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Voltage Profile Improvement in Radial Distribution System using Grasshopper Optimization Algorithm

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Abstract- Voltage profile improvement is very important because it will determine the economic operation of the power system. A good voltage profile appreciably results in loss minimization. Reactive power compensation with the help of placement of shunt capacitors using Grasshopper Optimization Algorithm (GOA) in radial distribution systems has been proposed in this work. The proposed methodology not only improves the voltage profile but reduces the system losses and minimizes the system cost which is a function of cost of loss and cost of capacitor placement. The grasshopper move instinctively in exploration and move locally in exploitation. This technique of exploration and exploitation is main searching aspects in Grasshopper Optimization Algorithm (GOA). The proposed method is applied to IEEE 15 bus radial distribution systems.

Keywords- capacitor placement, distribution losses, distribution system, reduction of losses, voltage improvement.

I. INTRODUCTION

An electricity distribution system must have god voltage profile at the consumer's end. Fluctuations in voltage may lead to loss of revenue in terms of power loss and cause permanent equipment failure. A distribution system should therefore ensure that voltage fluctuations at the end of the consumer must be within allowable limits. The stable voltage limit at user's end is +/-5 percent of the rated voltage [1]. The primary cause of the voltage drop into the line is the reactive power transfer by the line. Hence, for the reduction of power losses in distribution system and enhancement of voltage profile, many methods have been suggested by researchers in the past such as feeder reconfiguration, reactive power compensation, optimum distribution transformer location, distributed generation, locating substations near the load canter, balancing the three phases of the load etc [2-10]. In this proposed work, voltage profile improvement is done using reactive power compensation by the use of optimal size of capacitor at suitable bus locations. To find the optimal value of capacitor size, Grasshopper Optimization Algorithm (GOA) has been proposed in this work. Swarming behavior of the grasshopper is used an optimization tool to solve the objective function. Generally, grasshopper has two inviting habits. One is by exploring the food and another is by exploiting the food. The grasshopper move instinctively in exploration and move locally in exploitation. This technique of exploration and exploitation is main searching aspects in Grasshopper Optimization Algorithm (GOA).

II. GRASSHOPPER OPTIMIZATION ALGORITHM

GOA is based on the nature conduct of grasshopper swarms and was created by Seyedali Mirjali [11] to solve issues with optimization. Grasshopper is regarded as a plague as it damages plants. The distinctive element of the grasshopper swarm is that both nymph and adulthood find swarming behavior. Millions of nymph grasshoppers, like rolling cylinders, jump and move. They consume nearly all the vegetation on their route. After this behavior, they form a swarm in the air when they become adults. This is how big distances of grasshoppers migrate. Food source searching is significant feature of grasshoppers swarming. The search method is logically divided into two tendencies by nature-inspired algorithms: exploration and exploitation. In exploration, the search agents are urged to move suddenly, while during exploitation they tend to relocate locally. These two functions, as well as target seeking, are performed by grasshoppers naturally. These two tasks, as well as the search for targets, are obviously carried out by grasshoppers. Therefore, the grasshopper's swarming conduct is sought to address the issues of optimization. Hence, the swarming behavior of the grasshopper is procured to solve the optimization problems. In GOA, grasshoppers change their positions by flying around in a multi-dimensional search space until an objective has been encountered, or until the computational limitations are exploded. The location of the grasshopper with the highest fitness value will be regarded as the closest to the goal as the target position is unknown. Updating grasshopper's place in the social interaction network to balance worldwide and local search will move grasshopper along the goal and converge to the best solution.

III. Mathematical Model of GOA

The swarming behavior of grasshoppers can be written as [11]:

$$X_i^d = C\{\sum_{\substack{j=1 \\ j\neq 1}}^{N} C \frac{ub_d - lb_d}{2} S(|X_j^d - X_i^d|)\frac{X_j - X_i}{d_{ij}}\} + \hat{T}_d$$

Where,

C is a decreasing coefficient to shrink the comfort zone, repulsion zone and attraction zone.

ub_d is the upper bond in the D^{th} dimension.

Lb_d is the lower bond in the D^{th} dimension.

$\hat{T}_d$ is the main goal (best solution).

In order to balance between exploration and exploitation, coefficient C must be reduced as proportional to the amount of progressions of iterations and calculated as follows:

$$C = C_{max} - iter\frac{C_{max} - C_{min}}{iter\_max}$$

Where, C_{max} is the maximum value, C_{min} is the minimum value, *Iter* indicates the current iteration and *iter_max* is the maximum number of iterations. In this work, it is assumed that $C_{max} = 1$ and $C_{min} = 0.0001$

In GOA, the most fit grasshopper is presumed to be the target during optimization. During each iteration, this will help GOA save the most promising destination in the search space and require grasshoppers to move towards it.

IV. PROBLEM FORMULATION

Voltage profile can be improved by using optimal sizing of capacitors at optimum bus locations. There can be many capacitors combinations that can enhance voltage profile. But the best solution is the selection of capacitors for which the cost of the system (i.e sum of cost of losses and costs of capacitors placement) is minimal. Hence, the objective function can be considered as a cost function namely TC (Total Cost) to enhance voltage profile.

i.e. Objective Function F: Minimize (TC)

$$F = TC = K_P P_T, Loss + \sum_{i=1}^{n} K_i{}^c Q_i{}^C + K_f$$

Where, P_T Loss is the system's total power loss, which is the sum of losses from all the line sections of different feeders, K_P is the annual cost per unit of power loss in \$/ (Kw-year), $K_i{}^c$ is the annual cost of capacitor placement in \$/kVAr (it is assumed as 0.500 \$/kVAr), i= 1, 2,3,.... ,n are the indices of the candidate buses selected for compensation , $Q_i{}^C$ is the size of capacitor in kVAr connected to i^{th} bus.

The objective function is subjected to following constraints:

(i) Voltage limit:

$$V_{min,i} \leq V_i \leq V_{max,i}$$

Where, V_i is the voltage magnitude of i^{th} bus , $V_{min,i}$ $V_{max,i}$ are the minimum and maximum voltage limits of i^{th} bus. The voltage magnitude at each bus must be maintained within these limits.

(ii) Bus reactive compensation power:

$$Q_i{}^C \leq \sum_{i=1}^{n} Q_{Li}$$

Where, $Q_i{}^C$ is the reactive power compensated at bus i^{th} , Q_{Li} is the reactive load power at i^{th} bus.

V. IMPLEMENTATON OF GOA

Steps involved in GOA technique are discussed below:

Step1: Initialize population size, max number of iterations, C_{max}, C_{min} number of generators, generator limits, load demand, cost coefficients and emission coefficients.

Step2: Define initial total cost function F using equation

Step3: Randomly generate the initial positions of all the grasshoppers in the search space.

Step4: Evaluate fitness of each grasshopper of current population by using the fitness function while satisfying all the constraints and store the solution corresponding to the best-fit.

Step5: Sort the population from best to worst fitness value.

Step6: Assign the overall best fitness and the corresponding positions.

Step7: Initialize the iteration counter as 1.

Step8: Update the position of search agent by updating the value of C.

Step9: Evaluate fitness value corresponds to updated position while satisfying all the constraints.

Step10: Update overall best fitness value and the correspondingly position of grasshoppers.

Step11: Now check, if number of iteration is less than maximum iteration then go to step7 else terminate the program to find the optimal solution.

VI. TEST SYSTEM AND SIMULATION RESULTS

A 15-bus radial distribution system with main feeder and four lateral feeders is used [12]. The system's nominal line voltage is 11 kV Total power loss of the uncompensated 15-bus system and voltages of all buses are The voltage magnitude limit is taken from 0.95 to 1.01 p.u. Top four buses i.e. 6, 3, 11 and 4 buses are selected for the placement of capacitors using GOA [13]. Simulation results on 15 bus system using GOA is shown in table I. Voltages on 15 bus system before and after compensation is shown in table I.

Table I

Simulation Results of 15-Bus System

Parameters	**Uncompensated**	**Compensated using GOA**	
Optimal Bus No. and size in kVAr	---	Bus No.	Capacitor in kVAr
		6	367.18
		3	150
		11	249.60
		4	380.21
Minimum Voltage at bus 13	0.9445	0.9726	
Total losses (kW)	61.8	30.3	
Annual Cost in $	10,381	5670.3	

Table II

Compensated and Uncompensated Voltages of 15- Bus System

Bus No.	**Uncompensated Voltage**	**Compensated Voltage**
1	1	1
2	0.9713	0.9846
3	0.9567	0.9778
4	0.9509	0.9749
5	0.9499	0.9739
6	0.9582	0.9771
7	0.956	0.975
8	0.957	0.9759
9	0.968	0.9813
10	0.9669	0.9803
11	0.95	0.9739
12	0.9458	0.9698
13	0.9445	0.9726
14	0.9486	0.9726
15	0.9484	0.9725

Results obtained by GOA are compared with Improved Harmony Algorithm (IHA) [14] and are presented in Table III. Table III shows that the results correspond to objective function of annual cost obtained by GOA is less than Improved Harmony Algorithm (IHA) method.

Table III

Comparison of Result Obtained by GOA and IHA for 15-Bus System

Parameters	**Proposed GOA**		**IHA [14]**	
Optimal locations and Size in kVAr	Bus No.	Capacitor in kVAr	Bus No.	Capacitor in kVAr
	6 3 11 4	367.18 150.00 249.61 380.21	6 11 15	350 300 300
Total losses (kW)	30.3		31.8	
Annual Cost in $	5670.3		5995.905	

VII. CONCLUSIONS

The main cause of voltage drop on the line is the transfer of reactive power over the line. Thus, to maintain a good voltage profile, the control of reactive power is necessary. It has been observed that the reactive power compensation by shunt capacitors placement is simplest, cheapest and effective method to improve voltage profile. Grasshopper Optimization Algorithm (GOA) for the optimal sizing of the capacitors is used in the present dissertation. Test case for the proposed method is a 15 bus radial distribution system. Buses 6, 3, 11 and 4 can be selected as the candidate buses. Bus number 13 had the lowest voltage of 0.9445 p.u before compensation and when compensation has been applied using GOA, this voltage has improved to 0.9726. The initial power loss without capacitor placement was seen to be 61.8 kW. But after optimal capacitor placement using GOA the power losses are reduced to 30.3 kW. The uncompensated system's annual power loss cost was $10,381. The total annual cost of power loss and capacitor placement was reduced to $5670.3 after implementation of GOA technique.

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