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Effect of Reconfiguration and Capacitor Placement on Power Loss Reduction and Voltage Profile Improvement

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Reconfiguration is an important method to minimize power loss and load interruption by creating an optimal configuration of a system. Furthermore, by increasing demand and value of consumption, construction of new power plants can be postponed in networks by reconfiguration and proper arrangement of linkage switches. This method is feasible for radial networks, which create meshes of linkage switches. One convenient way to achieve a system with minimal power loss and interruption is to utilize capacitors. Optimal placement and sizing of capacitors in such applications is an important issue in the literature. In this paper, cat swarm optimization is introduced as a new metaheuristic algorithm to achieve this purpose. Simulation has been carried out in two feasible networks, 69-bus and 33-bus systems.

Keywords : Reconfiguration, Power loss reduction, Capacitor placement, Cat swarm optimization (CSO)

1. INTRODUCTION

Reconfiguration in power distribution systems is a change in system topology by opening or closing available system keys. Reconfiguration is one of the most important methods to minimize power loss in power systems. Feeders in the power distribution system feed combinations of several types of loads, such as residential, industrial, and vital loads. Each of these load has daily load patterns, which cause a change in the feeders' peak loads, such that each feeder may have several peak loads during a given duration. Under normal operating conditions, part of the feeders' peak loads can be moved to feeders with lower loads by system reconfiguration. This reconfiguration must be done with consideration of some important constraints, such as line transmission capacity, feeder thermal capacity, minimum voltage drop, and network reliability. In reconfiguration, the main purpose is to feed loads that are interrupted because of faults occurring in the system. This energy work must be done in a minimum amount of time with minimal switching. One of the best methods to minimize power is capacitor utilization. Capacitors are commonly used in distribution systems to reduce power loss, improve voltage profile, release system maximum capacity, or increase power transmission capacity of lines. One of the most important issues in the use of capacitors is their best placement in networks to satisfy their function. Optimal capacitor placement is the objective of most literature. The capacitors should be installed on the desired nodes of a radial distribution system such that the economic benefits due to peak power and energy loss reduction are weighed against the cost of installation, while keeping the voltage of the system within the defined limits. In [1], Baran and Wu decompose this problem into a master problem and a slave problem. The master problem is used to determine the location of the capacitors. The slave problem is used by the master problem to determine the type size of the capacitor to be placed on the system. The allocation problem is done with consideration of the harmonics in the unbalanced condition. In this paper, Particle Swarm Optimization has been used to achieve the best answer. In [3], the objective is the minimization of operation cost and improvement of bus voltage in all load conditions with static shunt capacitor allocation. In this paper, a cuckoo search algorithm has been used to solve the allocation problem. In [4], the objective was formed as a nonlinear problem and solved with mixed-integer linear programming. In [5], the authors use the ant colony search algorithm (ACSA) in order to present a new algorithm for solving the optimal feeder reconfiguration. In this paper, the

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reconfiguring problem is considered with capacitor allocations. Furthermore, cat swarm optimization (CSO) is introduced as a new metaheuristic algorithm for optimal allocation. The purpose of this paper is to determine the placement and size of the capacitor with minimal operation cost. Simulations have been carried out on IEEE 69 and 33 buses.

2. EXPERIMENTS

The main objective of the optimal capacitor placement in this article is the minimization of capacitor placement cost and power loss cost subject to power flow constraints, such as bus voltage and branch current. The mathematical function to introduce the objective function of the problem is defined as:

$$OF = Minimize\{Cost\}$$
$$Cost = \left(K_p \times P_{loss} \times T\right) + \left(\sum_{i=1}^{n_c} K_i^c \times U_i^c \times Q_c\right) \quad (1)$$

where

K_p: Annual cost of active power loss: $\left(.08 \frac{\$}{Kwh.year}\right)$

P_{loss}: Total losses of distribution power system (Kw)

K_i^c: Capacitor annual cost $\left(\frac{\$}{K \text{ var}}\right)$

Q_c: The smallest unit of capacitance $(K \text{ var})$

U_i^c: Capacitance number

T: Annual hours

2.1 Load flow equation

Power flow is one of the most important subjects in power system analysis. The Newton–Raphson and Gauss–Seidel methods are convenient techniques for load flow problems. Power distribution system specifications such as radial property, ohm-to-reactance ratio, and number of buses (which increase system complexity) cause inefficient results with those methods. These characteristics make power flow study of distribution systems more difficult than that of transmission systems. The power flow technique used in this paper is described as follows:

Consider a distribution line with an impedance, $R + jX$ shown in Fig. 1. Writing Kirchhoff's low in illustrated circuit, the relation between the sending and receiving voltage is:

$$V_r = V_s - Z \times I_s \quad (2)$$

Therefore, the power flow equation can be written as:

$$V_r^2 = V_s^2 - 2\times(P_s \times R + Q_s \times X) + \frac{(P_s^2 + Q_s^2)\times Z^2}{V_s^2} \quad (3)$$

and the active power loss is:

$$P_{loss}(s, s+1) = R_{s,s+1} \times \frac{P_s^2 + Q_s^2}{V_s^2} \quad (4)$$

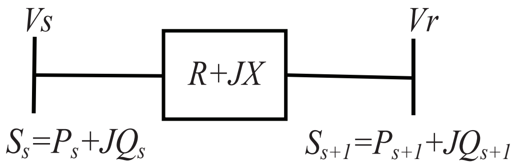

Fig. 1. Distribution line with impedance.

All active power loss in the feasible case study is:

$$P_{loss} = \sum_{s}^{n-1} P_{loss}(s, s+1) \quad (5)$$

where V_s and V_r are the voltage of the sending and receiving sides, respectively, and P_s and Q_s are the active and reactive power from the sending side, respectively:

In order to solve the reconfiguration problem, some other constraints have been considered, such as voltage and capacity restrictions:

$$.95 \le V_i \le 1.05$$
$$S_{LC} \le S_{LC,Max} \quad (6)$$

2.2 Reconfiguration problem definition

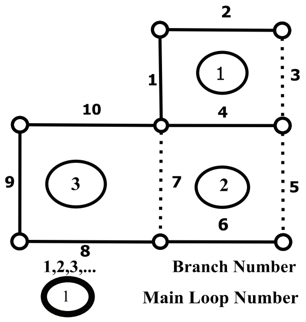

Fig. 2. Network coding according to main loops.

There are two types of switches in a power distribution system. One type is normally open (introduced as linkage switches) and the other type are normally closed. According to Fig. 1, virtual loops appeared in the network with both open and closed switches. Among these created virtual loops, a loop with minimum size is introduced as the main loop. Therefore, there is one main loop for every set of linkage switches. The solution to the network reconfiguration problem is in direct relation to system coding procedures. System codification in this paper is based on the main loops. Figure 2 illustrates system coding based on main loop considerations.

2.3 Metaheuristic algorithm

Metaheuristic algorithms are used for combinative optimization problems, in which an optimal solution is desired over a discrete search space. There are several metaheuristic algorithms, such as genetic algorithms (GA), particle swarm optimization (PSO), imperialist competitive algorithm (ICA), artificial bee colony, CSO, etc. In this paper, CSO is used for the optimization problem. This algorithm is introduced in the following section.

2.4 Cat swarm optimization

Cat swarm optimization is a new metaheuristic algorithm inspired by cats' behavior. This algorithm consists of two operational modes, known as seeking and tracing modes. Seeking mode models the cat during a period of resting while being alert. This mode consists of three essential factors—seeking memory pool (SMP), the depicted point which sleeked with cat; seeking range of the selected dimension (SRD), which is used to declare the mutative ratio for the selected dimensions; and the count of dimension to change (CDC).

The process of the seeking mode is as follows:

Step 1: Make j copies of the current position of cat$_k$, where j is equal to the SMP value. If the value of the self-position consideration (SPC) is true, consider j = SMP – 1.

Step 2: For each copy, according to the CDC, randomly add or subtract the SRD percent from the present values and replace the old ones.

Step 3: Calculate the fitness values (FS) of all candidates' points.

Step 4: If all the FS are not exactly equal, calculate the selecting probability of each candidate point using equation (2); otherwise, set all the selecting probabilities of each candidate point to 1.

Step 5: Randomly pick the point to move to from the candidate points, and replace the position of Cat_k.

$$P_i = \frac{FS_i - FS_b}{FS_{\max} - FS_{\min}} \tag{7}$$

The tracing process is as follows:

Step 1: Update the velocity for every dimension $V_{k,d}$ according to equation (3).

Step 2: Check if the velocities are within the range of maximum velocity.

Step 3: Update the position of Cat_k according to equation (4).

$$V_{k,d} = V_{k,d} + r_1 \times C_1 \times (X_{best,d} - X_{k,d}) \quad \text{where } d = 1, 2, \ldots, m \tag{8}$$

$$X_{k,d} = X_{k,d} + V_{k,d} \tag{9}$$

All of parameters could be defined as follows:

Seeking mode:

This sub-model is used to model the condition of the cat, which is resting, looking around, and seeking the next position to move to.

Four essential factors have been defined: SMP, SRD, CDC, and self-position consideration.

The SMP is used to define the size of the seeking memory for each cat, which indicates the points sought by the cat. The cat would pick a point from the memory pool according to the rules described previously.

The SRD declares the mutative ratio for the selected dimension. In the seeking mode, if a dimension is selected to mutate, the difference between the new value and the old one will not be out of the range defined by the SRD.

The CDC manifests how many dimensions will be varied. These factors all play important roles in seeking mode.

SPC is a Boolean variable that decides whether the point where the cat is already standing will be one of the candidates to move to. Whether the value of SPC is true or false, the value of SMP will not be influenced.

In this paper, CSO is used for optimal placement and sizing of capacitors with consideration of system reconfiguration with optimal arrangement of linkage switches (normally open switches) for power loss reduction of the network.

3. Case study

The proposed algorithm is applied on both 33- and 69-bus test distribution systems. Reconfiguration has been done in two cases: with capacitor allocation and without capacitor allocation. In order to improve the problem constraints, definition of the systems' features in normal conditions (without optimization) is the main work.

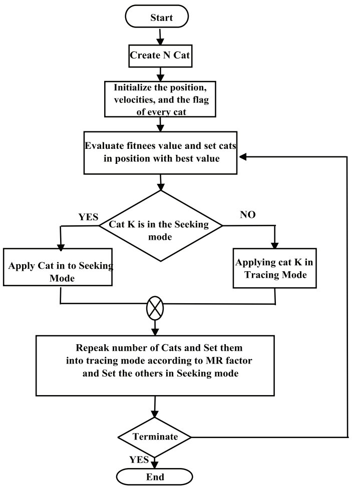

Fig. 3. Flowchart of the CSO algorithm.

3.1 33-, 69-bus test systems

In this paper, reconfiguration is carried out on both 33- and 69-bus systems. The general features of each system are as follows.

The total real and reactive powers of the 33-bus system are 3,715 kW and 2,300 kvar, respectively. Initial linkage switches in this system are {33, 34, 35, 36, and 37}. In this system, without optimization, network active losses are of 202.68 kW. For the 69-bus system, these values are 3801.89 kW and 2694.1 kvar, respectively. Initial linkage switches for this system are {65, 70, 71, 72, and 73}. Figures 4 and 5 illustrate both of them, respectively.

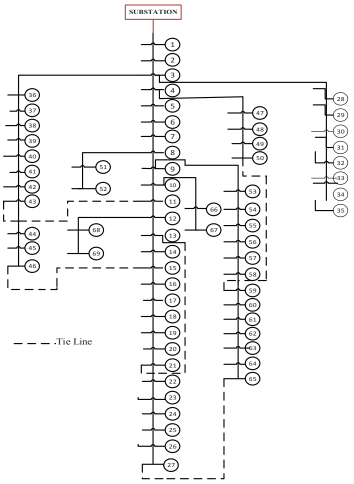

Fig. 4. IEEE 69-bus system.

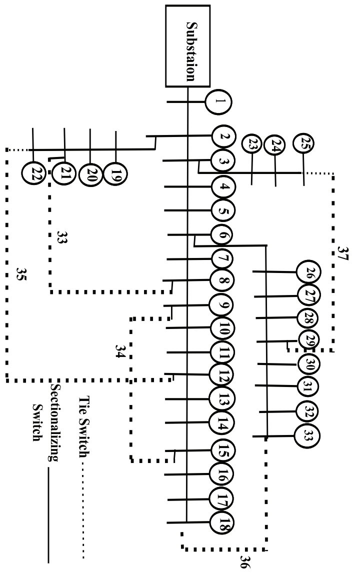

Fig. 5. IEEE 33-bus system.

Table 1. Result of optimization with CSO in both states for the 33-bus system.

Parameters	State I	State II
Linkage switches	7-9-14-32-37	33-34-35-36-37-38
Maximum voltage	1	1
Minimum voltage	0.9276	0.9315
Power loss (KW)	138.48	132.48
Cost ($)	72,458	53,584

Table 2. Result of optimization with CSO in both state for the 69-bus system.

Parameters	State I	State II
Linkage switches	11-66-13-20-15-69-54-39-48	11-66-13-20-14-15-51-47-48
Maximum voltage	1	1
Minimum voltage	0.941	0.9501
Power loss (KW)	154.209	150.63
Cost ($)	86,483.30	68,495.18

3.2 Simulation results

Considering both 33- and 64-bus systems with the aforementioned features and using CSO algorithms to solve the problem, the best configuration of the network with minimized active power loss has been achieved. Figure 6 shows the voltage profile of the 33-bus system in two case studies. Case I is the reconfigured system without capacitor placement, and case II is the reconfigured system with capacitor placement. As is clearly seen in the figure, the voltage profile in case II is improved over that of case I. Moreover, from the results, buses in critical condition, with maximum voltage drop, are considered the best points in the capacitor placement problem.

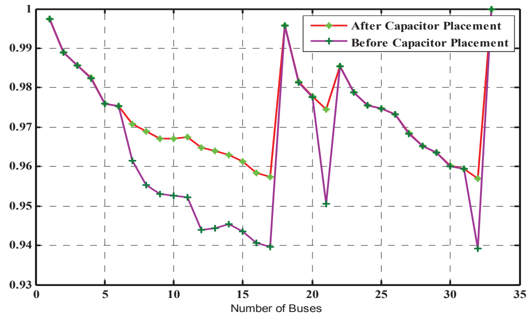

Fig. 6. Voltage profile for 33 buses network, before and after capacitor placement.

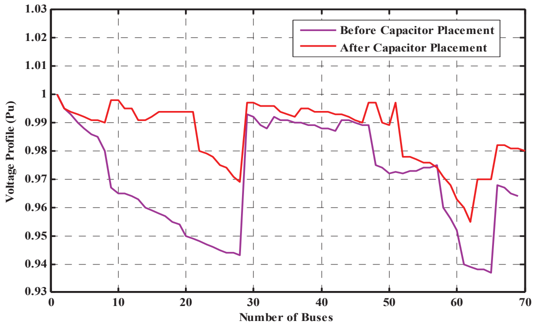

Fig. 7. 69-bus profile voltage in two position; without capacitor placement, with capacitor placement.

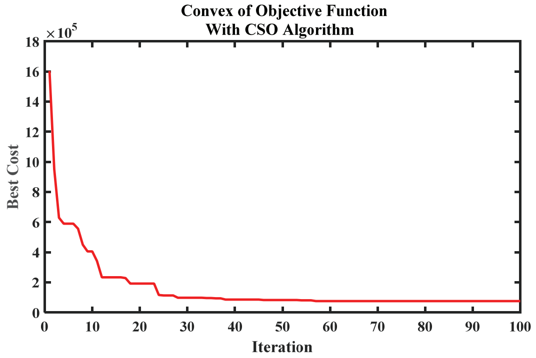

Fig. 8. Convex of objective function.

In Fig. 7, similar conditions for the 69-bus system is visible. In this system, the voltage profile is improved over the case of without capacitor placement in addition to reconfiguration.

Table 1 gives the results of the 33-bus system in two case studies. State (I) shows the result of reconfiguration without capacitor allocation, and state (II) gives the results of reconfiguration with capacitor placement. It can be seen from Table 1 that all of the parameters are modified. Table 2 shows the same results as the 69-bus system. In both systems, the algorithm creates switch arrangements to improve the problem constraints. Figure 8 shows convergence characteristics for the CSO algorithm.

3.3 Comparison of CSO results with other algorithms

In this section, voltage profile and investment cost of capacitor placement for particle swarm optimization (PSO) and CSO in a 33-bus system is analyzed. Figure 9 illustrates the bus voltage in three positions, before capacitor placement, capacitor placement with CSO, and capacitor placement with the PSO algorithm. As seen in the figure, the results achieved by the optimization algorithms have modified the voltage profile from the normal condition. Tables 3 and 4 show the results of optimization by PSO in both states. Comparing

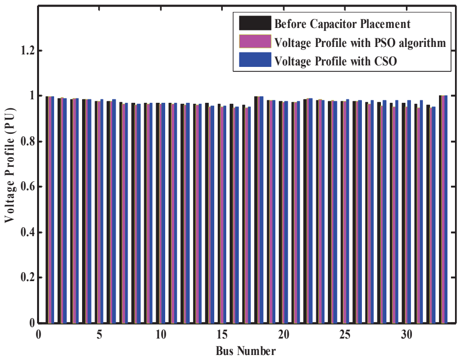

Fig. 9. Comparison of CSO and PSO Results in voltage profile of the 33-bus system.

Table 3. Simulation results for PSO algorithm in 33-bus test system.

Parameters	State (I)	State (II)
Linkage switches	7-9-14-32-37	33-34-35-36-37-38
Power loss (KW)	139.72	136.65
Minimum and maximum voltage	1 , 0.9375	1 , 0.9386
Cost ($)	76,158	57,684
Simulation time (s) (CSO-PSO)	96	189

Table 4. Simulation results for PSO algorithm in 69-bus test system.

Parameters	State (I)	State (II)
Linkage switches	11-66-13-20-15-69-54-39-38	11-43-13-21-12-58-59-27-65
Power loss	168.5	162.7
Cost ($)	87,158	63,657
Simulation time (s) (CSO-PSO)	108	216

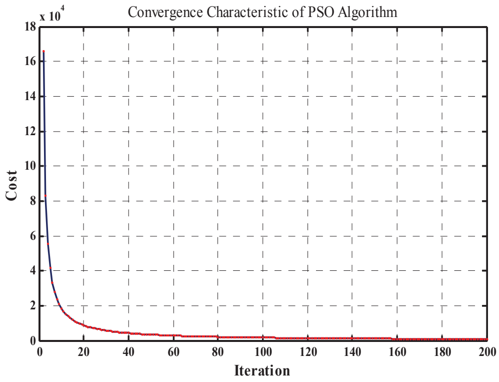

Fig. 10. Convex of objective function by PSO.

Table 5. Comparison of simulation results of PSO and CSO algorithm in the 33-bus system (without capacitor placement).

Parameters	State (I)	State (II)
Linkage switches	7-9-14-32-37	7-9-14-32-37
Power loss (KW)	141.6	139.72
Cost ($)	78,254	76,158
Simulation times (second)	154	96

these with Tables 1 and 2, the efficiency of CSO can be verified for optimal placement issues.

In Table 5, the results of applying PSO and CSO algorithms in the 33-bus system have been compared.

In order to illustrate the convergence of the PSO algorithm, the convergence characteristics are shown in Fig. 10.

4. CONCLUSIONS

In this paper, both reconfiguration issues and capacitor placement have been considered as the objective. A new metaheuristic algorithm has been introduced for determination of optimum size and best switching arrangement for the reduction of power loss. Using the CSO algorithm in both the feasible networks and comparing with other kinds of algorithms, the results verified that the CSO approach for optimal capacitor placement works properly. The results also show that applying both capacitor placement and reconfiguration together reduces the operation cost of the system in addition to improving system constraints.

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