

# Consideration of Uncertainty Factors in Search for High Risk Events of Power Systems Caused by Natural Disasters

TETSUSHI MIKI

Department of Electrical and Electronic Engineering  
 Anan National College of Technology  
 256 Aoki Minobayashi-Cho, Anan, 774-0017 Tokushima, JAPAN  
 tmiki@anan-nct.ac.jp <http://www.anan-nct.ac.jp/>

*Abstract:* - Power systems become large and complex, so the occurrence rates of a great deal of energy loss caused by faults become high. In this situation, the development of the efficient search method for high risk events of power systems is strongly required. Risk is defined as the product of energy loss and its occurrence rate, considering that the goal of power systems is the stable supply of power. This paper presents the developed method which can search accurately and efficiently high risk events of power systems caused by natural disasters in more safety side by considering uncertainty factors occurred in power systems. It was applied to the model system composed of 3 generators and 9 buses. The results of application have clarified its effectiveness.

*Key-Words:* - Power Systems, Transient Stability, Risk, Natural Disasters, Critical Fault Clearing Time

## 1 Introduction

Power systems become large and complex, so the occurrence rates of a great deal of energy loss caused by faults become high. In this situation, the development of the efficient search method for high risk events of power systems is strongly required. Risk is defined as the product of energy loss and its occurrence rate, considering that the goal of power systems is the stable supply of power. Researches which are related to the search method for high risk events of power systems are classified into ones about online security assessment based on risk and the other about offline risk assessment by use of Monte Carlo simulation.

### (1) Online security assessment based on risk

There are researches about security assessment based on risk caused by loss of transient stability [1], security assessment based on risk caused by overload [2], [3], and identifying high risk contingencies of substations for online security assessment [4]. The objective of these researches is online security assessment at full speed. Therefore, they do not show the efficient method for searching high risk events among all ones to be occurred in power systems.

### (2) Offline risk assessment

There is the research about offline risk assessment of power systems by use of Monte Carlo simulation [5]. The objective of this research is the average risk assessment of power systems. Because a great number of simulation times are required in order to assess accurately high risk events with very low frequency, it

is not appropriate to apply this method to search high risk events among all ones to be occurred in power systems.

Considering the above situation, the author developed the search method for high risk events of power systems caused by natural disasters [6]. This method gains the high search efficiency by use of knowledge bases. But, it does not consider uncertainty factors occurred in power systems because of the following reasons.

(1) It deals with equally both data about natural disasters which are much more uncertain and data gained by simulating transient phenomena of power systems after faults which are much less uncertain.

(2) It uses only average values without considering statistical scatter of input data.

There are some researches about consideration of uncertainty factors occurred in power systems.

(1) Risk assessment due to local demand forecast uncertainty in the competitive supply industry

This research investigates the risk index of domestic suppliers due to load forecast uncertainties in the competitive power market using the residuals from short-term electrical load forecast [7]. The objective of this research is to improve the accuracy of short-term electrical load forecast. Therefore, results of this research can not be applied to solve the above problems.

(2) The probabilistic transient stability indices after the incorporation of load forecast uncertainty

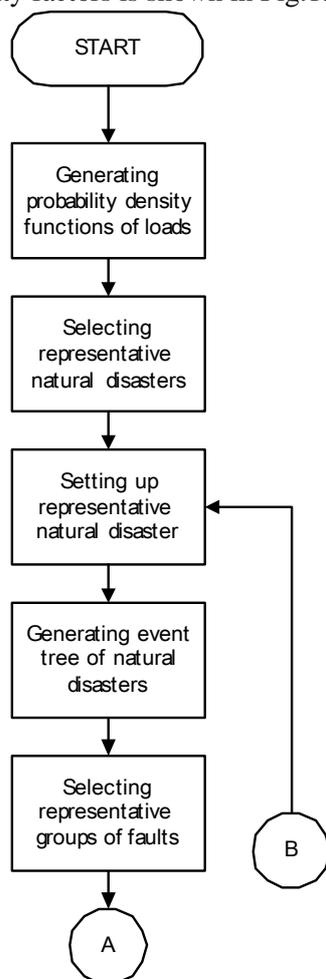
By assuming that the forecast load has a standard

deviation of 4 %, this research shows that the probability of stability indices with load forecast uncertainty are either equal to or less than those obtained with zero load forecast error [8]. The method used in this research is effective to solve the latter problem.

Considering the above researches, this paper presents the developed method which can search accurately and efficiently high risk events of power systems caused by natural disasters in more safety side by considering uncertainty factors occurred in power systems.

## 2 Efficient Search Method for High Risk Events of Power Systems

The flowchart of method without considering uncertainty factors is shown in Fig.1. The steps of this



**Fig. 1-(1/2).** Flowchart for efficient research method for high risk events of power systems.

flowchart are shown as follows. The detailed method is described in the reference [6].

(1) Generating probability density functions of loads  
Load change data are classified into ones which have similar change patterns with seasons, date and time and the others which have non-similar change patterns with them. The probability density functions of loads are generated by the former data. The joint probability density functions of loads are generated by the latter data.

(2) Selecting representative natural disasters

Representative natural disasters which will cause high risk events are selected as follows.

1) Enumerating all natural disasters

All natural disasters to be occurred in power systems are enumerated. Representative natural disasters are concretely lightning, earthquake, typhoon, tornado, heavy snowfall and so on.

2) Selecting representative natural disasters

(3) Setting up representative natural disaster

(4) Generating event tree of natural disasters

The event trees of natural disasters are generated based on statistics data of natural disasters. Their top events are natural disasters and their bottom events are groups of faults caused by natural disasters.

(5) Selecting representative groups of faults

Representative groups of faults are selected by product of estimated energy loss in bottom events and their occurrence rates.

(6) Setting up representative group of faults

(7) Generating event tree of group of faults

The steps of generating event tree of group of faults are shown as follows [9].

1) Generating event tree in case of protection system normal action

2) Reliability analysis of protection systems

3) Addition of event tree in case of protection system failure

(8) Selecting representative events

(9) Setting up representative event

(10) Calculating risk data in similar load change patterns

1) Generating critical fault clearing time function

The critical fault clearing time is the boundary value between stable and unstable value of fault clearing time. The critical fault clearing time function  $CCT(W:load)$  is defined by taking notice of the fact that transient stability is mainly controlled by fault clearing time and load. The detailed method for generating critical fault clearing time function is described in the reference [10].

2) Generating discrete risk function

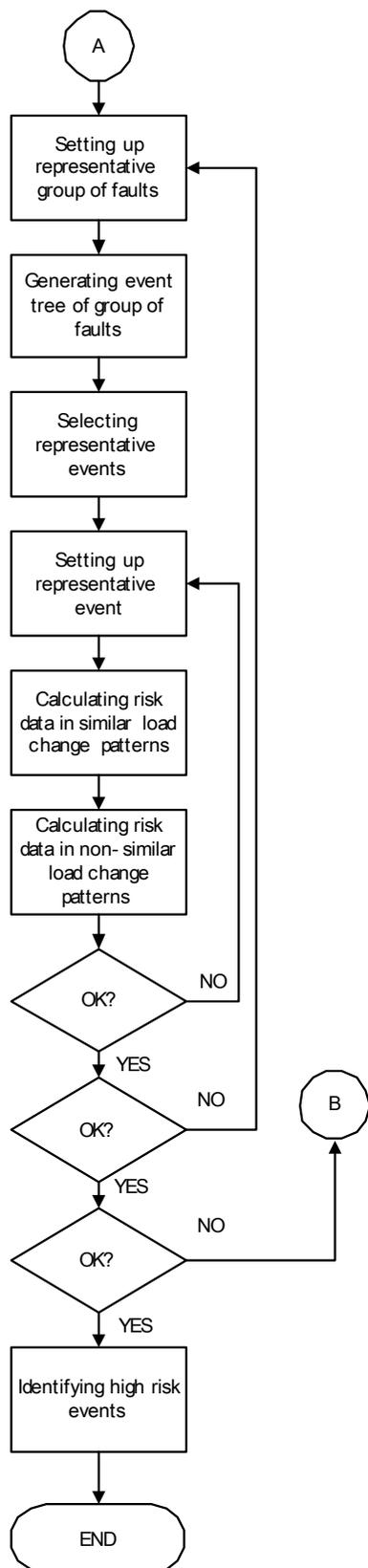


Fig. 1-(2/2). Flowchart for efficient research method for high risk events of power systems.

The discrete risk function  $R_{ij}(W)$  of fault  $i$ , bottom event  $j$  is generated as follows, cutting the low risk region of function.

$$R_{ij}(W) = F_i P_j \times \sum_{m=1}^{m=mt} PL(W) C_{ijm}(W) R_{ijm}(W) T_{ijm}(W) W \quad (1)$$

Where

$W$  : load,  $F_i$  : occurrence rate of fault  $i$ ,  $P_j$  : branch probability from top event to bottom event  $j$ ,  $mt$  : total mode number of instability,  $PL(W)$  : probability density function of load,  $C_{ijm}(W)$  : function for discriminating occurrence of instability defined as follows

$$CCT_{ijm}(W) - CT > 0$$

0 (stable)

$$CCT_{ijm}(W) - CT \leq 0$$

1 (unstable)

Where

$CCT_{ijm}(w)$  : critical fault clearing time function of fault  $i$ , bottom event  $j$ , mode  $m$ ,  $CT$  : fault clearing time

$R_{ijm}(W)$  : ratio of average energy loss of fault  $i$ , bottom event  $j$ , mode  $m$  to total average energy in normal state,  $T_{ijm}(W)$  : average fault duration time of fault  $i$ , bottom event  $j$ , mode  $m$

3) Check of request of changing load

4) Calculating risk data

The risk data  $R_{ijk}$  of fault  $i$ , bottom event  $j$ , load  $k$  is calculated as follows.

$$R_{ijk} = \int_{W_{k_b}}^{W_{k_t}} R_{ij}(W) dW \quad (2)$$

Where

$W_{k_b}$  : bottom (minimum) value of load  $k$ ,  $W_{k_t}$  : top (maximum) value of load  $k$

(11) Calculating risk data in non-similar load change patterns

1) Selecting representative non-similar load change patterns

2) Setting up representative no-similar load change patterns

3) Calculating average energy loss

The average energy loss  $WTA_{ijl}$  of fault  $i$ , bottom event  $j$ , non-similar load change pattern  $l$  is calculated based on simulation results of transient phenomena.

4) Checking completion of calculating all representative non-similar load change patterns

5) Calculating risk data

The risk data  $R_{ijl}$  of fault  $i$ , bottom event  $j$ , non-similar

load change pattern  $l$  is calculated as follows.  

$$R_{ijl} = F_i P_j W T A_{ijl} \quad (3)$$

Where

$F_i$  : occurrence rate of fault  $i$ ,  $P_j$  : branch probability from top event to bottom event  $j$

(12) Checking completion of calculating all representative events

(13) Checking completion of calculating all representative groups of faults

(14) Checking completion of calculating all representative natural disasters

(15) Identifying high risk events

High risk events are identified by sorting risk data according to values.

### 3 Method with Considering Uncertainty Factors

Two methods with considering uncertainty factors occurred in power systems are shown in the following.

#### 3.1 Method for processing input data with widely different degrees of uncertainty

Results of comparison between data about natural disasters and simulation data of power systems can be summarized as follows.

(1) Because occurrence rates of natural disasters in high level are very small, their statistics data are few and uncertain.

(2) It is not appropriate to estimate accurately damages of natural disasters by simulation, for it is difficult to make suitable models and data for simulation.

(3) Because standard simulation models of power systems have already been established, transient phenomena of power systems after plural faults can be accurately simulated.

(4) Based on the above reasons, flowchart of method without considering uncertainty factors can be classified into the following two parts.

1) Selecting representative groups of faults (the former part) which corresponds to step (1)~(5) of Fig.1-(1/2)

2) Identifying high risk events (the latter part) which corresponds to step (6)~(15) of Fig.1-(2/2)

Based on the above results of comparison, the following method has been developed.

(1) The former and latter parts are independently processed.

(2) In the former part, representative groups of faults are selected in various cases from optimistic to pessimistic ones.

(3) In the latter part, high risk events caused by representative groups of faults are identified.

(4) High risk events of power systems caused by natural disasters are searched and identified by combining results of the former and latter parts.

#### 3.2 Method for calculating risk increase rates per standard deviation of input data

The steps of the developed method are shown as follows.

(1) Selecting representative input data

The probability density functions of input data can be generally expressed by normal distribution. The input data are sorted according to their values of standard deviations. Only input data with high values are selected as representative ones.

(2) Setting up representative input data

Preceding input data with high values, the input data to be calculated next is set up.

(3) Calculating risk increase rates per standard deviation

Keeping values of other input data except the set up data average, the risk increase rates are calculated in case of that the values of the set up input data deviate by integer times of standard deviation from its average value.

(4) Checking completion of calculating all risk increase rates per standard deviation

If risk increase rates per standard deviation of all representative input data are calculated, this method is finished. Otherwise, step (2) is processed next.

## 4 Application to Model Power Systems

### 4.1 Conditions of Application

In order to confirm the effectiveness of the developed method, it was applied to a model power system under the following conditions.

(1) The constitution of a model power system is shown in Fig.2. The capacities of generators are 247.5, 192 and 128MVA in order of numbers.

(2) Only the loss of transient stability is simulated among fault cascading phenomena.

(3) All generators lose transient stability in occurrence of plural faults.

(4) The average fault duration time of one fault is 1 hour and that of plural faults is 10 hours.

### 4.2 Process of Search

The outline of search process of high risk events by using the method for processing input data with widely different degree of uncertainty is shown as follows.

(1) Generating probability density functions of loads  
 The total probability that the model power system is in

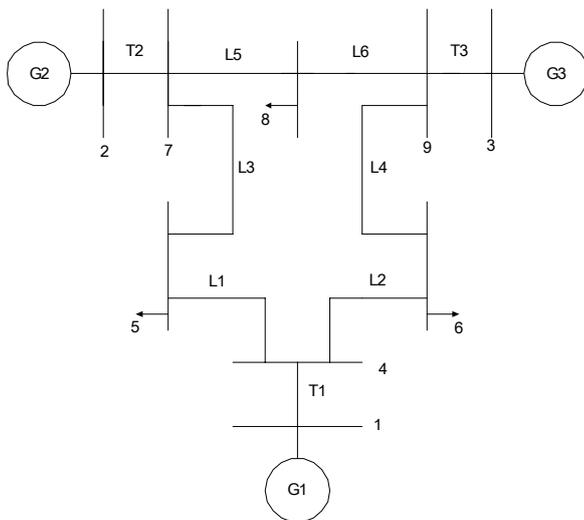


Fig. 2. Constitution of model power system

non-similar load change patterns is 0.4.

(2) Selecting representative natural disasters

Lightning is selected as representative natural disasters. Lightning occurrence data have been collected with the lightning location systems operated by electric power companies in Japan [11]. The paper which reports the above fact gives the following data.

1) Nine-year (1992-2000) average lightning stroke frequency maps in summer, winter and the whole year  
 2) Graph (X axis: annual number of lightning strokes, Y axis: outage / 100km / year) which shows the relation between the annual number of lightning strokes and the frequency of the faults on transmission lines. This graph shows that the number of faults is almost proportional to the annual number of lightning strokes.

(3) Generating event tree of natural disasters

Based on the above data, event tree is generated as follows.

The occurrence rate of lightning stroke = 550,000/year

Transition probabilities from top to bottom events

No fault = 0.9999908, One fault = 0.0000092

Plural faults in separated places = 0

Based on the above data, ANOF (the annual number of one fault / 100km) is calculated as follows.

$$\text{ANOF} = 550,000 \times 0.0000092 = 5.06$$

(4) Selecting representative groups of faults

LLG (two-phase-line-to-line-to-ground-fault) in buses are selected as representative fault in case of one fault based on results of simulation.

(5) Generating event tree of group of faults

(6) Selecting representative events

The events which satisfy the following conditions are selected as representative ones based on the generated event tree.

1) LLG occurs in buses. 2) Protection systems act normally. 3) Energy loss occurs by loss of transient stability.

(7) Calculating risk data in similar load change patterns

1) Generating critical fault clearing time function

2) Generating discrete risk function and calculating risk data

(8) Calculating risk data in non-similar load patterns

(9) Identifying high risk events

The highest event is occurred in case that all loads are 80% (70%~90%) of the rated load. In case of that the equivalent length of the bus is 50m, the high risk data per year in case of lightning are shown as follows.

Risk data calculated by this method

Optimistic case = 0.014 (% / year)

Average case = 0.043 (% / year)

Pessimistic case = 0.129(% / year)

Risk data of a equivalent real power system in a electric power company in Japan = 0.039 (% / year)

The value of risk data is relatively defined as 100% in case that the average fault duration time is 1 hour and average power loss is the rated power.

The results of application have clarified the following facts.

(1) The effects of occurrence rates and transition probabilities on high risk data per year in case of lightning can be assessed by simple calculation without additional simulation of transient phenomena of power systems after faults.

(2) High risk data of average case calculated by this method is almost equivalent to that of real system which is between those of optimistic and pessimistic case.

#### 4.3 Calculation of risk increase rates per standard deviation

Fault clearing times are adopted as uncertainty factors which affect most greatly transient stability of power systems. Based on data of a real system, it is assumed that their probability density functions can be expressed by normal distribution with average  $\mu$ , standard deviation  $\sigma$  (10% of  $\mu$ ) [8]. The loss probability function of transient stability which corresponds to risk is shown in Fig.3. This function has clarified the following facts.

(1) The larger upside deviation from average is, the larger value of this function is and the higher risk is.

(2) The probability that the value of the loss probability function of transient stability is smaller

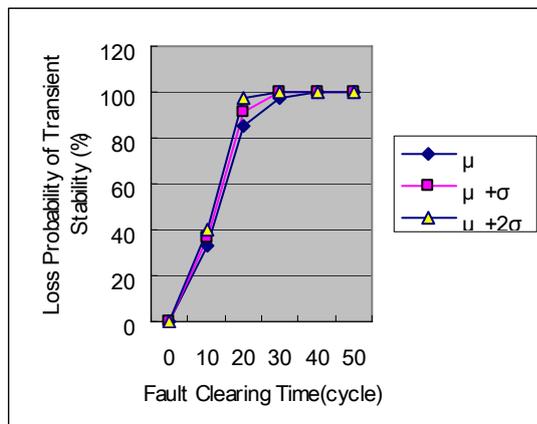


Fig. 3. Loss probability function of transient stability.

than that of the function deviated by one upside standard deviation from average can be gained as 0.8413 by using the value table of standard normal distribution function. The probability in case of two upside standard deviations from average is 0.9772.

(3) In a real power system, the value of  $\sigma$  is 12 (cycle) and that of  $\mu$  is 1.2 (cycle) [8]. It is confirmed that this system has the loss probability function with the small deviation.

(4) The high risk events can be searched in more safety side by considering uncertainty factors.

## 5 Conclusion

The results of application of the developed method to the model system have clarified its effectiveness.

In order to apply it to real power systems, the following works are required in the future.

(1) It will be applied to various power systems and will be improved by results of assessment.

(2) High risk events of natural disasters except lightning will be searched.

(3) The method in order to improve the accuracy of data base of natural disasters will be researched.

(4) Data about uncertainty factors in power systems will be collected and analyzed.

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