

Reliability Evaluation of High Voltage Circuit Breaker Based on IFAHP and GA

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Abstract. In order to assess the reliability of circuit breaker more scientifically and effectively, a method based on improved fuzzy analytic hierarchy process and genetic algorithm is presented in this paper. Firstly circuit breaker fault tree is established according to analyzing the circuit breaker failures and which make the complex circuit breaker system failures into all kinds of basic types of failures; Secondly, Improved Fuzzy Analytic Hierarchy Process(IFAHP) is designed to analyze the fault tree, it uses the relationship between the layers of fault tree to establish fuzzy judgment matrix and convert the fuzzy consistent qualification to constrained optimization problems; Then Genetic Algorithm(GA) is adopted to get the weight of each fault which can find the optimal solution quickly and accurately; Finally, according to the practical operation of circuit breaker, high voltage circuit breaker reliability evaluation model is established to assess the reliability of circuit breaker. The analytical result of practical sample verifies the accuracy of the proposed method.

Introduction

High voltage circuit breaker is the hub electrical equipment of the power system, so the reliability evaluation of circuit breaker is of great significance for the entire power system. Currently, Domestic and international studies of reliability evaluation of circuit breaker has made certain achievements. In [1], it introduced Fault Modes and Effects Analysis (FMEA) in the reliability evaluation. The process was simple and actionable, and the conclusion was intuitive. But the evaluation results could not be quantified, so the feasibility was not strong. In [2], failure severity analysis method was used in reliability evaluation. But it can only analyze a single failure mode and cannot reflect the multiple fault modes of system reliability effectively. So Fault Tree Analysis (FTA) was applied to analyze the circuit breaker structure. It divided the circuit breaker faults intuitively into basic fault type^[3]. Therefore, it could provide a good graphic effect for deciding the nature of defaults in an accurate way and lays the foundation for further quantitative analysis. In [4], FTA and FAHP were combined to analyze circuit breaker reliability. But the solving process required a foundation of fuzzy consistent judgment matrix which often needed manual amendment, which cannot be applied directly.

To solve the problem above, a method based on IFAHP and GA is presented in this paper. Firstly circuit breaker failures is analyzed. High voltage circuit breaker fault is divided into six categories. Secondly, circuit breaker fault tree is established, complex circuit breaker system failure is made into all kinds of basic types of failures step by step. Thirdly, IFAHP is designed to analyze the fault tree, it uses the relationship between the layers of fault tree to establish fuzzy judgment matrix and convert the fuzzy consistent qualification to constrained optimization problems. Finally, GA is adopted to get the weight of each fault which can find the optimal solution quickly and accurately, then high voltage circuit breaker reliability evaluation model is established and the reliability of high voltage circuit breaker is assessed scientifically and effectively.

Establishing Circuit Breaker Fault Tree

Considering the actual operating state and fault conditions of the circuit breaker, setting up the circuit breaker fault tree according to the follow steps^[5, 6]:

Step1: Determining the top event: circuit breaker fault.

Step2: Determining intermediate events: circuit breaker fault is divided into six kind of failure in this paper, and the corresponding six intermediate events are: resist-operation fault, fault of open and close down, insulation fault, misoperation fault, current-carrying fault, the external force faults and other fault.

Step3: Determining the bottom events: bottom events are the causes of intermediate events.

Getting the Weight of Each Fault by IFAHP

The Solving Steps of FAHP. Getting the weight by FAHP can accord to the following steps^[7]:

Step1: Building hierarchy structure model.

The hierarchy structure model here is the fault tree been established in previous chapter.

Step2: Building fuzzy judgment matrix.

By comparison between any two factors in the some layer (X_1, X_2, \dots, X_n), their importance to the same factor in the upper layer can be obtained. The matrix R usually is established in accordance with 0.1 ~ 0.9 scale method.

$$R = \begin{bmatrix} r_{11} & r_{12} & \mathbf{L} & r_{1n} \\ r_{21} & r_{22} & \mathbf{L} & r_{2n} \\ \mathbf{L} & \mathbf{L} & \mathbf{L} & \mathbf{L} \\ r_{n1} & r_{n2} & \mathbf{L} & r_{nn} \end{bmatrix}. \quad (1)$$

where r_{ij} in the matrix R is the importance to the same target element(O) of X_i and X_j , and its value can take any value between 0.1 ~ 0.9.

Step3: Calculating the weight of each factor.

For the matrix R in (1),

(a) If $r_{ii} = 0.5, i = 1, 2, \mathbf{K}, n$, the matrix R is called the fuzzy matrix;

(b) If $r_{ij} = 1 - r_{ji}, i, j = 1, 2, \mathbf{K}, n$, the matrix R is called the fuzzy reciprocal matrix;

(c) If $r_{ij} = r_{ik} - r_{jk} + 0.5, i, j, k = 1, 2, \mathbf{K}, n$, the matrix R is called the fuzzy consistent matrix.

In FAHP method, it is very difficult to guarantee the matrix above to satisfy the condition (c). So it always needs the man to calculate and adjust the matrix R by himself. Here, in this paper, path of constructing fuzzy consistent matrix is abandon and the consistent requirement is changed into a mathematical programming problem.

In research of the relationship between weight (ω) and r_{ij} , it is found that solving the weight vector $w = [w_1, w_2, \mathbf{L} w_n]$ is equivalent to solving the constraint programming problem.

$$\begin{cases} \min z = \sum_{i=1}^n \sum_{j=1}^n [0.5 + a(w_i - w_j) - r_{ij}]^2 \\ s.t. \sum_{i=1}^n w_i = 1, w_i \geq 0, (1 \leq i \leq n) \end{cases}. \quad (2)$$

For the above constraint programming problem, GA is introduced through which the weight of each fault cause can be viewed as chromosome in the space^[10]. The optimal solution is searched through the evolvement of chromosome, so that the optimal proportion (the weight of each fault cause: $w = [w_1, w_2, \mathbf{L} w_n]$) can be spotted quickly and accurately.

Risk Assessment of Circuit Breaker

The risk of each circuit breaker fault is not only related to its probability, but also to the severity of fault resulted from them. So the risk factor of certain circuit breaker fault cause is:

$$P_i = p_i \times w_i, (i=1,2,\dots,n). \quad (3)$$

where p_i is the probability of fault caused by the reason of type i ; w_i is the extent of this fault caused by the reason of type i ; n represents the number of the fault causes.

Analyzing the risk factor of each fault comprehensively, the probability of each kind of failure (fault rate: $P(T)$) and its reliability ($R(T)$) can be get:

$$P(T) = \sum_{i=1}^n p(X_i) \times w_i \quad (4)$$

$$R(T) = 1 - P(T). \quad (5)$$

where X_i is the reason of type i of fault X, $P(T)$ is probability of fault X, $R(T)$ is the reliability.

Applications

According to the statistics data of State Grid Corporation of China, in 2004, 46 sets of high voltage circuit breaker have accidents, and 346 sets have obstacles, the statistics of circuit breaker faults is shown in Table 1.

Table 1 Statistics of circuit breaker faults

fault types	total	the percentage %
Resist-operation fault	90	22.96
Fault of open and close down	15	3.83
Insulation fault	56	14.28
Misoperation fault	11	2.81
Current-carrying fault	9	2.30
The external force faults and etc.	211	53.82
Total	392	100

To access the reliability of the circuit breaker, it must access each component's reliability individually, it can be got by the method introduced above and the result is shown as in Table 2.

Table 2 the reliability of each circuit breaker faults

fault types	fault rate	reliability
Resist-operation fault	0.1280	0.8720
Fault of open and close down	0.0852	0.9148
Insulation fault	0.1022	0.8978
Misoperation fault	0.1341	0.8659
Current-carrying fault	0.0647	0.9353
The external force faults and etc.	0.0769	0.9231

Through the method above, the weight and risk factor of each circuit breaker fault are shown in table 3.

Table 3 The weight and risk factor of each fault

fault types	the weight	risk factor
Resist-operation fault	0.3047	0.0699
Fault of open and close down	0.4368	0.0167
Insulation fault	0.1526	0.0218
Misoperation fault	0.0419	0.0012
Current-carrying fault	0.0143	0.0003
The external force faults and etc.	0.0497	0.0267

According to the results above, the reliability of circuit breaker can be obtained:

$$R(T) = 1 - \sum_{i=1}^n p_i \times w_i = 1 - (0.0699 + 0.0167 + \dots + 0.0267) = 0.8634$$

Conclusions

In this paper, a new method for reliability evaluation of high voltage circuit breaker based on IFAHP and GA is proposed. It makes the complex circuit breaker system failures into all kinds of basic types of failures by establishing the circuit breaker fault tree, at the same time, it can make staff to master the root cause of failure and the influence of it; then, it takes quantitative analysis of the fault tree through IFAHP and uses the relationship between the layers of fault tree to establish fuzzy judgment matrix and convert the fuzzy consistent qualification to constrained optimization problems; then GA is adopted to calculate the weight of each fault cause, so the reliability of circuit breaker can be got even when fuzzy judgment matrix does not meet the fuzzy consistent conditions. The correctness and feasibility of this method is verified in the application. The result can provide guidance to circuit breaker in formulating maintenance strategies, contingency plans and the improvement of designing.

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