Distributed Generation unit and Capacitor Placement for Loss, Voltage profile and ATC Optimization

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ABSTRACT

Distributed Generation (DG) and capacitors placement and also the tap setting of ULTC transformers can be used individually to improve the voltage profile and loss reduction. In this article the Genetic Algorithm (GA) is applied to optimize the multi-objective function for of DG and capacitor placement with tap setting of ULTC. The objective function consists the loss reduction, voltage improvement and increasing the available transfer capability (ATC) of the distribution network. To show the effectiveness of the proposed method, it is applied to IEEE 41 bus radial distribution network. The results show that this method has a better effect on improving the objective functions.

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1. INTRODUCTION

DG and capacitor placement are nonlinear optimization problems with many variables and equality and inequality constraints. There are many methods for DG and capacitor placement for different purposes. A distribution network operation can be improved by adding DG and capacitor. Also, they can appropriately be controlled with existing equipments, too. Different papers have shown a lot of fitness functions in distribution control. The previous studies in this field can be categorized into three parts:

a. Capacitor Placement

Historically, improving of the system first initialized with the placement and the appropriate size of capacitor selection. A lot of studies on capacitor placement have been done. The recent works in this case are as follows: In [1], determining the place and the size of capacitor banks in distorted distribution systems is discussed and genetically optimized fuzzy is used for optimization. The fitness function is referred to reduce loss, optimize power and capacitors placement's cost, considering load voltage constrains and THD. Capacitor placement and reconfiguration for loss reduction of distribution networks are used in [2] by an ant colony search algorithm. Also a heuristic constructive algorithm for capacitor placement in distribution systems is applied in [3].

b. DG Placement

In recent decades different kinds of DGs have been made and different methods have been introduced for DG placement. In [4] a method for placement of a single DG on the distribution network has been proposed. This method is based on the determination of most sensitive buses with voltage collapse. The analysis was done to reduce losses and improve the voltage profile. ATC also has risen. In [5] a multi-objective optimization method for DG placement has been associated. One of the main factors in that paper is network loss. A heuristic DG optimization method for distribution network is proposed in [6] and the search space is reduced significantly. In [7] a method to select the load buses for the DG placement based on loss reduction and voltage improvement sensitivity of the system have been presented. An analytical approach for optimal placement of distributed generation sources in power systems are aimed to reduce loss by analytical methods in [8].

c. Simultaneous DG and Capacitor Placement

Nowadays different kinds of DGs and capacitors are simultaneously used in a lot of distribution networks. In [9] placement of DG and capacitors to reduce losses and improve the voltage profile using GA has been studied. In [10] two optimization models are proposed to improve the voltage profile. First, the DG placement problem is formulated. Then the capacitor placement problem is modeled and solved.

In this paper one GA is applied to the multi-objective fitness function includes: loss reduction, load voltage profiles optimization and ATC maximization. The objective of DG and capacitor placement is to determine the place and size of DG and capacitor. DG and capacitor are placed and the tap of ULTC transformer is set, so the system loss reduced, load voltage profiles optimized and ATC increased. There are some constraints on the voltage magnitude at each bus and passing apparent power through at each line. It should be mentioned that, other articles less attention have been paid to DG and capacitor placement with tap settings of ULTC simultaneously. In other articles tap of ULTC is usually assumed one and didn't attend to set adapting tap. The IEEE 41 bus radial distribution network is used to illustrate the effectiveness and feasibility of the proposed method. Simulation results show that system control, determining the location and size of DG and capacitor and the tap setting of ULTC transformer simultaneously, give more favorable results. The results show that the voltages in all buses remained within the desired range, loss reduced and ATC increased.

2. RESEARCH METHOD

The problem, which is formulated through a multi-objective mathematical model with three objectives, is as follows:

2.1 Determining the fitness function to decrease line loss

In the power distribution network, loss depends on two factors: line resistance and line current. Variations of the line resistance are low and negligible. Overall line loss is related to the current and the line current depends on system topology and loads, usually impossible to reduce the value of the load, but line currents can be reduced with DG and capacitor placement. Therefore with optimal DG and capacitor placement, line loss can be decreased.

Power flow and loss can be formulated as:

$$P_i = V_i \sum_{j=1}^{n} Y_{ij} V_j \cos(\delta_i - \delta_j - \gamma_{ij}) \qquad (1)$$

$$Q_i = V_i \sum_{j=1}^{n} Y_{ij} V_j \sin(\delta_i - \delta_j - \gamma_{ij}) \qquad (2)$$

Where, P_i and Q_i are active and reactive power of the i'th bus respectively, V_i is the i'th bus voltage, Y_i is the system admittance matrix element, δ is the bus voltage angle, and γ is the angle of the system admittance matrix element. The first objective fitness function (f_1) is defined as:

$$f_1 = P_{loss} = \sum_{i=1}^{n} P_{G_i} - \sum_{i=1}^{n} P_{D_i} \qquad (3)$$

This fitness function shows the total line loss in the entire system (P_{loss}). P_{Gi} is the injected active power from power system to distribution network or i'th bus generated power by i'th DG. P_{Di} represents the total connected load.

2.2 Determining the fitness function to improve load bus voltages

Voltage constraint of load buses is shown as:

$$V_i^{min} \le V_i \le V_i^{max} \qquad i \in N_b \qquad (4)$$

N_b stands for the total number of all the buses. V_i , V_i^{min} and V_i^{max} are i'th bus voltage magnitude, lower and upper boundaries of voltage magnitude of i'th bus respectively. Second fitness function is the voltage magnitude at load buses that is shown as (5). This fitness function must be decreased.

$$f_2 = \sum_{i=1}^{N_b} (V_i - V_n)^2 \quad (5)$$

V_n is the nominal voltage value which is considered to be one p.u. for all the buses in this article.

2.3 Determining the fitness function to increase ATC

ATC is one of the important factors in DG and capacitor placement in distribution network. The capability of transmission lines is limited by ATC in the distribution network. DG and capacitor placement are appropriately increased ATC, because they are injected active and reactive power in the distribution network. The third fitness funtion (f3) is used to increase the available transfer capability that is defined as (6)

$$\mathrm{f}_3 = \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{S}_{\mathrm{base}} - \mathrm{S}_{\mathrm{i-j}}) \quad (6)$$

$$S_{i-j} = \sqrt{P_{i-j}^2 + Q_{i-j}^2} \quad (7)$$

$$S_{base} = S_{1-2} = 6.9860\ MVA \quad (8)$$

S_{i-j} and S_{base} are described as (7) and (8). S_{i-j} is the value of apparent power flow of i'th bus to j'th bus. S_{base} is the Total Transfer Capability (TTC). S_{base} value is considered to be 6.9860 MVA, which is achieved from simulation the IEEE 41 bus system without any DG or capacitor, for all of lines, when the system doesn't have any DG and capacitor. Maximum S_{i-j} is S_{1-2} and equal to 6.9860 MVA. Bus one is a substation bus. P_{i-j} and Q_{i-j} are the value of active and reactive power flow of i'th bus to j'th bus.

***2.4* Multi-objective fitness function**

GAs can make possible simultaneous convergence to more than one optimum in a multimodal search. It is possible to adapt the genetic algorithm for determination of the global or near global optimum solution [11]. In this article GA is applied for DG and capacitor placement and determining active and reactive power value of DG, value of capacitor and regulation of tap settings of ULTC too. DG and capacitor are placed and the tap of ULTC transformer is set by GA, so that the multi-objective fitness function can be improved. It is described as:

$$F = f_1 + f_2 - f_3 \quad (9)$$

Where, F, f_1, f_2 and f_3 are multi-objective fitness function, loss reduction, load voltage profiles optimization and ATC maximization, respectively.

f_1 and f_2 must be minimized but f_3 must be maximized.

3. RESULTS AND ANALYSIS

The proposed method is applied to the IEEE 41 bus radial distribution network. The structure of the system is shown in Fig. 1. Bus one is a substation bus and distribution network has one ULTC transformer at the first bus. This network has 41 load buses and 40 transmission lines. Total active and reactive loads are 4.635 MW and 3.250 MVar, respectively. The parameters of the network are given in the appendix A.

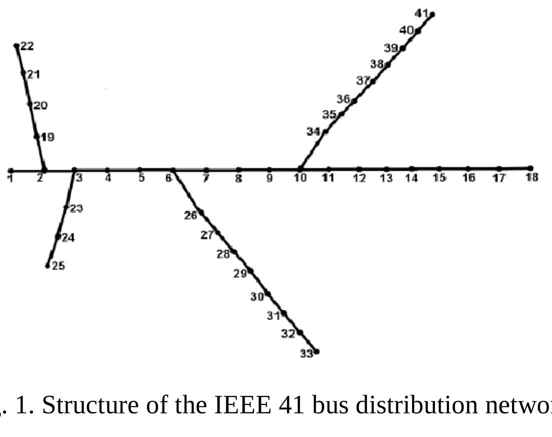

Fig. 1. Structure of the IEEE 41 bus distribution network

In this paper one DG and four capacitors are assumed to add in the network. DG and capacitor characteristics are given in the Table 1. ULTC characteristics are given in the Table 2.

At first stage, load flow was performed on the IEEE 41 bus distribution network. The voltage conversion ratio of the ULTC was set to one in this simulation. Power consumptions in distribution network are supplied only by the power system. At this stage the distribution Network have not any DG and capacitor. Numerical values of three fitness functions are shown in Table 3.

Table 1. DG and Capacitor Characteristics

	Number	Max. Active Power (MW)	Max. Reactive Power (MVar)
DG	1	4.0	2.0
Capacitor	4	-	0.4

Table 2. ULTC characteristics

	Tap Numbers	Min. (V_i /V_o)	Max. (V_i /V_o)
ULTC	6	1.00	1.05

Table 3. Numerical values of three fitness functions without DG and capacitor

variable	value
f_1	1.0075
f_2	1.8238
f_3	228.7923
$S_{1\text{-}2\ MVA}$	6.9860
$V_{trans\text{-}pu}$	1.00

In Table 3, the network seems to have relatively high losses. Load bus voltages aren't desirable. Also relatively a high power passes through the first lines of the network. Therefore active and reactive power generators are needed to improve network.

At second, third and fourth stages load flow was run again adding a DG and four capacitors in the network. The GA attempts to minimize the values of f_1 (available in equ 3) and f_2 (available in equ 5) and maximize the value of f_3 (available in equ 6). In the second stage, although this fitness function is reduced loss, but the effort has not been done to improve both the bus voltage profile and increasing the ATC. Also at third and fourth stages, each step is only considered as a fitness function; voltage profiles or ATC. The results are shown in Tables 4 up to 6.

Table 4. Numerical values of three fitness functions with loss reduction function

F = f1	
F	0.1114
f_1	0.1114
f_2	0.0575
f_3	259.9215
$S_{1\text{-}2\ MVA}$	2.386
$V_{trans\text{-}pu}$	1.05
$P_{DG\ MW}$	2.4
$Q_{DG\ Mvar}$	1.3
DG_{Place}	10
$C_{1\ Place}$	27
$C_{2\ Place}$	29
$C_{3\ Place}$	31
$C_{4\ Place}$	38

Table 5. Numerical values of three fitness functions with improving voltage profiles function

F = f2	
F	0.0057
f_1	0.1678
f_2	0.0057
f_3	258.4299
$S_{1\text{-}2\ MVA}$	1.556
$V_{trans\text{-}pu}$	1.01
$P_{DG\ MW}$	3.4
$Q_{DG\ Mvar}$	1.1
DG_{Place}	9
$C_{1\ Place}$	30
$C_{2\ Place}$	32
$C_{3\ Place}$	33
$C_{4\ Place}$	41

Table 6. Numerical values of three fitness functions with increasing ATC function

F = f3	
F	261.4437
f_1	0.1335
f_2	0.0152
f_3	261.4437
$S_{1\text{-}2\ MVA}$	1.870
$V_{trans\text{-}pu}$	1.03
$P_{DG\ MW}$	3.1
$Q_{DG\ Mvar}$	0.9
DG_{Place}	9
$C_{1\ Place}$	30
$C_{2\ Place}$	31
$C_{3\ Place}$	38
$C_{4\ Place}$	39

Main fitness functions of each stage are highlighted with gray color in tables. Comparing Tables IV and V, it is clear that in Table IV, losses are lower but bus voltage profiles are undesirable. Conversely, in Table V losses are higher and bus voltage profiles are more favorable. Adding DG and capacitors and comparing Table VI with two previous tables, it can be seen that ATC is improved, with any fitness function selection. Comparison of the apparent power flow between bus 1 and 2 ($S_{1\text{-}2}$) in all tables with Table III shows that line current in the distribution network with DG and capacitor significantly reduced. With only the ATC fitness function, the ATC considerably is improved, but losses are still considerable and the bus voltage profiles are more unfavorable. According to the mentioned results, using a mono-objective function cannot improve the network status.

In the next stage, the relative improvement fitness function is described for all three previous functions. The multi-objective function presented in (9) is used. In Tables IV, V and VI minimum f_1 and f_2 and maximum f_3 are highlighted with gray color. Following equations represented minimization and maximization results:

$$Min(f_1) = 0.1114 \quad (10)$$
$$Min(f_2) = 0.0057 \quad (11)$$
$$Max(f_3) = 261.4437 \quad (12)$$

Considering the optimized numerical values, the differences between three mono-objective function values (equations 10 - 12) are considerable. Therefore per unit system is required. Equations (13 - 15) have shown base values of each function.

$$f_{1\text{-}base} = 0.1114 \quad (13)$$
$$f_{2\text{-}base} = 0.0057 \quad (14)$$
$$f_{3\text{-}base} = 261.4437 \quad (15)$$

Thus a multi-objective function using a combination of three mono-objective functions is made. Placement results by using this fitness function are presented in Table 7. Table 8 shows the normalized values of Table VII. By comparing the gray area of Table 4up to Table 8, it can be shown that using the multi-objective function, each of the three functions is improved to acceptable values. In the other word, using an intelligent optimization algorithm with a multi-objective function, it is possible to improve the overall network status. Fig. 2 shows the results of bus voltage magnitudes using the proposed method. It shows that, voltage magnitudes in all the buses are favorable.

Table 7. Per unit values of three fitness functions with multi-objective function

$F_{pu} = f_{1pu} + f_{2pu} - f_{3pu}$	
F	1.2932 p.u.
f_1	1.2184 p.u.
f_2	1.0675 p.u.
f_3	0.9927 p.u.
$S_{1\text{-}2\ MVA}$	2.468
$V_{trans\text{-}pu}$	1.02
$P_{DG\ MW}$	2.4
$Q_{DG\ MVar}$	1.0
DG_{Place}	10
$C_{1\ Place}$	30
$C_{2\ Place}$	31
$C_{3\ Place}$	33
$C_{4\ Place}$	40

Table 8. Normalize values of three fitness functions with multi-objective function

	p.u.	normal
f_1	1.2184	0.1357
f_2	1.0675	0.0061
f_3	0.9927	259.5351

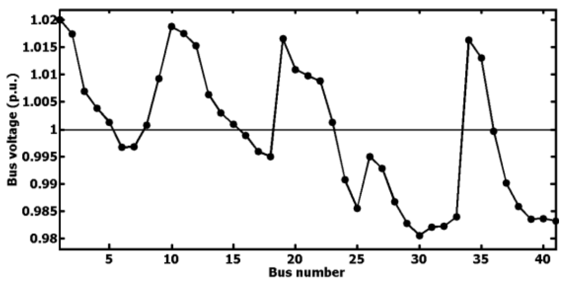

Fig. 2. Bus voltage magnitudes using the proposed method

4. CONCLUSION

In this paper, an improved GA based method for proper placement of a DG and capacitors and the tap setting of ULTC transformers are proposed. The proposed algorithm is based on a new multi-objective function, which is matched with three mono-objective functions to reduce losses, improve the bus voltage profiles and to increase ATC. A multi-objective function of several p.u. Objects are created. To verify the proposed method, simulations have been used based on the IEEE 41 bus distribution network. The capability of this method is well shown by the results. The simulation results using multi-objective fitness function has validated the effectiveness of the proposed approach.

APPENDIX

A. Parameters of the IEEE 41-bus distribution systems

Table 9.Parameters of the IEEE 41 bus radial distribution network

Line Index	To Bus Index	From Bus Index	R(ohm)	X(ohm)	bus load P(KW)	bus load Q(KVar)
1	1	2	0.0992	0.0470	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5470	90	40
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40
33	10	34	0.2030	0.1034	60	25
34	34	35	0.2842	0.1447	60	25
35	35	36	1.0590	0.9337	60	20
36	36	37	0.8042	0.7006	120	70
37	37	38	0.5075	0.2585	200	600
38	38	39	0.9744	0.9630	150	70
39	39	40	0.3105	0.3619	210	100
40	40	41	0.3410	0.5302	60	40

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