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Analysis of Capacitor Placement in Power Distribution Networks Using Body Immune Algorithm

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Abstract: In this study we present a new technique for analysis of capacitor placement in the power distribution systems considering the most of the parameters affected in this problem. Detection of capacitance and optimal placement of capacitors in power distribution system can lead to decrement in losses, enhancement in voltage profile, increment of power factor and freeing up generation capacityand energy distribution. The majority of literatures pay more attention to solve this problem considering only some of the parameters related to the capacitor placement. In this study for the analysis and formulation of the problem we consider six distinct objectives related to the cost of losses, cost of voltage profile, cost of power factor, cost of utilities development and cost of capacitors including the purchase and installation cost. To find the optimum location and capacitance of the capacitors, a proposed method based on the Immune algorithm has been employed in simulations. The important advantage of the Immune algorithm rather than the other methods is its performance in multifunction manner that can investigate many parameters in the target function. The proposed capacitor placement and detecting optimum capacitance method has been implemented and tested in a 9-bus IEEE sample network in DIGSILENT and MATLAB environments.

Keywords: Immune system, loss reduction, multifunction, optimal placement

INTRODUCTION

Reactive power being in generation system, transmission system and distribution system can lead to power losses and energy cost increment.On the other hand the power equipment such as transformers, power switchesand transmission lines are under overload, therefore it is needed to employhigher size equipment. For solving this problem the capacitor installation in power system is widely used. Capacitors are such economical devices providing required reactive power in the network. Capacitor installation can decrease losses, improve voltage profile and freeing up the extra capacity of the generators. There are many ways for optimal placement and size determination of capacitors in the power systems. These methods are useful and applicable but in the most of the proposed solutions in the papers in this field, only some of the parameters that are effective in this problem are taken into account. For example in the work presented in Baran and Wu (1989) only losses reduction and voltage profile enhancement were studied. In Gallego *et al*. (2001) to optimize capacitor placement only losses reduction, voltage profile enhancement, freeing up the capacity of the generators and cost of capacitors are taken into account. In D-Das (2008) only losses reduction, voltage profile enhancement and installation cost of capacitors were investigated. In Mahmoodianfard *et al.* (2011) losses reduction and voltage profile enhancement investigated and in (Ghose *et al.*, 1998) capacitor placement has been done only by considering losses reduction and the installation cost of the capacitors.In this study for optimal placement and estimation size of capacitors themajority of the effective parameters are considered in the target function of the optimization method based body immune algorithm.The simulated results are compared with the results obtained from general methods too M Davoodi *et al.* (2012).

Problem statement: The capacitor placement problem is solved optimally considering many factors such as reduction of Ohmic losses, voltage profile enhancement, freeing up the generators capacity, freeing up the distribution capacity, freeing up the distribution utilities starting from gathering voltage and current of all nodes in network by load distribution in DIGSILENT environment. Some candidate buses will be selected then by running

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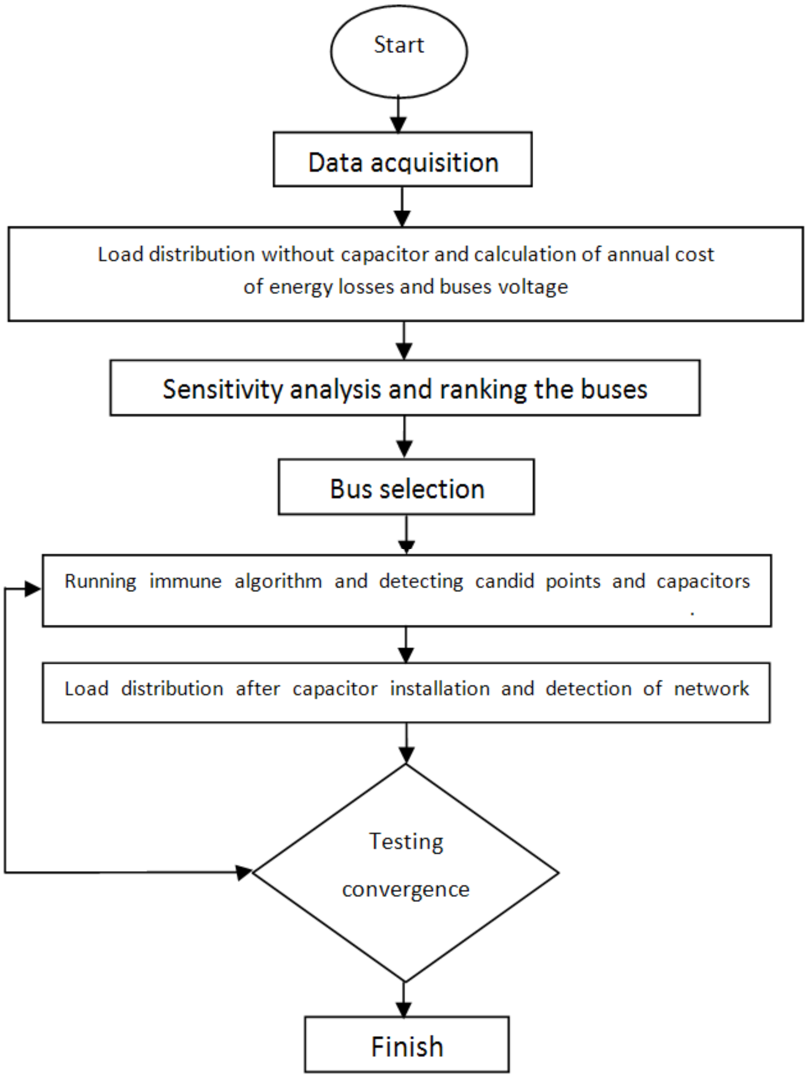

Fig. 1: The steps for finding the optimum points

immune algorithm in MATLAB to detect the optimum place and capacitance of capacitors. The network then is tested by load distribution to check whether the problem requests are met and the indexes are converged. Steps for finding these optimum points are shown in the Fig. 1.

Body immune algorithm: Immune algorithm is one of the optimization algorithms in the problem solving that inspired from Clonal selection theory in the body immune system. Castro *et al*. (2002) This algorithm is used for optimization with multi function. There are many ways for capacitor placement Such as Numerical programming which is one of the traditional methods to solve capacitor placement in the power distribution system. The current methods are complex and slow in computational point of view. Artificial methods for capacitor placement problem include TABU search, Steel plating, Particle crow theory, Fuzzy network theory, Artificial networks and Genetic algorithm that can used for capacitor placement problem (Ng *et al*., 2000).

This study implements immune algorithm for detection and placement of capacitors considering most of the influencing factors in target function. The proposed method compare to the current intelligent methods such as GA (Genetic Algorithm) that used in Delfanti *et al*. (2000) and PSO (particle crowd algorithm) that used in Xin-mei *et al*. (2004), diverges faster.

Steps of immune algorithm implementation are summarized as follows:

- **Coding:** Is mapping from problem area to search area (creating cells with enough length called anti body).

- **Production of initial population:** In this stage, anti bodies labeled randomly to create population of zero generation and by load distribution it's appropriation will be judge.
- **Affinity:** Similarity of anti bodies to each other is a parameter called dependency and is given by (1):

$$AFF_{mn}^{a-a} = \frac{1}{1+E(2)} \quad (1)$$

where, *m* and *n* are two distinct anti bodies and AFF is diversity between two anti bodies that is given by (2):

$$E_j(N) = -\sum_{ij=1}^{N} P_{ij}\, Log\, P_{ij} \quad (2)$$

where, P_{ij} is the probability of un-similarity between i^{th} anti body and j^{th} gen with next un-similar cell.

- **Selecting anti bodies with high dependency:** After calculating dependency level of anti bodies those have high level of dependency will be selected to continue.
- **Doing genetic action:** On the anti bodies with low dependency, genetic actors (e.g., mutation and crossover) imply to increase their level of dependency.
- **Clonal stage:** In this step anti bodies with high dependency are chosen as the next population in the second generation.
- **Controlling stop or continuation condition:** In the steps 3 to 7, the number of generations and the best anti bodies that are the answer of the problem are updated until convergence achievement.

THE PROPOSED METHODOLOGY

In this study to compute the capacitance and location of capacitor in the distribution system, the immune algorithm has been used. The target function of the immune algorithm is a cost function that includes most of the known parameters such as cost of decreasing losses, cost of voltage profile enhancement, cost of capacitor installation that include fix and variable cost that is based on capacitor capacitance and has following equation:

$$F_{cost}(x) = K_1C_l+K_2C_v+K_3C_i+K_4C_f+K_5C_r+K_6C_c(s/Kwh) \quad (3)$$

where,

$F_{cost(x)}$: Target function
C_l : Cost of losses in the network
C_v : Cost of voltage profile enhancement
C_i : Cost of each capacitor installment
C_f : Cost of capacitor (based on it's capacitance)
C_r : Cost of generators capacity, lines and distribution utilities development
C_c : Cost of power factor improvement
K_1 : Coefficient of transferring losses to cost
K_2 : Coefficient of transferring voltage profile enhancement to cost
K_3 : Coefficient of transferring each capacitor installation to cost
K_4 : Coefficient of transferring capacitor capacitance to cost
K_5 : Coefficient of transferring capacity of system an apparatus development to cost
K_6 : Coefficient of transferring power factor improvement to cost

As an example for calculating the cost of losses in the network, the differences of losses in each bus before and after capacitor installation is computed in DIGSILENT. This difference is used as K_1coefficient multiplied in the voltage profile enhancement cost. The other influencing cost parameters are calculated as like for this one. The K_i are the coefficients of the target function given to DIGSILENT as a matrix called *coefficients matrix*, which is discussed in the next sections. The Limitations faced while running the algorithm are as follows:

- **Limitation of the buses voltage:** $V_{min} < V <_{max}$, the buses voltage after capacitor installations have not to be more than detected boundaries.
- **Limitation of the capacitor bank:** Used capacitor bank has a fixed capacitance and can't be varied.

Table 1: The 9-bus IEEE network line data set

Sen.bus	Res.bus	X (ohm)	R (ohm)
0	1	0.4127	0.1233
1	2	0.6050	0.0140
2	3	1.2050	0.7463
3	4	0.6084	0.6984
4	5	1.7276	1.9831
5	6	0.7886	0.9053
6	7	1.1640	2.0552
7	8	2.7160	4.7953
8	9	3.0264	5.3434

Table 2: The 9-bus IEEE network buses data set

No.bus	P (Kw)	Q (Kvar)
1	1840	460
2	980	340
3	1790	446
4	1598	1840
5	1610	600
6	780	110
7	1150	60
8	980	130
9	1640	200

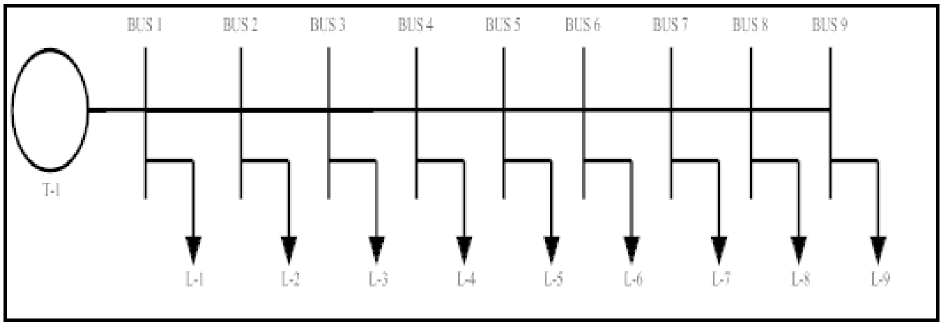

Fig. 2: The 9-bus IEEE single line diagram

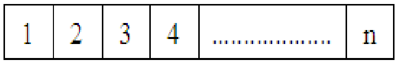

Fig. 3: A general form of antibodies used in the immune algorithm

In this study a sample network was selected to implement the optimal capacitor placement and capacitance detection by the proposed algorithm considering the most of the known influencing factors.

The simulated distribution network: In this study to compare the results achieved from the capacitor placement in the distribution system a standard 9-bus IEEE power network is selected (its single line diagram is shown in Fig. 2).

This network has one voltage source and a data set about its lines and buses shown in Table 1 and 2.

The antibodies (cells) used in the immune algorithm for solving the capacitor placement problem in this study has n member. Each member represents one bus in the network. Values of these buses in the i^{th} position show the capacitance of the installable capacitors in the i^{th} bus. A general form of antibodies is shown in Fig. 3.

The first generation of the antibodies is initialized randomly in the start of the immune algorithm.

SIMULATION RESULTS

In this study, the optimal placement and capacitance detection of the capacitors using the immune algorithm including the most of the influencing parameters in its target function has been implemented in a 9-bus IEEE network.

Input matrix of target function including coefficients such as cost of losses reduction, voltage profile increment, transferring capacitor installment to cost, transferring capacitor capacitance to cost and transferring over capacitance of systems and apparatus to cost that called K_1, K_2, K_3, K_4, K_5 and K_6 respectively in the target function. The parameters consider environmental, economical conditions such as weather and power market as well (Table 3).

Table 3: Destination function coefficients

Coefficient	Parameter	Coefficient applied to each parameter in the destination function(%)
K_1	loss reduction	25
K_2	voltage profile	15
K_3	capacitor installation cost	20
K_4	capacitor capacitance cost	15
K_5	system over capacitance cost	10
K_6	power factor cost	15

Table 4: Result of running algorithm on a 9-bus IEEE network

Bus	Capacitor size	Number of capacitor	PR
1	KVar300	1	
3	KVar300	1	0.89156
5	KVar600	2	
6	KVar1200	4	

These coefficients are computed based on their importance and influence on decreasing costs given as a column matrix to DIGSILENT. Notice that these factors may be changed in each network (Ali *et al*., 2012). Based on these factors, target function is created and the immune algorithm based optimization method is implemented. The proposed method has been developed in DIGSILEN and MATLAB environments. In MATLAB by assigning values to the algorithm, the results of the standard 9-bus IEEE network are shown in Table 4.

In Table 4, PR is the index of losses decrement which in the immune algorithm is the ratio of total losses in the system after capacitor placement to all of losses before capacitor placement:

$$PR = P_{loss\ new}/P_{loss} \tag{4}$$

where, $P_{lossnew}$ and P_{loss} refer to losses after capacitor placement and before it respectively.

Table 5: Comparison proposed capacitor placement with other methods

Bus	Solution 1	Solution 2	Solution 3	Solution 4	Immune algorithm
1	300	300	300		300
2	300			300	
3		300			300
4				600	
5	300	300	900		600
6	1200	1200	1200	1200	1200
7					
8					
9					
$F_{cost}(x)$	308964	309035	309041	309049	308705

Table 6: Comparing run time of the immune and genetic algorithms

Time of calculation	Number of iterations	Optimization algorithm
5.8 min	300	Genetic algorithm
35 sec	300	Immune algorithm

Achieved result from losses indexes are as follows:

- PR<1 : Capacitor placement results in costs reduction.
- PR = 1 : Capacitor placement does not have any effect on the network costs.
- PR>1 : Capacitor placement results in costs increment.

When there is no capacitor placement in the network, the value of the cost function is $F_{cost(x)} = 330125$ and after capacitor placement based on Table 4, $F_{cost(x)} = 308705$. In the Table 5 detecting the location and capacitance of the capacitors based on the influencing factors using immune algorithm is shown with comparison to the other methods. It can be seen that the results of the proposed method has lower cost than others.

Table 6 shows a comparison between immune algorithm and genetic algorithm. In this study we implement capacitor placement and it's capacitance detection for a sample 9-bus standard IEEE network by immune algorithm and genetic algorithm and as shown in table, for equal number of iterations the time of calculations in the proposed immune algorithm is pretty less than genetic algorithm.

DISCUSSION

Optimal placement of capacitor in distribution systems are among the on-going problems that many studies have been done in this area. Due to importance of this problem, different methods are used to find the optimal solution. In this section a couple of optimization methods (Genetic Algorithm and Plant Growth Simulation Algorithm) used in the previous studies are shortly described explained:

- Genetic Algorithm (GA) is one of the ways that used for optimal capacitor placement in the power distribution systems. GA works using inheritance mechanism, natural evolution and mutation in the gens life. This algorithm start by first population of solutions that are random and achieved the best solution using genetic operators. The solutions of each iterations of algorithm is called Generations. In each Generation the better solutions is replaced with the previous one. A limiting parameter (analogous to the environment in the real life) is controlling the optimization process. In capacitor placement problem a cost function including the optimization parameters, as described in Boone and Hsiao-Dong (1993) plays the rule of the limiting parameter. Immune algorithm that we used in this study for optimal capacitor placement is very similar to the GA because it uses mutation and rotation like in the GA. But immune algorithm is able to solve the problem and optimize the solution faster while it can deal with multi target functions as in the proposed method.
- Plant Growth Simulation Algorithm (PGSA) is another method that is used for optimal capacitor allocation. This algorithm is based on the plant growth process, in the way that a plant grows a trunk from its root, then branches will grow from the nodes on this trunk and then new branches will grow from old branches and this process continue until optimal response be found. In Srinivasas Rao *et al*. (2011) for optimal capacitor placement in distribution system PGSA is used, but target function in the previous studies checks only two parameters (comprehensive voltage profile and loss reduction) while leaving the other factors.

CONCLUSION

This study presents analysis of a new combined optimization approach for optimum capacitor placement and capacitance detection in power distribution networks using a proposed algorithm based on immune algorithm considering the majority of the influencing factors in its target function have been studied. The immune algorithm presented in this study has got remarkable superiority in computation speed and convergence speed compared to the other optimization methods. In the first step, the coefficient of the target function got weighted in a column matrix in which the value of each factor may be different for each network. Entering the factors of the target function in DIGSILENT and running immune algorithm, the results have been achieved. They show that in optimal placement of capacitors and detecting optimum capacitance considering most of the important factors (such as loss reduction, voltage profile enhancement, cost of installation and capacitor cost based on it's capacitance) the best values to target function can be achieved. The advantage of using the immune algorithm is its performance in convergence rate compare to the other methods like genetic algorithm.

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