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Symbiotic organism search for sizing and optimal location of distributed generation using novel sensitivity factor

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Abstract. Electric power systems consist of many interconnected buses. The most widely used network topology is Radial Distribution Network (RDN), the bus located furthest from generation has a significant voltage drop and the number of buses without any support from Distributed Generation (DG) inflicting in increased power losses and increased generation cost. DG is advantageous to reduce power losses and increasing voltage on the power system, but the location and sizing of DG in the distribution network requires great consideration. In this paper the method used to determine the location is Loss Reduction Sensitivity Factor (LRSF) and Voltage Improvement Performance Index (VIPI) and for sizing DG uses artificial intelligence Symbiotic Organism Search (SOS). This DG locating and sizing problem is associated with real power loss minimization and voltage profile improvement objectives. The proposed method has been demonstrated on IEEE 33-bus radial distribution system. Based on this research the identification of using LRSF location is better than VIPI.

1. Introduction

In the electrical system, supply of electrical energy to the load with sufficient quantities and good quality is a priority. The largest reserves of fossil energy and wisdom to reduce the effects of greenhouses gases, which promote to renewable energy. America, China and Brazil area the leading countries in the development of renewable energy potential. The number of plants in America 2010-2040 is estimated to increase by around 93 % where renewable energy sources reach 24 % with an annual increase of 2,8 % [1]. Demand for cheap electricity and quality electricity encourage application of electricity based on Distributed Generation (DG) or On Site Generation (OSG), a small scale electricity network and as a distributed energy resources [2]. Various types of DG technology are now available both renewable and non-renewable. DG which is non-renewable include Fuel Cell (FC), Reciprocating Engine (RE), GAS Turbine (GT), Micro Turbine (MT) etc. Renewable DGs include Photovoltaic (PV), Wind Turbine (WT), wave energy, geothermal energy, biomass etc. [3].

Identifying the DG concept can involve technology, location capacity and its impact on system operations [4]. In extensive area power system network, the identification of most compatible area for DG penetration is very significant. Two different sensitivity factor, based on loss reduction and voltage improvement have been proposed for selection of load buses to place the DG [5] and for size will be calculated by symbiotic organism search.



2. Mathematical Problem Formulation

The most important objective in this research to discover the optimal location and size of real power DG in RDS with a least power loss and voltage profile improvement. In this research, location is selected using LRSF and VIPI. The objective function can be separated into two parts [6], and are described as the inequality and quality constraints of the present optimization subject.

2.1. Power Losses Minimization

The major objective function of this research is to decrease the real power loss in the distribution system. It can be mathematically expressed as below:

$$P_{loss} = \sum_{i=1}^n \sum_{j=2}^n I_{ij}^2 R_{ij} \quad (1)$$

$$OF_1 = \text{Minimize}(P_{loss}) \quad (2)$$

Where P_{loss} is the real power loss of the RDS, n is the total number of buses in distribution system, I_{ij} is current branch between i and j , and R_{ij} is the resistance of the ij branch

2.2. Voltage Profile Improvement

The bus voltage of characteristic distribution network often experiences variations and even voltage may downfall under specific critical loading conditions with increasing load demand. DG are connected tightly to the load centers to avert voltage collapse and improve overall voltage profile of the distribution network. The objective function of voltage profile improvement may be expressed (3-4).

$$\text{Voltage}_{profile} = i = 1 \sum_{i=1}^n (V_i - V_{rated}) \quad (3)$$

$$OF_2 = \text{Minimize}(\text{Voltage}_{profile}) \quad (4)$$

Where V_i is the voltage of the i th bus, V_{rated} is the rated bus voltage of the network, which is equal to 1.0 pu. All these two single objective functions are combine to form a multi-objective optimization problem, whose fitness function (FF). Where w_1 and w_2 are weighting factors

$$FF = \min\{(w_1 \times OF_1) + (w_2 \times OF_2)\} \quad (5)$$

2.3. Constraint

The set of constraints is formed by (6-7)

$$V_{min}^{limit} \leq V_i \leq V_{min}^{limit} \quad (6)$$

$$\sum_{i=1}^n P_{load} \times 30\% \leq \sum_{i=1}^5 DG_i \leq 50\% \times \sum_{i=1}^n P_{load} \quad (7)$$

Where V_i is the voltage of the i th bus, $P_i DG$ is DG generation and P_{loss} total load in RDS. Based on location of DG, middle node and endmost node the total generation of DG cannot exceed 50 % because it will considerably reduce the system static voltage stability. However, if DG is located spread the maximum allowable penetration level is increased from 50 to 70 % [7].

3. Novel Sensitivity Factor

Novel sensitivity factor (NSF) consists of two indexes, loss reduction sensitivity factor (LRSF) and voltage improvement performance index (VIPI) [5]. In this paper, these indexes will be compared based on the effectiveness of DG location which will be placed in accordance with the objective function.

3.1. Loss Reduction Sensitivity Factor

LRSF is identified based on the reduction losses that develop because injection by DG, it can be defines as

$$LRSF_i = \frac{\Delta P_{loss}}{\Delta P_i} = \frac{P_{loss}^i - P_{loss}^b}{P_{DG}^{inj}} \quad (8)$$

Where P^i_{loss} is the system loss with injection DG capacity at i th load bus P^b_{loss} is the total system loss for base case, and P_{DG}^{inj} is the increment in DG capacity at i th bus. Based on above expression, the following calculation have been observed. $LRSF > 0$, $LRSF = 0$ and $LRSF < 0$ indicate that injection by DG has the impact of increased.

3.2. Loss Reduction Sensitivity Factor

Comparable expression equivalent to the voltage improvement performance index (VIPI) for the voltage security based ranking has been developed her for the selection of load buses [8].

$$VIPI_i = \sum_{j=1}^N \frac{w_j}{2n} \left(\frac{\Delta V_j^i}{\Delta V_j^{lim}} \right)^{2n} \quad (9)$$

$$\Delta V_j^i = V_j^i - V_j^{lim} \quad (10)$$

$$V_j^{lim} = \begin{cases} V_j^{maks}, & \text{if } V_j^i \geq 1.0 \\ V_j^{min}, & \text{if } V_j^i \leq 1.0 \end{cases} \quad (11)$$

$$V_j^i = \begin{cases} V_j^{maks}, & \text{if } V_j^i \geq V_{max} \\ V_j^{min}, & \text{if } V_j^i \leq V_{min} \end{cases} \quad (12)$$

$$\Delta V_j^i = \frac{V_j^{maks} - V_j^{min}}{2} \quad (13)$$

Where w_j is the weighting factor of bus j that is determined by the system operator depending upon the operating condition the system (=1). N is the total number of buses in the system, n the exponent of penalty function (=1 preferred), V_j^i is the voltage level at bus j .

4. Symbiotic Organism Search

SOS is a new metaheuristic developed for civil engineering application [9] [10]. This algorithm is built to resemble the symbiotic pattern of organism in an ecosystem. SOS has benefit factor (BF) and mutual vector (MV) parameters, it is consisting of mutualism, commensalism and parasitism phase are performed to implemented to main population (ecosystem) of candidate (organism) toward the global optimal region in the research space, In the mutualism phase, both organism benefit each other, in the commensalism phase, only one organism has an benefit while others are not impacted, in the parasitism phase, one organism must harm the other in order to gain the advantage. The process of three phase until stopping criteria are met as abridged in the following outline:

- a. Initialize ecosystem.
- b. WHILE
 - Simulate ecosystem through mutualism phase
 - Simulate ecosystem through commensalism phase
 - Simulate ecosystem through parasitism phase
- c. END



Figure 1. Symbiotic relations in ecosystem

4.1. Mutualism Phase

The mutualism phase counterfeits the mutual relations between two organisms in the ecosystem. In this phase, x_i is deliberated as the i th member of the ecosystem. Another organism x_j is then selected randomly from the ecosystem to interrelate with x_i .

$$X_i^{new} = x_i + rand(0,1) \times (X_{best} - MV \times BF_1) \quad (14)$$

$$X_j^{new} = x_j + rand(0,1) \times (X_{best} - MV \times BF_2) \quad (15)$$

$$MV = \frac{(x_i + x_j)}{2} \quad (16)$$

MV is mutual vector (that represent the mutual relationship between x_i and x_j), rand (0,1) is vector of random BF1 and BF2 are defines as benefits factors.

4.2. Commensalism Phase

New candidate solution X_i^{new} is calculating using (14) and compare with older x_i , the fittest organism as the solution to carry forward into the next iteration:

$$X_i^{new} = x_i + rand(-1,1) \times (X_{best} - X_j) \quad (17)$$

Where x_j is selected randomly from the ecosystem to interrelate with x_i , The equation $(X_{best} - x_j)$, denotes the advantage provided by x_j to help x_i to improve its degree of adaptation to the ecosystem.

4.3. Parasitism Phase

Parasite Vector is generated in the search space by duplicating organism x_i . Another x_j randomly selected dimensions using a random number. Parasite vector has a better fitness value, it will kill organism x_j and assume its position in the ecosystem. If the fitness value if x_j is better, x_j will have immunity from the parasite vector will no longer be able to live in that ecosystem.

5. Computational Procedure

The step-by-step procedure of the proposed SOS combine with NSF for the solution of the optimal placement and sizing DGs is given below:

Step 1: Identifying location for DG based on NSF equation (8-12)

Step 2: The capacity for DG as an organism based on location of DG

Step 3: Set maximum ecosize to determine the population on SOS

Step 4: Run power flow and find out real power loss and voltage profile

Step 5: Calculate the Fitness Function and recognize the best solution of organism in the ecosystem

6. Test System and Result

The step-by-step procedure of the proposed SOS combine with NSF for the solution of the optimal placement and sizing DGs is given below:

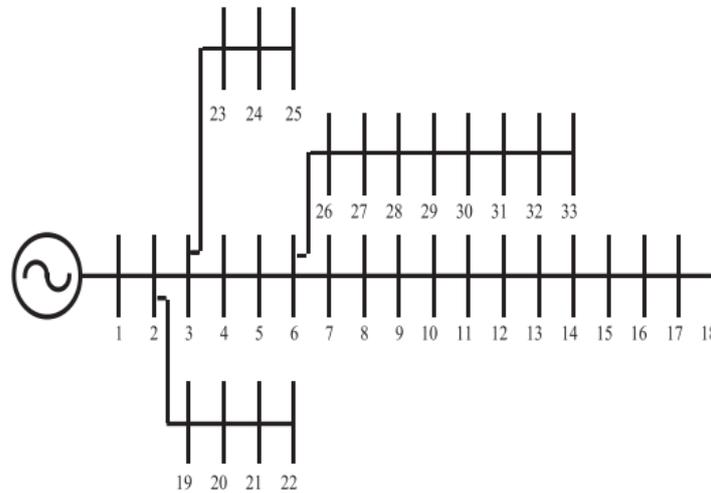


Figure 2. Single line diagram of IEEE 33 bus

6.1. Identify Location of DG

Those DGs produce only active power, for identification using LRSF, all buses on the system are tested with DG injection, equation (8) is used to get LRSF rank. The best location for DG is the minimum value LRSF. Fig 3 describes the comparison of LRSF.

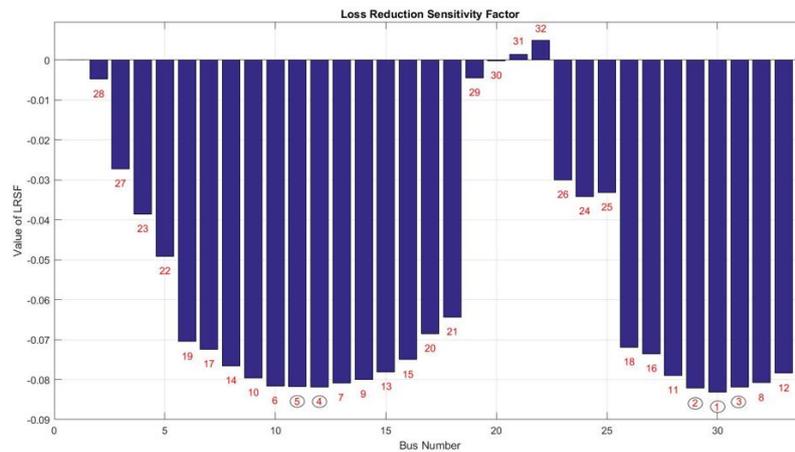


Figure 3. Comparison value of LRSF

Identify location with VIPI using equation (9-13), the bus noticed based on voltage deviation. The best location for DG is the maximum value of VIPI. Fig 4 describes the comparison of VIPI

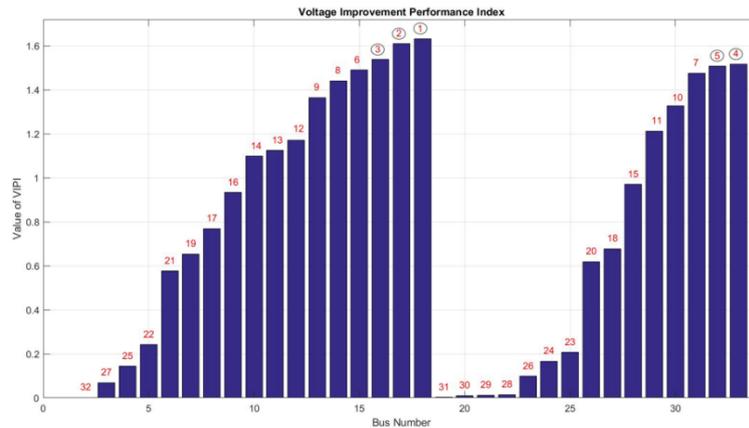


Figure 4. Comparison value of VIPI

6.2. SOS for Sizing Capacity of DG

The best location using LRSF method is 30, 29, 31, 11, and 12, while the best location using VIPI method is 16, 17 18, 33, and 32. The SOS program is built based on [9][10] using equations (14-17) and consists of 3 phases, mutualism, commensalism, and parasitism. Initialization is the number of ecosystems and the power flow backward forward as a function, equation (5) is a multi-objective function. Table 1 is a comparison when using LRSF and VIPI. Fig 5 is the voltage change before and after DG injection.

Table 1. Optimal location and sizing of DGs

Novel Sensitivity Factor + Symbiotic Organism Search						Power Loss	Total Reduction Power Loss	Voltage Profile
Without DG						224,02 kW	0%	0,1284
LRSF+SOS	11	12	29	30	31	88,22 kW	60,70%	0,016
	520 kW	510 kW	540 kW	300 kW	380 kW			
VIPI+SOS	16	17	18	32	33	101,71 kW	54,90%	0,0165
	300 kW	300 kW	300 kW	750 kW	300 kW			

7. Summary

Placement of different method for DG has a different impact in terms of power loss reduction and voltage profiles. Using LRSF and VIPI method combined with metaheuristic SOS will give different fitness value due to differences in the location of variables in a function affecting the fitness value which in turn affect DG capacity, LRSF+SOS can reduce power losses 60,70 % while VIPI+SOS reduce power losses 54,90 % Based on this paper the identification of locations using LRSF Is better than VIPI.

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