Optimal Allocation of Renewable Distributed Generations Using Sensitivity Analysis and PSO

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Abstract. A growing demand for electricity, along with a scarcity of available producing capacity, has fueled the growth of Renewable Distributed Generation (RDG), which includes wind, solar, and hydroelectric sources of energy. Abstract: The location of DG sources has a significant effect on the amount of system losses that occur in the distribution network. This study discusses the identification of the most suitable placement for the IEEE 30 Bus Test System to reduce power loss while simultaneously improving voltage deviation. It is necessary to utilize Sensitivity Analysis to determine the placement of DGs in the network, while Particle Swarm Optimization is used as the optimization method to determine the size of DGs in the network in order to minimize the power losses of the system. The findings demonstrate that the installation of three DGs is beneficial in minimizing power loss and voltage variation.

Keywords: Sensitivity, distribution network, Distributed Generation

1. Introduction

Because of the limited availability of fossil fuel supplies, alternative alternatives to conventional big power plants have gained significant attention in recent years as a means of meeting the anticipated increase in energy demand in the future. When compared to huge fossil-fuel-based power plants, the sizes of renewable-energy-based electricity producers would be very tiny. They are strictly speaking only appropriate for installation on lower voltage grid systems, close to load centers [1]. DG may be used in a variety of applications, including industrial, commercial, and residential. To compete with conventional big generators in certain places, DG makes use of cutting-edge contemporary technology that is both efficient and dependable. As a result of Indonesia's geographic position inside the ring of fire and volcanic line, it possesses a large amount of geothermal potential. Sumatra, Java, Bali, Nusa Tenggara, and Sulawesi are just a few of the islands where this site may be found, with 312 locations scattered throughout the country. Geothermal energy potential is estimated to be about 29 GW in capacity. This Renewable distributed generation (DG) systems may provide both active and reactive electricity to the load center [3]. The difficulty, however, is the location of the facility and the size of the facility. It is possible that the installation of DG units in less than ideal locations and with less than optimal size may result in an increase in system losses and damage to the voltage state. The technical component of renewable DG may be used to evaluate its performance. One of the most significant factors in almost all DG assessments is the influence on power quality, such as energy losses in [4] and sufficient power in [5]. However, this factor is insufficient for complete evaluations. Despite its promise, connecting renewable distributed generation (DG) to a power grid is not a straightforward "plug and play" issue. When several kinds of renewable DGs are taken into consideration, the issue becomes more complicated.

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A multi-objective optimization problem with several objectives may be used to describe the difficulties associated with renewable DG deployment. Power losses, voltage state, fuel cost, and investment cost are all considered objective functions in [6]-[7], and they are all improved simultaneously using a specific optimization method described in [6]. The multi-objective optimization approach has the potential to provide a number of interesting trade-offs. The techno model, which incorporates both power losses and voltage state features that have been optimized concurrently [8]-[9]-[10], has been one of the most prominent multi-objective functions in recent years. When the designer's primacy is taken into consideration, the chosen optimizing technique may be decided successfully without sacrificing generality. Renewable distributed generation (DG) units in a grid system may be represented as a non-deterministic polynomial optimization problem, as illustrated in Figure 1. Heuristic methods are more successful in determining the solution to such complicated issues [11]. However, despite the fact that the technique is successful in terms of site selection, it requires more computing work. Every bus is equipped with a computer that calculates the optimum value of DG for minimizing system losses. The associated system losses are computed and compared for each bus in turn, using the estimated DG size for each bus. This allows us to determine the most suitable placement. Furthermore, the heuristic search entails a thorough search for all potential sites, which may not be relevant to more than one DG because to the lengthy search involved. The intelligent search-based population techniques have mostly been investigated for the purpose of solving multi-objective problems [12, 13]. Particle Swarm Optimization, often known as PSO, is a technique that may be used to discover solutions that are more quickly convergence. The benefits of PSO are thus straightforward to implement, with just a few parameters to tweak [13]. PSO-based method that takes the number and location of DGs as input has been developed to find the optimum size of DG in order to reduce actual power losses in grid systems. The optimal size of DG is determined in order to minimize real power losses in grid systems. The benefits of relieving PSO of the responsibility for determining the locations of DGs include better convergence characteristics and reduced calculation time. Tests are carried out using the IEEE 30 Bus Test System to validate the suggested algorithm-based method.

2. Methods of Investigation

Most of the time, the reduction in actual power loss results in increased reflection for the utilities as a result of the reduction in proficiency throughout the energy distribution process. The decrease of power loss via properly positioned Renewable DGs along the grid feeder may be very beneficial if the goal of the planning is to minimize losses while simultaneously improving network performance. On the contrary, the grid system is obliged to maintain the voltage level of each user bus within the limits set by the regulatory body in place. In order to ensure that voltage profiles in grid systems are appropriate, the usual voltage has been developed to provide criteria for use. Furthermore, reactive power loss seems to be no less significant than active power loss since it reduces the possibility of providing actual power to consumers via transmission lines. Following that, it is necessary to ensure that the flow of reactive power in the system is well-preserved at the desired voltage level. Power system real and reactive power flows in a line connecting two buses, power system real and reactive power losses in a line connecting two buses, power system real and reactive power losses in a line connecting two buses, and may be characterized as follows:
[14]:

$$P_{ij} = V_i V_j Y_{ij}\cos(\theta_{ij}+\delta_{ij}) - V_i^2 Y_{ij}\cos\theta_{ij} \qquad Q_{ij} = V_i V_j Y_{ij}\sin(\theta_{ij}+\delta_{ij}) - V_i^2 Y_{ij}\sin\theta_{ij} - \frac{V_i^2 Y_{sh}}{2}$$

(1)

$$P_{L(ij)} = g_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}) \quad Q_{L(ij)} = -b_{ij}^{sh}(V_i^2 + V_j^2) - b_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij})$$

(2)

The analysis of sensitivity is used to circumvent recalculation of the power flow solution. The used parameters is the power transfer distribution factors and are defined as the changes in the line power flows due to a change in power injection at a specific bus. The sensitivities is to be calculated by examining the Jacobian matrix at a particular solution of the network [15].

By definition power sensitivity is the alteration in real power flow (ΔP_{ij}) and reactive power flow (ΔQ_{ij}) in a transmission line-*k* connected between bus-*i* and bus-*j* due to unit change in the power injection (ΔP_n) and (ΔQ_n), respectively, at any bus-*n*. Mathematically, the power flow sensitivity can be written as $\frac{\Delta P_{ij}}{\Delta P_n}$ and $\frac{\Delta Q_{ij}}{\Delta Q}$ [16]. Expending Taylor series approximation, change in line flows can be written by ignoring second and higher order terms as

$$\Delta P_{ij} = \frac{\partial P_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial P_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial P_{ij}}{\partial V_i}\Delta V_i + \frac{\partial P_{ij}}{\partial V_j}\Delta V_j \qquad \Delta Q_{ij} = \frac{\partial Q_{ij}}{\partial \delta_i}\Delta\delta_i + \frac{\partial Q_{ij}}{\partial \delta_j}\Delta\delta_j + \frac{\partial Q_{ij}}{\partial V_i}\Delta V_i + \frac{\partial Q_{ij}}{\partial V_j}\Delta V_j \quad (3)$$

From these equations power flow, sensitivity factor can be calculated which is giving by

$$\begin{bmatrix}\frac{\partial P_{ij}}{\partial P_n}\\ \frac{\partial P_{ij}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}F_{P-P}\\ F_{P-Q}\end{bmatrix} = [J^T]^{-1}\begin{bmatrix}\frac{\partial P_{ij}}{\partial \delta}\\ \frac{\partial P_{ij}}{\partial V}\end{bmatrix} \qquad \begin{bmatrix}\frac{\partial Q_{ij}}{\partial P_n}\\ \frac{\partial Q_{ij}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}F_{Q-P}\\ F_{Q-Q}\end{bmatrix} = [J^T]^{-1}\begin{bmatrix}\frac{\partial Q_{ij}}{\partial \delta}\\ \frac{\partial Q_{ij}}{\partial V}\end{bmatrix}$$

(4)

While power loss sensitivity factor can be assessed using

$$\begin{bmatrix}\frac{\partial P_{L(ij)}}{\partial P_n}\\ \frac{\partial P_{L(ij)}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}S_{P-P}\\ S_{P-Q}\end{bmatrix} = [J^T]^{-1}\begin{bmatrix}\frac{\partial P_{L(ij)}}{\partial \delta}\\ \frac{\partial P_{ij}}{\partial V}\end{bmatrix} \qquad \begin{bmatrix}\frac{\partial Q_{L(ij)}}{\partial P_n}\\ \frac{\partial Q_{L(ij)}}{\partial Q_n}\end{bmatrix} = \begin{bmatrix}S_{Q-P}\\ S_{Q-Q}\end{bmatrix} = [J^T]^{-1}\begin{bmatrix}\frac{\partial Q_{L(ij)}}{\partial \delta}\\ \frac{\partial Q_{ij}}{\partial V}\end{bmatrix}$$

(5)

Both power flows and power losses can be incorporated into the form of factor of combined sensitivity (CSF) as follows:

$$CSF_i = (F_{P-P_i} \times F_{Q-P_i}) + (F_{P-Q_i} \times F_{Q-Q_i}) + (S_{P-P_i} \times S_{Q-P_i}) + (S_{P-Q_i} \times S_{Q-Q_i})$$

(6)

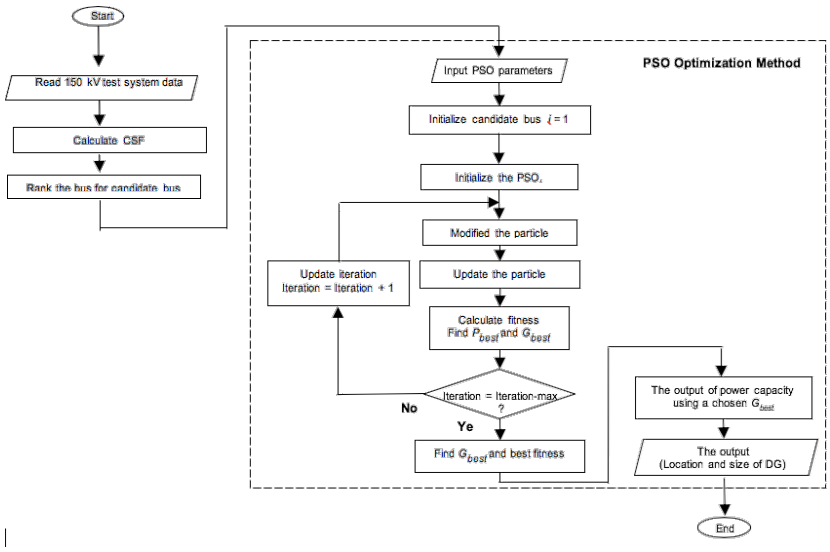

Fig. 1. Flowchart of proposed algorithm

The mentioned multi-objective function is minimized with attention paid to many operational restrictions, such as the real and reactive power generation limits, the voltage limit, and the DG's real and reactive power production limits, in order to meet the electrical requirements of the grid system. The following is the performance calculation of the suggested multi-objective function (MOF) for allocating renewable distributed generation (DG) in grid systems:

$$MOF = w_1 PLRI + w_2 QLRI + w_2 VPI \qquad |w_1| + |w_2| + |w_3| = 1 \tag{7}$$

Real power loss reduction index (PLRI), reactive power loss reduction index (QLRI), and voltage profile improvement index (PVII) are all measures of power loss reduction. The suggested PSO-based approach for optimum placement of renewable DG in the distribution system is shown in Figure 1 as a flowchart.

3. Results and Discussion

The single line diagram of IEEE 30 Bus test system is shown in Fig. 2.

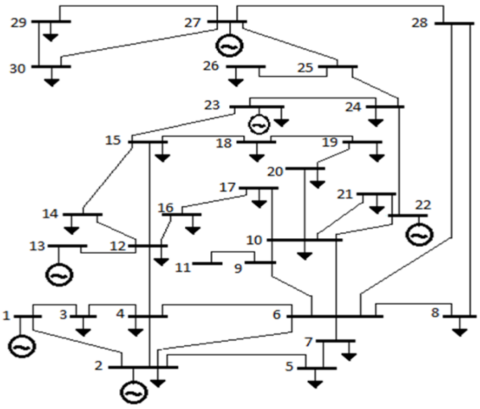

Fig. 2. Single line diagram of Test System [17]

The CSF all buses of IEEE 30 Bus Test System were calculated based on Equation 7. Candidate buses were selected by choosing CSF values more than 0.8. The optimal placement of the Renewable DGs could be able to choose by carefully observing at all the candidate buses, shown in Table 1.

Table 3: Results for CSF, Fitness, and optimal DG sizes (Based 120 MW) for candidate buses

Candidate Bus	CSF	Fitness	DG size (MW)
10	0,8808	0,9164	110,680
11	0,9266	0,9188	116,445
15	0,8377	0,9182	114,582
17	0,8755	0,9151	107,347
18	1,0218	0,9188	115,198
19	1,0945	0,9206	119,289
20	1,0631	0,9203	118,929
21	0,9973	0,9093	92,237
22	1,0554	0,9194	117,708
23	0,9911	0,9204	118,984
24	1,0350	0,9205	119,112
25	0,8770	0,9155	107,875
26	1,0086	0,9195	119,082
30	0,8160	0,9209	118,938

Table 4. Comparison of Results using DG

Bus No.	DG size (MW)	Power Losses (MW)	Power Loss Reduction (MW)	Percentage Power Loss Reduction (%)
10	110,680	136,69	38,59	22,02
19	119,289			

26	119,082			

The findings for actual power losses and voltage levels were obtained via the use of Newton-Raphson load flow. The inclusion of DGs has no impact on the departure of voltage levels outside of permissible limits [13], as previously stated. Evidently, all of the bus voltages are in the region of 1.0 pu to 1.1 pu, which is consistent with the data. Table 4 demonstrates that renewable distributed generation (DG) contributed to a substantial reduction in actual power loss. The percentage decrease in actual power loss is 38,59 MW, or 22,02 percent, according to the data.

4. Conclusion Remarks

It has been successfully applied the PSO-based method for system loss reduction and voltage profile enhancement in the IEEE 30 Bus Test System by optimizing the placement and size of renewable DG units, such as geothermal power plants. The combined sensitivity factors were developed and used successfully in order to reduce the number of candidates placed in Renewable DGs. When utilizing this test system, this optimization technique resulted in a substantial loss reduction when compared to other methods. The percentage decrease in actual power loss was 38,59 MW, or 22,02 percent, according to the results. When it comes to bus voltage, the lowest voltage level has been increased from 0.9953 pu to 1.0012 pu, while the maximum voltage level has remained at 1.0710 pu.

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