Research Journal of Applied Sciences, Engineering and Technology 8(18): 1933-1938, 2014
DOI:10.19026/rjaset.8.1184
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: May 19, 2014 Accepted: June 18, 2014 Published: November 15, 2014

Research Article

Implementation of Rank Evolutionary Programming (REP) in 16 kV Feeder Reconfiguration for Convergence Time Improvement

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Abstract: The increase of energy demand has generated a complexity of electrical network while contributing to the numbers of power losses in the system. This study presents a Distribution Feeder Reconfigurtion (DFR) by using heuristic algorithm which is called as Rank Evolutionary Programming (REP). The main objectives of this study are to improve the computing time and minimize the power losses effectively. The performance of the REP method will be investigated and the impact to the test system IEEE 16-kV distribution network will be analyzed accordingly. The results of this study is hoped to help the engineers in order to secure and increase the efficiency of the real power distribution system in the future.

Keywords: Convergence time, distribution feeder reconfiguration, power losses, rank evolutionary programming

INTRODUCTION

Over 70% of the total losses in power system come from the distribution network. Almost every year, the electricity providers' companies have reported that one of the scopes for critical money goes to the research on reducing the losses, secure the demand and balance the load effectively. The minimum power losses and quality of voltage profile are the major aspect for an efficient distribution system. Therefore, the distribution feeder reconfiguration is needed; and become more popular to explore in order to get the ideal solution during the high demand of electrical energy. The distribution feeder reconfiguration is defined as changing the open and close feeder switches in the network system and usually done for loss reduction via the solution involves a search over relevant radial configurations (Savier and Das, 2007; Liu *et al*., 1989).

There are many existing methods have been proposed to solve the problems for feeder reconfiguration such as Genetic Algorithm (GA) and Evolutionary Strategies (ES), Tabu Search (TS), Artificial Neural Network (ANN), Simulated Annealing method (SA) and Fuzzy mathematics with the objectives to solve the optimum power losses for distribution feeder reconfiguration problems (Aman *et al*., 2013; Hu *et al*., 2010; Sulaima *et al*., 2013, 2014a).

Evolutionary programming has been introduced in the research of distribution power system over the year (Whitley, 2001; Milani and Haghifam, 2013; Miranda *et al*., 1998). The evolutionary programming is a technique that can be applied to identify an optimal switching feeder for plan reconfiguration (Tsai and Hsu, 2010). During reconfiguration, two objectives are considered by the operating system operator. They are minimum losses and excellence voltage profile. The computer program that is giving adequate switching plan to reconfigure the feeders can be referred by the engineers in order to get the appropriate number tie switches to be opened in the system.

The best radial configuration of switches (on/off) is an important element in minimizing the energy loss in large power distribution system (Taleski and Rajicic, 2007). Many researchers have proposed a lot of techniques for energy loss reduction by developing several new heuristic rules to lead the iterative process, make the less energy loss, effective convergence time, robust and fast.

There are numerous optimization methods in solving the 11, 33 and 69 kV, respectively distribution network reconfiguration, but there are small numbers for 16 kV network systems. In this study, in order to solve the problems in minimizing the time for computational time while searching for optimal power losses; a modified heuristic method which is called as Rank Evolutionary Programming (REP) is introduced. The 16 kV test system is chosen because of it easy to involve with losses increment due to the change of the network environment such as backup load demand, human error and nature disaster. The performance analysis of Rank Evolutionary Programming (REP), conventional Evolutionary Programming (EP) and Genetic Algorithm method (GA) will be investigated,

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respectively. The results will be analyzed in order to select the best technique with optimal convergence time while reducing the feeder losses in 16 kV power distribution network system.

METHODOLOGY

Mathematical model for a DFR: The most important criterion for distribution feeder reconfiguration is to search a radial operating structure that minimizes the system power loss while satisfying operating constraints. Thus, the network reconfiguration for loss minimization can be formulated as shown in Eq. (1) and (2).
Minimize:

$$f_c = \sum_{i=1}^{n} Loss\ i \qquad i \in NL \tag{1}$$

$$\text{i.e., } f_c = \sum_{i=1}^{n} |I_i|^2 k_i R_i\ i \in N \tag{2}$$

where, f_c is the loss function, I_i is the current in branch i, R_i is the resistance of branch, NL is the total number of branch and k_i is the variable that represents the topological status of the branch (0 = open, 1 = close). From the Eq. (1), the total power loss can be increased when the main source is sending the large amount if current, I_i through certain branch in the network to achieve the target demand at the end of feeder. But, with the reconfiguration network, it can be solved the problem to minimize the power losses by changing the closed and open switching in the network accordingly.

There are several constraints that must be satisfied during the network reconfiguration:
Radial network constraint: Distribution network should be composed of the radial structure considering operational point of view.

Node voltage constraint: Voltage magnitude at each node must lie within their permissible ranges to maintain power quality. The standard minimum voltage used is 0.95 and maximum voltage is 1.05 (1±5%):

$$V_{min} \le V_{bus} \le V_{max} \tag{3}$$

Feeder capability limits:

$$|I_k| \le I_k^{max} \in \{1,2,3 \ldots\} \tag{4}$$

where,
I_k^{max} = Maximum current capability of branch k

Load flow and line losses formulation: In this study, the Newton Raphs on Load Flow method has been used. Where, load flow studies are needed in scheduling, economic planning, control of the existing system and planning its future expansion. The Newton-Raphson Load Flow equations as follow:

$$P_i = \sum_{j=1}^{n} \frac{|Y_i||V_j||Y_{ij}|}{\cos(\theta_{ij} - \delta_i + \delta_j)} \tag{5}$$

$$Q_i = -\sum_{j=1}^{n} \frac{|Y_i||V_j||V_{ij}|}{\sin(\theta_{ij} - \delta_i + \delta_j)} \tag{6}$$

where,
V_j, V_i : Voltage magnitude of bus i and j respectively
δ_i, δ_j : Voltage angle of bus i and j respectively
Y_{ij}, θ_{ij} : Magnitude and angle of Y_{ij} element in the bus admittance matrix, respectively

The equations for the difference in real power (ΔP_i) and reactive power (ΔQ_i) are:

$$\Delta P_i = P_i^{sp} - P_i \tag{7}$$

$$\Delta Q_i = Q_i^{sp} - Q_i \tag{8}$$

P_i^{sp} and Q_i^{sp} are the specified real and reactive power at bus i, respectively.

The rectangular Newton-Raphson power flow is expresses as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{9}$$

Power loss equation as follow:

$$P_{loss} = \sum_{i=1}^{n} \sum_{i=1}^{n} A_{ij}(P_i P_j + Q_i Q_j) + BijQiPj\text{–}PiQj \tag{10}$$

$$A_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_i V_j} \tag{11}$$

$$B_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_i V_j} \tag{12}$$

where,
P_i : Real power at bus i, respectively
P_j : Real power at bus j, respectively
Q_i : Reactive power at bus i, respectively
Q_j : Reactive power at bus j, respectively
R_{ij} : Line resistance between i and j
$V_i\, V_j$: Voltage magnitude of bus i and j, respectively
$\delta_i \delta_j$: Voltage angle of bus i and j, respectively

Implementation of REP: The REP search method for determining the optimal solution to the feeder reconfiguration problem is implemented. The programming has been written and the entire data network has been used. The REP programming has been tested on MATLAB for result analysis accordingly. The network is determined based on the switches position as representing the fitness function. Tie switches are symbolized by using the integer such as 1, 2 or 3. The main body of REP comes from Evolutionary Programming (EP) that was originally conceived by Fogel *et al*. (1966). Nevertheless, in REP, the "Ranking" concept is introduced in order to boost the convergence time while searching for the superior numbers of losses reduction.

The REP technique has used the frame of EP and is rejuvenated with the ranking concept with the objective to find the optimal solution in a complex problem. Generally, there are several steps of REP method. The proposed rank selection concept is explained in Step 6 (red doted). The steps for proposed REP are.

Step 1: Random generation of initial population: The process for the optimal solution is done by determining a population of candidate solution over a number of generations randomly.
Step 2: Fitness computation: The strength of each candidate solution is determined by its fitness function which is evaluated based on the constraint in the objective function of the optimization process.
Step 3: Mutation: Others will combine through a process of mutation to breed a new population.
Step 4: Combination: Combination process will occur after the mutation that will combine the parent and offspring.
Step 5: Tournament: Tournament is done to select the survival for the next generation.
Step 6: Ranking selection: The survival selection population from the tournament is ranked and selected to next generation.
Step 7: Transcription of next generation: The new population is evaluated and the process is repeated.

Optimization in the conventional method which is EP can be summarized into two major steps. They are mutational of the solution in population and mutational transformations (β) play a crucial role in EP. The mutation is the key of search operator which generates new solutions (offspring) from the current one (parent). But the solution of conventional method is not completely enough to select the mature and optimal new population. Due to that reason, the proposed method which is REP presents the rank process that has been used to rank the score after the tournament is done. This process will create the best mature of the survival population for the next generations. The implementation of the REP method in DFR is explained as below.

Initialization: Input system data includes network data, buses data, lines data and load data are called to REP programming while value for maximum iteration, population size and accuracy are set accordingly. The initialization population is determined by selecting tie switches from the set of original tie switches. After that, the variable will be generated by the system via a random generator available in the program and they will be utilized to compute the power losses in the next step. Equation of tie switches as shown:

$$X = [S_1, S_2, S_3 \dots\dots\dots S_Y] \tag{13}$$

where,
S = Variable for tie switch
γ = Number of tie switches

Furthermore, to ensure the radial network is maintained, several constraints need to be considered in the system. There are several conditions have been adopted for the selection switches:

- **Condition 1:** All switches that do not belong to any loop are to be closed.
- **Condition 2:** All switches are connected to the sources are to be closed.
- **Condition 3:** All switches contributed to a meshed network need to be closed.

Fitness calculation: For the fitness calculation is the type of objective function that need to optimized and solved for the power loss of the system. The power flow will be accomplished and the total power loss will be calculated using the Newton-Raphson load flow program for each particle that fulfills the constraint. Subsequently, evaluation of maximum, sum and average of fitness is carried out which will be utilized in the mutation process.

Mutation: Mutation is the process of generating the offspring of the random numbers. The Gaussian mutation technique has been used significantly. It has been implemented by using below equation:

$$X_i = X_{i,j} + N(0, \gamma^2) \tag{14}$$

$$\gamma^2 = \beta\left(X_{jmax} - X_{jmin}\left(\frac{f_i}{f_{max}}\right)\right) \tag{15}$$

where,
X_{i+mj} = Mutated parents (offspring)
X_{ij} = Parents
N = Gaussian random variable with mean μ and variance γ^2
β = Mutation scale, $0 < \beta < 1$
X_{jmax} = Maximum random number for every variable

X_{jmin} = Minimum random number for every variable
f_i = Fitness for the i^{th} random number
f_{max} = Maximum fitness

The mutation scale or search step, β determine the convergence rate. Large value or β will cause slow convergence of the REP since it implies to a large search step. Thus it will lead to large computation time.

Fitness calculation and combination: At this stage, the fitness function (value of power losses) is recalculated in order to get new fitness value based on the new generate state variables (new tie switch) during mutation process. Subsequently, the combination process will combine the parents and offspring in cascade mode.

Tournament process: REP employs a tournament scheme as to choose the survivals (new tie switches) to the next generation. This process is used to identify the candidates that can be transcribed into the next generation from the combined populations of the parent and offspring.

Ranking selection: The ranking selection is used to identify the candidates (new tie switches) that can be transcribed into the next generation from the tournament process. The ranking concept been done by sort and rearrange the priority mature survival (best new tie switches) to be selected for the next generation while the priority selection was done whereby the populations of individuals with better fitness (best value of optimal power losses) were sorted in descending order according to their fitness values (losses value).

Convergence test: Convergence test is required to determine the stopping criteria of the evolution. The convergence criteria are specified by the difference between maximum and minimum fitness ≤ 0.0001. The mathematical equation is given as follow:

$$maximum_{fitness} - minimum_{fitness} \leq 0.0001 \quad (16)$$

The simulation and test system: The 16-bus radial distribution system as shown in Fig. 1 is used for this work. The system consist of 3 feeders, 13 sectionalizing switches (normally close switches) and 3 tie switches (normally open switches with dotted line) and located on branch No. 14, 15 and 16. It also has 13 load centres and is assumed to be constant with initial load capacities for total real and reactive power is 28.7 MW and 16.3 MVAr, respectively. The base MWA for the system is set at 100 MVA. In other word, the total optimization variable is represented by combination of 3 switches (X1, X2 and X3) (Sulaima *et al*., 2014b). The calculations for all the techniques are carried out in the per-unit system.

Four cases have been executed in determining their reliability of having REP, EP and GA in the system to achieve best configuration.

The first case: The system follows the original network distribution of 16-bus without any alteration done. All the switches in the network remain the same.

The second case: The reconfiguration strategy is applied in the system is based on GA method.

The third case: The reconfiguration strategy is applied in the system is based on EP method.

The fourth case: The reconfiguration strategy is applied in the system is based on REP method.

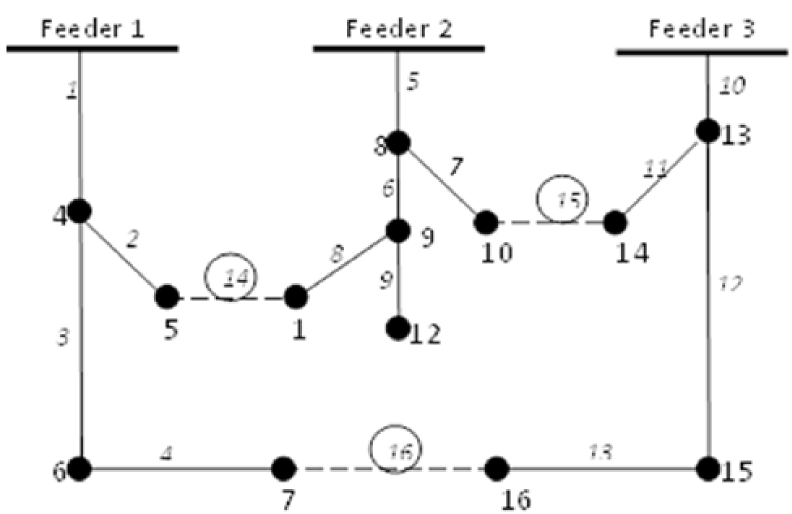

Fig. 1: Sixteen kV initial test network system

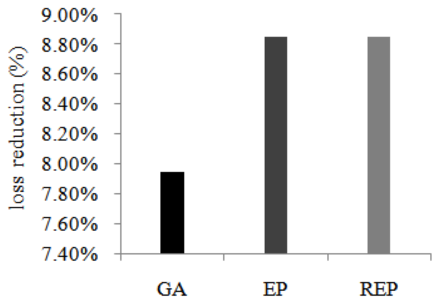

Fig. 2: Comparison of total power losses reduction

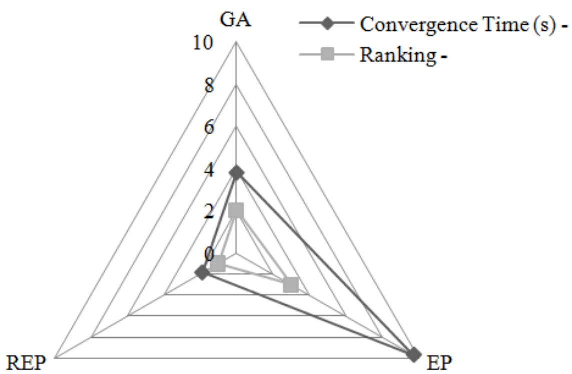

Fig. 3: Computing times

Table 1: Summary of simulation results for four cases

Parameters	Initial	GA	EP	REP
Tie lines	14,15,16	16,8,11	7,8,16	16,14,7
Power loss (MW)	0.5114	0.4707	0.4661	0.4661
Loss reduction (MW)	-	0.0407	0.0453	0.0453

Table 2: Summary of simulation computational time

Parameters	GA	EP	REP
Convergence time (sec)	3.8	9.7	1.88
Ranking	2	3	1

RESULT ANALYSIS

The proposed algorithm is tested on radial 16-bus distribution test system. The numerical result of power losses and the number of switches to be opened are summarized in the Table 1. The radial constraint is sustainable by three switches to be opened when the GA, EP and REP techniques are applied to the system. REP selects the switches (16, 14, 7) to be opened while the EP and GA show the different number of open switches which are 7, 8, 16 and 16, 8, 11, respectively. Nevertheless, the value for minimum power losses between REP and EP are remain the same number (0.4661 MW) but they are better than GA technique which is only 0.4707 MW of the power loss. Furthermore, in terms of loss reduction; the case 2, 3 and 4 has the significant reduction if to be compared to the case 1. Figure 2 shows the percentage of comparison in terms of total power losses reduction. By using the GA technique, the total loss reduction has decreased approximately 7.95% while EP and REP techniques have presented a better percentage which is 8.85% concurrently.

Conversely, in scope of computational time results, the proposed technique which REP (case 4) has proven the superior finishing due to find the optimum value with the fast respond. The ranking concept by sorting and rearrange the priority new tie switches while the priority selection was done whereby the opened switches with better value of optimal power losses are detected in a fast way. The Table 2 and Fig. 3 show the summary of convergence time that has been taken from case 2, 3 and 4 accordingly. REP shows the better result if to be compared to the others techniques which 1.88 sec to get converge. The convergence time for GA and EP are 3.8 and 9.7 sec, respectively. Other than that, the proposed technique (REP) has improved the computational time for conventional EP as presented in previous study (Sulaima *et al*., 2014a, b).

CONCLUSION

In this study, REP algorithm has been developed to solve the DFR with the objectives to find the optimum computational time and improve the losses reduction. The REP and EP are seen to share the same number of power losses reduction but REP is superior in terms of fast to respond in providing the optimal results. As the conclusion, the REP produces a feasible and encouraging solution better than GA and conventional EP methods while giving a great impact for the whole 16 kV distribution feeder reconfiguration system. The future investigation can be done by implementation of the proposed technique to the huge scale of network such as 33 and 69 kV with the objectives to reduce the power losses, balance the load and improve the voltage profile simultaneously.

ACKNOWLEDGMENT

The authors would like to thank the Universiti Teknikal Malaysia Melaka (UTeM) and University Putra Malaysia (UPM) for all the support given. This research is supported by the PJP grant; UTeM (PJP/2013/FKE (29C) S01271.

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