Optimal penetration of distributed generation system in radial distribution network using adaptive scheme

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Abstract. In this paper, an adaptive scheme based on biogeography based optimization and particle swarm optimization method for optimal penetration and sizing of distributed generation system in the existing radial distribution network at the optimal bus is suggested. Power losses and voltage profile maintenance are the biggest restrictions of the existing power system. These power losses will be calculated by load flow analysis and the adaptive scheme has been applied for power loss reduction and enhancing voltage profile. The testing of the adaptive scheme for optimal penetration and sizing of distributed generation system will be done at the IEEE 69 bus radial distribution network. This adaptive scheme and IEEE 69 bus radial distribution network are modelled with the help of Matlab software.

1. Introduction

Distributed generation (DG) systems are the small power generating sources (from a few kW to 10MW). According to the fuel used for the operation, DGs are categorized into two various types, non-renewable DG systems and renewable DG systems. Nowadays, the penetration level of the DG system in the distribution network (DN) is increasing due to its advantages like technical, financial and ecological. The placement of DG units in the DN is boosting swiftly as a result of a high rate of worldwide electrical energy consumption. The use of DG in a modern-day power system assists consumers to satisfy their needs for continuous and high-quality power, as a result, DG systems innovations are extra effective and trusted. But if the DG systems are not used optimally, it shows an unfavourable effect on the system efficiency [1]. So to obtain optimum advantages, optimal penetration of DG systems in the distribution system plays an important function. Different restraints related to DG system placement are power restraints, voltage restraints, current restraints and DG system restraints. For managing power restraints supply of power, the balance of load flow, quality of power and power factor have to be managed. For managing voltage restraints, voltage profile and voltage angle have to be managed [2]. For managing current restraints thermal limit of line, level of short circuit and ratio of the short circuit has to be managed. For managing DG system restraints placement, size and number of DG systems have to be managed. Distribution networks are originally designed and created to deal with uni-directional power circulations from generation to load. But with the placement of DG systems in DN power circulations has become bi-directional, which affects the working of relays. The DN having DG systems are prone to system islanding, which is the risk for working staff, people passing under that network and can trigger over-voltages. In a renewable DG system (solar, wind etc.), the output power is not continuous and they can’t be dispatched from the network [3]. So, the optimal penetration and sizing of DG systems in the DN is an extremely
significant problem. The majority of the researchers have attained appealing lead to resolving various problems related to DG penetration, voltage profile, power loss etc. in the radial distribution network (RDN) by using various techniques, but there are particular constraints regarding computational time, operating effectiveness of the system and the convergence rate of the remedy. So, to lower these issues, a population-based search strategy is needed. This paper proposed modelling of the adaptive scheme based on particle swarm optimization (PSO) and biogeography based optimization (BBO) technique for optimal penetration and sizing of distributed generation system in RDN for power loss minimization, voltage profile enhancement and convergence rate fitness.

2. Problem Formulation

Load flow analysis is used to discover power loss and voltage representing each branch. The two bus DN is displayed in figure 1. The voltage representing that bus $k+1$ is figured out by using KVL and it is offered by (1).

$$V_{k+1} = V_k - I_{k,k+1} (Z_{k,k+1})$$

Where, $Z_{k,k+1} = R_{k,k+1} + jX_{k,k+1}$; is the impedance of the line between $k$ and $k+1$, $V_k$ is the voltage at bus $k$, The current injected at node $k$ is established as well as it is given up (2).

$$I_k = (P_k + jQ_k) V_k$$

Where $P_k$ and $Q_k$ are the true and reactive power supplied at bus $k$.

Branch current is figured out at the buses $k$ and $k+1$ by using KCL and it is offered by the (3).

$$I_k = I_{k+1} + I_{k+2}$$

The true and reactive power loss representing the buses $k$ and $k+1$ is established from (4) and (5).

$$P_l(k,k+1) = R_{k,k+1} \left( \frac{P_{DG,k,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2} \right)$$

$$Q_l(k,k+1) = X_{k,k+1} \left( \frac{P_{DG,k,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2} \right)$$

The complete power loss represents all buses is the addition of losses which is identified making use of (6) and (7).

$$P_{TI} = \sum_{k=1}^{b} P_l(k,k+1)$$

$$Q_{TI} = \sum_{k=1}^{b} Q_l(k,k+1)$$

Power Loss with Positioning of DG, Whenever DG devices are put at the optimum area they will minimize power loss in a line, boosts the voltage profile, voltage security and peak demand saving. The power loss after positioning of DG at equivalent buses $k$ and $k+1$ can be calculated as:

$$P_{DGl}(k,k+1) = R_{k,k+1} \left( \frac{P_{DG,k,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2} \right)$$

$$Q_{DGl}(k,k+1) = X_{k,k+1} \left( \frac{P_{DG,k,k+1}^2 + Q_{DG,k,k+1}^2}{|V_k|^2} \right)$$

The total power loss with the penetration of DG can be calculated by the addition of the total losses of the network as adheres to:

$$P_{DG, TI} = \sum_{k=1}^{b} P_{DG,l(k,k+1)}$$
Where \( b \) is for the total number of buses.

True Power Loss minimization with DG Positioning is calculated by power loss index, which is the proportion of total power loss with the placement of DG to the total amount power loss without positioning of DG can be created as:

\[
F_1 = \text{Power loss index} = \left( \frac{P_{DG, Tl}}{P_{Tl}} \right)
\]

(11)

The overall quantity of power loss can be minimized with the positioning of DG can be improved by reducing the power loss index.

Voltage Inconsistency Index, when the DG systems are placed optimally in the distribution network, it improves the voltage profile of this network. This is given by the voltage inconsistency index principle.

\[
F_2 = \text{Voltage inconsistency index} = \max \left( \frac{|V_1| - |V_k|}{|V_1|} \right)
\]

where \( k = 1, 2, \ldots, n \)

(12)

Where \( V_1 \) is the nominal voltage i.e. 1 pu. Throughout positioning of DG in the distribution network which gives greater voltage inconsistencies from the real value, the suggested method reduces the voltage inconsistency index near to zero and boosts the voltage security of the network [4].

2.1. Objective Feature formulation

The multi-objective feature is developed to reduce the actual power loss, voltage discrepancy of the RDN that is offered as adheres to.

\[
\text{Min}(F) = \text{Min}((\phi_1 F_1 + \phi_2 F_2))
\]

(13)

In the multi-objective function, the weighting variables (\( \phi_1, \) and \( \phi_2 \)) are taken as 0.5, and 0.4 for the BBO scheme and 0.7, and 0.5 PSO scheme respectively. The above-discussed weights are altered according to the value. The established objective feature is to satisfy numerous restraints of RDN.

3. Adaptive schemes

3.1. Particle Swarm Optimization (PSO) based adaptive scheme

A fundamental version of the PSO algorithm functions by having a populace (called a swarm) of prospect remedies (called fragments). These fragments are moving in the search area following basic regulations. Their best-recognized placement directs the motion of the fragments in the search area as well as the whole swarm's best-recognized placement. When enhanced placements are being found these will certainly that involve directing the motions of the swarm. This procedure is repeated and also by doing, so it is wished, however not ensured, that a satisfying solution will be found.

Assume \( F: F^n_c \rightarrow F_c \) be the cost feature which should be reduced. The feature takes a prospect remedy as an argument in the form of a vector of real numbers. It generates a real number as an outcome which suggests the objective feature value of the provided prospect remedy. The gradient of \( F \) is unknown. The objective is to discover a remedy \( B \) for which \( F(B) \leq F(A) \) for all \( A \) in the search area, which would suggest \( B \) is the global minima. Maximization can be executed by taking into consideration the feature \( H = -F \) rather.

Assume \( s \) be the variety of fragments in the swarm, each having a placement \( X_j \in F^n_c \) in the search area as well as a speed \( V_j \in F^n_c \). Assume \( P_j \) be the best-recognized placement of fragment \( j \) and also assume \( G \) be the very best-recognized placement of the whole swarm [5].

3.2 Biogeography based optimization (BBO) based adaptive scheme

BBO formula is an effective optimization method. This method was originated from the bio-organics circulation method in various environments. A collection of prospect remedies called Islands, islands that are well-matched as environments for organic species are stated to have a high island viability index (IVI). Various specifics like rains ranking, plant life density, temperature level and the soil kind is determining IVI ranking. All remedy features are called a viability index variable (VIV). VIV’s are independent variables of the island as well as IVI, is the dependent variable. An excellent method illustrates an island with high IVI, and a weak one defines a low IVI island. The high IVI methods
have an extra propensity to share function with the low IVI approach, and it is executed by immigration as well as emigration drivers. Immigration to low IVI island can enhance its IVI. Emigration and immigration are standard principles of the stated formula, and they are:

\[ \rho_s = e^{s/s_m} \]  
\[ \sigma_s = i\left(1 - \frac{s}{s_m}\right) \]

Here \( i \) is the optimum practical immigration rate, which happens when there are zero species on the island and \( e \) is the optimum practical emigration rate, which happens when the island has the biggest variety of species \( (s_m) \). As the variety of species rises, fewer species can go into the island, so the value of \( i \) declines. The factor at which \( i \) end up being zero is the widest practical variety of species on the island \( (s_m) \).

For emigration contour, if the variety of species is zero, then the value of \( e \) should be zero. As the variety of species rises, even more species will certainly leave the island, so the value of \( e \) rises. Whenever the island has the widest variety of species, the maximum value of \( e \) happens. The balance variety of species is the factor at which \( i \) and \( e \) are equivalent [6].

4. Results and Discussion

The adaptive scheme based on BBO and PSO technique has been applied for optimal penetration and size of the DG system. The adaptive scheme is tested on 12.66 kV, 69 bus RDN. The total actual and reactive load is 3.72 MW as well as 2.3 MVAR. Line and bus data’s for the 69 bus RDN are taken from [7]. The true power loss is 230.341 kW and the minimum bus voltage is 0.9072 per unit (pu). Table 1 and 2 shows the comparison results of the adaptive scheme based on BBO and PSO technique with the base model (without any DG penetration) and Load (Random DG penetration). Here penetrations of the DG system are shown at different buses which reduce the existing power loss of the base model and voltage deviation is shown at these buses. The final optimized results with BBO and PSO based adaptive scheme are displayed in table 1, these results are compared with load (with random penetration of DG) and base (without any DG penetration).

By BBO technique the optimal sized 38 kVA DG system is connected with the optimal bus 33. By the PSO technique the optimal sized 40 kVA DG is connected to the optimal bus 30. BBO technique reduced the DG size by 10 kVA. PSO technique reduced the DG size by 8 kVA. The power loss obtained from the BBO technique is 185.101 kW, the PSO technique is 199.125 kW, 227.783 kW with load model and the 230.341 kW from the base model.

Minimization of power loss by the BBO technique is 19.64%, the PSO technique is by 13.56% as compared with 1.11% by load case. The voltage profile enhances from 0.9072 pu to 0.9601 pu from the base model to the adaptive scheme. Figure 2 and 3 shows the voltage profile and power loss comparison due to the optimal penetration and size of DG unit with BBO and PSO based adaptive scheme, load and base model.

| IEEE 69 Bus RDN | Voltage Profile (pu) | Power Loss (kW) | Power Loss Minimization (%) | DG Size (kVA) | DG placed at optimal Bus No. |
|-----------------|----------------------|-----------------|----------------------------|----------------|-----------------------------|
| Base            | 0.9072               | 230.341         | _                          | _              | _                          |
| Load            | 0.9176               | 227.783         | 1.11                       | 48             | 36                          |
| PSO             | 0.9492               | 199.125         | 13.56                      | 40             | 30                          |
| BBO             | 0.9601               | 185.101         | 19.64                      | 38             | 33                          |
The fitness of the BBO based adaptive scheme i.e. 70 iterations and fitness of the PSO based adaptive scheme i.e. 85 iterations to reach the optimal results shown in figure 4.

5. Conclusion
This paper applied BBO and PSO based adaptive scheme technique for optimal placement and sizing of DG system in existing RDN. This penetration has been done for power loss reduction, enhancing the voltage profile and convergence rate fitness. This adaptive scheme is successfully simulated utilizing MATLAB software and tested into the IEEE 69 bus RDN. The optimal placement and sizing of the DG system have been successfully done by the BBO and PSO based adaptive scheme for power loss reduction, enhancing the voltage profile and convergence rate fitness. BBO based adaptive scheme has better results than the PSO based adaptive scheme.

6. References
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