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Application of Fuzzy Random Theory for Relay Protection Reliability

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Abstract. Relay protection and safety device are regarded as the sentry of safe and reliable operation of the power grid. It plays a very important role in the power grid, and can determine whether the normal operation of the power system. This article considers the influence of the fuzzy uncertainty of relay protection failure rate to power system on the basis of Markov model, and researches the dynamic fault tree analysis method in the case of fuzzy failure parameter. A dynamic fault model has been built.

Keywords: relay protection, dynamic fault tree, uncertainty

1 Introduction

At present, the analytic method is widely used in reliability assessment, Such as the Markov space conversion method [1, 2] and the fault tree analysis method [3, 4] etc. They have different strengths. The Markov model [1, 5] is a state space method which is commonly used. Since the model is a kind of global state space model, the computation of which would happen state explosion with the system scale growth. Therefore to adopt this method is not desirable directly. Traditional fault tree analysis (FTA) method is an effective e tool for system reliability analysis. But in the reality, failure systems often have dynamic characteristics, and the traditional FTA as an analysis method of static logic or static failure mechanism is unable to describe the dynamic behavior based on system failure.

Aiming at the drawbacks of fault tree analysis method, some scholars have put forward the hybrid method combining analytical method and simulation method. Rao [6] presents a simulation method based on Monte Carlo, the method can be used for failure distribution under non exponential distribution case, and can also handle the dynamic logic gate in a cascade. Owing to various factors, the state and probability of relay protection system are often fuzzy. The above several analytical methods have not considered the fuzzy uncertainty problems in the system.

In order to solve simultaneously these two problems of dynamic feature and fuzzy uncertainty in the systems, this chapter presents a dynamic fault tree analysis method based on fuzzy Markov model. The dynamic fault tree establishes the reliability model of system. Triangular fuzzy numbers describe the fuzzy probability of the

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bottom events, and describe the transfer rate between states in Markov model. The membership functions of fuzzy failure probability on the fault tree top event are calculated by extension principle and parameter programming method of fuzzy numbers. Finally, the correctness and effectiveness of the method are verified through an example.

2 Dynamic fault tree analysis method

2.1 The dynamic logic gate

One of the main disadvantages of the conventional fault tree analysis method is not modeled on the order of correlation in the system. In order to solve this problem, Dugan [10-12] proposed a new method for reliability analysis—Dynamic fault tree analysis. The method introduces a series of dynamic logic gates to describe the failure behavior of the system on timing rules and dynamic. These four kinds of typical dynamic logic gate mainly include Sequence Enforcing Gate (SEQ), Functional Dependency Gate (FDEP), Priority-AND Gate (PAND) and Spare gate (SP) etc.

(1) Sequence Enforcing Gate (SEQ)

SEQ has n input events, only when all events occur with the order from 1 to n sequence, the output event occurs.

(2) Functional Dependency Gate (FDEP)

When the trigger event T occurs and causes events A, B to occur, the top event happens. Or any of the basic events A, B alone occurs, the top event also occurs.

(3) Priority-AND gate (PAND)

When the basic events occur as the order from left to right, the output occurs. For example, the two inputs A and B, when A firstly occurred before B, the output of system occurs. Therefore the PAND is a special case of the SEQ as when the number of the bottom events is two.

2.2 The Markov model

In the dynamic fault tree, the occurrence probability of the sequence cut sets contains not only with combinations of events related, but also with order of the basic event occurs. Thus, the Markov model is used to simulate the process of failure and evaluate the reliability of the dynamic system.

Assuming that T is an infinite set of real numbers, if every and $X(t)$ is a random variable, $\{X(t), t \in T\}$ will be called random process. When a random process satisfies the following conditional probability relation, the random process is called a Markov process.

$$P\left\{X(t_n)=x_n \middle| X(t_1)=x_1, X(t_2)=x_2, \cdots, X(t_{n-1})=x_{n-1}\right\}$$
$$=P\left\{X(t_n)=x_n \middle| X(t_{n-1})=x_{n-1}\right\} \tag{1}$$

Where $x_i \in S$, S is the state space of the stochastic process , and $t_1 < t_2 < \cdots t_{n-1} < t_n$.

Pattern (1) reflects that Markov process has no memory, it is expressed that random process at probability of in depends only on the state of which has nothing to do with the previous time state. Under normal circumstances, the state space and the time parameter of Markov process can be discrete or continuous. Markov chain is the Markov process whose time and state are the discrete.

In a dynamic system, the failure process of the system can be described as the Markov process.

Assume that the system has n state $s_i(i=1,2,\cdots,n)$, the failure process of the system is described by Markov process $\{S(t), t \geq 0\}$. Where $s_i \in H$, the H is the state space Markov process.

The transfer rate of the state i and state j is expressed by $\lambda_{i,j}$

Assume $p_i(t)$ is the probability of every state s_i during t of the system, where $i=1,2,\cdots,n$. The differential equations of the above Markov model correspond to the following:

$$\begin{cases} \dfrac{dp_1(t)}{dt} = -p_1(t)\sum\limits_{j=1}^{n} \lambda_{1,j} \\ \dfrac{dp_i(t)}{dt} = \sum\limits_{j=1}^{i-1} p_j(t)\lambda_{1,j} - \sum\limits_{j=i+1}^{n} p_i(t)\lambda_{i,j} \ ,1 < i < n, t \geq 0 \\ \dfrac{dp_n(t)}{dt} = -\sum\limits_{j=1}^{n-1} p_j(t)\lambda_{j,n} \end{cases} \tag{2}$$

The initial conditions of the model being: $\begin{cases} p_1(0)=1 \\ p_i(0)=0(i=1,2,\cdots,n) \end{cases}$

To solve the above model can get the probability $p_n(t)$ of n states, which corresponds to the probability of top event of the fault tree, it is failure probability of the system in t time.

2.3 Dynamic fault tree conversion to Markov model

As the fault tree includes one or more dynamic logic gates, the fault tree is called dynamic fault tree. According to the graphical advantage of the Markov model, the dynamic logic gate converts to the Markov model, which can effectively solve the problem of solving the dynamic logic gate. The combination state of the dynamic logic gate input event used as the basic state of the Markov model, at the same time, the state transition probability of Markov model is set as a fault probability of input event, which can convert dynamic logic gate for the Markov model. The following will introduce how some typical dynamic logic gates are converted to Markov model.

(1) PAND: The two input PAND is converted into the Markov model.

(2) FDEP: FDEP is converted into the Markov model. λ_A and λ_B respectively represent failure rate of input parts A and B, λ_T is the failure rate of the triggering event. “000” for the three parts are all in the normal state of the system; “001” for the only part B of the system fails; “010” for the only part A of the system fails; “Fail” for the system fails.

(3) SEQ: Like the previous two kinds of dynamic logic gate, The λ_i represents the failure rate of sequential input event A_i. The meaning of its every state is similar to the one before in Markov model.

(4) Spare gate: CSP, WSP and HSP are converted into Markov model. Which A being the basic input, S being the space. λ_A and λ_S respectively express the failure rate of the operating state of A and S, The meaning of every state is same with the Markov model of the PAND (two input) in the state. According to the failure mechanism of all three kinds of spare gates, the space of the WSP also has a certain failure rate before the basic input failure, which expressed as $\lambda_s^{'}$, and also $\lambda_s^{'} < \lambda_s$. When A fails, S will be fully working, and $\lambda_s^{'} = \lambda_s$. For the HSP, the spare S is always in working state, so $\lambda_s^{'} = \lambda_s$.

3 Summary

Whether the relay protection system is reliable for fast and accurate action is directly related to the safe and stable operation of power system. According to the structural property of the relay protection system, the paper use these advantage that dynamic fault tree establishes the model, qualitatively and quantitatively evaluate in the system of relay protection.

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