Research on Short-Term Reliability of Master Slave Control Based on Running Microgrid

Peng Gu[1], Shuai Yuan[1], Zhixiong Yang[2, a], Jun Li[1], Aikun Ma[1], Yuting Wang[1], Bo Hong[1], Liyue Yuan[1]

[1]State Grid Liaoyang Electric Power Supply Company, Liaoyang 111000, China
[2]Kunming Institute of Physics, Kunming 650223, China

*xiongmaoer39@126.com

Abstract. A short-term reliability evaluation method based on time-varying dynamic fault tree is proposed for the time-varying and redundancy dynamic characteristics of the short term reliability of the microgrid operating in the main and Slave Island. First, a time varying dynamic fault tree is defined, and the solution process of dynamic subtree and static subtree is given. Then the top event is divided into direct and indirect events based on the power supply interruption of the load point, and the probability calculation is carried out. On this basis, the load probability and the expected power outage of the load point of the microgrid with master-slave control are calculated, and the reliability evaluation process is given. The validity and effectiveness of the proposed method are verified by an example analysis. The results can provide a basis for the operation and operation of the microgrid operating in the isolated island.

1. Introduction

Power system reliability assessment methods include analytic method, simulation method and fault tree analysis method. In the short term reliability evaluation of isolated island operating microgrid, the random output of intermittent DG makes the system state large, and the short term fault probability of the component is lower .[1, 2] The analytical method and simulation method have some defects in its reliability evaluation. Fault tree analysis (FTA) is a kind of graphic deduction method which makes the cause of system failure according to the shape of branches. It is an internationally recognized and effective method of reliability evaluation. Document uses fault tree analysis to evaluate the reliability of the isolated island operation microgrid, but only considers the reliability of the power supply, and does not account for the influence of the uncertainties on the reliability. Fault tree analysis is based on static fault mechanism or static logic relation. [3] It cannot describe dynamic failure behaviour such as system redundancy. The dynamic fault tree analysis method combines the advantages of fault tree analysis and Markov model, and introduces dynamic logic gates to describe the dynamic logical relationship between events. [4, 5] At present, the dynamic fault tree analysis (FTA) is applied to the reliability evaluation of the machinery, relay protection system and the risk assessment of the cascading failure of the power system. [6, 7] However, the dynamic fault tree analysis method considers that the probability of occurrence of events is constant, and is not suitable for short-term reliability evaluation of islanding microgrids.

In this paper, a short-term reliability evaluation method based on time-varying dynamic fault tree is proposed in this paper for the time-varying and redundant dynamic characteristics of the communication system.

2. reliability index and evaluation process

2.1. Definition of reliability index

The short-term reliability level of the power system is measured by the short-term reliability index. This paper defines 2 short-term reliability indexes: the load point load probability (loss of load probability, LOLP) and the system power outage expectation (expected demand not supplied, EDNS).

$$L_{OLPLPj}(t)=\bigcup_{i=1}^{m}\Omega(S_i),\ j=1,2,...,z \tag{1}$$

In the formula, $L_{OLPLPj}(t)$ is the load probability of load point LPj at t moment; Z is the number of load points; S_i is the smallest cut set of i ; $\Omega(g)$ is the time variation probability of a minimum cut set; m is the minimum cut set in the time variable dynamic fault tree corresponding to the load point LPj .

$$E_{DNS}(t)=\sum_{j=1}^{z}\bigcup_{i=1}^{m}\Omega(S_i)\bullet P_{LPj}(t) \tag{2}$$

The $E_{DNS}(t)$ is the expected value of power outage at t.

2.2. Reliability evaluation process

Assume: 1) all components are repairable components, their failure time and repair time are exponentially distributed, and the repair time of the same component fault caused by different bottom events is the same;

2) The interaction between the reliability indexes between different load points is ignored. The short term reliability evaluation process of the master slave control islanding microgrid is shown in Figure 1.

The concrete steps are as follows:

1) Parameter initialization. Set the sampling times M, assess initial time t, assess interval Δt , and assess time T.

2) According to formula (1), we calculate the time varying probability of T bottom events.

3) According to the historical data of wind speed, photovoltaic cell output, load and other historical data and the time variation probability of the failure state of DG (or energy storage device) at the time of T, M samples are sampled.

4) According to the formula (2), the wind power output of M samples is calculated, and the time varying probabilities of all indirect events are calculated.

5) Calculate the short-term reliability index of t time; and make $t=t+\Delta t$

6) if $t\ge T$, the simulation ends and gets the reliability index of each time; otherwise, step 2.

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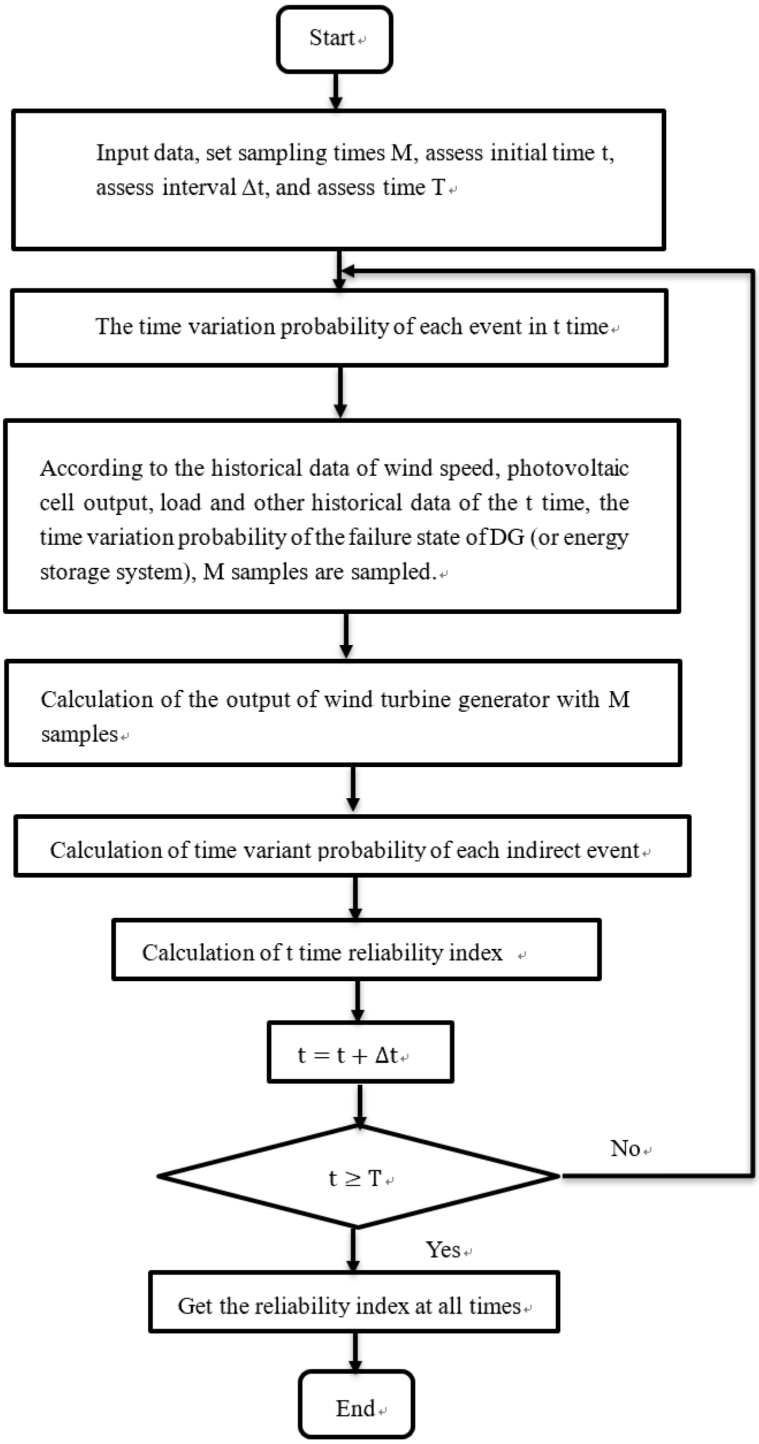

Figure 1. Flow chart of short-term reliability assessment of islanded microgrid

3. Example analysis

3.1. Example system

On the computer with Intel Core i5 processor and 4.0G memory, the simulation software Matlab R2013a is used to compile the short term reliability evaluation program of the slave Island running microgrid based on the time-varying dynamic fault tree analysis method.

The 1 main control unit of the micro turbine is set up to establish the time-varying dynamic fault tree of all load points, in which the time-varying dynamic fault tree of the load point LP1 is shown in Figure 2, and the time variable dynamic fault tree bottom event is shown as the appendix table A1. In Figure 2, load point LP1 power interruption is the top event, and direct and indirect events are two events. The direct events are composed of communication system faults, micro turbine 1 faults, and L2, L3 and L4 three feeder faults connected with LP1 and micro turbine 1. The indirect event consists of 3 parts: 1) L6, circuit breaker failure as trigger event 1, indirect event set 1 including load point LP1, LP2 and mini turbine 1, energy storage device 2 power. 2) take L8 fault as trigger event 2, indirect event set 2 contains load point LP1, LP2, LP3 and micro turbine 1, energy storage device and photovoltaic battery 3 power supply. 3) L6, L8 and X1 are the trigger events 3, and the indirect event set 3 contains all the load points and the power supply.

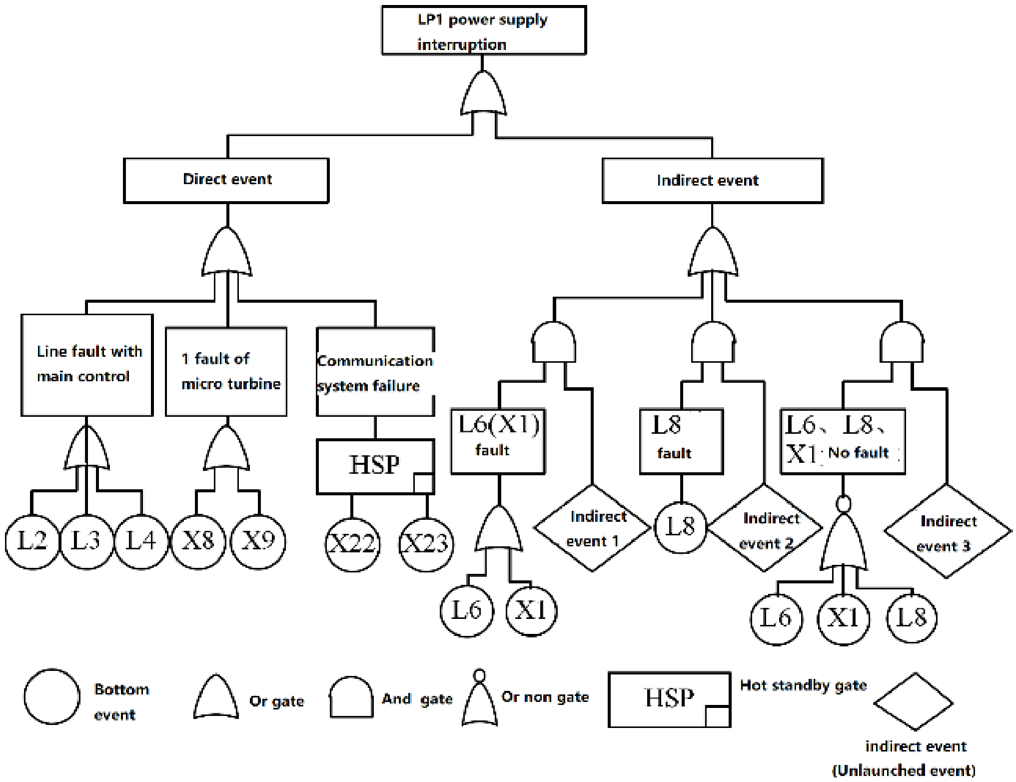

Figure 2. Time-varying dynamic fault tree of power with load LP1 interruption

3.2. *Method verification*

1) The time variability of the reliability evaluation results.

Set t=0 minute steam turbine 1 in working state, the time variation probability curve of the 1 fault of micro turbine by the bottom event X8 and X9, as shown in Figure 3; take M=100 000, and the 3 time variation probability curve of the indirect event in the dynamic fault tree of the load point LP1, as shown in Figure 4.

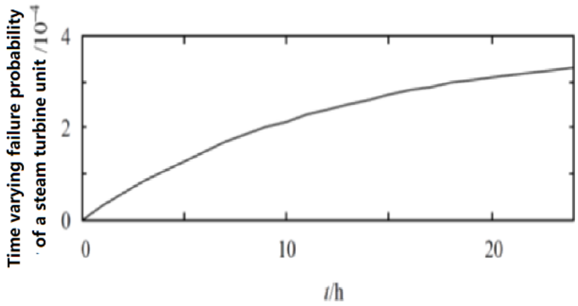

Figure 3. Time-varying failure probability curves of MT1

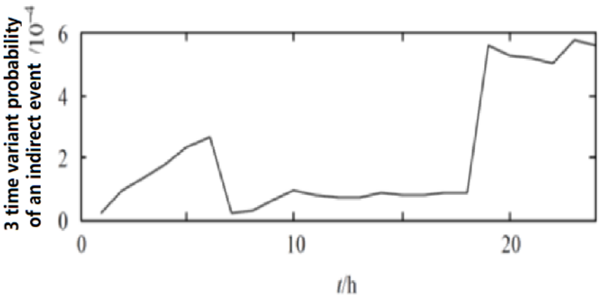

Figure 4. Time-varying probability curves of indirect event3 (load point LP1)

As shown in Figures 3 and 4, the probability of occurrence of bottom events and indirect events in time variant dynamic fault trees is sometimes variable. Among them, the probability of bottom events increases monotonously with the increase of running time. The time varying probability of indirect events is related to time. This is due to the time-varying characteristics of load model, intermittent DG output and system component failure probability. Therefore, if the bottom event adopts a steady-state probability model, it cannot reflect the real short term reliability level of the islanding microgrid.

2) Comparison of different reliability assessment methods. The number of sampling times M=100 000, given the same fault probability parameters and DG, energy storage device output and other parameters, the proposed method and Monte Carlo simulation method are used to evaluate the reliability of the example system respectively. The LOLPLP1 index, the system EDNS index and the simulation time of the t=8 h moment are used as comparison objects, and the reliability evaluation node is used. The comparison is shown in Table 1.

Table 1. Comparison of short-term reliability assessment results under different methods

Method	$L_{OLPLP1}/(10^{-3})$	E_{DNS}/kW	computing time/s
This paper method	0.3572	0.4872	1.48
Monte Carlo simulation	0.3513	0.4844	8.17

As shown in Table 1, the relative error of LOLPLP1 index② is 1.65%, the relative error of the system EDNS index is 0.57%, and the relative error is in the acceptable range, which proves the correctness and accuracy of the proposed method. ② The method proposed in this paper is only 0.181 times that of the Monte Carlo simulation method, because the proposed method is only sampled in the solution of the time variant probability of the indirect event. Compared with Monte Carlo simulation, the method proposed in this paper greatly reduces the sampling scale and has higher computational efficiency.

The convergence curve of system EDNS index using different methods at different times of sampling times M and t=8 h is shown in Figure 5.

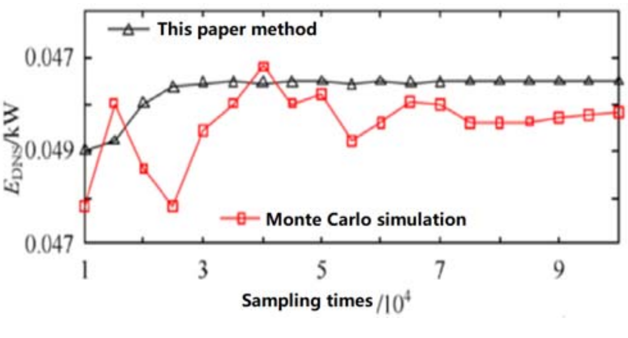

Figure 5. Convergence curves of system EDNS index under different methods

From Figure 5, we can see that the system EDNS index has converged when sampling times M= 25000, and the system EDNS index of the Monte Carlo simulation method until M=80 000 tends to be stable, which shows that the proposed method is faster and more efficient than the Monte Carlo simulation method. This is because the short term fault probability is low, the Monte Carlo simulation method is not sensitive to the low probability events, and the convergence speed is slow. The method proposed in this paper is small in size, and the basic sample of the indirect event is obtained by Latin hypercube sampling, and the Latin hypercube sampling belongs to the sub stratified sampling, which can reflect the integral part of the random variable. The speed of convergence is faster.

3.3. The results of short-term reliability evaluation of the example system

T=24 h, Δt =1 h, the sampling number of M=100 000, is used to evaluate the reliability of the example system. The LOLP index curve of each load point, as shown in Figure 6, is shown in the system EDNS index, as shown in Figure 7.

From Figure 6 and Figure 7, we can see: 1) the short-term reliability index of the main slave island operation microgrid varies with time. It shows that the short-term reliability index of the main slave island operation microgrid is time-varying, which is the time variation of the system component state, the photovoltaic cell output and the load.

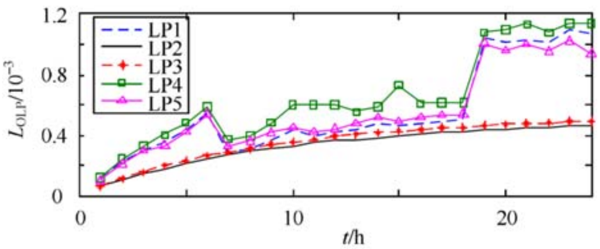

Figure 6. Curves of LOLP index

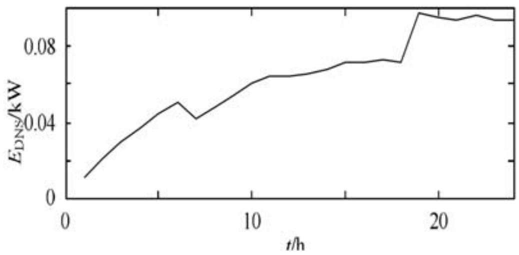

Figure 7. Curve of system EDNS index

The result of the randomness of the wind and the wind speed. 2) The reliability level of LP2 and LP3 at the load point is relatively high, and the reliability index increases monotonously with the increase of time. This is because the peak load of LP2 and LP3 at load points is relatively large and will not be removed under normal circumstances. The interruption of power supply is mainly caused by direct events. 3) The reliability level of LP1, LP4 and LP5 at load point is relatively low. This is because the peak load point LP1, LP4, LP5 peak load is relatively small. If there is a shortage in the isolated island running microgrid system, the 3 load points may be removed, and the interruption of power supply is caused by direct events and indirect events.

4. Conclusion

The short term reliability evaluation method based on the time-varying dynamic fault tree analysis method based on the time-varying dynamic fault tree analysis method is proposed for the short run characteristics of the main and subordinate isolated island microgrid and the dynamic redundancy of the communication system. The results and analysis of the example show that:

1) The bottom events and indirect events used in this paper are all time-varying models, which can truly reflect the short-term reliability level of isolated island microgrids. Considering the influence of control strategy and communication system faults on short-term reliability index, it is suitable for short-term reliability evaluation of master slave controlled islanding microgrids.

2) Compared with Monte Carlo simulation method, the method proposed in this paper is accurate, at the same time, the sampling scale is reduced, the convergence speed of the reliability index is faster, and the calculation efficiency is higher.

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