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An Adaptive Scheme for Optimal Siting of Distributed Generation System in a Distribution Network

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Abstract: ***In this paper an adaptive scheme is proposed for optimal siting of distributed generation (DG) system for the power loss minimization and voltage profile improvement in the existing radial distribution system. The proposed adaptive system is based on Adaptive Neuro Fuzzy Inference System (ANFIS) model, it is utilized for estimating the adequate parameters and The objective of the proposed technique is developed to describe the most advantageous reactive and real power production and utilization requirements for the best possible sizing and locating the nodes to find power loss minimizations and maintaining the voltage profile. The proposed method is implemented using MATLAB/Simulink platform and tested into the IEEE 69 radial distribution system and assessed for voltage variation due to power losses and results are compared with biogeography-based optimization (BBO) methodology.***

Index Terms: Reverse power flow (RPF), adaptive neuro-fuzzy inference system (ANFIS), Radial distribution system (RDS), biogeography-based optimization (BBO) and Distributed generator (DG).

I. INTRODUCTION

In earlier times the power systems were dependent on large generating plants like thermal, nuclear, hydro plants etc. The electric power produced by these plants were transmitted to customer loads over a long distances. The current scenario has changed a lot due to conditions prevailed like constraints raised due to environmental and geographical conditions, problems related to security and stability of generating stations, day by day increasing power demand, deregulation and privatization of power system [1]. These conditions has changed the traditional power system and introduction of distributed energy sources has changed the distribution network from unidirectional to multidirectional.

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The DG systems are improving the system reliability, use of renewable sources as DG system is a benefit to the environment, minimization of power losses as DG systems are very near to the consumer load as compare to the conventional sources so current flow is minimized which result in minimization of power loss, It improves the voltage profile and the power quality [2]. DG systems are the small power generating sources (from few kW to 10MW). It has eliminated the need of reserve margin [4]..

DG systems are based on various technologies like combined cycle gas turbine (35-400MW), internal combustion engine (5kW-10MW), combustion turbine (1-250MW), micro turbine (35kW-1MW), fuel cells (200kW-5MW), small hydro power (1-25MW), micro hydro power(25kW-1MW), wind turbine(200W-3MW), solar PV cell(20W-100kW), solar thermal(10-80MW), biomass gasification(100kW-20MW), geothermal(5-100MW), ocean energy(0.1-1MW) etc. [3]. There are three initial factors (area, sort and size of DG units) which can enhance the fault current levels, protection coordination of relays, power quality and stability, and this can restrain the penetration of DG unit [4]. In the RDS it effects on the protection scheme, for example, false tripping of protective devices, security blinding, increasing and decreasing of short circuit levels, unintentional islanding of the system, reverse power flow and out-of-synchronism re-closers. To assure the constant power supply is the required capacity of every distribution framework. Thinking about the importance of lightning insurance, a Smart Grid and its distribution framework could develop more upgraded lightning assurance determinations. The execution of DG can create problems for the being power system security plans and create insurance protection devices erroneously. It is doable for adaptive protection approach to take care of the issues that DG system transfers to the protection system [5]. An ANFIS based adaptive protection approach for DG in an RDS is suggested by this work. To raise the execution of the ANFIS display, the ANFIS established is applied for estimating the satisfactory parameters. Resulting in that the weak buses are recognized on the premise of the power loss and voltage stability index (VSI) factors and settling the DG. Here power loss is minimized and voltage profile is improved by the proposed technique.

II. MODELING FOR PROPOSED SCHEME

The objective function and the modeling of the suggested system are introduced by this section. The contribution of this paper is a mixed-integer non-linear optimization trouble. For the minimization of the power losses in the network, the objective function is conceived. The power flow equations are the equality restraints. The node voltage and line thermal limits are the inequality restraints. Both equality and inequality restraints are embedded in the target function and therefore form the penalty function [6].

A. Problem Formulation

This problem is a mixed-integer non-linear optimization trouble. It can be expressed as equation (1),

$$\text{Minimize } O(x)$$

$$\text{sujbject to} \begin{cases} E(x) = 0 \\ I(x) \le 0 \end{cases} \tag{1}$$

Equality restraints E(x) and inequality restraints I(x) are converted into penalty terms and the penalty function is formed by adding them, the objective function is written as equations (2) and (3),

$$P(x) = O(x) + p(x) \tag{2}$$

$$p(x) = \delta\left\{E^2(x) + \left[\max(0, I(x))\right]^2\right\} \tag{3}$$

Here, $P(x)$ is the penalty function, $O(x)$ is the objective function (O_{loss}) , $p(x)$ is the penalty term, and δ is the penalty factor. The restrained optimization trouble is transformed into an unconstrained optimization trouble, so the penalty function described above is reduced [7].

B. Objective function

The power loss function is set as the objective function by this paper. Conceiving the line b among the buses i and j , the power loss can be denoted as equation (4),

$$O_{loss} = \min \sum_{b=1}^{nl} g_{i,j}\left(V_i^2 + V_j^2 + 2V_iV_j\cos(\theta_i - \theta_j)\right)$$

(4)

Here, O_{loss} is the objective function, $g_{i,j}$ is the conductance between the buses i and j , V_i is the voltage at bus i , V_j is the voltage at bus j , nl is the total number of branches in the network, θ_i is the voltage angle for bus i , θ_j is the voltage angle for the bus j .

C. Equality constraints

The equation (5) is for the active power flow and the equation (6) is for the reactive power flow in all the branches of the system.

$$p_P\left(V, \theta, P_g\right) = P_c + P_d + P_g = 0 \tag{5}$$

$$p_Q\left(V, \theta, Q_g\right) = Q_c + Q_d + Q_g = 0 \tag{6}$$

D. Inequality constraints

Bus voltages and line current thermal limits are the inequality constraints.

Bus voltage: The voltage at each bus must lie within the prescribed limits, which is depicted as equation (7),

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{7}$$

Line current: The line current thermal limits through each branch should not be exceeded, which fulfilled as equation (8),

$$I_b \le I_b^{\max} \tag{8}$$

This problem is resolved by an ANFIS algorithm and the objective function are reduced under the restraints mentioned and the final results compared with the biogeography-based optimization (BBO) technique.

III. ANFIS TECHNIQUE

ANFIS uses the learning ability of neural network for evaluation the fuzzy parameters. These Parameters are auto-tuned by neural network. ANFIS needs less input and output training data for modelling of complex and nonlinear systems. The architecture of ANFIS is shown in figure 1, the process of proposed error minimization technique is shown. ANFIS is having five layers the node function is defined for each layer. The parameter sets presented in square boxes are adjustable in the system known as the adaptive nodes. The parameter sets presented in circles boxes are fixed in the system known as the fixed nodes. The output data from the nodes in the previous layers is the input in the present layer. Zero order or first-order Sugeno inference system or Tsukamoto inference system are applicable for fuzzy system [8].

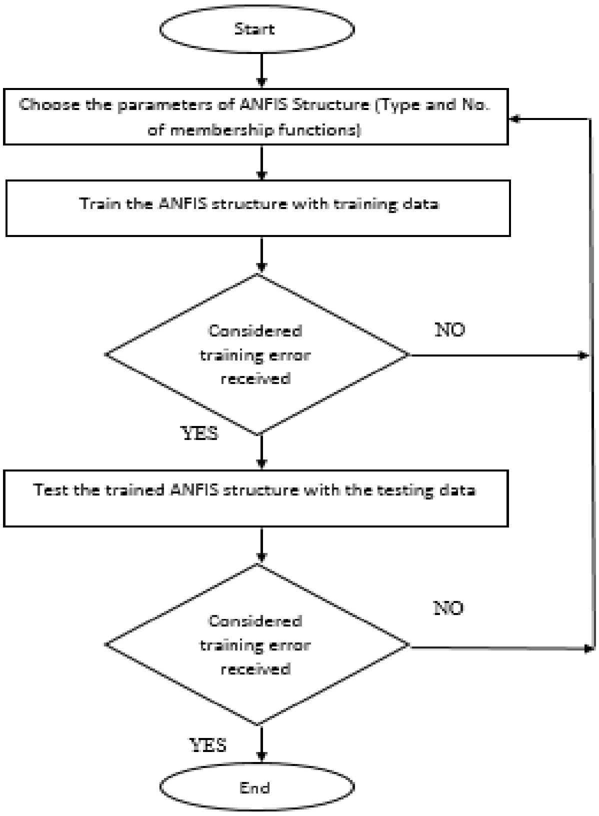

Figure 1. The proposed architecture of ANFIS

The Objective function of this technique is shown in equation (9).

$$O = Min(E) = Min\{P^{ref} - P^{real}\} \qquad (9)$$

Where, E is the value of error, P^{ref} is the reference power and P^{real} is the real power. The change in error (ΔE) is evaluated by equation (10).

$$\Delta E = E(p) - E(p-1) \qquad (10)$$

Where, $E(p)$ is the value of instant error, $E(p-1)$ is the value of previous error. The input nodes represent the training values and the output nodes represent the predicted values by this connected structure, respectively, the nodes functioning as membership functions (MFs) and rules are in the hidden layers. This structure neglects the disadvantage of a normal feedforward multilayer network, where it is hard for an observer to understand or alter the network. A first order sugeno inference system is used for fuzzy which comprises of two rules, as shown in the equation (11) and (12),

Rule 1: If E is G_1 and ΔE is H_1, then

$$l_1 = a_1 x + b_1 y + c_1 \qquad (11)$$

Rule 2: If E is G_2 and ΔE is H_2, then

$$l_2 = a_2 x + b_2 y + c_2 \qquad (12)$$

Here, G_1, G_2, H_1 and H_2 are nonlinear parameters and a_1, a_2, b_1, b_2, c_1 and c_2 are linear parameters. ANFIS is having the five layer feed forward network architecture. Here, an output is derived from an input vector $[E, \Delta E]$ by the fuzzy reasoning mechanism.

IV. BIOGEOGRAPHY-BASED OPTIMIZATION (BBO) TECHNIQUE

Biogeography is the ecological science that deals with the geographical distribution of species and also the environment in the geographic space. BBO is inspired by the island biogeography. BBO formula runs on a populace of individuals called a environment. An environment is a geographically separated island. The health and fitness of any environment are shown by a habitat suitability index (HSI). The variables that define habitability are called suitability index variables (SIVs). Among the vital variables that impact the species circulation on the islands is the migration. Migration is represented by two procedures, the emigration and the immigration between islands. Emigration is the sharing of any solution includes from one person to another so that the remedy attributes continues to be the same in the emigrating individual. While the immigration is the process in which the solution features of an individual is changed by a brand-new option feature from another individual. When there are no species in the environment, the optimum immigration rate is I_r , in which it is accomplished and the emigration is equal to zero. NS_{max} is the maximum number of species in the environment. When NS_{max} is achieved the immigration rate equals to zero and also the emigration rate is at its maximum (E_{max}). Mutation is one more aspect affecting the types richness of an island. The mutation operator is used to maintain the variety of people and escape neighbourhood optimums, similar to the genetic algorithm. For each candidate solution s, there is a mutation possibility linked shown by the equation (13).

$$m(s) = m_{max}\,(1 - Ps)\,/P_{max} \qquad (13)$$

Where m_{max} is a user specified criterion, Ps is the types count of habitat and also P_{max} is the optimum species count. Mutation is accomplished based upon the mutation probability of an environment by replacing a specific SIV with an arbitrary generated one [9].

V. RESULTS AND DISCUSSIONS

Here we will discuss the performance of our proposed technique and it is tested with IEEE 69 BUS radial distribution system. It consists of one slack bus and 68 load buses. An IEEE 69 BUS RDS is simulated using MATLAB software for evaluating the performance of the proposed technique as shown in the figure 2. Analysis of this system is done from the line and bus data available in [10]. The total real power demand 3.501 MW and reactive power demand 2.563 MVAr, respectively. The real power loss is 228.36 kW and minimum bus voltage is 0.9132. pu. The performance of the of power transfer by DG system to an optimal node by proposed approach is compared with other existing techniques, which is described in table 1. The total reactive power used in the proposed method are 125.51 kVAR which is less when compared with 161.72 kVAR by BBO, and 212.89 by base model.

Table 1: Comparison of power transfer by DG to an optimal node by various techniques

Techniques	Real power (KW)	Reactive power (KVAr)
Proposed Technique	226.99	125.51
BBO Technique	226.71	161.72
Base model	225.51	212.89

Comparison of result obtained by various techniques are shown in the table 1.Figure 3 and 4 shows the comparison of the bus voltage profile and the power loss for IEEE 69 bus RDS without DG, with DG placement, BBO and proposed technique. For multiple DGs placements very promising results are generated by the proposed technique .After applying the various techniques, the obtained results for IEEE 69 bus RDS are compared. By the proposed technique the optimal size of 40 MVA DG is connected to the node 38, The power loss obtained from the proposed method is 174.51 kW which is less when compared to 198.07 kW by BBO and 223.64 kW is connected with DG and the 228.36 kW in without connected any DG. The power loss minimized by the proposed technique is by 23.58% as compared to 13.26% by BBO and 2.11% by connection with DG. The bus voltage is enhancing from 0.9132 pu to 0.9791 pu from base model to the proposed technique.

Table 2: Comparison of various techniques

Techniques applied on IEEE 69 Bus RDS	Voltage Profile (V)	Power Loss (Kw)	Power loss Minimization (%)	DG Capacity (MVA)	DG Location Bus No.
Without DGs	0.9132	228.36	_	_	_
With DGs	0.9267	223.64	2.11	45	36
BBO	0.9493	198.07	13.26	42	40
Proposed technique	0.9791	174.51	23.58	40	38

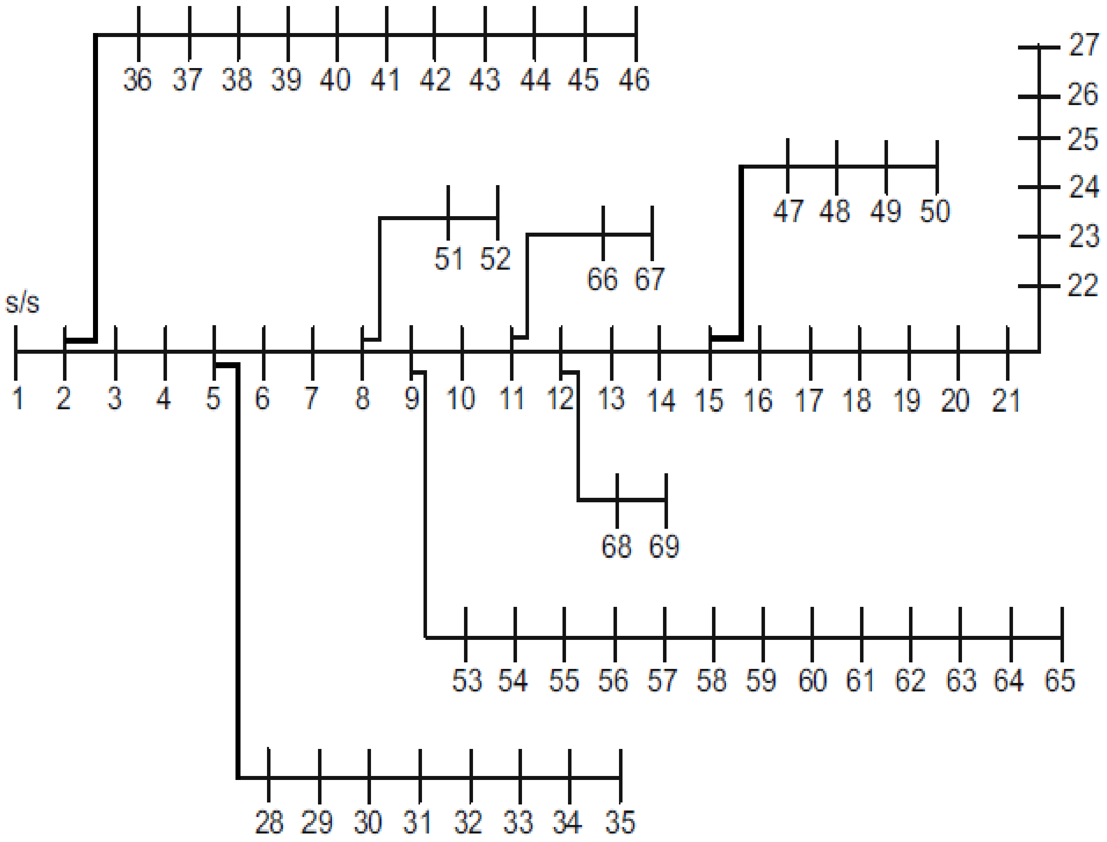

Figure. 2 The IEEE 69 Bus Radial distribution system

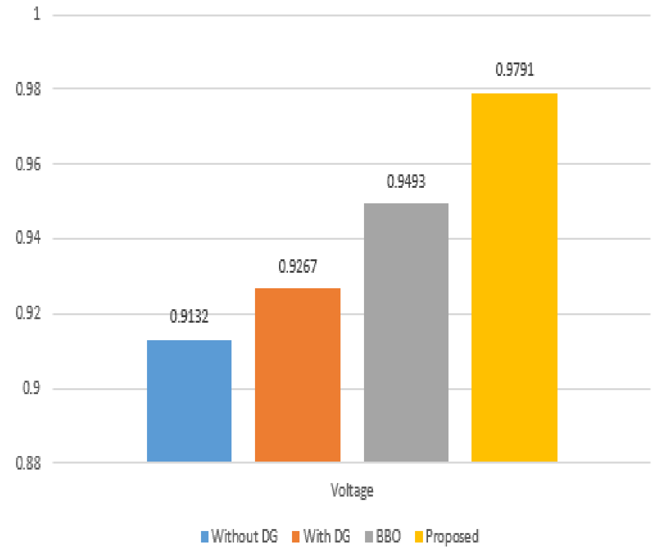

Figure. 3 The comparison analysis of voltage profile

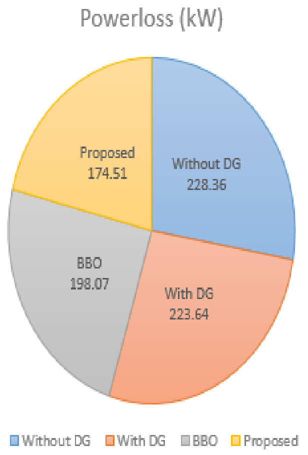

Figure. 4 The comparison analysis of power loss with proposed technique

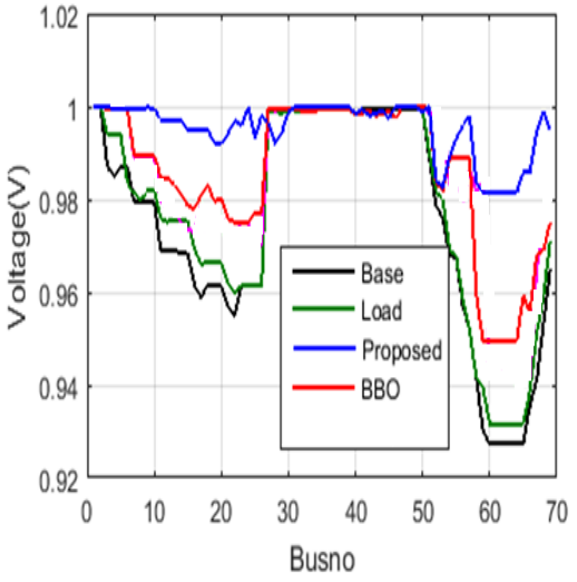

Figure. 5 The comparison analysis of Voltage profile in some different techniques

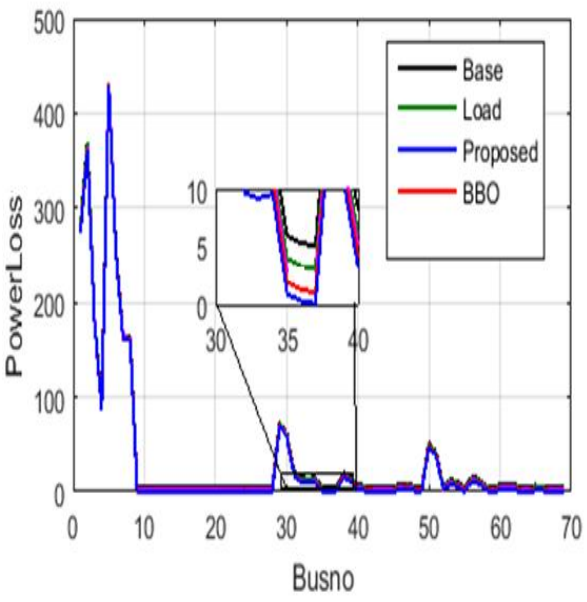

Figure. 6 The comparison analysis of Power loss in some different techniques

Figure 5 & 6 shows the comparison analysis of effect of optimal siting of DG system at different buses on power loss and voltage profile with various techniques. The fitness of the BBO is near 70 iterations but the proposed technique is required only 50 iterations to reach the optimal results. The performance of the proposed method is better than other techniques used in this paper in terms of quality of solutions.

VI. CONCLUSION

Hence this paper proposed ANFIS based adaptive scheme for optimal siting of DG system in an existing radial distribution system for power loss minimization and voltage profile improvement. This proposed scheme is simulated using MATLAB platform and tested into the IEEE 69 RDS and results are compared with the BBO methodology. The distribution system power loss is evaluated and measured the values and then the maximum power loss bus can place the DG and reduce the power loss. Here, the optimal DG is installed for minimization of the power loss on the optimal bus and hence improving the voltage profile.

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