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A COMBINED APPROACH FOR LOSS REDUCTION AND VOLTAGE PROFILE IMPROVEMENT IN DISTRIBUTION SYSTEMS

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Abstract- In this paper, the active and reactive power losses reduction and voltage profile improvement in distribution system with installation of distributed generations and capacitor banks, have been considered. By installation DGs in distribution systems, different objectives can be pursued. The main objective of this paper is reducing the active and reactive power losses, and also improving the voltage profile. In this paper, the sensitivity analysis is used to optimize the placement of DG. To reduce the search space and more influence on the voltage profile improvement, this method is applied on candidate buses. Also, to optimal sizing of DG, the plant growth simulation algorithm (PGSA) is used. In this paper the capacitor placement method has been used to improving the voltage profile and reducing the power losses. For optimal placement of capacitor banks, the ETAP software is used. To evaluate the effectiveness of the proposed method, this method, tested on the 33-bus IEEE test system and the results are satisfying.

Keyword: Distribution System, Distributed Generation Resources, Loss Reduction, Voltage Profile Improvement, PGS Algorithm, Optimal Capacitor Placement, ETAP Software.

I. INTRODUCTION

Distribution system is the final link between high voltage transmission systems and consumers [1]. The main purpose of an electrical distribution system is responding to demand of all consumers in all positions in the network, so that all relevant factors, including economic indicators, indicators of assurance and quality indicators related to electricity, both for companies and for consumers to be provided. To the high level of current in distribution systems, it causes a voltage drop and power losses. Substantial losses and voltage drops in the distribution system, causing economic losses and usually causes the load terminal voltage is not desirable. The use of distributed generation sources such approach is used to solve this problem in distribution systems. DG is small-scale of electricity production which usually connected to the distribution systems and is closer to the consumers.

Electric Power Research Institute (EPRI) defined distributed generation produces electricity from a few kilowatts to 50 megawatts [2]. Widespread deregulation of electricity markets in most countries represents a new perspective for DG using renewable energy sources with low capacity. Electricity produced from renewable energy can be generated by solar panels and wind turbines or by various other methods. Due to the several features of DG in distribution systems, we have focused on the placement and sizing of them in this paper. Many studies have been conducted to date in this regard.

In [3], for optimal placement of DG on distribution system, due to economic constraints and limitations of stability, a method is presented based on Lagrange. In [4], for optimal placement and sizing of DG in distribution systems, a multi-objective algorithm using GA has been presented. In [5] for finding the optimal placement and sizing of DGs, tabu search algorithm is used. In [9] a method for optimal placement and sizing of DGs, considering the power factor of distributed generation is presented.

A method based on multi-objective function aims to reduce the active and reactive power loss is presented in [10]. In [11] for the optimal placement and sizing of DGs aims to reduce losses, the PSO algorithm is used. For optimal placement and sizing of DG in [12] ACO algorithm is proposed. Installation of distributed generation to reduce losses and improve the voltage profile is presented in [13].

Optimal capacitor placement in distribution networks is one of the most economical and common methods to reduce the losses and improvement of the voltage profile. Optimal placement of capacitor banks is so important and various methods already have been proposed for this problem. The basic theory of optimal capacitor placement is as a 2/3 rule and is presented in [14]. A method with mixed integer programming (MIP) is presented in [15]. Using the modified differential evolution algorithm (DE) is presented in [16]. Tabu search algorithm for optimal capacitor placement is presented in [17], and the combination of fuzzy and genetic algorithms is used in [18].

II. LOSS REDUCTION

Typically, power losses in the distribution systems highly regarded for power utility companies because the losses, reducing the efficiency of energy transfer to the consumer and the economic losses caused by the losses imposed on electricity companies. Various solutions have been proposed for reducing of power losses in the distribution system. Optimal network reconfiguration can be an effective strategy to be considered [19]. One other practical ways to loss reduction is capacitor installation in the system that must be done optimal [20]. As mentioned earlier, one of the important applications of distributed generation resources is loss reduction in the distribution system. In fact the presence of distributed generation sources in the network, have the greatest impact on loss reduction.

III. VOLTAGE PROFILE IMPROVEMENT

Due to the variability of loads in the distribution systems and change it time to time, and also due to the radial structure of power distribution system, most consumers in end of the radial system, has not desired voltage level, while one of the main purposes of distribution systems operators is providing of desirable voltage levels for consumers. This is why requires the use of appropriate strategies to deliver voltage to optimal level. DGs and capacitors installation in the distribution system can help to improve the voltage profile. Voltage variations in the distribution systems must be control in specified range (+7% to -13%) [21]. Distributed generation units with changing load flow patterns in the distribution system, helps to improve the voltage profile. Optimal location and sizing of distributed generation units also has a significant impact on the improving of voltage profile.

IV. DEFINITION OF THE PROBLEM

In this paper, the fundamental problems are power loss reduction and voltage profile improvement using optimal placement and sizing of DGs and compensating capacitor banks that proposed as an optimization problem.

A. The Objective Function

The main objective of the proposed method is minimizing the losses in the distribution system that with determining the size and location of distributed generation in radial distribution system is done. The total active loss of the system is formulated as follows:

$$\min P_{loss} = \min \left(\sum_{i=1}^{n} R_i I_i^2\right) \quad (1)$$

B. Limitations

1. Capacity limitations of power transmission line

$$|P_{ij}^{line}| \le |P_{ij,\max}^{line}| \quad (2)$$

where, P_{ij}^{line} is power crossing of the line and $P_{ij,\max}^{line}$ is maximum power is crossing the line between buses *i* and *j*, respectively.

2. Limitation of bus voltage

$$V_{\min} \le V_i \le V_{\max} \quad (3)$$

where, $V_{\min}$ and $V_{\max}$ are the minimum and maximum acceptable voltage for bus *i*, respectively.

3. Limitation of the active power generated by the DGs

$$P_{DGi}^{\min} \le P_{DGi} \le P_{DGi}^{\max} \quad (4)$$

where, P_{DGi} are active power injected by DG at bus *i*.

4. The power balance constraints

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \quad (5)$$

where, P_{DGi} the power generated by the DG, P_{Di} is connected load to bus *i*, and P_L the total network losses.

V. OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION

In this paper, to obtain the optimal position for DG installation, the sensitivity analysis is used [22].

A. Sensitivity Analysis for DG Placement

The sensitivity analysis is widely used for the placement of DG and placement of capacitors. The sensitivity analysis helps to reduce the number of solution space. In this paper to minimize the search space and make more effect on voltage profile improvement, the candidate buses have been considered. The candidate buses are the buses that have low voltage level and sensitivity analysis, applies on these buses. According to Figure 1, the sensitivity analysis equations for active power, is described as the following.

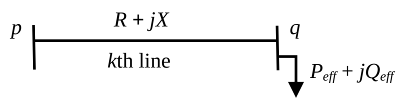

Figure 1. Single line diagrams to formulate the sensitivity analysis

Losses between buses *p* and *q* are as follows.

$$P_{lineloss}[q] = \frac{(P_{eff}^2[q] + Q_{eff}^2[q])R[k]}{(V[q])^2} \quad (6)$$

Sensitivity factors is also calculated by using Equation (7).

$$\frac{\partial P_{line\,loss}}{\partial Q_{eff}} = \frac{\left(2P_{eff}[q]R[K]\right)}{\left(V[q]\right)^2} \quad (7)$$

After calculation, the sensitivity factors in descending classification and buses with high sensitivity considered for installation of distributed generation sources. In this paper the size of distributed generation units, is calculated with plant growth simulation algorithm.

B. Plant Growth Simulation Algorithm (PGSA) for DG Sizing

The PGSA is based on the process of plant growth, in which a trunk grows from the root of the plant; and a number of branches grow from the nodes on the trunk; and then some new branches grow from the nodes on the branches [23].

This procedure continuously repeats itself up to a plant is designed. Inspired by the plant growth process similarity, an optimization process can be described. The first system is optimized to be at the root of a plant grows at the beginning and then keeps growing branch to the optimal solution.

C. Probability Model of Plant Growth

A probability idea has been recognized by analyzing the growth process of plant phototropism [20]. In this simulation, a function $g(Y)$ is obtained to describe the setting of the node Y on a plant. For reaching to a new branch in node Y setting the best option is the smallest value of $g(Y)$. The original designing model is as follows: Firstly, a plant grows a body M from its root B_0. If we assume that there are k nodes from B_{M1} to B_{MK} with better setting than the root B_0 on the body M, sensing that the function $g(Y)$ of the nodes from B_{M1} to B_{MK}, and B_0 satisfy $g(B_{Mi}) < g(B_0)$, (i=1,2,3,..,k), then the morphactin concentrations from C_{M1} to C_{Mk} of the nodes B_{M1} to B_{MK} can be obtained by using the following equation.

$$\begin{aligned} C_{M1} &= \frac{g(B_0)-g(B_{Mi})}{\Delta_1} \quad \left(i=1,2,\ldots,k\right) \\ \Delta_1 &= \sum_{i=1}^{k}\left(g(B_0)-g(B_{Mi})\right) \end{aligned} \tag{8}$$

The importance of Equation (8) is that the morphactin focus of the nodes are relevant to the magnitude of the gap of the environmental functions between the root and the equivalent node in overall nodes. It serves the real relationship between the morphactin concentration and the environment [24, 25].

From equation (8), we get $\sum_{i=1}^{k} C_{Mi} = 1$. It satisfies the morphactin focus, from C_{M1} to C_{MK} of the nodes B_{M1} to B_{MK} system of a state space described in Figure 2.

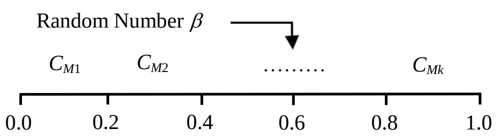

Figure 2. Morphactin concentration state space [24]

If we select a random number β in the interval [0, 1] then β will be as a ball thrown into the interval [0, 1]. Therefore, it will include one of C_{M1} to C_{MK} as in Figure 2. Then in the next step, the priority of growing a new branch will be taken by the relevant node as the preferential growth node. The node B_{M2} will grow a new branch m, if random number β drops into C_{M2} regarding to the condition of $\sum_{i=1}^{1} C_{Mi} < \beta \le \sum_{i=1}^{2} C_{Mi}$.

Suppose that q nodes from B_{m1} to B_{mq} including better environment than the root B_0, on the branch m, and C_{m1} to C_{mq} are their relevant morphactin concentrations. The morphactin concentrations of the nodes on branch m should be calculated. Then the branch m will be grown and after that the branch m on the body M will be recalculated as well as the morphactin concentrations of the nodes except B_{M2} the morphactin concentration of the node B_{M2} becomes zero. Equations (8) and (9) shows the related calculations by adding the related terms of the nodes on branch m and leaving the related terms of the node B_{M2}.

$$\begin{cases} C_{Mj} = \dfrac{g(B_0)-g(B_{Mi})}{\Delta_1} \\ C_{mj} = \dfrac{g(B_0)-g(B_{mj})}{\Delta_1+\Delta_2} \\ \Delta_1 = \sum\limits_{i=1, i\neq 2}^{k} (g(B_0)-g(B_{Mi})) \\ \Delta_2 = \sum\limits_{j=1}^{q} (g(B_0)-g(B_{Mi})) \end{cases} \tag{9}$$

Therefore, a new state space will be formed by morphactin concentrations of the nodes (except B_{M2}) on trunk M and branch m. In the next step, as the similar way as B_{M2}, a new preferential growth node, on a new branch will grow. The mentioned process will be continued until no new branch is satisfied for growing, and after that the plant will be formed.

The $g(Y)$ describes the objective function; the length of the trunk and the branch describe the search domain of possible solutions; the plant root describes the initial solution; the preferential growth node matches to the basic point of the next searching iteration. Therefore, the problem solving of integer programming can be done by the growth process of plant phototropism [24, 25].

The stages of distributed generation placement and sizing are as follows.

Step 1: run load flow and calculation active power losses and selection the candidate buses.

Step 2: Sensitivity analysis is applied to the selected candidate buses.

Step 3: Placing DGs in buses obtained from sensitivity analysis.

Step 4: Sizing of DG using plant growth simulation algorithm.

Step 5: Compare the Real Power losses for every size of DG.

Step 6: Save the DG size corresponding to minimum real power loss.

Step 7: Continue Steps 3 to 6 for 50 iterations with 5 different sizes of DG in every iterations

Step 8: Choose amount of 50 values obtained that has the best reduction of active power losses and stop iteration.

VI. OPTIMAL CAPACITOR PLACEMENT AND SIZING

Capacitor placement in distribution network is one of the most common methods that used in the distribution network to reduce the power losses and improving the voltage profile. Optimal capacitor placement in distribution networks is a complex optimization problem that requires a complex computer program. In this paper we use ETAP software for optimal capacitor placement [26]. ETAP software is powerful software for simulation and analysis of power systems. This software has a graphical environment for power system simulation and has a special feature, for optimal capacitor placement (OCP), along with other capabilities. Optimal Capacitor Placement (OCP) in ETAP software is based on genetic algorithm.

VII. SIMULATION AND RESULTS

The proposed method in this paper, applied on 33-bus IEEE test system. For the simulation, we consider the following scenarios:

I. Base system;

II. Optimal placement and sizing of DGs using sensitivity analysis and PGS algorithm;

III. Optimal capacitor placement in the system with DGs using ETAP software.

A. 33-Bus Test System

This experimental system is a radial 33-bus system and via a transformer is connected to the main network and system voltage is 12.66 KV. The structure of this experimental system is shown in Figure 3. Total active and reactive loads in system respectively are 3715 KW and 2300 KVAR. Information about the 33 bus system is presented in Table 1.

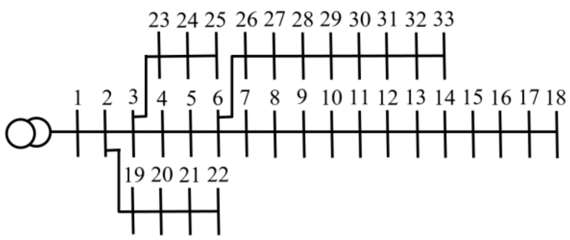

Figure 3. The 33-bus test system

Table 1. The 33-bus test system data

S. bus	R. bus	R, Ω	X, Ω	P, MW	Q, MVAR
1	2	0.0922	0.0477	0.1	0.06
2	3	0.493	0.2511	0.09	0.04
3	4	0.366	0.1864	0.12	0.08
4	5	0.3811	0.1941	0.06	0.03
5	6	0.819	0.707	0.06	0.02
6	7	0.1872	0.6188	0.2	0.1
7	8	1.7114	1.2351	0.2	0.1
8	9	1.03	0.74	0.06	0.02
9	10	1.04	0.74	0.06	0.02
10	11	0.1966	0.065	0.045	0.03
11	12	0.3744	0.1238	0.06	0.035
12	13	1.468	1.155	0.06	0.035
13	14	0.5416	0.7129	0.12	0.08
14	15	0.591	0.526	0.06	0.01
15	16	0.7463	0.545	0.06	0.02
16	17	1.289	1.721	0.06	0.02
17	18	0.732	0.574	0.09	0.04
18	19	0.164	0.1565	0.09	0.04
19	20	1.5042	1.3554	0.09	0.04
20	21	0.4095	0.4784	0.09	0.04
21	22	0.7089	0.9373	0.09	0.04
22	23	0.4512	0.3083	0.09	0.05
23	24	0.898	0.7091	0.42	0.2
24	25	0.896	0.7011	0.42	0.2
25	26	0.203	0.1034	0.06	0.025
26	27	0.2842	0.1447	0.06	0.025
27	28	1.059	0.9337	0.06	0.02
28	29	0.8042	0.7006	0.12	0.07
29	30	0.5074	0.2585	0.2	0.6
30	31	0.9744	0.963	0.15	0.07
31	32	0.3105	0.3619	0.21	0.1
32	33	0.341	0.5302	0.06	0.04

A. Base System (I)

First studied system is base system that is free of DGs and capacitors. The results are presented in Table 2.

Table 2. Result of scenario (I)

Minimum voltage increase percent	Minimum voltage	Loss reduction percent		Loss	
%	p.u.	KVAR	KW	KVAR	KW
0	0.9131	0	0	135	203

B. Optimal Placement and Sizing of DG Using Sensitivity Analysis and PGS Algorithm (II)

In this scenario, using the proposed method, the best position and size of DG units is calculated. Limits the number of units of DG is intended 3 units. Capacity constraints for each unit of DG, is intended 0 to 2 MW. By applying this scenario, the results of position and size of DG, obtained and presented in Table 3. With the installation of distributed generation units in obtained positions and capacities, the results are presented in Table 4. It can be observed that the active and reactive power losses associated with a reduction and minimum voltage is increased.

Table 3. DGs Location and capacity

DG Capacity (KW)	DG Location
181.8	18
573.5	17
983.6	33

Table 4. Result of scenario II

Minimum voltage increase percent	Minimum voltage	Loss reduction percent		Loss	
%	p.u.	KVAR	KW	KVAR	KW
5.5	0.9664	48.15	52.22	70	97

C. Optimal Capacitor Placement in the System with DGs Using ETAP Software (III)

In this scenario, according to proposed method, the optimal capacitor placement operation using ETAP is applied on the network with distributed generation resources. Location and size of DG units and capacitor banks is provided at the Table 5. The capacity of each capacitor bank is 300 KVAR.

Table 5. Location and size of DG units and capacitor banks

Capacitor bank size (KVAR)	Capacitor bank location	DG Capacity (KW)	DG Location
1×300	32	181.8	18
1×300	31	573.5	17
1×300	30	983.6	33
1×300	25	-	-
1×300	10	-	-
1×300	8	-	-

The results of scenario III, is provided in Table 6. Can be seen that active and reactive power losses are considerably reduced and minimum voltage is increased.

Table 6. Results of scenario III

Minimum voltage increase percent	Minimum voltage	Loss reduction percent		Loss	
%	p.u.	KVAR	KW	KVAR	KW
7.12	0.9831	78.52	82.76	29	35

By comparing the results of the above scenarios, it is shown that the active and reactive losses during the first scenario to last scenario, has been accompanied with reduction. Active power loss has reached from 203 KW to 35 KW and 82.76 percent declined. Reactive power loss, has reached from 135 KVAR to 29 KVAR and 78.52 percent declined. Also improvement in minimum voltage been considerable and has increased from 0.9131 to 0.9831. It represents an improvement of voltage profile. The voltage profile improvement curve and loss reduction diagram are presented in Figures 4 and 5, respectively.

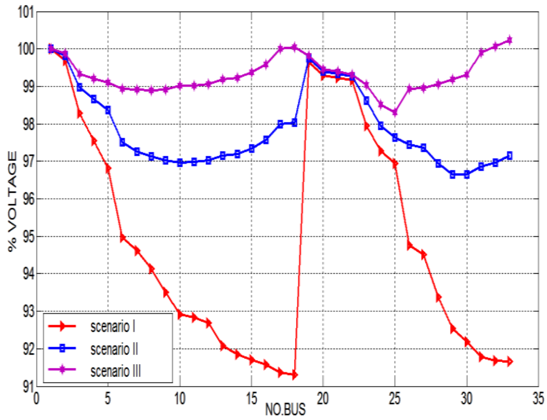

Figure 4. Voltage profile improvement curve

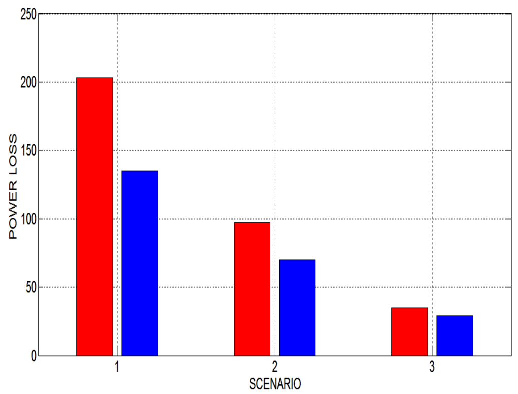

Figure 5. Loss reduction diagram

VIII. CONCLUSION

In this paper, a combined and practical approach for optimal placement and sizing of DG and capacitor banks in the distribution system, in order to reduce the active and reactive power losses and improve the voltage profile, was presented. The sensitivity analyses were used for the optimal placement of distributed generation sources. In which to reduce the search space, and obtain better results, the candidate buses were considered and the sensitivity analysis was applied to the candidate buses and the optimum position for the installation of distributed generation was obtained.

For optimal sizing of distributed generation, the plant growth simulation algorithm (PGSA) was used. As noted above, this algorithm is based on the plant growth process and its probability model is based on plant phototropism property. For optimal capacitor placement ETAP software was used. The proposed combined method was applied on the IEEE 33-bus test system. It was observed that the active and reactive power losses are significantly reduced, and also voltage profile was improved. These satisfactory results show the effectiveness of this method.

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