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Optimal DG sizing and siting in radial system using hybridization of GSA and Firefly algorithms

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ABSTRACT

In order to improve the Voltage Stability Index (VSI), real and reactive power loss compensation, there is a solution in terms of Distributed Generation (DG). By incorporating DGs at proper location with suitable size, the power losses will reduce and there is an improvement of voltage profile. For this a new approach was introduced which is a hybridization of Firefly Algorithm (FA) with Gravitational Search Algorithms (GSA). After finding the real power losses using conventional method like Backward/Forward (BW/FW) sweep approach, the new approach was implemented to prove that it was the better algorithm than the other approaches. All these approaches have been implemented on standard IEEE-33 radial test system. MATLAB software was used to simulate the results and to find optimal DG sizing and siting on IEEE-33 test system.

1. INTRODUCTION

Due to the presence of heavy non-linear loads in the distribution system, a huge real power losses and reactive power losses are taking place in the radial distribution system. Now a day a new approach is implemented that generation of energy at load centers to compensate this loss of power. This small-scale generation of power is directly connected to grid in order to improve the power quality in terms of good voltage profile and quality of power. This kind of small-scale generation at load centers is well known with the name of Distributed Generation (DG) [1]. This DG will provide by means of PV cells, wind energy and other types of renewable sources. This kind of generation at load centers not only reduces losses in the system, it also helps to reduce transmission cost also.

Recent work: A brief

Georgilakis and Hatziargyriou et al. [2] Placement DG affects mainly on the distribution system operation. Inappropriate placement of DG placement will lead to increase losses in the system, initial and maintenance costs. On the other hand, optimal allocation of DG can improve performance in terms of real and reactive power losses, improve voltage profile mean while power quality improvement, and supply reliability

Soudi et al. [3] given that the major benefit of DG installation in the system depends on finding the optimal location and capacity of DG. From the results that the optimal allocation of DG will reduce the power losses up to 47%, cost of power up to 92% and cost of energy not supplied by 40%.

Few methods, objectives and constraints have been discussed by different authors. Methods used include the classical or numerical method as presented by; the analytical approach as presented. Some researchers have also used combined solution methods which involve using more than one approach as shown. All these techniques have discussed different types of objective functions either single or multiple objectives and various types of constraints have also been discussed.

In this research, FF and GSA were combined for the optimal location of DG in distribution system for power loss reduction of power loss and voltage profile improvement has been proposed. In this approach, the DG capacity is evaluated at every bus and the location is determined. Both the approaches proposed and conventional GSA are tested on 33-bus test system and the obtained results are compared.

Initially by implementing BW/FW sweep approach [4] on IEEE-33 radial bus test case the real and reactive power losses and the voltage profiles at each bus could be found under normal condition. Later by adding load on different busses again, the real and reactive power losses and the voltage profiles at each bus could be found. Then by using GSA approach real power losses and voltage profiles at each bus could be found. Finally, by implementing a new hybridizing approach that is FA with GSA approach, the real power losses and voltage profiles could be found and all the results would be compared.

2. POWER FLOW ANALYSIS FORMULATION FOR RADIAL DISTRIBUTION SYSTEM

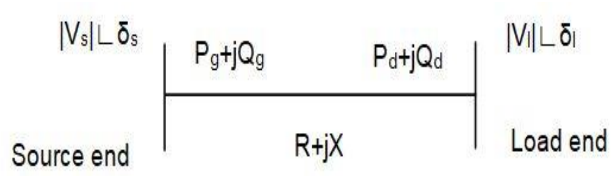

Figure 1. Single line diagram of a simple radial distribution system

This research mainly concentrated on minimization of real power losses and voltage profile improvement for a given test system by introducing DGs with proper size and at proper site.

The objective function of the system is represented as following:

$$Voltage = \sum_{ni=1}^{n} \left(V_{ni} - V_{specified}\right)^2 \tag{1}$$

where: V_{ni} is ni bus voltage, $V_{specified}$ is $1\angle 0^0$ Per Unit.

$$\text{Real power loss} = \left(\sum_{i=2}^{n} \left(\begin{array}{c} P_{gi} - P_{di} - |V_{mi}||V_{ni}| \\ |Y_{mni}| \cos(\delta_{mi} - \delta_{ni} + \theta_{ni}) \end{array} \right) \right) \tag{2}$$

where: P_{gi} is Generator active power output at i^{th} bus, P_{di} is Active power demand at i^{th} bus, V_{mi} is mi bus voltage, V_{ni} is ni bus voltage, Y_{mni} is admittance of branch between mi and ni bus, δ_{mi} is mi bus voltage phase angle, δ_{ni} is ni bus voltage phase angle, θ_{ni} is angle of admittance of Y_i is $Y_{ni}\angle\theta_{ni}$, n is total number of buses, ni is bus number of receiving end, mi is bus number of sending end, i is branch number.

$$\begin{aligned} VSI(ni) = &|V_{mi}|^4 - 4\left[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}\right]|V_{mi}|^2 - \\ &4\left[P_{ni}(ni)R_{ni} + Q_{ni}(ni)X_{ni}\right]^2 \end{aligned} \tag{3}$$

where: $P_{ni}(ni)$ is Total real power fed through bus ni, $Q_{ni}(ni)$ is Total reactive power through bus ni, R_{ni} is i^{th} branch resistance, X_{ni} is i^{th} branch reactance and $SI(ni)$ is VSI (*Voltage stability Index*) of ni node.

In order to improve the VSI in a given test system it is necessary to find the bus which is having low value of VSI. Because low value of VSI leads to system instable.

$$\min(VSI(ni)) = \left(\frac{1}{VSI(ni)}\right); \; ni = \{1,2,\ldots,N_n\} \tag{4}$$

The tolerance range of voltage of all buses,

$$V_{\max} \geq V_{ni} \geq V_{\min} \tag{5}$$

The operation of DGs is different from one other due to their type. So, it is required to keep the size constraint within tolerance limits as,

$$S_{\max}^{dg} \geq S_{ni}^{dg} \geq S_{\min}^{dg} \tag{6}$$

where: S^{dg}_{max} is at bus ni maximum apparent power and S^{dg}_{min} is at bus ni minimum apparent power, S^{dg}_{ni} is at bus ni apparent power.

3. BW/FW SWEEP APPROACH FOR POWER FLOW ANALYSIS

The BW/FW sweep approach having a distinguish advantage over many other conventional approaches to solve power flow analysis on radial bus system. This approach is having the elapsed time for operation is much lesser than the other. BW/FW sweep analysis will gives better results when compared real and reactive power losses with other approaches. The flowchart and the algorithm for BW/FW sweep analysis are very simple as shown.

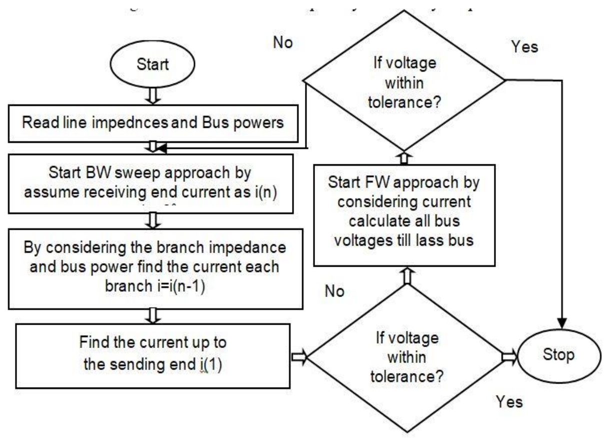

Figure 2. Flowchart for BW/FW sweep approach

4. GSA APPROACH

The GSA approach [5] is the one of the algorithms that has been developed by laws of Newtonian of motion and gravity in the year 2009. The parameters in GSA are specified in terms of objects. The objects characteristics are determined by their individual mass. The attractive force between objects due to gravity force. Because of this force with huge mass of the object a movement taking place. Therefore, masses are communicated using the force of gravitational. The objects that are having lightweight can move faster than the heavy weight objects. However, the slow movement of objects will give better results. This is the important point of GSA. In this approach, inertia mass. Position, passive and active mass gravitational is the characteristics of objects.

4.1 GSA Mathematics formulation

As said earlier there is an attractive force between two objects. This force is called gravitational force between objects and is given by,

$$GF_{ij} = GC\frac{M_i M_j}{D^2} \tag{7}$$

where: GF is Gravitational Force, GC is Gravitational Constant M_i is Mass of object i, M_j is Mass of object j, D is Distance between objects.

For optimized solution, the above equation has changed by setting the power of distance in GF is set as one. Now the modified GF equation is as,

$$GF_{ij} = GC\frac{M_i M_j}{D} \tag{8}$$

For the implementation of GSA for optimal solution and the problem of DG output, the output of DG is set as object (ai). The loss of power is calculated in GSA as

$$Power\ loss = \sum_{i=1}^{n} I_D^2 R \tag{9}$$

From the above equation, an object, which is having high mass will, leads to less power loss given distribution system. Due to this this objects movement is becomes slow than the objects, which are having, light weight.
Each object mass (M) at present as,

$$x_i = \frac{fit - bad}{good - bad} \tag{10}$$

$$M_i = \frac{x_i}{\sum x_i} \tag{11}$$

where: i = 1, 2, … n, *fit* is fitness (Power loss), *Bad* is high power loss, *Good* is low power loss.

$$New\ position = a_i^d = a_i^{dold} + v_i^{dnew} \tag{12}$$

$$New\ velocity = v_i^{dnew} = rand_i + v_i^{dold} + b_i^d \tag{13}$$

$$New\ acceleration = b_i^d = \frac{f_i^d}{M_i} \tag{14}$$

$$f_i^d = \sum_{i=1,\, j\neq 1}^{n} rand_i \tag{15}$$

where: d is dimension.

Figure 3. Flowchart for GSA approach

5. FIREFLY APPROACH

As the case of GSA, FA is also a heuristic approach [6]. Natural processor in the world like flashing behavior of fireflies inspires this approach. This approach is developed in the year of 2009. It has three factors depends on fireflies behavior.

First, one is attraction of fireflies with gender independent. The second one is the attraction of fireflies is directly proportional to their brightness. The brightness of the firefly can be calculated by the objective function that is used to solve a particular problem.

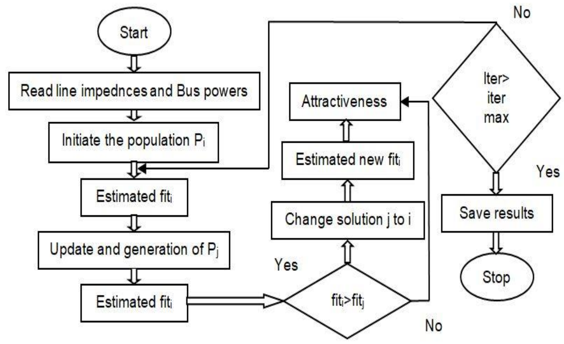

Figure 4. Flowchart for FA approach

5.1 Mathematical formulation for FA

Consider that all fireflies are same gender and the attraction between them is proportional to their flash intensity or light intensity. The firefly, which is having more brightness, will attract nearby firefly, which is having less brightness. If there is no firefly nearby then it will move in random direction. The brightness of the firefly is related to the function of fitness. According to law of Inverse Square, the IL is calculated as,

$$IL(d) = \frac{I_s}{D^2} \tag{16}$$

where, *IL (d)* is Intensity of light at *d* distance and I_s is Source Intensity.

The distance *d* between two fireflies can be calculated as if *i* and *j* are the two fireflies,

$$d_{ij} = \sqrt{\sum_{k=1}^{n}\left(a_{i,k} - a_{j,k}\right)^2} = \left\|a_i - a_j\right\| \tag{17}$$

The *IL* is varies with varying distance. Then the new *IL* is calculated as,

$$IL = IL_0 \exp(-\beta d^2) \tag{18}$$

where, IL_0 is Original *IL*, β is Absorption coefficient.

The attractiveness of firefly is proportional to *IL* and it can be represented as,

$$\alpha = \alpha_0 \exp(-\beta d^m) \qquad m \geq 1 \tag{19}$$

where, α_0 attractiveness at *d* = zero.

6. NEW APPROACH USING FIREFLY WITH GSA

Here a new concept is introduced for proper size and site for DG placement by considering a hybrid approach in radial distribution system. When the load is added to the system, the voltage profiles and real and reactive power losses are varied from BW/FW sweep approach. By using this new approach, the size of the DG can be determined by using the equation (6) from FA. GSA approach will gives the information about real power losses and bus voltage. By the information obtained from GSA, the proper location can be obtained. Then by combining approach Firefly with GSA after adding load on individual buses the proper size of the DG can be identified. This can be demonstrated by using the flowchart.

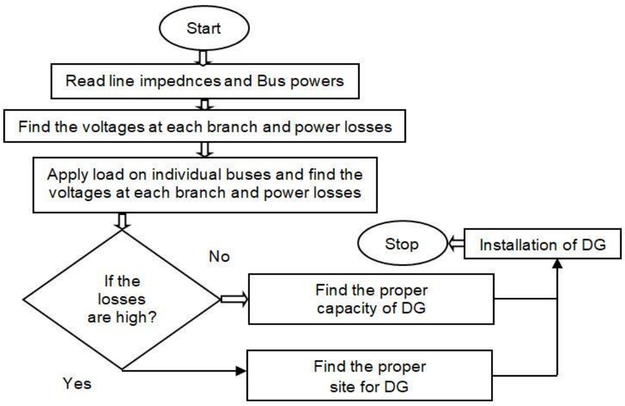

Figure 5. Flowchart for new approach

7. TEST SYSTEM

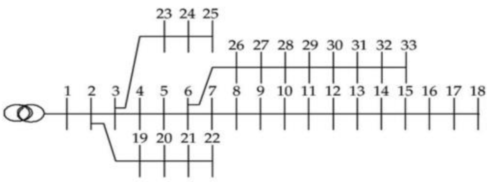

Figure 6. IEEE-33 radial distribution system

8. RESULTS AND DISCUSSION

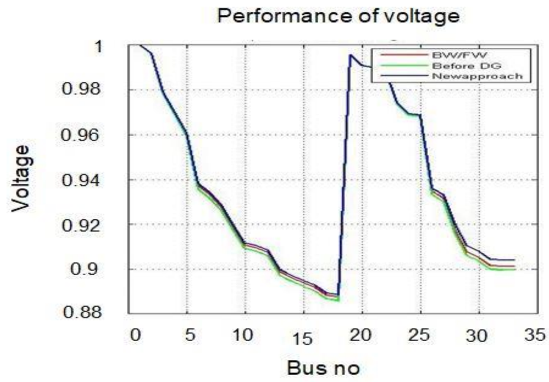

Figure 7. Performance of voltage by new approach after DG connected

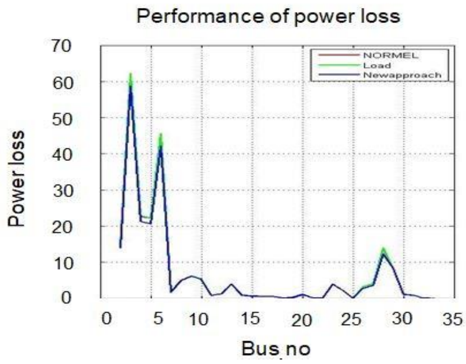

Figure 8. Real power loss variation using new approach

Table 1. Optimal location and capacity of DG using GSA and Proposed method

S. no	GSA power loss (kw)	New approach (After DG) (kw)	With Load power loss (Before DG) (kw)	Without load BW/FW (kw)	DG Connected Bus	DG Value (kw)	Load Added Bus
1	224.97	222.871	232.328	232.328	28	108	1
2	225.78	217.020	232.599	232.328	28	109	2
3	227.62	220.335	234.451	232.328	28	117	3
4	226.07	220.586	233.849	232.328	28	106	4
5	227.17	218.121	234.330	232.328	28	118	5
6	231.59	224.959	240.030	232.328	28	116	6
7	230.88	222.681	237.609	232.328	28	103	7
8	228.47	220.128	235.860	232.328	28	118	8
9	228.60	146.826	236.373	232.328	5	41	9
10	228.60	221.353	235.717	232.328	28	118	10
11	229.68	220.758	236.948	232.328	28	95	11
12	229.17	222.691	237.098	232.328	28	88	12
13	233.70	221.046	241.794	232.328	28	109	13
14	229.25	223.738	237.767	232.328	28	105	14
15	230.14	224.011	237.906	232.328	28	69	15
16	230.06	224.094	238.050	232.328	28	115	16
17	233.66	221.558	241.285	232.328	28	119	17
18	234.88	225.334	241.380	232.328	28	117	18
19	225.11	219.048	232.646	232.328	28	105	19
20	225.57	216.905	232.973	232.328	28	102	20
21	225.46	221.218	233.034	232.328	28	119	21

22	226.46	222.020	233.000	232.328	28	110	22
23	235.19	225.650	241.683	232.328	28	110	23
24	236.16	227.434	243.744	232.328	28	105	24
25	226.37	217.813	233.897	232.328	28	118	25
26	228.49	219.320	235.502	232.328	28	109	26
27	227.81	183.140	235.671	232.328	2	83	27
28	232.86	220.928	240.319	232.328	28	113	28
29	239.21	229.513	247.287	232.328	28	92	29
30	236.15	227.990	243.853	232.328	28	90	30
31	240.66	232.413	248.589	232.328	28	114	31
32	229.26	222.410	237.062	232.328	28	111	32

Table 2. Power loss and VSI using different approaches

Approaches	Power Loss (*kW*)	VSI (p.u)
New approach	146.826	0.5241
GSA approach	228.6094	0.9064

9. OBSERVATIONS

By observing the plots obtained from the new approach, the performance of voltage is improved. The VSI is also improved using new approach. The VSI using GSA is 0.9064 and the VSI with new approach is only 0.0924. The power losses are reduced by introducing DG at bus 5 in the given test system. The real power loss using BW/FW sweep analysis is 232.3284 kW and using GSA is 228.6094 kW before loading and it is 236.3735 kW and finally the real power loss using the new approach is 146.826 kW. By this it is concluded that the real power losses are reduced about 35 % using the new approach.

10. CONCLUSIONS

The objective this paper is to present a new approach to reduce the real power loss, improving VSI and improve the performance of voltage. The new approach is tested on IEEE 33 radial distribution bus and it is worked on MATLAB/Simulink software. Firstly the power flow analysis is performed by using BW/FW sweep approach and finds the value of real power loss and the performance of voltages. Then by using GSA power flow analysis is performed and also finds the value of real power loss and VSI and the performance of voltage are obtained. Finally by performing the new approach the real power loss and VSI and the performance of the voltage is obtained. The comparison of performance of voltage is plotted and the comparison of real power loss is plotted. And the comparison of VSI is tabulated. From the plots and tables it is clear that the new approach is the improved approach than the GSA.

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NOMENCLATURE

Vni	ni bus voltage
Vspecified	Specified Voltage ($1\angle 0^0$ Per Unit)
Pgi	Generator active power output at ith bus
Pdi	Active power demand at ith bus
Vmi	mi bus voltage
Ymni	admittance of branch between mi and
N	ni bus
Ni	total number of buses
Mi	bus number of receiving end
I	bus number of sending end
$P_{ni}(ni)$ $Q_{ni}(ni)$ R_{ni}	branch number
X_{ni}	Total real power fed through bus ni
$SI(ni)$	Total reactive power through bus ni
	ith branch resistance
$V_{\max}$	ith branch reactance
	VSI of ni node
$V_{\min}$	Maximum Voltage
$S^{dg}_{\max}$	Minimum Voltage
	at bus ni maximum apparent power
$S^{dg}_{\min}$	at bus ni minimum apparent power
	Gravitational Force

S_{ni}^{dg}	Gravitational Constant
	Mass of object i
GF	Mass of object j
GC	Distance between objects
Mi	fitness
Mj	high power loss
D	low power loss
fit	dimension
Bad	Intensity of light at d distance
Good	Source Intensity
d	Original IL
IL (d)	
Is	
ILO	

Greek symbols

δ_{mi}	mi bus voltage phase angle
δ_{ni}	ni bus voltage phase angle
θni	angle of admittance of $Y_i = Y_{ni}\angle\theta_{ni}$
η	density factor
β	Absorption coefficient
α_0	attractiveness at d = 0
δ_{mi}	mi bus voltage phase angle

Subscripts

FA	Firefly Algorithm
GSA	Gravitational Search Algorithm
DG	Distributed Generation
FW/BW	Forward and Backward
PV	Photo Voltaic