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Markov Assessment on Operational Reliability of Power Grid

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Abstract: ***In view of the defects in power system reliability analysis that discrete Markov chain model simulation stays longer in the same state often, from the viewpoint of operation and based on continuous time Markov chain and under the premise that equipment failure rate complies with exponential distribution characteristics, a model, by which fast analytical analysis on power system operation reliability can be carried out, is proposed. The core of the proposed model lies in following aspects: firstly, based on historical operation data of power system, a corresponding Q-matrix of the continuous time Markov chain equivalent to power system operation is attained; secondly, according to the current power system operating condition and utilizing the concept of stopping time of Q-process, such reliability indices for some time to come as steady state probability and mean time to first failure of power system can be rapidly analyzed. So the rapid assessment of power system operation reliability can be implemented. A numerical example is computed by using the proposed method.***

Keywords: power system, continuous time Markov chain; reliability assessment; mean time to first failure

1. Introduction

The technology of the reliability theory and its application is a new technology. It has important effect to ensure and improve the quality of the products. From the perspective of probability, the evaluation and prediction of the reliability of power grid operation becomes more and more important to the science formulation of the power grid operation and control strategy [1]. Because of the scale of power grid is large, the number of components is large, the current reliability assessment of power grid always adopt Monte Carlo simulation method [2-5]. Because of Monte Carlo simulation method needs large computing resources and convergence slow, so it is difficult to use in the operating environment. Therefore, many references adopt the mixed form of simulation and analysis[6], or adopt the analytical method directly[7-8] , to get the reliability indices quickly. Reference [6] presented a Markov chain Monte Carlo method on the research of power grid reliability evaluation. This paper used the Gibbs sampler to generate Markov chain in the component state sampling. Although the method can improve the convergence speed of Monte Carlo method, but it cannot compensate the defects of the simulation method fundamentally. Basing on minimal cut set theory, reference [8] proposed an analytical calculation method of the probability density distribution of power grid. But it is still in the theoretical stage, it is difficult to use in engineering practice. From the viewpoint of operation and based on Markov chain, reference [9] proposed an assessment method on power grid operation reliability. Reference [9] used the discrete time Markov chain model. In view of the defects in power grid reliability analysis that discrete Markov chain model simulation stays longer in the same state often, from the viewpoint of operation and based on continuous time Markov chain with jump process and under the premise that equipment failure rate complies with exponential distribution characteristics, a model, by which fast analytical analysis on power grid operation reliability can be carried out, is proposed.

2. An Assessment method on operational reliability of Power Grid

Reference [9] divided the power grid operation states into 3 types .such as: state 1 (normal state). In this state, there is no component fault in the power grid, and no unplanned cutting load, that is, the power grid operates in the planned way, meets the requirements of N – 1. State 2 (fault state). In this state, there is the component fault in the power grid, but the system can operate by readjustment, without the need for load shedding. At this time, possibly due to component failure, there is a temporary power outage, but it can recover in a short period , the lack of short-term power load is negligible. State 3 (risk state). In this state, some constraints of the system cannot be satisfied. The power grid have to remove part of the load to ensure the safe, stable operation of the system, which needs longer recovery time, and have a greater impact on the reliability indices of the power grid. In this paper, letting the state space of power grid be $I=\{1,2,3\}$.

Corresponding to the state transition probability matrix of discrete time Markov chain, continuous time Markov chain has Q-matrix. Q-matrix $Q=\left(q_{ij}:i,j\in I\right)$ satisfies the following conditions:

1. For arbitrary $i\in I,\ 0<-q_{ii}<+\infty$ holds.
2. For arbitrary $i,j\in I, i\neq j,\ q_{ij}\geq 0$ holds.
3. For arbitrary $i\in I,\ \sum_{j\in I}q_{ij}=0$ holds.

and the Q-matrix satisfies

$$P(t)=e^{tQ} \tag{1}$$

where $P(t)$ is the transition probability matrix of the power grid at time t. For convenience, we note that $-q_{ii}=q_i$. The Q - matrix can form an important continuous time Markov chain with jump process. The jump process corresponds to a jump matrix $\Pi=\left(\pi_{ij}:i,j\in I\right)$。 The jump matrix Π is determined by the Q - matrix as follow:

$$\pi_{ij} = \begin{cases} q_{ij}/q_i, & \text{if } j \neq i \text{ and } q_i \neq 0; \\ 0, & \text{if } j \neq i \text{ and } q_i = 0. \end{cases} \quad (2)$$

$$\pi_{ii} = \begin{cases} 0, & \text{if } q_i \neq 0; \\ 1, & \text{if } q_i = 0. \end{cases} \quad (3)$$

By the jump matrix Π, we can get the following conclusion [10]: When the power grid is in state 1, the stopping time that the system in state 1 obey exponential distribution with para meter $\lambda = \pi_{12} + \pi_{13}$, whose mean value is $1/\lambda$ .The power g rid turns into state 2 from state 1 with probability $\pi_{12}/(\pi_{12}+\pi_{13})$,turns into state 3 from state 1 with probability $\pi_{13}/(\pi_{12}+\pi_{13})$.

By the jump matrix Π, we get the steady state distribution $\pi = (p_1, p_2, p_3)$ of the power grid as follow

$$\begin{cases} (\pi_{12}+\pi_{13}) p_1 = \pi_{21} p_2 + \pi_{31} p_3 \\ (\pi_{21}+\pi_{23}) p_2 = \pi_{12} p_1 + \pi_{32} p_3 \theta \\ (\pi_{31}+\pi_{32}) p_3 = \pi_{13} p_1 + \pi_{23} p_2 \end{cases} \quad (4)$$

Due to two independent equations only in (4), so it needs

$$p_1 + p_2 + p_3 = 1 \quad (5)$$

to get the simultaneous solution.

3. Example

For testing the effectiveness of the proposed method, this paper studies the example in [9] (detailed data can be seen in[9]). Reference [9] gave the transition probability matrix of the power grid as follow:

$$P = \begin{bmatrix} 0.986741 & 0.013227 & 0.000033 \\ 0.008691 & 0.986617 & 0.004692 \\ 0.001011 & 0.185775 & 0.813214 \end{bmatrix}$$

By the transition probability matrix above and (1)- (3), we get the corresponding jump matrix as follow:

$$\Pi = \begin{bmatrix} 0 & 0.125 & 0.00625 \\ 0.0833333 & 0 & 0.004692 \\ 0.0041666 & 0.25 & 0 \end{bmatrix} \quad (6)$$

By (4)- (6), we get the steady state distribution of the power system as follow:

$$\pi = (0.391, 0.594, 0.015)$$

The result has no changes with the result in [9].

The following figures are the probabilities of the system indif ferent states with the increase in time(The probability of the system in state i at time t is the total residence time that the system stays in state i by the time t divided by t).

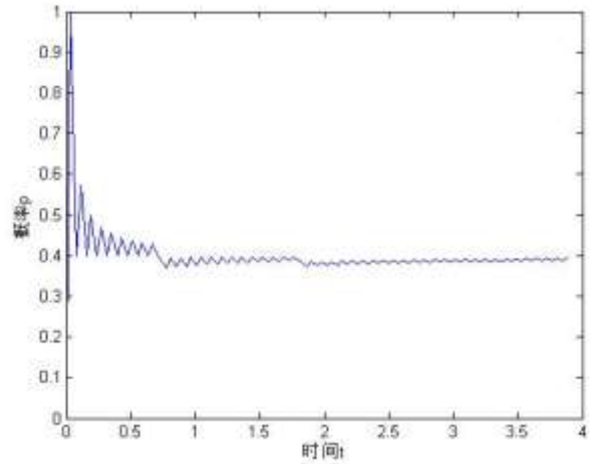

Figure 1: The probability of the system in state 1 .

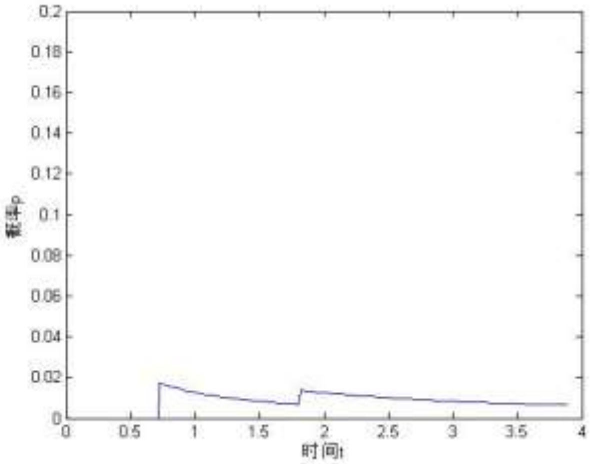

Figure 2: The probability of the system in state 2 .

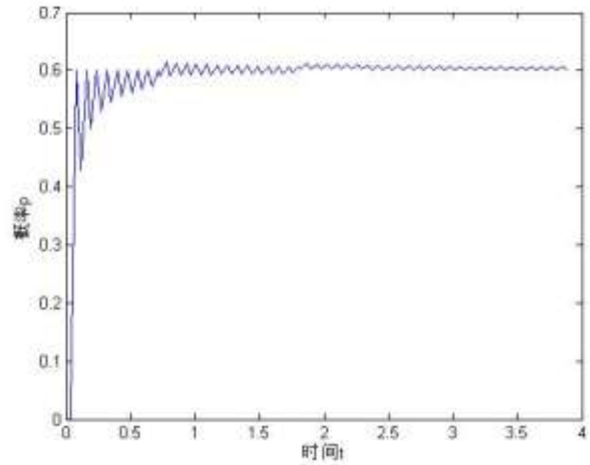

Figure 3: The probability of the system in state 3 .

By the proposed method , the mean time to first failure of the power grid is 7.619. By Monte Carlo simulation , the mean time to first failure of the power grid is 7.614 (reference [9]). The error is in the Monte Carlo simulation error range.

4. Conclusion

In view of the defects in power grid reliability analysis that discrete time Markov chain model simulation stays longer in the same state often, from the viewpoint of operation and based on continuous time Markov chain and under the premise that equipment failure rate complies with exponential distribution characteristics, a model, by which fast analytical analysis on power system operation reliability can be carried out, is proposed. The core of the proposed model lies in following aspects: firstly, based on historical operation data of power grid, a corresponding Q-matrix of the continuous time Markov chain equivalent to power grid operation is attained; secondly, according to the current power grid operating condition and utilizing the concept of stopping time of Q-process, such reliability indices for some time to come as steady state probability and mean time to first failure of power grid can be rapidly analyzed. So the rapid assessment of power grid operation reliability can be implemented. A numerical example is computed by using the proposed method. It turns out that the method can quickly, accurately obtain the reliability indices of power grid.

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Jin Shaohua, born in 1965, graduated from Hebei University of Technology in 1990.He has been engaged in teaching and the research on reliability theory of electrical apparatus since 1990 and became a Professor in 2003.