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Simultaneous Reconfiguration, Optimal Placement of DSTATCOM, and Photovoltaic Array in a Distribution System Based on Fuzzy-ACO Approach

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ABSTRACT

In this paper, a combination of a fuzzy multi objective approach and ant colony optimization (ACO) as a met heuristic algorithm is used to solve the simultaneous reconfiguration and optimal allocation (size and location) of photovoltaic (PV) arrays as a distributed generation (DG) and distribution static compensator (DSTATCOM) as a distribution flexible ac transmission system (DFACT) device in a distribution system. The purpose of this research includes loss reduction, voltage profile (VP) improvement, and increase in the feeder load balancing (LB).

The proposed method is validated using the IEEE 33-bus test system and a Tai-Power 11.4-kV distribution system as a real distribution network. The results proved that simultaneous reconfiguration and optimal allocation of PV array and DSTATCOM unit leads to significantly reduced losses, improved VP, and increased LB. Obtained results have been compared with the base value and found that simultaneous placement of PV and DSTATCOM along with reconfiguration is more beneficial than separate singleobjective optimization. Also, the proposed fuzzy-ACO approach is more accurate as compared to ACO and other intelligent techniques like fuzzy-genetic algorithm (GA) and fuzzy-particle swarm optimization (PSO).

INTRODUCTION

Distribution systems have two types of switches, i.e., 1) tie and 2) sectionalizing. By changing the switches status between feeders, the structure of the distribution network will change and it is known as reconfiguration. The main objective of reconfiguration is to reduce losses, increase stability and reliability, improve voltage profile (VP), and relieve overload in the distribution network. The concept of reconfiguration of distribution network was first proposed by Merlin and Back in 1975. A number of methods of reconfiguration in distribution networks have been proposed by researchers and also available in literature. Recently, Kavousi-Fard and Niknam have proposed the reconfiguration problem with respect to the reliability using a self-adaptive modified optimization algorithm. In restructured power systems, the use of distributed generation energy resources including photovoltaic (PV), fuel cells, small wind turbines, etc., is playing an important role because of various advantages. The advantage of distributed generation energy resources includes reduction in power loss, improvement in VP, and increase in the reliability of the network. To achieve the benefits of DG units, the selection of optimal locations and capacity is becoming the major problem. Various methods have been proposed by researchers in order to find the optimal placement and capacity of DG units. These methods are often based on artificial intelligence

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and heuristic algorithms. Kollu *et al.* proposed a Harmony Search (HS) algorithm-based novel method to allocate DG units optimally in distribution system for power loss reduction and VP improvement.

Distribution flexible ac transmission system (DFACT) devices are used in distribution systems with different applications and controlling methods for improving the power quality indices. DSTATCOM, unified power flow controller (UPFC), and dynamic voltage restorer (DVR) are widely used DFACT devices. To find the optimal location and capacity of DFACT devices has a considerable impact in distribution systems. Some researchers have proposed various methods to find the optimal location and size of DFACT unit. Farhoodnea *et al.* presented a firefly algorithm-based novel method to optimally place the DSTATCOM in distribution system. In addition, several methods have been proposed for the simultaneous reconfiguration and optimal allocation of DG or DFACT unit in distribution system. However, simultaneous reconfiguration with both DG and DFACT is rarely available in the literature. In this paper, the ant colony optimization (ACO) approach has been used for simultaneous multi objective reconfiguration and optimal allocation of PV and DSTATCOM in a distribution network. The main objective of the work includes loss reduction, VP improvement, and equalizing the feeder load balancing (LB). To avoid the convergence problem, the input and output data are normalized in the same range based on fuzzy sets.

ACO:

The ACO is a swarm intelligence-based technique, proposed by Dorigo *et al.* for the solution of combinatorial problems. The ACO algorithm is originally inspired by the biological behavior of the ants and specifically their way of communication. This inspiration comes from the ability of real ants to find the short paths in their movement from and to their nests when searching for food source . However, ants do not communicate with each other in a direct way but they exchange information through what is known as pheromones. A simple diagram of ant foraging. Two ants leave their nest in different directions at the same time for searching the food. As they move about, they deposit a pheromone trail that evaporates slowly and is detectable by other ants. If no pheromone exists initially outside the nest, the paths of the two ants are generally random. The evaporation of pheromone is also an important part of the foraging process that helps deemphasize older trails leading to exhausted food sources. The ACO algorithms attempt to exploit the efficiency of ant foraging behavior by creating an abstract environment of possible paths, and simulating ants traveling along these paths.

Each individual chooses a different path and comes up with different solutions in the search space region. When an ant passes through a path, it deposits the pheromone. This approach helps ACO algorithms avoid getting trapped in local optim.

ACO Procedure:

The following procedure has been applied for the given problem
1) appropriate problem representation;
2) heuristic desirability (η) of edges;
3) construction of feasible solutions;
4) pheromone updating rule;
5) probabilistic transition rule.

A suitable heuristic desirability of traversing could be any subset evaluation function. The heuristic desirability of traversal and edge pheromone levels is combined to form the socalled probabilistic transition rule, denoting the probability of an ant at feature *i* choosing to travel to feature *j* at time *t*:

$$P^k{}_{i,j}(t) = \begin{cases} \frac{[\tau_{i,j}]^{\alpha}[\eta_{i,j}]^{\beta}}{\sum\limits_{i\in T}[\tau_{i,j}]^{\alpha}[\eta_{i,j}]^{\beta}}, & \text{if } i,j \in T \\ 0, & \text{otherwise} \end{cases} \quad (12)$$

where k is the kth ant, $\alpha > 0$ and $\beta > 0$ are two parameters (the choice of α and β is determined experimentally), $\tau_{i,j}$ is the pheromone value for the ijth path of the ACO algorithm, $\eta_{i,j}$ is heuristic desirability for the ijth path of the ACO algorithm, and T is the total number of paths currently not visited by an ant.

As suggested in (12), the transition probability is determined by the pheromone and heuristics of the trail, which corresponds to the individual cost of the *ij*th path. This path is said to be accepted when higher probability value is gained as a result of high quantity of pheromone or heuristic desirability. After all ants have completed their tours, the pheromone level is updated by

$$\tau_{i,j}(t+1) = (1-\rho)\cdot\tau_{i,j}(t) + \sum_{k=1}^{m}\Delta\tau_{i,j}^{k}(t) \qquad (13)$$

where $\rho \in (0, 1)$ is the pheromone trail evaporation rate and m is the number of ants. The parameter ρ is used to avoid unlimited accumulation of the pheromone trails and enables the algorithm to forget previously done bad decisions. $\Delta\tau$ *k i,j*(*t*) is the amount of pheromone ant *k* deposits on the paths; it is defined as

$$\Delta\tau_{i,j}^{k}(t) = \begin{cases} 1/L^{k}(t), & \text{if path } ij \text{ is used by ant } k \\ 0, & \text{otherwise} \end{cases} \qquad (14)$$

where *Lk*(*t*) is the length of the *k*th ant's tour. According to , the shorter the ant's tour is, the more pheromone is received by paths belonging to the tour.

The flowchart of the ACO procedure is described in the following steps:

1) Reading the input data;
2) Initializing the system;
3) Creating the graphs for each ant, with its respective nodes and edges;
4) Updating the list of feasible operation and probability values so that ants schedule their next operation until they reach food node; and
5) Analysis of the best solution, updating pheromones, and checking the stopping criterion.

PROPOSED FUZZY-ACO METHOD

In this section, the proposed fuzzy-ACO approach has been used for reconfiguration and optimal placement of DSTATCOM and PV array in distribution system. An optimal feeder topology can be represented as

$$S^{1} = \left[\text{tie switches}^{1},\ \text{PV}^{1},\ \text{DSTATVOM}^{1}\right].$$

In the ***S***1 vector, PV1 is a matrix with two columns as follows:

$$\text{PV}^{1} = \left[\text{size}_{\text{pv}}{}^{1}\ \ \text{location}_{\text{pv}}{}^{1}\right]$$

and DSTATCOM is a 1 × 2 matrix as follows:

$$\text{DSTATCOM}^{1} = \left[\text{size}_{\text{DSTATCOM}}{}^{1}\ \ \text{location}_{\text{DSTATCOM}}{}^{1}\right]$$

where size1 pv and location1 pv are the initial proposed capacity and bus location for the PV unit, respectively, and size1

DSTATCOM and location1 DSTATCOM are the initial capacity and bus candidate to install the DSTATCOM unit, respectively.

By updating the ACO algorithm, the second, third, and the *i*th solution vectors are generated with the new proposed tie switches, PV, and DSTATCOM size and location as follows:

$$S^{i} = \left[\text{tie switches}^{i},\ \text{PV}^{i},\ \text{DSTATVOM}^{i}\right].$$

For each *i*th solution, a power flow program is carried out, the fuzzy membership values, and the fitness of objective function are evaluated and compared with the previous solution and the better solution has been selected and replaced. The proposed method is summarized in the following steps. Step 1) Read data of distribution system (bus, load, branch, sectionalizing, number of tie switches, etc.), initialize the ACO parameters and run the power flow program. Step 2) Generate a solution vector as "***S***" by offering the tie switches, PV, and DSTATCOM sizes and locations in the network without violating the constraints. Run the power flow program, evaluate the fuzzy membership value (μ) based on (10) for each objective function. Calculate the fitness of fuzzy objective function according to (11). Save the solution as the best solution. Step 3) Update the ACO pheromone value using (13) and (14). Generate a new solution by updating ACO, and compare the fitness value of the new solution with the best solution. If the new generated solution has a better fitness value than best solution, save it as the best solution. Step 4)

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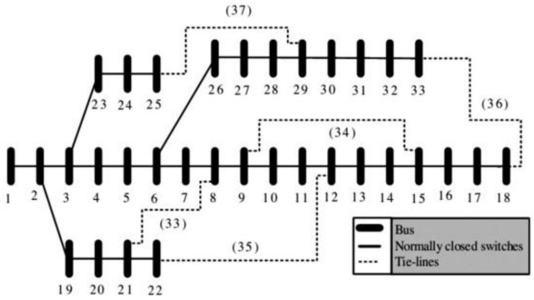
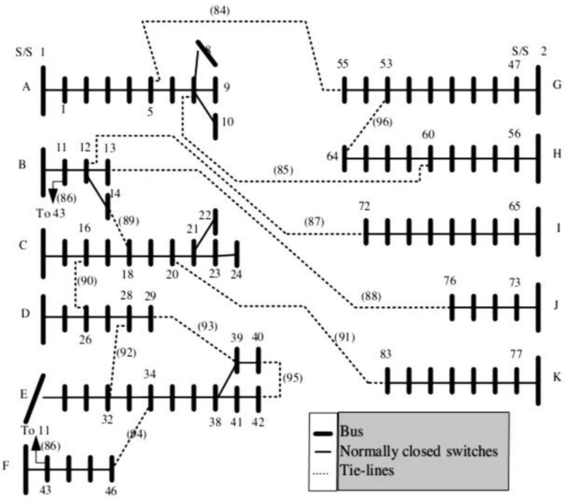
Check the number of iterations, and if the number of iterations does not exceed from the specified value, repeat step 3).

RESULTS:

33-Bus test system with five tie lines.



TPC test system with 13 tie lines.



CONCLUSION

A fuzzy-ACO-based algorithm has been presented for simultaneous reconfiguration and allocation of PV and DSTATCOM units. The proposed approach is employed to mitigate the power loss, VP improvement, and equalizing the feeder LB in distribution system. To test the effectiveness of the proposed approach, five different cases have been tested on 33-bus test system and a real distribution network, i.e., Taiwan Power Company. Among the five cases, the multi objective reconfiguration and simultaneous PV and DSTATCOM allocation case is found to be better than the others. For 33-bus system, the loss reduction is 75.93%, VP and LB improvements are 51.76% and 36.42%, respectively, as compared to the base system. However, in case of Taiwan power company network, the loss reduction is 44.71%, and VP and LB improvements are 33.2% and 29.86, respectively. Obtained results are compared with the fuzzy-GA and fuzzy-PSO at nominal load and found to be better than the above-mentioned approaches because of the lowest fitness. Also, the performance of fuzzy-ACO is better as compared to the ACO method. Furthermore, the reconfiguration along with PV and DSTATCOM is more advantageous than the individual one. Finally, obtained results confirm the satisfactory operation of the proposed approach at different load levels.

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