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Performance Enhancement in Optimal Placement and Sizing of Wind Based DG in Distribution System Using Firefly Optimization Technique

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Abstract-Proper placement of DG in distribution system is still very challenging issues for obtaining their maximum potential benefits. This paper suggest a multi objective fire fly algorithm based performance model of Wind Turbine Generation Unit placement suggest for power loss reduction and voltage stability improvement of radial distribution system. This paper reflects the effectiveness of WTGU model in DG placement problem formulation. Voltage Stability Factor has been used in this paper which can quantify the voltage stability levels of buses in the distribution system.
Keywords-Voltage stability factor, Distributed generation, firefly algorithm

I. INTRODUCTION

With growing load demand in the distribution network, it provisions of potential scope for research in terms of analyzing the distribution network to meet the demand with the present infrastructure. Shortage of distribution power carrying capabilities and increased interest in application of green technology can be use of Distributed Generation (DG) [1]. DG units are mainly energized by wind, solar and fuel cell. There are a more number of DG technologies available in the market today and a few are still at the research and development stage. In the available technologies, wind and solar based DG technologies are going to dominate the electricity market because of their free environment characteristics and abundant availability of resources.

Normally the structure of distribution system is radial because of their simplicity. Most of the radial distribution system suffers with high power losses because of high resistance and reactance ratios. The overall efficiency of the system can be improved by using DG units. It is very necessary to determine the optimal location for sitting of DGs. DG devices can be strategically placed in power systems for reinforcing grid, minimizing power losses and on-peak operating costs, improving voltage profiles and load factors and improving system integrity, reliability, and efficiency [2]. Installing DG units at non-optimal places may result in an increase in system losses, implying an increase in cost of system and therefore having an opposite effect to what is desired. Moreover, if multiple DG units are installed, optimal approach for placement of DGs [3] in order to maintain the stability and reliability of the system.

In case of placement of multiple DGs, the problem of optimal placement of DGs is already solved by optimization techniques such as Genetic Algorithm (GA) [4], Particle Swarm Optimization (PSO) technique [5] Artificial Bee Colony (ABC) optimization [6] and Ant Colony optimization [7]. In this paper, a new swarm intelligence approach that utilizes Firefly algorithm (FA) to determine the optimal DG unit's size and location in order to minimize the total system power loss and voltage stability improvement is proposed. By using FA, the size and location of DG can be determined simultaneously.

II. PROBLEM FORMULATION

A. Formulation of voltage stability measurement

Voltage stability has become a major concern in modern power system scenario. Voltage Stability Factor (VSF) is helpful to measure voltage stability of the system or to find out weak buses in the network. Among different techniques, VSF based method has emerged as very fast tool for off-line voltage stability analysis.

1) *Voltage Stability Factor:* A novel technique for determination of voltage stability [8] is discussed in detail here. Considering two bus section of distribution system of Fig. 2.1, branch current of any branch 'i' can be obtained as follows.

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$$I_i^2 = \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (1)$$

Where P_{m+1}, Q_{m+1} and V_{m+1} are the active load, reactive load and bus voltage magnitude at bus '$m+1$'.

So, active and reactive power losses in the branch are given by

$$P_{lossi} = r_i \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (2)$$

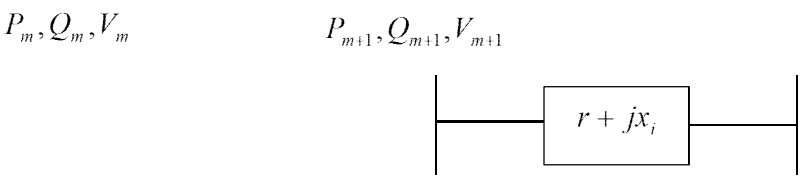

Fig. 1. Two bus section of radial distribution system

$$Q_{lossi} = x_i \left(\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} \right) \quad (3)$$

Here P_{lossi} and Q_{lossi} are active and reactive power losses of branch 'i'

$$I_i^2 = \frac{P_{lossi}^2 + Q_{lossi}^2}{(V_m - V_{m+1})^2} \quad (4)$$

From (5) and (8), equating I_i^2 becomes

$$\frac{P_{m+1}^2 + Q_{m+1}^2}{V_{m+1}^2} = \frac{P_{lossi}^2 + Q_{lossi}^2}{(V_m - V_{m+1})^2} \quad (5)$$

Putting the values of P_{lossi} and Q_{lossi} in eqn (5)

$$\left(P_{m+1}^2 + Q_{m+1}^2\right).\left(r_i^2 + x_i^2\right) = \left(V_{m+1}^2 - V_{m+1}.V_m\right)^2 \quad (6)$$

Taking positive root of (6)

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$$S_{m+1} = \left(\frac{V_{m+1}^2 - V_{m+1}.V_m}{Z_i} \right) \quad (7)$$

S_{m+1} is the magnitude of complex power at receiving end .For critical power flowing at receiving end.

$$\frac{dS_{m+1}}{dV_{m+1}} = \left(\frac{V_{m+1}^2 - V_{m+1}.V_m}{Z_i} \right) = 0 \quad (8)$$

For stable operation of the system

$$\frac{dS_{m+1}}{dV_{m+1}} > 0 \quad ie \ (2V_{m+1} - V_m) > 0 \quad (9)$$

Voltage stability factor for any bus 'm+1' is designated as

$$VSF_{m+1} = (2V_{m+1} - V_m) \quad (10)$$

At voltage collapse point VSF become zero and that will be occurred when magnitude receiving end bus voltage become half of magnitude of sending end bus voltage. The value of the VSF of buses nearer to zero, the system is more vulnerable.
Voltage stability condition of the whole distribution system can be proved summing the values of VSF of all the load buses.
So,

$$VSF_{total} = \sum_{m=1}^{k-1} (2V_{m+1} - V_m) \quad (11)$$

'k' is the total number of buses in the system and V_1 is the magnitude of substation voltage. The higher value of VSF_{total} indicates more voltage stable operation.

2) Performance modeling of wind based generation

Power generation of Wind Turbine Generation Unit (WTGU) depends on their model and resource such as wind speed [9]. In this section modeling of WTGU is discussed to understand wind based DG placement technique in better way.

1) Performance model of WTGU

Depending on the rotational speed WTGUs can be broadly classified into two types namely fixed speed WTGU and variable speed WTGU. Commonly variable speed WTGU is used in which real power output varies wind speed. For a typical WTGU, the output electrical power generation is given by

$$P_w = \begin{cases} 0 & v_w < v_{cin} \quad or \quad v_w > v_{cout} \\ P_{rated} \dfrac{v_w - v_{cin}}{v_N - v_{cin}} & v_{cin} \le v_w \le v_N \\ P_{rated} & v_N \le v_w \le v_{cout} \end{cases} \quad (12)$$

v_{cin}, v_{cout}, v_N are cut-in speed, cut-out speed and nominal speed of wind turbine, respectively; v_w is the average wind speed; P_{rated} is the rated output power of turbine and can be represented as

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$$P_{rated} = 0.5\rho A v_w^3 C_p \quad (13)$$

Where A is the swept area of rotor; ρ is the density of air; v_w is wind speed and C_p is the power co-efficient.

III. FIREFLY OPTIMIZATION TECHNIQUE

Firefly Algorithm is a meta-heuristic algorithm inspired from behavior of fireflies' swarm [10]. This algorithm is based on attractiveness and light intensity [11]. The firefly algorithm is made using the following assumptions:

Fireflies are affected by the attractiveness and brightness as they are unisex.

The attractiveness increases as the brightness of the firefly increases and it decreases as the distance from each other increases.

The firefly move in random when there is on brighter one

The brightness of the firefly depends on the shape of the objective function

These rules are used to get the optimal value of the objective function.

A. *Firefly Algorithm*

Objective function A(x), $x = (x_1, \ldots x_d)^T$

Generate initial population of fire flies $x_i, (i = 1, \ldots n)$

Light intensity I_i *at* x_i *determined by* $A(x_i)$

Define light absorption coefficient γ

while *(t<Max Generation)*

for *i=1; n all n fire flies*

for *j=1; i all n fire flies*

if $(I_j > I_i)$ *More fire fly I towards j in d-dimension;* ***end if***

Attractiveness varies with distance r *via* $\exp[-\gamma r]$

Evaluate new solution and update light intensity
end for j
end for i
Rank the fire flies and find the current best
end while
Post process results and visualization

IV. OPTIMAL PLACEMENT USING MULTI OBJECTIVE FFO TECHNIQUE

Step 1: Initialize the parameters such as bus number, number of DG units and its minimum and maximum capacity of generation,

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maximum number of iteration, total loss of the system (eqn. 14), total VSF of the system(eqn. 15)

$$Sloss_{total} = \sum_{i=1}^{n} \sqrt{\left(Ploss_i^2 + Qloss_i^2\right)} \quad (14)$$

$$VSF_{total} = \sum_{m=1}^{k-1} \left(2V_{m+1} - V_m\right) \quad (15)$$

Step 2: Randomly place the DG unit in distribution system and calculate generation of real (eqn. 16) and reactive power (eqn. 17) of DG units using the below equations.

$$P_{DG,i} = I_i * DG_i * \cos\theta \quad (16)$$

$$Q_{DG,i} = I_i * DG_i * \sqrt{1 - \cos^2\theta} \quad (17)$$

Using newton raphson power flow solution calculates voltage magnitude of buses.

Step 3: Check the each bus voltage magnitude by below equation

$$|V_{i,bus}| \leq 1.05 p.u \quad (18)$$

If above equation satisfied means compute and store the values of total loss (eqn) and total VSF (eqn). If above equation not satisfied, increase the iteration and increase the DG units until reach the maximum number of DG units and repeat the step 2

Step 4: Continue the process until reach maximum number of DG unit. Update the total loss and total VSF of the Distribution system.

Step 5: Check for maximum number of iteration. If satisfied store the location of DG at the bus and number of DG unit at connected bus. If not satisfied, go to step 2.

Step 6: calculate the optimal size of DG for the results obtained from step 5 using below equation.

For WTGU,

$$DG_{wind,i} = \sum_{n_i=1}^{n_i,\max} n_i * P_w \quad (19)$$

Stop the process.

V. RESULTS AND DISCUSSIONS

DG placement technique has been tested on IEEE 14 bus system. Using VSF calculation bus-4 and bus-7 was found as weak bus and initial total VSF obtained as 13.4521. The tested systems incur total loss of 62.12 KVA. So there is provision of improvement of voltage stability level and reduction of power loss for test system. DG placement in distribution system using firefly optimization technique, the voltage magnitude improvement by DG placement show in fig 2, voltage magnitude of 14-bus system for optimal placement of WTGUs in 0.955 lagging, leading and unity p.f mode shown in fig 3.

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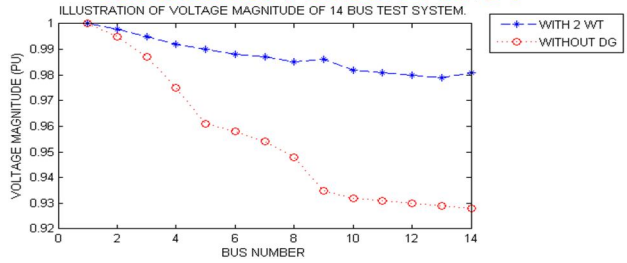

Fig. 2. Illustration of voltage magnitude of 14-bus test system

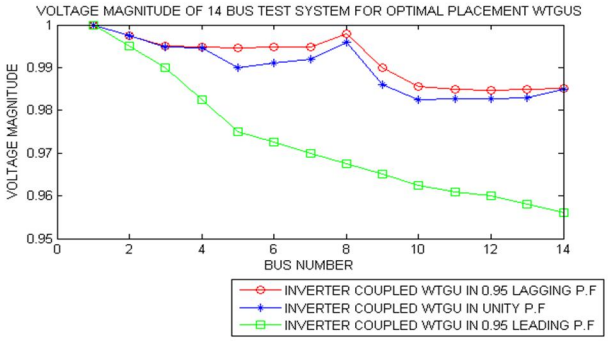

Fig. 3. Voltage magnitude of 14-bus system for optimal placement of WTGUs in 0.95 lagging, leading and unity p.f mode

Utilities may be interested to locate WTGU at certain number of buses. Considering the fact, detail allocation of WTGU from minimum penetration to maximum is experimented.
After placed the WTGU in found weak bus system the voltage stability factor of bus was increased and total loss of the bus system can be minimized.
Total VSF has been increased up to 3.24%, total power loss minimized up to 45.237% comparatively initial total loss and VSF. The placement result shown in Table 1

14-Bus system	No.of connection bus	Location at bus(no.of WTGU)	Total VSF	Improvement in voltage stability (%)	Total loss(KVA)	Power loss minimization (%)
	1	Bus-4(5)	13.4521	2.46	62.122	38.342
	2	Bus-4(4), Bus-7(3)	13.5643	3.24	52.464	45.237

Table 1. Optimal location and number of WTGU units at unity power factor for 14-bus system along with voltage stability improvement and power loss reduction.

VI. CONCLUSION

This paper has presented a multi-objective Firefly Optimization (FFO) based method for optimal placement of wind based Distributed Generation (DG) units into distribution system. The suggested method can comply with voltage and power limit constraints specified by utility. The method targets to improve the voltage stability margin and reduce network power losses utilizing supply from DG units. VSF is used to quantify voltage stability condition of the whole network also. Utilizing performance modeling, optimal location and size selection of Wind Turbine Generation Unit (WTGU) array in distribution system are discussed.

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Optimal placement of WTGUs has been investigated on 14-bus radial distribution system.

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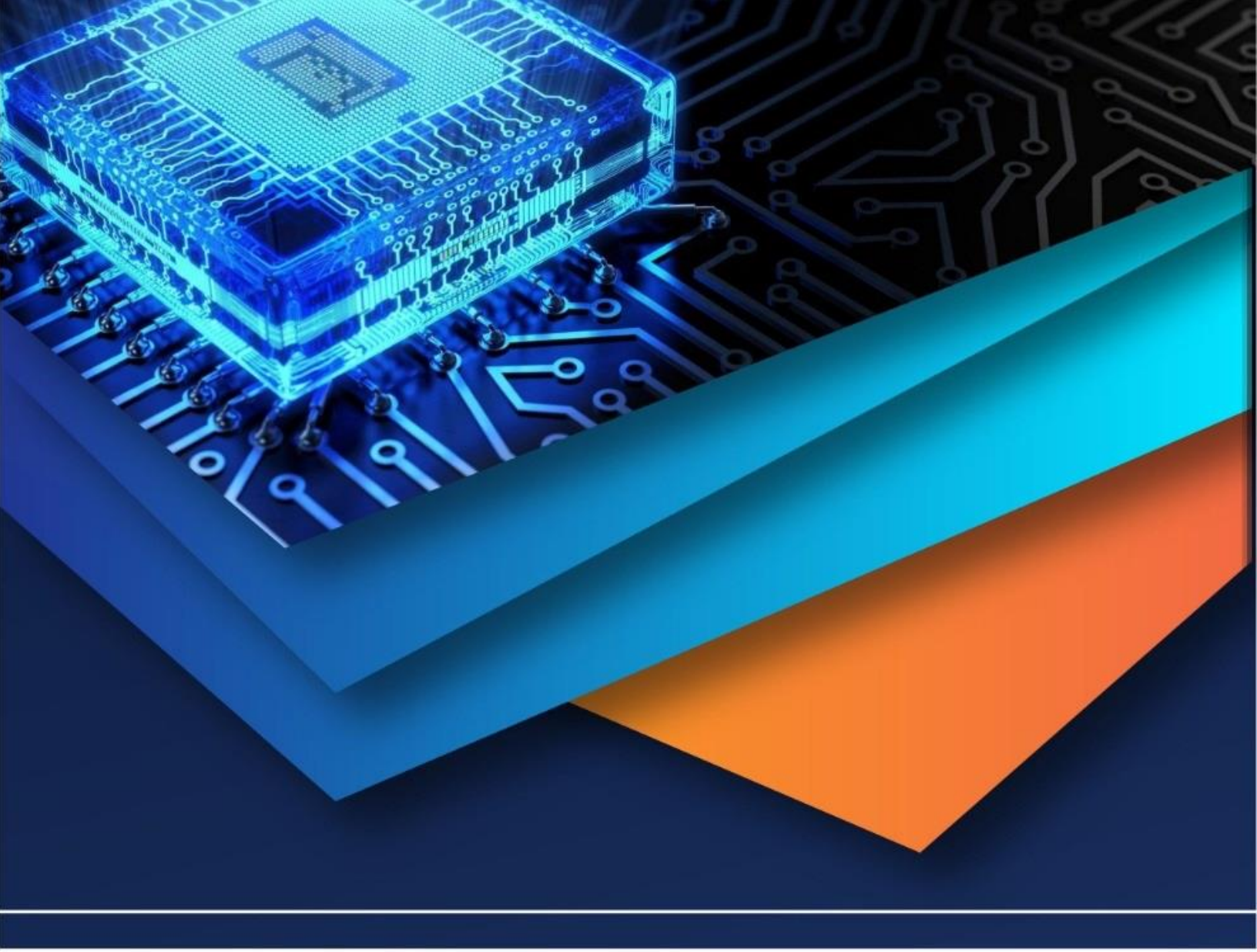

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