the system during normal operation and by acting as a backup power source for part of the load during failure of the utility. For modern distribution system installing DG is an effective and economically affordable method to mitigate the ever- increasing power demand.

## 8 Conclusion

Particle swarm optimization technique is used to locate and size solar based DG for minimizing the total power loss and the voltage deviation index of the system. Moreover, PSO based multi-objective function with voltage sensitivity factor is used for sizing and siting of DG in the distribution system using MATLAB software. Proper sizing and placement of DG bring the better result in performance improvements like the reduction of voltage deviation index and power loss of the system. The reliability of the proposed system is also studied using ETAP software and the result shows the reliability of the system increased after integration of DG. The abundance solar power resource of Ethiopia specifically Bahir Dar city indicates to shift the old energy resources to renewable which have a mutual benefit in the environment and economy. Distribution system companies use the proposed method to identify the optimum size and locations of solar based DG units to integrate with in their systems. Consequently, utilities can have a better understanding of the installation points and their impacts on system reliability and losses in the distribution network to mitigate the challenges of power demand.

## Nomenclatures

| | |
|---|---|
| ASAI | Average Service Availability Index |
| ASUI | Average Service Unavailability Index |
| BFS | Backward Forward Sweep |
| CAIDI | Customer Average Interruption Duration Index |
| DG | Distributed Generation |
| DSTATCOM | Distribution Static Compensator |
| EENS | Electrical Energy Not Supplied |
| EEP | Ethiopian Electric Power |
| ETAP | Electrical Transient Analysis Program |
| GA | Genetic Algorithm |
| GW | Giga Watt |
| HPSO | Hybrid Particle Swarm Optimization |
| IEEE | Institute of Electrical and Electronics Engineering |
| KCL | Kirchhoff Current Laws |
| KV | Kilo Volt |
| KVar | Kilo Var |
| KVL | Kirchhoff Voltage Laws |
| KW | Kilo Watt |
| KWh | Kilo Watt hour |
| m | Meter |
| MATLAB | Matrix Laboratory |
| mm | Millimeter |
| MVar | Mega Var |
| MW | Mega Watt |
| NPSO | New Particle Swarm Optimization |
| P | Active Power |

| | |
|---|---|
| Pd | Power Demand |
| $P_{DG}$ | Power Injected by DG |
| $P_{DG}$ ($^{max}$) | Maximum Power Injected by DG |
| $P_{DG}$ ($^{min}$) | Minimum Power Injected by DG |
| Pgrid | Power Supplied by Grid |
| Ploss (ik) | Real Power Loss between Bus i and k |
| PSO | Particle Swarm Optimization |
| PV | Photovoltaic |
| Q | Reactive Power |
| Qloss (ik) | Reactive Power Loss between Bus i and k |
| Rik | Resistance of the line between Bus i and k |
| SAIDI | System Average Interruption Duration Index |
| SAIFI | System Average Interruption Frequency Index |
| VDI | Voltage Deviation Index |
| VSF | Voltage Sensitivity Factor |
| VSI | Voltage Sensitivity Index |
| Xik | Reactance of the line between Bus i and k |

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