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Reliability forecasting models for electrical distribution systems considering component failures and planned outages

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ABSTRACT

Many utilities in developing countries are investing in installation and renewing of Electrical Distribution System (EDS) components, such as overhead lines, cables and switching devices, to improve the EDS reliability and meet the rapid increase of load demand. In the beginning stage of investment, it is very difficult to evaluate the EDS reliability by using traditional methods due to EDS topology not being fully determined. This paper presents a comprehensive model for forecasting EDS reliability, which is built separately into two parts, i.e. the models for EDS failures and planned outages. Firstly, a three-layer Artificial Neural Network (ANN) model is proposed to forecast the EDS reliability considering EDS failures. Each neuron in the ANN input layer represents a key influencing factor of EDS failures, which are recognized by Gray Relational Analysis (GRA) method. The proposed ANN is trained using historical reliability data of an EDS. In addition, a planned outage reliability model is also built according to the magnitude of investment and type of planned outage. The priorities of improvement measures can also be obtained using the GRA to improve the EDS reliability. Case studies of practical EDSs illustrate the efficiency and applicability of the proposed techniques.

Introduction

Forecasting technique is widely used in many research fields, such as load forecasting, temperature forecasting and stock market forecasting. Reliability forecasting of a power system, such as an Electrical Distribution System (EDS), is a statement about the system reliability performance that will be realized in the future based on current information.

EDS is an important link between power system supply and the distribution customers. EDS reliability forecasting techniques can be used to directly evaluate the reliability performance of an EDS in the future, analyze the reliability performance trend of an EDS, recognize the weak parts of an EDS, propose reliability improvement suggestions to design schemes, and address reliability price and unreliability cost contributions in an electricity market [1,2]. In other words, reliability forecasting techniques are considerably helpful in the processes of EDS design, planning and operation.

Currently, there exists considerable research on non-power-system reliability forecasting techniques. Ref. [3] proposed a software reliability forecasting model using support vector regression, which was solved by a combination of genetic algorithm and simulated annealing algorithm. Ref. [4] proposed a real-time reliability forecasting technique for dynamic systems based on an online failure forecasting method. Ref. [5] proposed a reliability forecasting model for semiconductors using a combinatorial technique using fuzzy logic and component failure modes. Compared with other forecasting methods, Ref. [1] discussed the effectiveness of support vector machine in reliability forecasting for generating units. Ref. [6] proposed several pattern recognition algorithms and analyzed their practicability in component reliability forecasting. Ref. [7] used a technique called Group Method of Data Handling (GMDH) to forecast the reliability of flexible manufacturing systems.

Unfortunately, there has not been work on reliability forecasting of EDS. Ref. [8] proposed a forecasting method of EDS reliability indices by using logistic regression and dynamic regression models. Ref. [9] proposed a method for forecasting the reliability parameters, such as failure rate, of overhead distribution lines using radial-basis-function Artificial Neural Network (ANN), which was built by using data fitting techniques. Ref. [10] proposed a reliability forecasting method for EDS feeders using fuzzy set theory. It can be seen from the above discussion that time series methods, ANN and similar methods were used to forecast the reliability

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performance for a component or an EDS based on the collected reliability information.

There is one key assumption implicit in the methods described, i.e. the component or EDS system reliability performance parameters have steady values. The behavior of component failures is typically a random process, which always results in the difficulty of establishing an accurate model for the component reliability parameters, such as failure rate. More importantly, many measures were used in EDS in these cases, such as replacing feeders and installation of switching devices and tie lines, which resulted in changes in the EDS system performance. Therefore, the above methods are unsuitable to forecast the changing reliability performance of an EDS. In addition, these methods lack inclusion of the effect analysis of key influencing factors on the EDS reliability, such as the number of tie lines, the average length of feeder sections and the ratio of insulated feeders to total feeders.

Although there are many factors influencing the EDS reliability performance based on the above analysis, there is relatively little research on the model of EDS reliability forecasting considering influencing factors. It is, therefore, important to propose an EDS reliability forecasting technique considering all key influencing factors.

This paper proposes an ANN model for forecasting the system reliability considering EDS component failures by exploring the relationship between the key influencing factors and the system reliability. It should be noted that the proposed method is mainly used in the following cases: (1) the EDS reliability performance may be change due to component installations and the change of EDS structure; (2) the network structure is not still fully determined and even parts of planning scheme need a little adjustment after taking improvement measures. In the developing countries, the EDS engineers always face these situations.

In the foregoing situations, on one hand, the EDS reliability evaluation cannot be conducted due to uncertainty of component reliability parameters and the structure of an EDS; on the other hand, directly evaluating the reliability performance of an EDS is a time-consuming process for an EDS with a large number of feeders. Therefore the reliability forecasting methods may provide a suitable tool to deal with these issues and situations.

Influencing factors of EDS component failures

EDS reliability indices

Total Customer Outage Hours (TCOH) is defined as the sum of products of the number of customers at each load point and its annual outage time. Total Customer Outages (TCO) is defined as the sum of products of the number of customers at each load point and its annual outages.

$$\mathrm{TCOH} = \sum_{i \in R} U_i N_i \tag{1}$$

$$\mathrm{TCO} = \sum_{i \in R} \lambda_i N_i \tag{2}$$

where U_i, λ_i and N_i are the annual outage time, outages and the number of customers at load point i, respectively; R the set of load points of an EDS.

There are many common EDS reliability indices being widely used in practical EDSs [11], including SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), ASAI (Average Service Availability Index) and ASUI (Average Service Unavailability Index).

$$\mathrm{SAIDI} = \frac{\mathrm{TCOH}}{\sum_{i \in R} N_i} \tag{3}$$

$$\mathrm{SAIFI} = \frac{\mathrm{TCO}}{\sum_{i \in R} N_i} \tag{4}$$

$$\mathrm{ASAI} = 1 - \frac{\mathrm{TCOH}}{8760 \sum_{i \in R} N_i} \tag{5}$$

$$\mathrm{ASUI} = 1 - \mathrm{ASAI} \tag{6}$$

It can be seen from (3)–(6) that the key step in the reliability forecasting and evaluation of an EDS is the calculation or forecasting of TCOH and TCO.

Both component failures and planned outages contribute to the unreliability of an EDS. Therefore, TCOH can be divided into two parts, i.e. TCOH-F (Total Customer Outage Hours due to component failures) and TCOH-P (Total Customer Outage Hours due to planned outages). Similarly, other indices, such as TCO-F, TCO-P, SAIDI-F and SAIDI-P, can be defined. For simplicity, TCOH is used as an example to explain the proposed concepts and forecasting processes.

Influencing factors of EDS component failures

Many factors, such as management level of utility, technical level of EDS engineers, average reliability performance of each type of component, proportion of each type of components and EDS configuration, influence the EDS reliability performance considering component failures. The reliability management level of utility, technical level of EDS engineers and average reliability performance of each type of components are assumed to be unchanged. Therefore, this paper studies the influencing factors of EDS component failures from other aspects, which are as follows:

(1) F_1: Ratio of available tie lines (%), ratio of the number of feeders in an EDS, which can be transferred to other feeders, to the number of total feeders;
(2) F_2: Ratio of cables (%), ratio of the length of cable feeders in an EDS to the total length of feeders;
(3) F_3: Ratio of insulated feeders (%), ratio of the length of insulated feeders in an EDS to the total length of feeders;
(4) F_4: Average length of each section (*km*/section), the total length of all feeders divided by the number of total sections in an EDS;
(5) F_5: Average number of customers in each section (customers/section), the number of total customers divided by the number of total sections in an EDS;
(6) F_6: Average number of circuit breakers of each feeder (breakers/feeder), the number of total circuit breakers divided by the number of total feeders in an EDS;
(7) F_7: Average number of transformers at each feeder (transformers/feeder), the number of total distribution transformers divided by the number of total feeders in an EDS;
(8) F_8: Average capacity of transformers at each feeder (MVA/feeder), total capacity of distribution transformers divided by the number of total feeders in an EDS;
(9) F_9: Ratio of tie lines (%), ratio of the number of feeders with tie lines in an EDS, to the number of total feeders;
(10) F_{10}: Average number of switching devices at each section (devices/section), the number of total switching devices, such as disconnect switches and sectionalizing switches, divided by the number of total sections in an EDS;
(11) F_{11}: Average sections of each feeder (sections /feeder), the number of total sections divided by the number of feeders in an EDS;
(12) F_{12}: Average load factor of feeders (%), average load factor (the load of a feeder divided by the capacity of feeder) of feeders in an EDS in a year.