TELKOMNIKA, Vol. 11, No. 12, December 2013, pp. 7793~7800
e-ISSN: 2087-278X

An Adequacy Evaluation Model for Power System

Nian Liu*[1], Buxiang Zhou[1], Bo Lin[1], Luofang Zhu[2], Ming Liu[2]
[1]School of Electrical Engineering and Information, Sichuan University 610065, Chengdu, China
[2]Guizhou Electric Power Grid Dispatching and Control Center 550002, Guiyang, China
Corresponding authors, e-mail:liu.nian@gmail.com

Abstract

The variety of the weather condition in which a transmission and distribution hybrid system resides has a significant impact on the reliability results of power systems; therefore, model is the key point of reliability evaluation when considering weather change. This paper illustrates a model that can be utilized for the evaluation of adequacy in weather conditions, and presents a calculation method for system component failure rate in the adverse weather conditions. Using Monte-Carlo simulation which based on component state duration sampling to get the evaluation results of the power system, and provide the basis for power system adequacy analysis. Results of calculation examples show that the proposed model is feasible and effective in power system.

Keywords: *adequacy model, power system, adverse weather, adequacy evaluation*

1. Introduction

The reliability of the power system including two aspects of adequacy and security. Adequacy refers to the power system within the system generation, transmission and substation equipment rated capacity and voltage fluctuations within tolerable limits, to consider elements planned and unplanned outage and operation condition the ability continuously to the user to provide power and electric energy demand. Adequacy index reflected in the study period of power system under static conditions the system capacity to meet the load of electric power and electric energy needs. Experience shows that, the possibility of disaster weather conditions of component failure will greatly increase, because the power system transmission and distribution lines especially in long distance transmission line in the long-term complex weather environment, the fault is very big, affected by changes in the weather. So, element (the part of the study called components) of the original parameters such as failure rate is a function of the state of the weather. Although the probability of bad weather there is not high, but the chance of element failure in adverse weather conditions increased obviously, and has the huge destructive effect to the element, the possibility of transmission and distribution network has a variety of related and unrelated fault increases dramatically, the so-called "fault aggregation" phenomenon [1]. Therefore, in the adequacy assessment of power system is very necessary to consider the influence of weather changes. Method for adequacy evaluation of power system can be divided into two categories: analytical method and simulation method. The fault enumeration method is the main analytical method, when the power system scale is small, the effect of fault enumeration method is better; when the system is large and complex factors require consideration of actual operation, the simulation method is more effective [2-3].

For large power system, simulation components are many need, such as generators, transformers, transmission lines, bus, circuit breakers and relay protection and so on, but also consider the generating unit maintenance scheduling and derating running state, under disastrous weather system fault, load forecast uncertainty and correlation, the common mode failure and related fault, so, the state space is very large, even with the fault state and simplify the occurrence probability of smaller events, the number of states required to still a lot of, the analytical method is very difficult to give an accurate mathematical model, or even given, is also difficult to calculate the accurate results. In this case, the probability method is more suitable for simulation, sometimes even is the only feasible evaluation method. Therefore, in the large-scale power system reliability evaluation, Monte-Carlo simulation method has attracted more and more attention of scholars at home and abroad [4-7].

Received March 3, 2013; Revised August 27, 2013; Accepted September 7, 2013

This paper established a mathematical model to evaluate adequacy consider weather condition, put forward in the calculation method of system component failure rate of disaster weather conditions, and using the Monte Carlo simulation method based on component state duration sampling, obtained grid evaluation results through simulation, and provide the basis for the adequacy analysis system. Finally, the numerical example demonstrates that the application of this model in power system is feasible and effective.

2. Evaluation Model

2.1. Equivalent Weather Condition

Because the power system especially in long distance transmission lines long in different weather conditions, the physical parameters directly influenced by the environment, therefore the fault rate of components is a continuous function of the weather [8], however, due to system modeling, data collection, data inspection and other difficulties, in practice cannot be treated as a continuous function or highly discrete function. For the convenience of analysis, it must be treated as a state finite function and this function has small enough states but completely describe the fault "agglomeration effect". Based on this, in the IEEE 346 [9] standard, the weather is divided into 3 categories: normal weather, disaster weather, major storm disaster weather.

Due to the opportunity of large disaster weather is minimal, so most weather conditions can be classified as normal and disaster case. The component failure rate was less affected by weather generally classified as normal weather, the component failure rate was heavily influenced by the weather in general to weather disasters, such as hurricanes, typhoons, snow and ice.

Figure 1 represents the random change of weather in a statistical period T. In the picture, λ' said element failure rate expectations under disaster weather, s_i is the duration of the disaster weather, λ said element failure rate expectations under normal weather, n_i is the duration of the normal weather. See from Figure 1, the change in the weather is one that can be treated as a random process of two kinds of weather conditions [10], namely normal weather and disaster weather. Normal weather the expected duration of N can be expressed as: $N = \sum_i n_i / T$, the disaster weather, the expected duration of S can be expressed as: $S = \sum_i s_i / T$. So, in period T the relationship of normal weather and disaster weather expected value of Figure 2 equivalent.

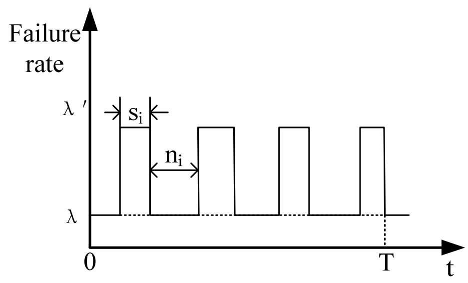

Figure 1. Diagram of the Random Weather Distribution

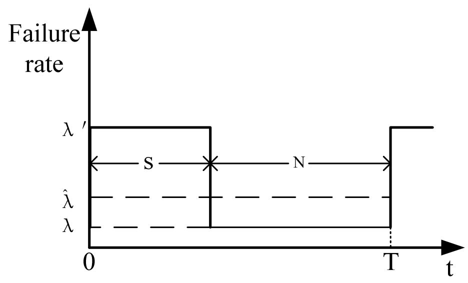

Figure 2. Expected Value of Two States Weather in a Cycle.

2.2. Component Failure Rates of Disaster Weather Conditions

The rate of component failure in different weather conditions converted into the number of component failure with the unit for the years, attention, not a calendar year in the weather conditions of failure times. So it is obvious, because in 1 years (365 d) of disaster weather accounted for a relatively short time, so to achieve number of failure of digital representation under disastrous weather, needs statistical results of several calendar years.

Therefore, the average value of failure rate with 1 calendar years as the unit (as shown in Figure 2) can be expressed as:

$$\hat{\lambda} = \frac{N}{N+S}\lambda + \frac{S}{N+S}\lambda' \quad (1)$$

Usually, N>>S, so $\hat{\lambda} \approx \lambda$

In practice, it is difficult to obtain λ and λ′ value, just $\hat{\lambda}$ value obtained from statistics. So if we know the percentage F that fault occurred in the disaster weather, can be obtained from the formula (1).

$$\begin{cases} \lambda = \hat{\lambda}\dfrac{N+S}{N}(1-F) \\ \lambda' = \hat{\lambda}\dfrac{N+S}{S}F \end{cases} \quad (2)$$

Based on the calculation results of λ and λ ' when F values different, the component failure rate in disaster weather conditions is much larger than the failure rate in normal weather conditions and the same to the average failure rate, the disaster weather system is more prone to failure. Considering the fault rate in two-state weather conditions when the F=0 and consider only the fault rate of a weather system is different, from the type (2) can be seen, at this time, $\lambda = \hat{\lambda}(N+S)/N$ is greater than $\hat{\lambda}$, the reason lies in the calculation of reliability index under the two-state weather condition considering the influence of the disaster weather expected duration of S on failure rate, and in a weather condition does not exist the disaster weather expected duration, there is no S. Here, just a λ, λ′, N, S related statistics, it can not reflect the real physical behavior of element, only the λ and λ′ is to reflect the real parameters of component failure rate.

3. Evaluation Algorithm

3.1. Monte Carlo Simulation Model

In the Monte Carlo simulation method, first of all to state sampling for each component in the system, which includes various kinds of system equipment, (such as generators, transformers, lines etc.) and different load levels.

For any element of the K in the power system, the disaster weather element failure rate is $\lambda_k^{'}$, X_k is its running state, probability function for X_k :

$$P(X_k) = \begin{cases} \lambda_k^{'} & k\,\text{fault},\ X_k = 1 \\ 1-\lambda_k^{'} & k\,\text{function},\ X_k = 0 \end{cases} \quad (3)$$

The system comprises M element, $X_i = (X_{i1}, X_{i2}, \ldots, X_{ik}, \ldots, X_{im})$ is a sample of the running state of the system. According to the components of the disaster weather element failure rate and mutual relations, can determine the joint probability distribution function $P(X_i)$.

3.2. Evaluation Index

Abundance index divide into load point indices and system index. Load point indices for each load point in the system, which show that the fault local impact, And as the next level of system reliability evaluation. System index is global, showed that the effect of faults on the system. System index including the basic indicator (1~6) and derived indicators (7~9). Basic indicators include probability, frequency, duration and the expected value, export index is derived from the basic index, which can be used for comparison between different scale system. The index definition and calculation formula:

(1) Probability of load curtailments P_{PLC}

$$P_{PLC} = \sum_{i \in S} \frac{t_i}{T}$$

In the formula, S is the state of the system load cutting set; t_i is the duration of system states in i, T is the total simulation time.

(2) Expected frequency of load curtailments F_{EFLC}

$$F_{EFLC} = (8760 / T) \cdot N_i$$

In the formula, N_i is the load shedding state number.

(3) Expected duration of load curtailments T_{EDLC}

$$T_{EDLC} = P_{PLC} \times 8760$$

(4) Average duration of load curtailments T_{ADLC}

$$T_{ADLC} = \frac{T_{EDLC}}{F_{EFLC}}$$

(5) Expected load curtailments C_{ELC}

$$C_{ELC} = \frac{8760}{T} \sum_{i \in S} C_i$$

In the formula, C_i is the amount of load shedding system state i.

(6) Expected energy not supplied E_{EENS}

$$E_{EENS} = \frac{8760}{T} \sum_{i \in S} C_i t_i$$

(7) Bulk power interruption index I_{BPII}. A system failure in the power supply point load shedding sum and the system maximum load ratio, it is shown that in a year per megawatt power load average MW power blackout, formula:

$$I_{BPII} = C_{ELC} / L$$

(8) Bulk power energy curtailment index I_{BPECI}, it is the sum of the system to cut power when system failures caused by power supply points and in the annual maximum load ratio.

$$I_{BPECI} = E_{EENS} / L$$

(9) Severity index S_{SI}

$$S_{SI} = I_{BPECI} \times 60$$

The S_{SI} table of transmission system in the maximum load of whole system outage cumulative time (min) is a measure of the severity of system failure.

4. Evaluation Process
4.1. The Duration of Sampling Element State

Component state duration sampling method is a sequence of Monte-Carlo method. Assume that components running time and fault repair time obeys a certain probability distribution, Usually the power system reliability evaluation used exponential distribution, then according to the failure rate and repair rate of the components to determine the elements in a given period of time of the state and the state duration. When all the elements for a given time period of the state and the state duration is determined, the system can be obtained and the duration of the state sequence. Sampling principle as shown in Figure 3. The first through the 3 elements (A, B and C) of the operation and failure state duration model, then get the system state and state duration. In a given time period a total of 11 states are simulated, contains 8 different states of the system (the same system state refers to the system of state failure element exactly the same). Can be seen from the sampling principle, difference between adjacent system state in a sequence of two state only a single element state changes (component failure or component repair). So it can be converted multiple fault evaluation assessment into single fault in the former state basis (such as status 4 is the 3 fault, can be components of the C assessment of single fault in state 3 basis). This can greatly simplify the evaluation process of multiple faults. The system state sampling produced in many of the same system state. Can storage the system state and condition assessment results to reduce the number of system state assessment, Figure 3 in state 10 can directly read the evaluation results from state 6, does not need to compute.

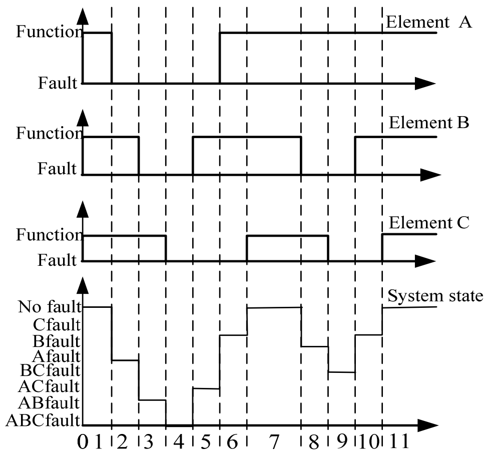

Figure 3. Schematic of Component State Sampling

4.2. Algorithm Flow Chart

Adequacy evaluation target is the probability of obtaining all the possible state of power system and load shedding, and then statistical adequacy index. For a detailed evaluation of multiple faults, to solve the contradiction between calculation speed and accuracy, on the one hand is to try to reduce the number of state needs assessment, on the other hand to try to accelerate the speed of each state assessment. By using the Monte Carlo simulation method to obtain the system state sequence, and the use of storage technology, combined with state and condition assessment results in the same system, greatly reducing the need to evaluate the number of state. The multiple fault evaluation into single fault evaluation in order to accelerate the speed of evaluation, but the need to ensure that in any system state place an order fault flow calculation converges at take no component overload occurs due to generator power adjustment and load shedding measures. Adequacy evaluation process is shown in Figure 4.

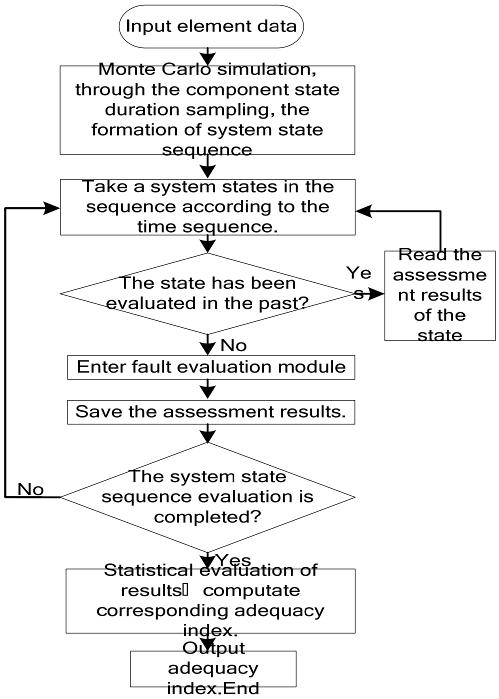

Figure 4. Flowchart of Power System Adequacy Evaluation

5. The Example Analysis

According to the evaluation model and evaluation algorithm, the IEEE-RTS79 power system adequacy is evaluated. Application of Matlab software to write the corresponding program. The simulation time were 100000h, 400000h and 700000h. The results of the calculation and analysis of IEEE-RTS79 system are listed below.

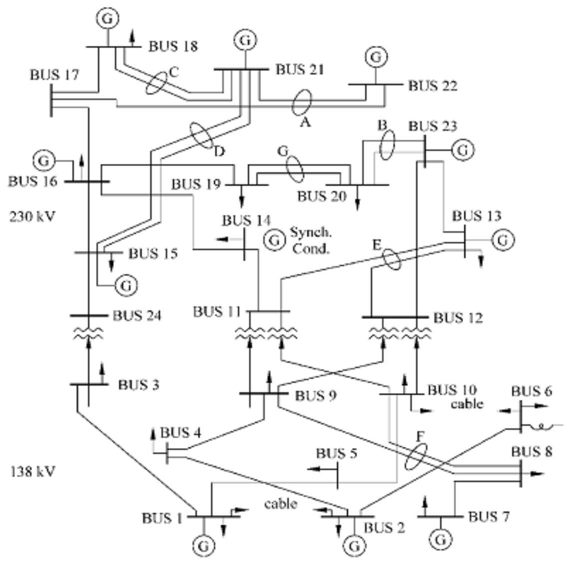

Figure 5. The Wiring Diagram of the IEEE-RTS 79 system.

The network consists of 32 generators, 33 lines, 5 transformers. The calculation results are shown in Table 1.

Table 1. Adequacy Evaluation Results under Different Simulation Time

Adequacy index	Parameters		
Simulation time/h	100000	400000	700000
The number of simulation state	5623	22436	39250
The number of calculation state	1718	4843	7177
The number of load shedding state	722	3052	5559
Probability of load curtailments P_{PLC}	0.091	0.0952	0.0996
Expected frequency of load curtailments F_{EFLC}	19.2729	22.6411	23.0421
Expected duration of load curtailments T_{EDLC}	806.061	830.18	869.079
Average duration of load curtailments T_{ADLC}	42.568	38.68	39.229
Expected load curtailments C_{ELC}	9855.95	10017.15	10802.47
Expected energy not supplied E_{EENS}	126064	121023.4	137081.5
Bulk power interruption index I_{BPII}	45.1	43.3	47.1
Bulk power energy curtailment index I_{BPECI}	3.50	3.59	3.97
Severity index S_{SI}	2670.915	2578.135	2863.129

As can be seen from Table 1, with the increase of the total time required for the simulation calculation of the number of state also increases, the adequacy evaluation index tends to be stable. In order to calculate the accuracy and calculation quantity balance, In this paper, the adequacy indices of total simulation time of 400000 hours as the object of study, Table 2 is the total simulation time of 400000 hours the adequacy evaluation results in different weather conditions.

Table 2. Adequacy Evaluation Results under Different Weather Conditions

Adequacy index	Normal	Disaster
Probability of load curtailments P_{PLC}	0.0817	0.0952
Expected frequency of load curtailments F_{EFLC}	18.6591	22.6411
Expected duration of load curtailments T_{EDLC}	800.52	830.18
Average duration of load curtailments T_{ADLC}	36.12	38.68
Expected load curtailments C_{ELC}	9835.12	10017.15
Expected energy not supplied E_{EENS}	119553.1	121023.4
Bulk power interruption index I_{BPII}	40.5	43.3
Bulk power energy curtailment index I_{BPECI}	3.19	3.59
Probability of load curtailments P_{PLC}	2467.96	2578.135

As can be seen from Table 2, compared to the normal weather, adequacy evaluation results under disastrous weather system decreased significantly. According to CIGRE index partition method, the disaster weather under the IEEE-RTS 79 system severity index of grade 3, is not reliable and having very serious impact on users.

6. Conclusion

This paper has proposed the algorithm model adequacy evaluation of power system based on Monte Carlo simulation method, which get plenty of relative indexes through the calculation of the IEEE reliability test system. The results have show that the model and the algorithm is feasible, which can correctly reflect the adequacy evaluation system in disaster weather, and the software can be used for adequacy evaluation for large-scale practical power system.

References

[1] Ding Ming, Hong Mei, Hu Zhenbin, et al. Overall Modeling for Transmission Network Reliability. *Journal of Hefei University of Technology (Natural Scied).* 1997; 20(6):1–9.
[2] Guo Yongji. The theory of reliability engineering. Beijing: Tsinghua University press. 2002.
[3] Guo Yongji. New development of electric power system. Beijing: Metallurgical Industry Press. 2000.
[4] Ding Ming, Dai Renchang, Liu Yacheng, et al. Monte-Carlo simulation approach to probabilistic stability. *Journal of Tsinghua University*. 1999; 39(3): 79–83.
[5] Ju Ping, Wu Gengyang, Li Yang. *Fundamental theorems on probabilistic stability of power systems.* Proceedings of the CSEE. 1991; 11(6): 17–25.
[6] Guo Yongji, Xi yongjian, Xiao Kai etal. Composite system reliability evaluation based on Monte-Carlo simulation combined with outages screening*. IEEE Trans on PWRS*. 1999; 14(2): 785–790.
[7] Billinton R, Li Wenyuan. Reliability assessment of electric power systems using Monte-Carlo methods. New York and London: Plenum Press. 1994.
[8] Billinton R, Gupta R Goel L. *Reliability Evaluation of Subtransmission Systems.* WESCANEX 1991 IEEE Western Canada Conference on Computer, Power and Communications Systems in a Rural Environment.
[9] IEEE Standard 346-1973 Terms for Reporting and Analyzing Outages of Electrical Transmission and Distribution Facilities and Interruptions to Customer Service.
[10] Billinton R, Wu Chenjian. *Predictive Reliability Assessment of Distribution Systems Including Extreme Adverse Weather.* Proceedings of the IEEE Canadian Conference on Electrical and Computer Engineering. IEEE. 2001; (2): 719–724.