The Optimal Placement of Capacitor in Order to Reduce Losses and the Profile of Distribution Network Voltage with GA, SA

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Abstract—Most of the losses in a power system relate to the distribution sector which always has been considered. From the important factors which contribute to increase losses in the distribution system is the existence of radioactive flows. The most common way to compensate the radioactive power in the system is the power to use parallel capacitors. In addition to reducing the losses, the advantages of capacitor placement are the reduction of the losses in the release peak of network capacity and improving the voltage profile. The point which should be considered in capacitor placement is the optimal placement and specification of the amount of the capacitor in order to maximize the advantages of capacitor placement.

In this paper, a new technique has been offered for the placement and the specification of the amount of the constant capacitors in the radius distribution network on the basis of Genetic Algorithm (GA). The existing optimal methods for capacitor placement are mostly including those which reduce the losses and voltage profile simultaneously. But the retaliation cost and load changes have not been considered as influential UN the target function .In this article, a holistic approach has been considered for the optimal response to this problem which includes all the parameters in the distribution network: The price of the phase voltage and load changes. So, a vast inquiry is required for all the possible responses. So, in this article, we use Genetic Algorithm (GA) as the most powerful method for optimal inquiry.

Keywords—Genetic Algorithm (GA), capacitor placement, voltage profile, network losses, Simulating Annealing (SA), distribution network.

I. INTRODUCTION

THE researches show that about 13% of the power produced in the system wastes as ohmic losses [1]. The reactive flows dedicate a percentage of these losses to themselves and by increasing the reactive flow of the loads, the losses of the system will increase as well. The appropriate placement of capacitors and the peak consumption losses could release the capacity of the equipments installed in the system and recover voltage profile.

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The capacitor placement methods are classified to 4 major groups: analytic, programming, numerical, innovative and artificial intelligence [2]. The most useful method is the analytic method. This method supposes that the feeder hasn't any sub branches. Its cross-section is the same in all parts and has been distributed equally in the feeder [3]. The analytic methods need a few numerical data from the distributive system and their application is very easy in practice. So, in spite of the existing unreal hypotheses in them, some of the regional electricity companies have established the basis of their capacitor placement programs on this law [4], or some of the capacitor manufacturing factories, recommend this law in the manual of their manufactured products [5]. The most popular result of the abovementioned method is (2/3) law. According to this law, in order to come up with the maximum reduction, a capacitor with (2/3) drag reactive power from the beginning of the feeder must be installed in a place which its distance is (2/3) feeder length in comparison to the beginning of the feeder. The simplifying hypotheses in the abovementioned method certainly cause errors in obtaining the best results. Index [6] shows that how the application of law (2/3) could be resulted into the increase of losses. In this paper, a general approach has been considered in order to come up with an optimal answer for this problem which includes all the parameters of the distribution network: The price voltage capacitor and load changes. So, a vast inquire into all the possible answers is needed. So, in this paper, a Genetic Algorithm has been used as the most powerful method for optimal inquiry.

II. LOAD MODEL AND CONFUMPTION PATTERN

In the distribution network, there are all kinds of subscribers with different consumption patterns that are divided into different load classes: Although, in practice, the load changes curve is consistent, but since the load distribution calculations are not possible for the consistent load changes, the load changes are approximated by a number of levels.

III. THE OBJECTIVE CAPACITOR PLACEMENT FUNCTION

The issue of capacitor placement is to determine the location, number & the sizes of the capacitors in a radius distribution network. The aim is to reduce energy losses and

World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:5, No:2, 2011

peak network losses, considering that the cost of the capacitor will be reduced to its minimum. In order to calculate energy losses in the network, the load changes in the network are applied for a "T" time period. It is supposed that there is N load level and M is the selection point to place the capacitor in the existing network. The aim is to minimize the energy losses, peak losses and the capacitor's cost.

The cost function = The cost of energy losses + The cost of constant capacitors

Usually, all abovementioned costs are calculated in a yearlong period according to the capital return rate, the longevity of the power plant and network equipments.

A. The Energy Loss Cost

In order to calculate the cost of energy losses in the network, the total energy loss in different load levels is calculated during the period which is under study and is usually one year. In the equation (1), the method of calculating the energy loss has been offered.

$$P_{Eloss} = \sum_{i1}^{n} P_i T_i \qquad (1)$$

n = The number of the load levels in the period which is under study.

P_i = The losses in the ith load level (KW)

T_i = The time period of the ith load level by (hour)

The cost of energy losses is calculated according to equation (2) and the cost of each kilowatt hour energy (K_e).

$$\text{The cost of energy losses} = K_e . P_{Eloss} \qquad (2)$$

B. Production cost on peak

Establishing the power plants in a power system is usually enough to meet the power which is demanded by the subscribers in the peak time. Usually, the cost of power plants establishment is calculated according to the cost of establishing each kilowatt for the power plant and the longevity of the power plant. For example, if the establishment cost of each kilowatt of A_1 power plant is the currency and the longevity of the power plant is (n_1) year and the capital return rate is "B" percent, the annual production cost in the peak for each produced kilowatt is calculated according to the equation (3).

$$K_p = A_1 \frac{(1+B)^{n_1} \times B}{(1+B)^{n_1} - 1} \qquad (3)$$

So, the production cost is calculated by determining the annual peak (P$_0$).

The annual production cost in peak = $K_0 \times P_0$ \qquad (4)

C. The equipment and network linescost

The equipment and network lines have one kilovolt limit of nominal ampere.

By increasing the number of subscribers and the consumption of the working point, the equipment and network lines will come closer to their nominal limits and in practice, the need for establishing new lines and increasing the capacity will become apparent. By compensating the reactive power, the kilovolt amount of the ampere which crosses the network will be reduced and the working point will be detached from the nominal limits of the equipment, and so establishing the new lines will be hindered. In order to calculate the cost of each kilovolt ampere, the longevity of the equipment as well as the network lines must be considered. For example, if the establishment cost of each kilovolt ampere of the network equipment is A_2, the currency & the longevity of equipment and n_2 and the year and cost of the capital return are B percent.

The annual cost of each kilovolt ampere of the equipment is calculated according to the equation (5).

$$K_R = A_2 \frac{(1+B)^{n_2} \times B}{(1+B)^{n_2} - 1} \qquad (5)$$

According to the equation (5), if the kilovolt consumed ampere in peak load is S_{peak}, the annual cost for each kilovolt ampere of the lines and equipment is calculated by equation (6):

The annual cost of the equipment and lines = $K_R \times S_{peak}$ \qquad (6)

D. The cost of constant capacitors

The total cost of each capacitor applied in the network has been consisted of parts: One of the costly parts is a cost which is consumed for each kilovar of the capacitor, and according to this price and the amount of kilovar, the capacitor bank of the total consumed kilovar is calculated.

The costly part is another cost which must be consumed before the capacitor placement on some cases like establishing the constituents like: laying the foundation, establishing platforms for capacitors, replacing the foundations and etc.

This part of cost has been considered as the constant costs. Totally, if the capacitor network has been placed in the location (M) of the capacitor network, the total cost for all capacitors is calculated according to the equation (7).

$$C_{fix-Total} = K_C \sum_{j=1}^{M} C_j \qquad (7)$$

In which, K_c = the capacitor placement cost. According to the aforementioned notes, the capacitor placement function (target function), is expressed mathematically by equation (8):

$$K_e \sum_{i=1}^{n} P_i . T_i + K_p P_0 + K_R S_{PEAK} + K \sum_{J=1}^{M} C_J \qquad (8)$$

World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:5, No:2, 2011

So, in order to come up with the best result, the capacitor placement for a network must be the cost function in its minimum amount. In addition to this answer which minimizes the target function, it must also satisfy some limits of this issue. In the following parts of this paper, some limits of the capacitor placement have been offered.

E. The limits of this issue:

1) The convergences condition of load distribution:

The first condition which must be observed in each capacitor placement mode is the convergency condition of load distribution.

2) Voltage condition:

In order to observe the quality of the power delivering to the subscribers, the voltage of each node in the distribution network must be located in a minimum and maximum limit of the permitted voltage. (usually between the minimum 96% of nominal amount and a minimum of 1/02 nominal amount).

$$\forall\ i \in n \qquad V_{min} \leq V_i \leq V_{max}$$

V_i = Voltage in the ith node

V_{max} = The maximum permitted voltage

V_{min} = The minimum permitted voltage

n = The total nodes of the network

3) The flow condition:

In the distribution network, the conductives are used which have cross-sections and the limit of the flow which crosses through them is different. So, in each capacitor placement modes, it should be investigated that in each mode of the capacity placement, the flow of each branch does not go beyond its permitted limit.

$$\forall k \in b \qquad I_k \leq I_{k_{MAX}}$$

I_k = The flow in the Kth branch

$I_{k\,max}$ = The maximum permitted flow in the Kth branch

b = The collection of network branches

4) The maximum compensation limit in the network:

There is a possibility that the number of the existing banks for installation is limited in the network, so the optimal amount for the cost function must be determined so that the compensation in that mode does not go beyond the maximum amount.The maximum compensation limit could be useful in the faster convergence to the optimal response.

$$\sum_{i=1}^{M} Q_i \leq Q_{max}$$

M = The number of selection nodes for compensation

Q_i =The compensation amount in i^{th} node

Q_{max} = The maximum compensation in the network

F. The selection points for capacitor placement:

Before the capacitor placement and finding its amount, the capacitor placement point must be specified.The more the number of the selection points is, the larger space is dedicated to the Genetic Algorithm research to find the optimal andwer and the possibility to reach the optimal point will be less.

G. Genetic Algorithm

According to the nature of the Genetic Algorithm which is a suitable method to obtain the optimal point of the complex and multivariable functions, this method could be started from different points in the research space and come closer to the optimal point by a trend on which the basis of Genetic Algorithm methods is established, considering that the Algorithm starts from various points and also these points are not the same in each performance. So, if the Algorithm doesn't come up with the final result, it will be specified in the various performance times, So, when the specified trend for the evaluation course of the Genetic Algorithm is correct, the Algorithm could reach the absolute optimal point; otherwise, it will be trapped into the local point and couldn't continue moving. There are different structures for Genetic Algorithm which is defined according to the conditions of the issue, type of encoding, selection and production are the important issues in the Algorithm and if there isn't any agreement between them, a good response could not be obtained.

H. Simulated Annealing Algorithm

The idea for this algorithm has been driven from the Simulated Annealing to it is stronger.

The method is that in each iterations Algorithm creates a neighboring mode like (S) and according to one possibility, the issue turns from the "S" mode or remains in the same "S" mode. This trend continues so that we reach a rather optimal response or has done the maximum number of iterations (e, e', T) function determines the acceptance possibility of the neighboring mode. "e" is the optimal existing mode and (e') is the optimal neighboring mode. If the neighboring mode is worse than the existing mode, we select "T" parameter so that the maximum neighboring modes are acceptable. "T" parameter indicates the temperature and the amount of this parameter decreases gradually.We select the amount of "T" parameter so that before the maximum iteration times, its amount almost becomes zero. In this method, even if the optimal neighboring response is worse than the existing mode, the existence of "T" parameter will also lead to the probable acception of this mode. Accepting the undesirable will be resulted in the successful passing of this Algorithm through the local optimum.In order to reduce the temperature, we multiply "T" in a similar coefficient (r) which has an amount between o and 1. The fast reduction of the temperature will lead to come across the optimal problem. So, we always select the amount of this parameter about 1.

World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:5, No:2, 2011

IV. SIMULATING AND THE SAMPLE NETWORK

The proposed Algorithm for the optimal placement of the capacitor and determining its optimal amount in a sample system and IEEE 34 bus network has been simulated and the network information exist in index [5]. The curve of the bus load is divided into three time periods and in each period, according to the load coefficient and the bus nominal load, the load amount is determined. The capacitor cost, energy wastes and peak have been mentioned in table (1). By this analysis, the sensitive buses of the network were introduced and after executing of the Genetic Algorithm, the capacitor amount of these buses was specified. The results of the sensitivity analysis and Genetic Algorithm have been shown in table (2). By the analysis of load distribution and calculation of the line losses, after placement of capacitors and their amounts in the related buses, the amount of network losses was calculated in this state.

TABLE I PRICES

5.5	The annual price of capacitor
120	The production price of active power in the peak
0.07	The energy cost

TABLE II THE RESULTS OBTAINED OF EACH LOAD LEVEL BY GENETIC ALGORITHM

the level of the third load	the level of the second load	the level of the first load	
25—0.312 19—0.061 9—0.24 20—0.071 10—0.045	25—0.375 18—0.091 9---0.166 19—0.379 20—0.061	25—3.026 20—2.356 17—0.785 9—1.525 18—0.839	Selection points and the capacitors amounts
0.731	1.074	8.532	The sum of capacitor placement
770	900	423	Voltage losses befor capacitor placement(mwh)
208180	217230	451340	The cost of energy losses befor capacitor placement($/Mwh)
612	683	474	Energy losses after capacitor placement(Mwh)
19719	202130	187550	The cost of energy losses after capacitor placement($/year)
9025	10910	51929	The cost of capacitor placement($/Mvar/year)
1964	4190	211870	The resulted profit($/year)

The analysis of the results:

A. The first load level:

After executing the program and selecting 25, 20, 17, 9 and 18 buses as the most sensitive buses of the network, then by Genetic Algorithm, the amount of capacitors was obtained as 3.026, 2.35, 0.78, 1.52 and 0.83 Megavar alternatively. The important point is the considerable reduction of the energy losses which has been mentioned in table [2]. Also by a cost of less than 51929$ for the annual capacitor placement, the company will receive about 211870$ profit. Another important point is the great recovery of the buses voltage in the level of the first load which has been obtialed in the buses. This voltage recovery has been shown in fig. 1, before and after the recovery. But we see that, yet, some buses haven't been located in the permitted limit of voltage which could have various reasons such as the unbalanced network.
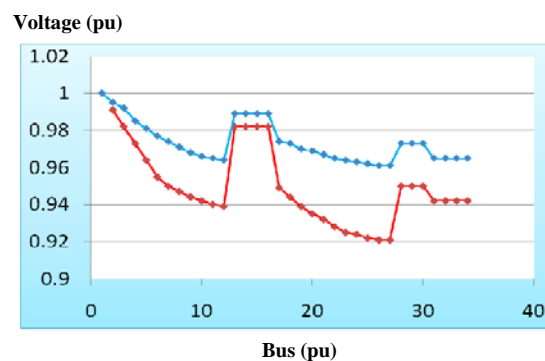
Voltage (pu)

Bus (pu)

Fig. 1 The voltage amounts in the level of the first load befor capacitor placement (red points) and after capacitpr placement (blue points)

B. The second load level:

In this state, after sensitivity analysis, 25, 18, 9, 19 and 20 buses were selected as the most sensitive buses. After executing the Genetic Algorithm, the optimal amounts of the capacitors were calculated as 0.375, 0.091, 0.166, 0.379 and 0.061 alternatively. By performing the analysis of load distribution and calculating the network losses and bus voltage, the annual profit was calculated about 4190$. Improving the voltage amounts in the level of the second load was specified before capacitor placement and after that in fig. 2. Because of the different consumption pattern, the resulted profit in this level is less than the first level.
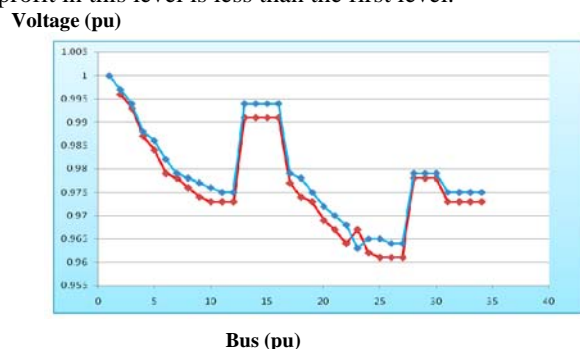
Voltage (pu)

Bus (pu)

Fig. 2 The voltage amounts in the level of the second load befor capacitor placement (red points) and after capacitpr placement (blue points)

World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:5, No:2, 2011

C. The level of the third load:

Also in this state, 25, 19, 9, 20 and 10 buses have been selected by amounts which are alternatively, 0.312, 0.061, 0.24, 0.071 and 0.045. The voltage amounts in the level of the third load before and after capacitor placements are not very different from the second load level and it id shown in fig. 3.

Voltage (pu)

Bus (pu)

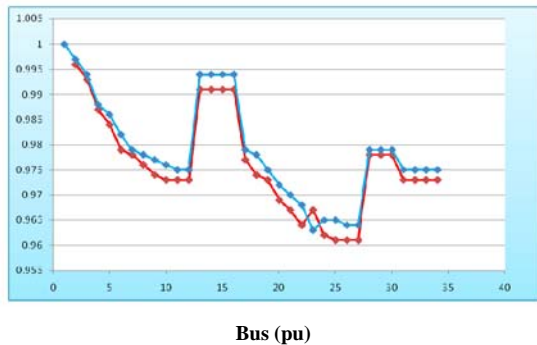Fig. 3 The voltage amounts in the level of the third load befor capacitor placement (red points) and after capacitpr placement (blue points)

TABLE III THE RESULTS OBTAINED BY SIMULATING ANNEALING AFTER SOME ITERRATIONS

Capacitor amount in bus25 (MVAR)	Capacitor amount in bus19 (MVAR)	Capacitor amount in bus9 (MVAR)	Capacitor amount in bus20 (MVAR)	Capacitor amount in bus10 (MVAR)
iterations=10				
0.3000	0.0926	0.0926	0.1076	0.0406
iterations=20				
0.3000	0.0926	0.0926	0.1076	0.0406
iterations=50				
0.3000	0.0926	0.0926	0.1076	0.0406

TABLE IV THE RESULTS OBTAINED BY SIMULATING ANNEALING

The level of the third load	The level of the second load	The level of the first load	The resulted profit ($/year)
1871	4097	211777	

By comparing the obtained results with two Algorithms using in this paper for the 34 buses test network, the capacitor amounts obtained by SA after some iterations have been shown in the table (3). It is clear that the optimization by Genetic Algorithm is more accurate & economical and also is done in a shorter time. That we can see in the table (2), (4). Also we used the Genetic Algorithm Responses as the first guess for the Simulated Annealling Algorithm. So, in the Simulated Annealling Algorithm, we must know the response scope from the beginning and it is a disadvantage.

The capacitor amounts obtained by GA after some iteration have been shown in the table (5).

TABLE V THE RESULTS OBTAINED BY THE GENETIC ALGORITHM AFTER SOME ITERATION

Capacitor amount in bus25 (MVAR)	Capacitor amount in bus19 (MVAR)	Capacitor amount in bus9 (MVAR)	Capacitor amount in bus20 (MVAR)	Capacitor amount in bus10 (MVAR)
Population=20	Crossover=0.2	Generations=100		
0.2425	0.0462	0.1626	0.1405	0.3743
Population=25	Crossover=0.2	Generations=100		
0.2094	0.3049	0.2659	0.0915	0.1269
Population=30	Crossover=0.2	Generations=100		
0.2788	0.0228	0.2760	0.2794	0.0046
Population=35	Crossover=0.2	Generations=100		
0.2013	0.1132	0.0314	0.1250	0.3182
Population=40	Crossover=0.2	Generations=100		
0.3079	0.0946	0.0737	0.2455	0.0412
Population=50	Crossover=0.2	Generations=100		
0.3785	0.0891	0.1260	0.0792	0.0760
Population=40	Crossover=0.3	Generations=100		
0.2491	0.0891	0.0836	0.2027	0.0373
Population=40	Crossover=0.4	Generations=100		
0.2728	0.1859	0.0713	0.0670	0.0749
Population=40	Crossover=0.5	Generations=100		
0.2435	0.1399	0.0929	0.1462	0.0387
Population=40	Crossover=0.6	Generations=100		
0.2453	0.0964	0.0611	0.2208	0.0388
Population=40	Crossover=0.2	Generations=20		
0.2892	0.0672	0.2741	0.0844	0.1385
Population=40	Crossover=0.2	Generations=30		
0.1616	0.1457	0.0969	0.1027	0.0460
Population=40	Crossover=0.2	Generations=40		
0.3510	0.0597	0.2258	0.1896	0.0085
Population=40	Crossover=0.2	Generations=50		
0.3872	0.0939	0.1324	0.0535	0.0010
Population=40	Crossover=0.2	Generations=60		
0.2659	0.0905	0.1421	0.1785	0.0744

V. CONCLUSION

In this paper, Genetic Algorithm has been used as an optimal research method and the results of capacitor placement have been compared with the Simulated Annealling. For large networks which it is impossible to consider all the points as the voluntary points of capacitor placement, one of the best methods is to use the Innovative Algorithm Method.

One of the aims of compensating reactive power is to set bus voltages within the permitted limit. But the voltage reduction which could be resulted from the active power may be so great that even if all the reactive power is also compensated, the voltage of the buses will not be set within this limit. On the other hand, since the R/X of the conductives in the distribution networks is considerable, the extra capacitor placement which is more than the reactive power of network could not be resulted in the considerable increase in the network.

The important feature of this research is the high accuracy in selecting the sensitive buses of the network. In many papers which are introduced into this area, the most sensitive bus is a bus which has the most changes of the active power into the reactive power. But in addition to this issue, the condition of

World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:5, No:2, 2011

bus voltages was considered as another important parameter in selecting the buses & had ideal results.

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