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A Hybrid Intelligent Method for Estimating Distribution Network Reconfigurations

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Abstract: This paper proposes a hybrid intelligent method for estimating distribution network reconfigurations. As the idea of smart grid is well-spread in the world, a good method is required to deal with distribution network operation. In this paper, distribution network reconfigurations are discussed to evaluate the distribution network losses. The emergence of renewable energy such as PV system and wind power generation makes nodal voltage magnitudes fluctuate due to weather conditions. In this paper, a hybrid intelligent method of RBFN (Radial Basis Function Network) of ANN (Artificial Neural Network) and Regression Tree of Data Mining is proposed to estimate distribution network reconfigurations to reduce distribution network losses efficiently. RBFN is used to estimate network reconfigurations from the network conditions. As a prefiltering technique, Regression Tree plays a key role to classify input variables into some clusters where RBFN is constructed at each cluster. The use of the technique makes the learning process of RBFN much easier. The proposed method is successfully applied to a sample system. A comparison is made of the proposed and the conventional methods in terms of errors and computational time.

Keywords: Distribution network, Distribution automation, Loss minimization, Artificial intelligence, Neural networks, Estimation, Data Mining

1. INTRODUCTION

This paper presents a method for estimating network reconfigurations to minimize distribution network losses. Since distribution networks are radial, optimal network reconfigurations need that one sectionalizing switch is opened while another is closed under some constraints. In recent years, it is very hard for human dispatchers to deal with distribution network operation due to the complexity. To smooth distribution system operation, distribution automation plays an important role to improve reliability of power supply (Ross, et al., 1981). It may be classified into the following: network loss minimization (Civanlar, *et al.,*1988; Nara, *et al.,* 1992), network reconfigurations (Aoki, *et al,* 1987; Baran and Fu, 1989b; Chiang and Jean-Jimeau, 1990; Kim and Jung, 1993; Jiang and Baldick, 1996; McDermout, *et al.,* 1999; Mori and Ogita, 2000; Ogita and Mori, 2012), voltage and reactive power control(Baran and Fu, 1989a; Mori and Hayashi, 1997), service restoration (Liu, *et al.,* 1988; Mori and Ogita, 2002; Mori and Furuta, 2005), state estimation, *etc.* This paper focuses on the above network reconfigurations to reduce distribution network losses. By network reconfigurations we means that distribution system operators determine which switches are turned on or off while satisfying the constraints. The mathematical formulation may be expressed as one of combinational optimization problems. However, it is well-known that combinatorial problems are hard to solve. So far, a lot of studies have been done in distribution network reconfigurations. The conventional methods may be classified as follows:

a) Mathematical programming
b) Heuristics
c) Meta-heuristics

Mathematical programming is too time-consuming to evaluate solutions although there is possibility that the optimal solution is theoretically obtained as well as the problems of evaluating a local minimum. Heuristics provides solutions fast, but the quality of solutions are not satisfactory. Apart from items a) and b), meta-heuristics is one of promising methods. It gives better solutions by repeating some heuristics or rules and does not require more computational time relatively while it keeps the solution quality. Smart Grid is one of hot topics in distribution systems. Renewable energy such as PV systems and wind power generation is positively introduced into Smart Grid. Although the use of renewable energy leads to the contribution of low carbon society, it often gives uncertain generation output due to changeable weather conditions. As a result, it is afraid that nodal voltages changes in distribution systems significantly. Distribution system operators are interested in solving the following:

i) To solve operational problems efficiently
ii) To consider the uncertainties

In this paper, item i) is discussed to make distribution automation smooth. An ANN-based efficient method is proposed to evaluate the distribution network reconfigurations with Radial Basis Function Network (RBFN) of Artificial Neural Network (ANN) (Powell, 1987). RBFN is well-known for good performance of nonlinear approximation for nonlinear systems in a sense that it outperforms the conventional ANN like MLP (Multi-layered Perceptron). To improve the performance, this paper makes

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use of the prefiltering technique of classifying input variables into some clusters, where RBFN is independently constructed at each cluster (Mori and Yuihara, 2001; Mori and Kosemura, 2001). It makes the learning process much easier so that the model accuracy is improved. The proposed method is successfully applied to the 32-node distribution system.

2. DISTRIBUTION SYSTEM RECONFIGURATION

This section describes the distribution network reconfiguration. The objective of distribution network reconfiguration is to optimize a certain cost function under the constraints through turning on/off sectionalized switches. Specifically this paper focuses on the cost function of distribution network losses. Also the constraints mean the upper and the lower bounds of nodal voltage, the limitation of feeder currents, the conditions of radial networks. The distribution network reconfiguration may be expressed as a combinational problem of sectionalize switches. Thus the mathematical formulation may be written as

Cost function :

$$f = P_{loss} \rightarrow \min \tag{1}$$

Constraints :

$$y_s = g(\mathbf{x}) \tag{2}$$

$$V_i^m \leq V_i \leq V_i^M \tag{3}$$

$$I_j \leq I_j^M \tag{4}$$

where,

f : cost function

P_{loss} : active power loss

y_s : nodal specified value

$g()$: power flow equation

$\mathbf{x}$: nodal voltage vector

V_i : *i-th* nodal voltage magnitude

$V_i^M \left(V_i^m\right)$: upper (lower) bound of V_i

I_j : *j-th* feeder current

I_j^M : upper bound of I_j

As a metaheuristic method, the solution may be evaluated by introducing the penalty function method into Eqns.(1)-(4).

3. TABU SEARCH

This section describes Tabu Search (TS) (Glover and Laguana, 1989, 1990). It is one of meta-heuristics for solving combinational optimization problems. It is based on the process that iteratively makes use of rules or heuristics to obtain a highly approximate solution to a globally optimal solution. Apart from TS, SA (Simulated Annealing) (Kirkpatrick, *et al.,* 1983), GA (Genetic Algorithm) (Holland, 1975; Goldberg, 1989), PSO (Particle Swarm Optimization) (Kennedy and Eberhart, 1995), and ACO (Ant Colony Optimization) (Dorigo and Stutzle, 2004) are quite popular in the engineering fields. Among them, TS is better than others in terms of computational efficacy and solution accuracy in solving combinatorial optimization problems. In addition, it has less parameters to be tuned up than others. This paper focuses on TS to solve the problem of distribution network reconfiguration. TS creates the neighborhood around a solution at each iteration, where the best solution is selected in them and becomes an initial solution of the next search process after creating the neighborhood and examining the solution candidates. This process corresponds to local search of the hill climbing method that easily gets stuck in a local minimum. To escape from a local minimum, TS introduces the tabu list into the local search. It serves as the adaptive memory function that keeps some attributes fixed for while. The technique avoids getting stuck in a local minimum. The length of the tabu list is referred to as tabu length. It is noteworthy that TS has only a parameter to be tune up, *i.e.,* the tabu length. To enhance the performance of TS, this paper employs the aspiration level that allows updating the attributes in the tabu list if the solution candidate gives a better solution. As mentioned before, TS is better than SA and GA. However, TS is inclined to be more time-consuming in applying it to a large scale problem because of the increase of the solution candidates in the neighbourhood. Therefore, it is necessary to consider more sophisticated strategies that improve the search process in the neighbourhood. In other words, a strategies TS is required to handle a complicated combinatorial optimization problems.

4. DATA MINING

4.1 Regression Tree

This section describes a regression tree that is one of data mining methods. It aims at discovering important rules in large database. This paper focuses on CART(Classification and Regression Trees) (Breiman, *et al.,* 1984). The decision tree allows to extract rules and clarify the relationship between input and output variables. The decision tree may be classified into the classification and regression trees. The classification tree may be expressed as the relationship between quantitative input and qualitative output variables. On the other hand, the regression tree handles a quantitative one. In this paper, the regression tree is employed since distribution network losses may be expressed as a quantitative variable. Fig. 1 shows the concept of the regression tree, where it consists of the splitting and terminal nodes. The split nodes S_1~S_4 have splitting conditions and terminal nodes T_1~T_5 indicate the classification results with similar data. The top node is called *root node* that is the starting node of the tree. The input data is compared with the

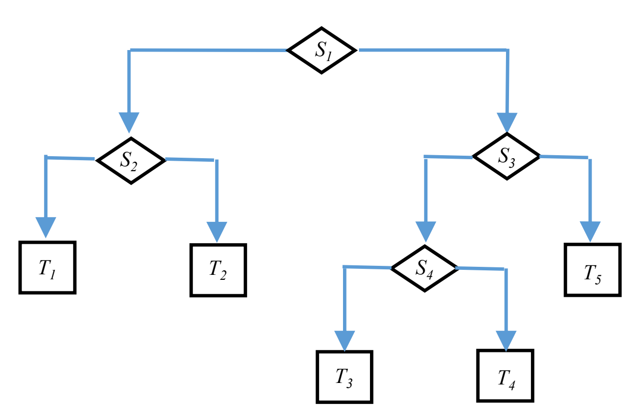

Fig. 1. Structure of regression tree.