Finding the Optimal Path to Restoration Loads of Power Distribution Network by Hybrid GA-BCO Algorithms Under Fault and Fuzzy Objective Functions with Load Variations

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ABSTRACT

In this paper proposes a fuzzy multi-objective hybrid Genetic and Bee colony optimization algorithm (GA-BCO) to find the optimal restoration of loads of power distribution network under fault. Restoration of distribution systems is a complex combinatorial optimization problem that should be efficiently restored in reasonable time. To improve the efficiency of restoration and facilitate the activity of operators an efficient GA-BCO algorithm is developed. To investigate the efficiency of proposed algorithm, the algorithm is applied to a real case of distribution system from Taiwan Power Company (TPC) and compared with those of existing approaches in the literature. Experimental results show the capability of proposed algorithm in finding the optimal distribution system restoration in reasonable time.

KEYWORDS: Restoration of distribution network, Genetic Algorithm, Bee colony optimization, Fuzzy multi-objective functions.

1. INTRODUCTION

Service restoration is an emergent task in the operation of distribution systems. When a fault occurs, the blackout area and the number of customers affected heavily depend on the effectiveness of the service restoration algorithm. Generally, the TPC operators tend to restore the electricity power based on of their existing knowledge and heuristic rules. However, owing to the multitude of feeders, laterals, and switches in a typical distribution system, it is not easy to restore an out-of-service area solely depending on the past experiences of human operators. Therefore, how to devise a rapid and effective restoration plan is of major concern in this paper. Much research

has been developed to deal with the problems of service restoration. The heuristic-based approach [1] has been developed by the operators at many utilities including those of TPC to reach a proper restoration plan in a short period. Since the heuristic rules are often expressed in imprecise linguistic terms, the fuzzy reasoning approach [2]-[3] was proposed to achieve an efficient inference for the problem of service restoration. To deal with the problem of service restoration with many conflicting objectives, the multi-objective functions with fuzzy and non-fuzzy reasoning approaches were presented in [4]. Traditionally, the techniques mentioned above can serve as useful tools to reach a proper restoration plan. However,

because of the many switches in a typical distribution system, the related inference programs may stall at the local optimal solutions, leading to an unsatisfactory restoration plan. Further, the related inference approaches still have the problem of slow convergence during the optimization process.design [13]. In this paper, a GA-BCO algorithm was presented that the number of the switches used in EDE algorithm is the same, but the convergence in comparison to it is better [8-9].

2. DESCRIPTION OF OBJECTIVE FUNCTIONS

Service restoration of a distribution system is a complex and urgent task that must be performed rapidly by system operators. In this paper, we focus the objectives of the restoration plan on the following concerns:

1) Restore as much load within the out-of-service area as possible

2) Operate a minimal number of switches

3) Devices should not overload too much, and if they must

4) Keep the load balanced as much as possible.

Other issues such as maintaining the radial system Structure and voltage drop are considered as system constraints. The definitions below are the fuzzy objectives and their associated membership functions.

2.1. LOAD RESTORATION (LR) OBJECTIVE

The load restoration objective considered in this paper is to restore as much load within the out-of-service area as possible. As depicted in Fig.1(a), the associated membership function is denoted as:

$$\mu_1 = \begin{cases} 1 & , \ if \quad R_L = R_{LA} \\ R_l / R_{lA} & , if \quad 0 < R_L < R_{LA} \\ 0 & , \ if \quad R_L = 0 \end{cases} \quad (1)$$

Where RL represents the amount of loads actually restored and RLA means the amount of total lateral loads in the out-of-service area. Note, the case of $R_L > R_{LA}$ does not exist in the restoration plan.

2.2. SWITCHES OPERATION (SO) OBJECTIVE

The second objective is to operate a minimal number of switches. a decreasing membership function, as shown in Fig.1(b) for lateral (or feeder) switches, is utilized as follows:

$$\mu_2 = \begin{cases} 1, & if \ S_W \leq \underline{S} \\ 1 - \dfrac{S_W - \underline{S}}{\bar{S} - \underline{S}} & if \ \underline{S} < S_W < \bar{S} \\ 0 & if \ S_W \geq \bar{S} \end{cases} \quad (2)$$

Where S_w the total number of switches operation is, $\underline{S}, \bar{S}$ are the possible minimal and maximal number of switches operation, respectively.

2.3. DEVICES OVERLOAD (DO) OBJECTIVE

Since a light overload is rather common in the daily operation of TPC, the associated membership function of devices overload, including the supporting feeders and laterals, is depicted in Fig.1(c) which can be expressed as:

$$\mu_3 = \begin{cases} 1, & if \quad D \leq \underline{D} \\ 1 - \dfrac{D - \underline{D}}{\bar{D} - \underline{D}} & if \quad \underline{D} < D < \bar{D} \\ 0, & if \quad D \geq \bar{D} \end{cases} \quad (3)$$

where D represents the actual load of one particular device (feeder or lateral), $\underline{D}$ is the capacity of the devices, $\overline{D}$ is the maximal allowable overload (in Amperes). If several devices are overloaded, including the supporting feeders and supporting laterals, the resulting membership function is the one obtained by the AND-operation of all corresponding membership functions.

2.4.LOAD BALANCE (LB) OBJECTIVE

The forth objective is to keep the load balance on the devices as much as possible to relieve the overloads in the distribution system. The associated membership function of the load balance objective, as shown in Fig.1(d), is defined to show the degree of current variation for one device as follows:

$$\mu_4 = \begin{cases} 1, & if & I \leq I_b \\ 1 - \dfrac{I - I_b}{\overline{I} - I_b} & if & I_b < I < \overline{I} \\ 0, & if & I = \overline{I} \end{cases} \quad (4)$$

Where I_b is the device current before restoration and I denotes the maximal allowable current capacity. The AND-operation is also used to attain the resulting membership function among all of the corresponding membership functions.

Based on the fuzzy objective as well as their corresponding membership functions described above, the weighted-sum strategy is utilized to determine the fuzzy objective value of the Ith feasible solution as follows.

$$\underset{I \in \psi}{MAX}\, \tilde{\mu}_i = \sum_{K=1}^{4} W_K \times \mu_K \quad (5)$$

Where Ψ denotes the set of feasible solutions for each optimization process, W_k is the weighting value of the kth objective, and μk means the membership function of the kth objective.. The optimal decision is the one with the largest fuzzy objective value in the solution domain. Note, determining of a rational weighting value wk in (5) is important for the system operators. In this paper, the analytical hierarchy process (AHP) method [11] is used to help the operators obtain the weighting value of each objective.

After a general introduction to the subject, at the first to express a brief history of the subject and the works done with the features of them. The attempts done in the article for clarifying the issue are to pave the way for complementing the defects, accordingly Loosening the knots or moving towards the new achievements, which are explained within one or more paragraphs. In this section the scientific and technical achievements of the research compared to the other works are intended to be stated clearly in order to clear the innovation of the research compared to the other ones.

3. ALGORITHM GA-BCO

Schematic of combined algorithm GA-BCO is as follows:

step1: Randomly generate the Initial chromosome (initial population or basic solutions).

step2: Evaluate violation of the provisions of the initial solution is performed.

step3: Evaluate Solve the initial assessment using fuzzy objective function is defined.

step4: Initial population in terms of fitness is listed and half are elected solutions with lower cost (parent choice for the next generation).

step5: Initial population the offspring are produced by applying the intersection operator on parent chosen.
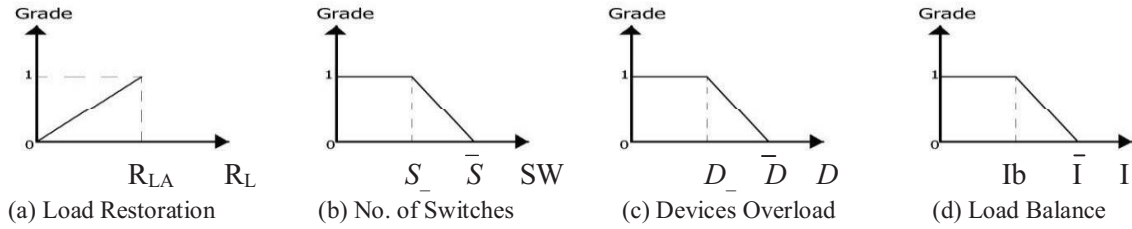
Fig. 1. The membership functions of the four objectives

step6: Apply operator mutation based on a population that includes children and is parent.

step7: Check non-violation of the provisions of the new solution is performed.

step8: Evaluation of a new approach using fuzzy objective function is defined.

step9: The best results are stored. If you limit the number of iterations (half Iteration) is passed on to the next step, otherwise it goes back to the second stage.

step10: The best solution to solve the proposed genetic algorithm as the basic algorithm is considered to be a bee.

step11: Count the bees are zero.

step12: Move the worker bees that do include them all is to repeat the following steps:

− random selection of resources (for example $\theta_{ij}(t)$, one of the solutions)

− a neighboring solution ($\theta_{kj}(t)$)

− random generate a number between zero and one (φ)

− bees locate new audiences using the following equation:

$$X_{ij}(t) = \theta_{ij}(t) + \varphi(\theta_{ij}(t) - \theta_{kj}(t))$$

− Evaluate new location (new address). If an optimal solution which is better than obtained so far, the solution of the optimal solution obtained. This happened also to be stored and the timer is zero, otherwise we add the value of the counter.

step13: Move the onlooker bees following steps:

− calculate the probability of food sources (pi) using the equation:

$$p_i = \frac{F(\theta_i)}{\sum_{k=1}^{S} F(\theta_k)}$$

− Random generate a number between zero and one. If this random number is smaller than Step 12 is repeated. Otherwise it goes to the next step.

step14: Move the scout bees involve the following steps:

−check counters are all solutions. Any solution that Counter <Limit it with a random solution (scout bees) are replaced.

− Generated solution is evaluated.

− The cost of this solution is compared with the cost of the best solution obtained. If the replacement is better.

step15: Convergence limitation has been done here, as the number of repeats is checked. If the algorithm is set to end and the results stored in output is the best solution. Otherwise, the algorithm is repeated from step 11.

To evaluate the performance of the proposed method, this algorithm on a sample network shown in Fig.2, is used.

4.   SIMULATION RESULTS

The combinatorial Hybrid optimization process was implemented using the commercial MATLAB package to the network shown in Fig.2. For comparison, the heuristic-based fuzzy (HBF) method [2]

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and DE algorithm [8] and EDE algorithm are also tested using the same database . Similar to what is shown in Fig.2, suppose one fault took place at point J located at feederYD28. The circuit breaker CB2 was then tripped and the faulted zone was isolated, leaving lateral loads from LAT1 to LAT9 out-of-service. Our goal is to restore the nine lateral loads using the supporting feeder YE29 and eight supporting laterals of LAT10 to LAT17. Since LAT9 is not equipped with a supporting lateral, it must be supplied power from the supporting feeder YE29.

Four objectives including load restoration, switches operation, devices overload, and load balance are considered. Since there are nine lateral loads to be restored, the parameter RLA, as shown in Fig.1(a), is set at 9. The operation switches of $\underline{S}, \overline{S}$ depicted in Fig.1(b) are set at 3 and 17, respectively. In addition, the rated capacities ($\underline{D}$) for the feeder and lateral are 450A and 100A, respectively. However, in the daily operation of TPC, especially in the summer peak season, overloads of 10% and 20% for feeder and lateral, respectively, are allowed within a one hour period.

Therefore, the parameter of $\overline{D}$ depicted in Fig.1(c) for feeder and lateral is set at 495A and 120A, respectively. The same parameter for load balance objective is set. Further, the weighting values obtained by the AHP method [11] are 0.4673, 0.2772, 0.1601, and 0.0954 for LR, SO, DO, and LB objectives, respectively.

Table 2 shows the pre-fault data for lateral loads and feeders for different cases. These data are acquired for simulating the possible scenarios of the TPC distribution system. Fig.3 depicts the optimization processes of

the best fuzzy objective value obtained by the HBF, DE, and EDE, GA-BCO methods. As can be seen from the proposed method (GA-BCO) is able to find optimal solution than other methods .Also speed of convergence of this method is higher than the first two methods. In other words, an optimal solution is obtained in early iterations of the algorithm, the answer is a more efficient than DE and HBF methods require about 21 and 53 iterations, respectively. (The number of iterations required to reach convergence) are obtained.

Half of iterations (50 iterations First) algorithm by using GA and the other half (50 iterations II) was performed using the BCO algorithm. Carefully at how the convergence results in Fig.3 show can be seen that the optimal solution the algorithm to GA in 50 first iteration has to better answer than other methods, but the optimal solution final by doing more iteration with Algorithm BCO to The answer is better.

In other words, if each of these algorithms (GA, BCO) to be applied individually to obtain an optimal solution, worse than the optimal solution is the combination of these two methods is obtained.

To verify the convergence performance of the proposed method, the simulations of convergence time through 100 trials with different random numbers are also executed. As shown in Table 1, time obtained by the AHP, HBF, DE, EDE and GA-BCO methods is 6.10s, 11.25s, 2.05s and 1.24s, respectively.

The best fuzzy objective value and associated membership values obtained by each method are shown in Table 3.
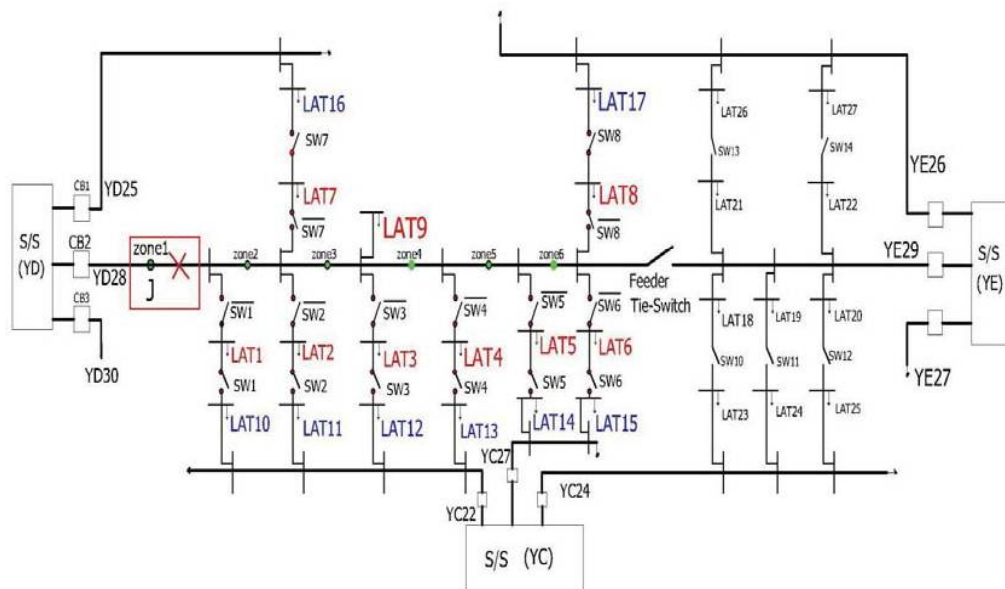
Fig. 2. Typical TPC 11-22 KV network to evaluate the performance of the proposed algorithm

Compared to the EDE method, the proposed GA-BCO yields a better result from the view of load balance condition, as shown in Table 3.

Table 1. Run time of simulations

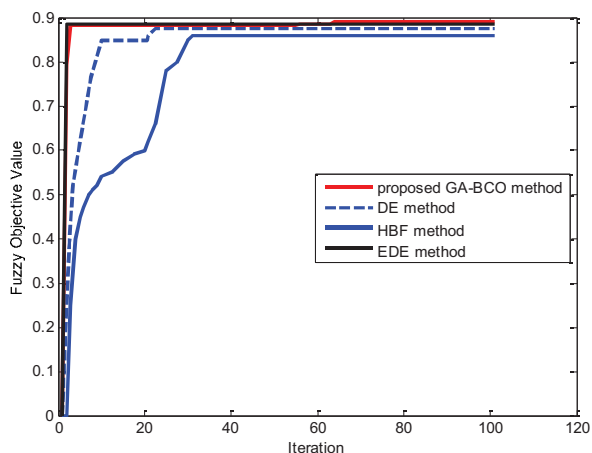| Method	Average time (s)	minimum time (s)	Maximum time (s)
HBF	11.25	11.05	12.65
DE	6.1	5.69	6.18
EDE	2.05	2.03	2.13
GA-BCO	1.24	1.11	1.28

Fig. 3. The best value of the objective fuzzy optimization particle population

5. CONCLUSIONS

In this paper, the optimal method combined GA-BCO; distributed systems have been developed for fast retrieval. By using hybrid algorithm makes it possible to utility the advantages of both algorithms and to improve the defects of them. In the proposed method, at first, genetic algorithms search to solve the speed of the whole space generally. After 50 iterations of the relative optimal solution are obtained. In this solution as the initial solution BCO algorithm is considered. The algorithm is checked carefully more details about the relative optimal solution found with genetic algorithms and put the final optimal solution. To prove the efficiency of the proposed method is tested on different modes of distribution system of Taiwan Power Company was 11-22 KV. The results show that this method is better than other methods. Although this paper was to evaluate the performance of the algorithm in a fault place, but using this algorithm for fault in other areas of the network better answers than other methods will follow.

Table 2. Pre-fault data for lateral loads and feeders

	lateral loads (Amperes)	LAT1 37	LAT2 47	LAT3 33	LAT4 19	LAT5 56	LAT6	LAT7 53	LAT8 27	LAT9 22
Case I	supporting laterals (Amperes)	LAT_{10} 51	LAT_{11} 39	LAT_{12} 46	LAT_{13} 37	LAT_{14} 34	LAT_{15} 38	LAT_{16} 23	LAT_{17} 80	
	Feeder (Amperes)	YD28 346	YD25 240	YC22 220	YC27 260	YE26 250	YE29 175			
Case II	lateral loads	LAT1 29	LAT2 43	LAT3 40	LAT4 22	LAT5 24	LAT6 31	LAT7 63	LAT8 52	LAT9 63
	supporting laterals	LAT10 74	LAT11 56	LAT12 61	LAT13 63	LAT14 78	LAT15 35	LAT16 69	LAT17 47	
	feeder	YD28 394	YD25 351	YC22 283	YC27 369	YE26 280	YE29 203			
Case III	lateral loads	LAT1 29	LAT2 49	LAT3 69	LAT4 51	LAT5 69	LAT6 71	LAT7 49	LAT8 28	LAT9 67
	supporting laterals	LAT10 51	LAT11 39	LAT12 24	LAT13 37	LAT14 34	LAT15 31	LAT16 60	LAT17 80	
	feeder	YD28 446	YD25 240	YC22 220	YC27 260	YE26 256	YE29 127			
Case IV	lateral loads	LAT1 35	LAT2 45	LAT3 31	LAT4 17	LAT5 54	LAT6 61	LAT7 51	LAT8 25	LAT9 20
	supporting laterals	LAT10 51	LAT11 39	LAT12 46	LAT13 37	LAT14 34	LAT15 38	LAT16 23	LAT17 80	
	feeder	YD2 346	YD25 240	YC22 220	YC27 260	YE26 250	YE29 175			

Table 3. Best fuzzy objective value and the associated membership functions for different cases

Case	Methods	LR^{1}	SO^{2}	DO^{3}	LB^{4}	Best Fuzzy Objective Value
Case I	HBF	1	0.8571	0.95	0.2317	0.8791
	DE	1	0.8571	1	0.1906	0.8832
	EDE	1	0.8571	1	0.225	0.8865
	GA-BCO	1	0.8571	1	0.2656	0.8903
Case II	HBF	1	0.7143	0.9	0.2	0.8285
	DE	1	0.7143	1	0.1938	0.8439
	EDE	1	0.8571	0.8889	0.137	0.8603
	GA-BCO	1	0.8571	0.8889	0.1617	0.8626
Case III	HBF	1	0.7143	0.85	0.1977	0.8202
	DE	1	0.7143	0.85	0.1977	0.8202
	EDE	1	0.7143	1	0.1688	0.8415
	GA-BCO	1	0.7143	1	0.1764	0.8422
Case IV	HBF	1	0.8571	1	0.2688	0.8903
	DE	1	0.8571	1	0.2561	0.8889
	EDE	1	1	0.9333	0.1313	0.8932
	GA-BCO	1	1	0.9333	0.1549	0.9087

1: Load restoration, 2: Switches operation, 3: Devices overload, 4: Load balance

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