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Whale Optimization Algorithm For Intogreting Distributed Generators In Radial Distribution Network

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Abstract— *This paper introduces a hybrid approach to find the optimal location and size of distributed generations (DG) in the radial distribution network (RDN). The proposed approach is based on the whale optimization algorithm (WOA) technique to calculate the optimal allocation of DGs and loss sensitivity index (LSI) to obtain the best buses for DGs installation in RDN. The presented approach is applied to the standard 33-bus RDN to minimize power losses. The results obtained prove that the developed approach can be highly effective in integrating DG into RDN in comparison with other methods in the literature.*

Keywords— whale optimization algorithm distributed generation; photovoltaic; wind turbines; distribution network

1. Introduction

Due to the huge growth in electricity demand, the use of traditional energy sources is causing environmental problems. These power units emit huge amounts of greenhouse gases. With a global concern to reduce addiction to fossil fuels and reduce climate change, an alternative paradigm for electricity generation has been adopted. Distribute generation across the radial distribution network (RDN) [1-2]. The RDN is the endpoint of the power system. It acts as a link between the power supply area and individual consumers with unidirectional power flow. Research shows that about 70% of the total power loss in a power system is attributed to the DS side. A small source of energy directly connected to the grid or close to the consumer is called "Distributed Generation (DG)". DG is an attractive replacement for centralized power generation. DG divisions include both renewable and non-renewable energy sources. DGs have tremendous technical, economic, and environmental benefits. These technical and economic benefits can be achieved by choosing the location, size, and type of DG for installation in an electrical power system (EPS). The integration of a DG based on Renewable Energy Sources (RES) into the RDN has environmental benefits such as environmental friendliness (no emissions), free availability, abundance in nature, and so on [3-4].

The most commonly used DG systems in the residential sector are solar photovoltaic (PV) technology, small wind turbines (WT), fuel cells, natural gas-fueled ultrasounds, and emergency standby generators, usually fueled by diesel or gasoline. However, the commercial and industrial sectors use solar photovoltaic panels, hydropower, biomass combustion, biomass or natural gas fuel cell combustion, reciprocating internal combustion engines, and standby generators powered by petroleum-type diesel systems. Integration of DG units does not guarantee the reliability and stability of the system if they are placed in non-optimal places with different sizes. Instead of improving reliability and maintaining system stability, this will affect the voltage profile and increase system losses [5]. The optimal placement of the DG has taken on great importance due to its various advantages. However, integrating DG into an existing system will be an important and challenging task. As DG integration changes the behavior of the network from passive to active. Bidirectional power flow ultimately increases system losses and affects the reliability and stability of operation [6]. Planning to integrate a DG into an existing system requires optimal location, size, type of DG, and network connectivity. This reduces overall power loss, improves the system voltage profile and stability, reliability, safety, power quality, power factor, and overall system efficiency. Incorrect placement of WG units will distract from all of the above advantages [7]. Therefore, it is very important to place the DG unit in an optimal location and with a suitable size.

2. Problem Formulation

As mentioned above, the optimal allocation of DG is achieved to minimize system power losses. The power loss calculations can be achieved as follows. If we assume the two buses radial distribution network as shown in Fig. 1.

The active and reactive power flow can be calculated as follows [8-9]:

$$P_i = P_{i+1} + P_{L,i+1} + R_{i,i+1}\left(\frac{P_i^2 + jQ_i^2}{|V_i|^2}\right) \tag{1}$$

$$Q_i = Q_{i+1} + Q_{L,i+1} + X_{i,i+1}\left(\frac{P_i^2 + jQ_i^2}{|V_i|^2}\right) \tag{2}$$

The voltage at receiving bus can be calculated using (3).

$$V_{i+1}^2 = V_i^2 - 2*(R_{i,i+1} * P_i + X_{i,i+1} * Q_i) + (R_{i,i+1}{}^2 + X_{i,i+1}{}^2)*\left(\frac{P_i^2 + jQ_i^2}{|V_i|^2}\right) \tag{3}$$

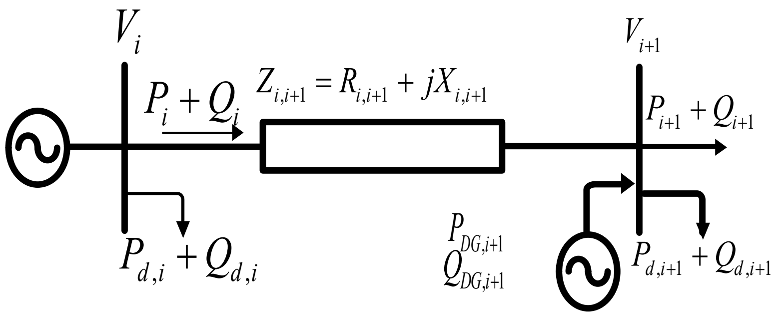

Fig. 1. Equivalent scheme of RDN.

The active and reactive power losses between buses *i* and *i+1* can be expressed as follows:

$$P_{loss(i,i+1)} = R_{i,i+1}\left(\frac{P_i^2 + jQ_i^2}{|V_i|^2}\right) \tag{4}$$

$$Q_{loss(i,i+1)} = X_{i,i+1}\left(\frac{P_i^2 + jQ_i^2}{|V_i|^2}\right) \tag{5}$$

The main objective function is the minimizing total active power losses that can be given as follows:

$$F_{obj} = minimize(P_{loss}) \tag{6}$$

where, P_{loss} is the total power loss.

The above objective function is subjected to some constraints such as DG size, bus voltage, and branch current.

2.1 Equality constraints

The generated power must be equal to the demand loads and power losses as [10]:

$$P_{swing} + \sum_{i=1}^{N_{DG}} P_{DG}(i) = \sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{k=1}^{N} P_d(k) \tag{7}$$

$$Q_{swing} + \sum_{i=1}^{N_{DG}} Q_{DG}(i) = \sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{k=1}^{N} Q_d(k) \tag{8}$$

where, P_{swing} and Q_{swing} are the active and reactive powers of swing bus, N_{DG} is the number of DGs, and L is the number of transmission lines.

2.2 Inequality constraints

- Voltage limitation

The bus voltages must be within the minimum voltage value ($V_{\min}$) and the maximum voltage value ($V_{\max}$)

$$V_{\min} \le |V_i| \le V_{\max} \tag{9}$$

- The limits of power generated from DG

The DG's installation capacity in the network is limited. Therefore, it must not exceed the power provided by the substation [11] to prevent reverse power flow.

$$\sum_{i=1}^{N_{DG}} P_{DG}(i) \le \frac{3}{4} * \left[\sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{k=1}^{N} Pd(k) \right] \tag{10}$$

$$\sum_{i=1}^{N_{DG}} Q_{DG}(i) \le \frac{3}{4} * \left[\sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{k=1}^{N} Qd(k) \right] \tag{11}$$

$$P_{DG}^{\min} \le P_{DG}(i) \le P_{DG}^{\max} \tag{12}$$

$$Q_{DG}^{\min} \le Q_{DG}(i) \le Q_{DG}^{\max} \tag{13}$$

where, $P_{DG}^{\max}$ and $P_{DG}^{\min}$ are the maximum and minimum active powers generated by DG unit, $Q_{DG}^{\max}$ and $Q_{DG}^{\min}$ are the maximum and minimum reactive outputs of DG unit.

- Transmission line current limitation

The maximum transmission line current must meet the following constants [12].

$$I_k \le I_{\max,k} \tag{14}$$

where I_{max} is the maximum allowed current through the branch *k*.

2.3 Loss sensitivity index

The appropriate buses for the integrating of the DGs are definite by using the LSI. The LSI widely used to solve DG sizing and locating problems in RDN [13-14].

LSI can be expressed as:

$$\frac{\partial P_{loss}}{\partial Q_m} = \frac{2Q_m * R_{lm}}{(V_m)^2} \tag{15}$$

After determined the PLS index for all buses organized in descending order. The order determines the priority of buses for DG installing. The calculated PLS index values are illustrated in Fig. 2.

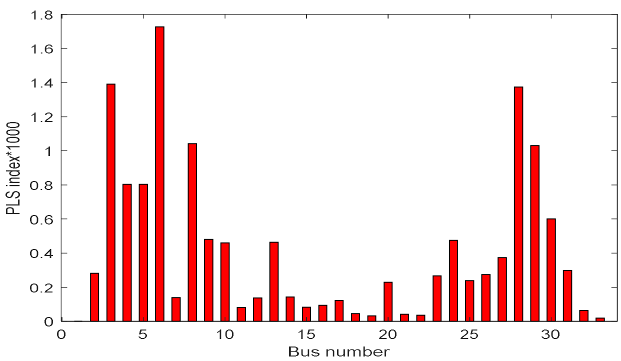

Fig. 2. The calculated LSI values.

2.4 Whale optimization algorithm

Mirjalili developed the WOA approach in 2016 [15] as a novel nature-inspired heuristic technique to solve problems related to engineering and different mathematical optimization issues. The common behaviors of humpback whales are the basis of the WOA. This optimization technique is inspired by the bubble net hunting approach of humpback whales as they follow a circular shaped route for hunting small fish near the surface. This feeding process is a distinctive behavior of humpback whales, making this optimization unique among other nature-inspired optimization methods. To design the mathematical model of the WOA, three steps are involved in the bubble-net hunting process.

3. NUMERICAL RESULTS AND DISCUSSION

To show the effectiveness of the proposed approach applied to IEEE 33-bus RDS. This RDS with real and reactive power is 3715 kW and 2300 kVAr, respectively. The base power loss of this system is 210.98 kW and the lower bus voltage is 0.9038 p.u. Other information can be found in [16]. The single line scheme of the standard 33-bus system is shown in Fig 3.

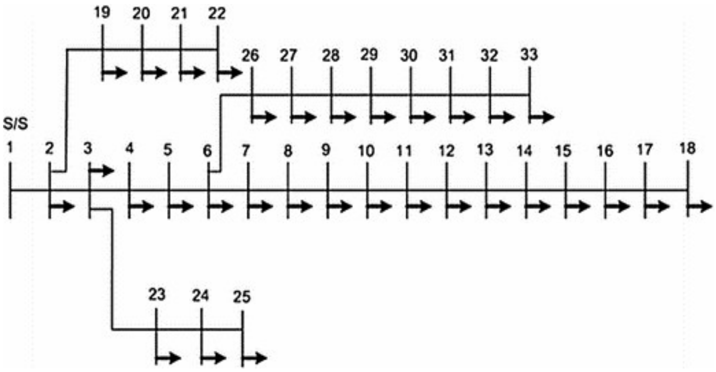

Fig. 3. Single line diagram of standard 33-bus system.

The system power loss is decreased to 111.027 kW, 87.166 kW, and 72.79 kW by integrating one, two, and three PV units, and power loss is decreased to 67.83 kW, 28.63 kW, and 11.74 kW by integrating one, two, and three WT units in RDS, respectively. Integration of one, two, and three PV units improves the minimum voltage to 0.9424 pu, 0.9685 pu, and 0.96868 pu, and integration of one, two, and three WT units improves the minimum voltage to 0.95835pu, 0.98025 pu, and 0.99212 pu, respectively as shown in Fig.4. From these figure, it is clear that the voltage profile of each bus has been significantly improved relative to the base case by optimally determining the sizes and locations of the DG units by using the proposed approach. Besides, the proposed approach obtains the minimum power loss compared to other techniques as shown in Table.1.

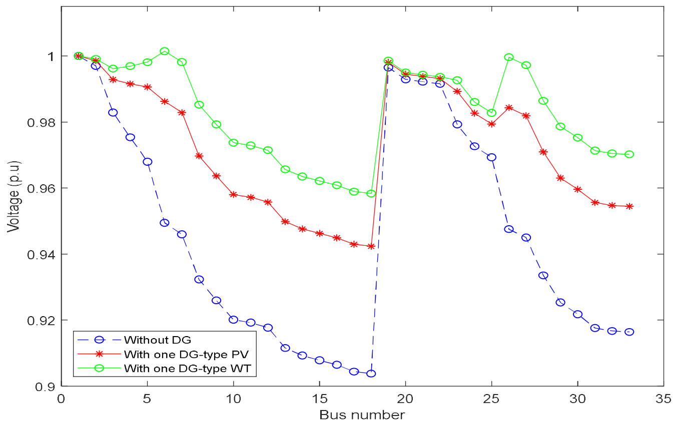

Fig. 4. Impact of two DG units on the voltage profile.

Table 1: The results comparison of proposed approach and other methods

Number and type of DG	Hybrid approach [13]	EA [14]	PSO [4]	**Proposed method**

One PV	Bus (Size (KW /P.F))	6(2530/1)	6(2530/1)	6(2590/1)	**6 (2590.2/1)**
	Power loss (KW)	111.42	111.07	111.03	**111.027**
Two PV	Bus (Sizes (KW /P.F))	13(844/1) 30(1149/1)	13(844/1) 30(1149/1)	13(850/1) 30(1160/1)	**13(851.5/1)** **30 (1157.6/1)**
	Power loss (KW)	87.43	87.172	87.170	**87.165**
Three PV	Bus (Sizes (KW /P.F))	13 (798/1) 30 (1050/1) 24 (1099/1)	13(798/1) 30(1050) 24 (1099)	14(770/1) 30(1070/1) 24(1090/1)	**13(801.71/1)** **30(1053.6/1)** **24 (1091.3/1)**
	Power loss (KW)	72.79	72.79	72.790	**72.786**
One WT	Bus (Size (KW /P.F))	6 (3028/0.82)	6(3119/0.82)	6(3035/0.82)	**6(2558.5/0.82)**
	Power loss (KW)	67.937	67.937	67.928	**67.83**
Two WT	Bus (Sizes (KW /P.F))	13(1039/0.91) 30(1508/0.72)	13(938/0.90) 30(1573/0.73)	13(914/0.91) 30(1535/0.73)	**13(858.3/0.91)** **30 (1089.1/0.7)**
	Power loss (KW)	28.98	28.98	28.56	**28.50**
Three WT	Bus (Sizes (KW /P.F))	13 (873/0.9) 30(1439/0.71) 24(1186/0.89)	13(886/0.90) 30(1450/0.71) 24(1189/0.90)	13(863/0.91) 30(1431/0.71) 24(1188/0.9)	**24(1069.9/0.9)** **30(1029.9/0.71)** **13 (793.8/0.9)**
	Power loss (KW)	11.76	11.8	11.76	**11.740**

4. CONCULISION

In this paper, whale optimization algorithm (WOA) with a loss sensitivity index (LSI) has been proposed for the solution problem of optimal allocation of DG units in RDN. The main goal of the proposed technique is to minimizing power losses. The proposed approach has been applied to the standard 33-bus system and compared results obtained with existing optimization techniques. The proposed approach is very effective in finding the optimal solution (minimum power loss) compared to other optimizations technique. This study also focuses on parameters that depend on optimal DG allocation and sizing.

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