



The Efficient Search for High Risk Events of Power Systems Caused by Lightning

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Abstract—This paper presents the developed method which can search accurately and efficiently high risk events of power systems resulted from the loss of transient stability caused by natural disasters. It was applied to the model system composed of 3 generators and 9 buses, selecting lightning as representative natural disasters. The results of application have clarified its effectiveness.

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. There are some researches which are related to the search method for high risk events [1]-[3]. 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.

Considering the above situation, the author developed the search method for high risk events of power systems caused by loss of transient stability which is the most important characteristic to assess in power systems [4]. This method gains the high search efficiency by use of knowledge bases. But, it has the limit that it can not search high risk events of power systems caused by natural disasters, for its top event is the fault occurred in power systems. In order to overcome this limit, steps for selecting representative groups of faults caused by natural disasters have been newly developed.

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

The flowchart of this method is shown in Fig.1. Steps from (2) to (5) have been newly developed. The steps of this flowchart are shown as follows.

(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 independent variables

of these functions are common relative loads of power systems. The joint probability density functions of loads are generated by the latter data. The independent variables of these functions are each relative loads of power systems.

(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

Representative natural disasters which will cause high risk events are selected based on the characteristics of the region where power systems present.

(3) Setting up representative natural disaster

Preceding natural disasters which will cause high risk events, the representative natural disaster to be assessed next is set up.

(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

Preceding representative group of faults which will cause high risk, the representative group to be assessed next is set up.

(7) Generating event tree of group of faults

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

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

Representative events are selected by product of estimated energy loss in bottom events and their

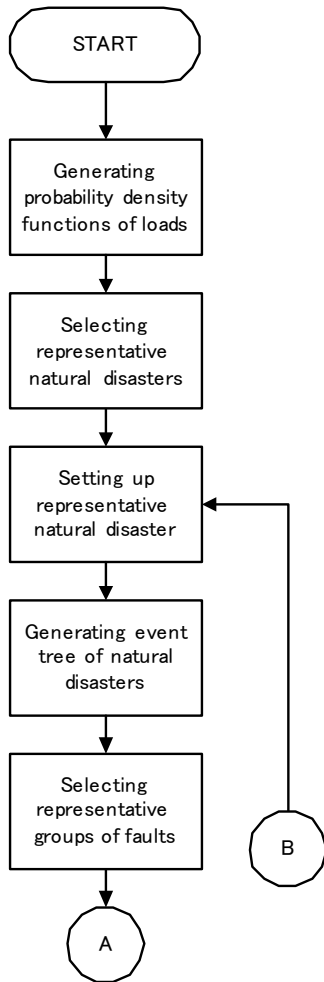


Fig. 1-(1/2). Flowchart for efficient research method for high risk events of power systems.

occurrence rates.

(9) Setting up representative event

Preceding event which will cause high risk, the representative event to be assessed next is set up.

(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 [4].

2) Generating discrete risk function

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

$$R_{ij}(W) = F_i P_j \times$$

$$\sum_{m=1}^{m=mt} PL(W) C_{ijm}(W) R_{ijm}(W) T_{ijm}(W) W$$

(1)

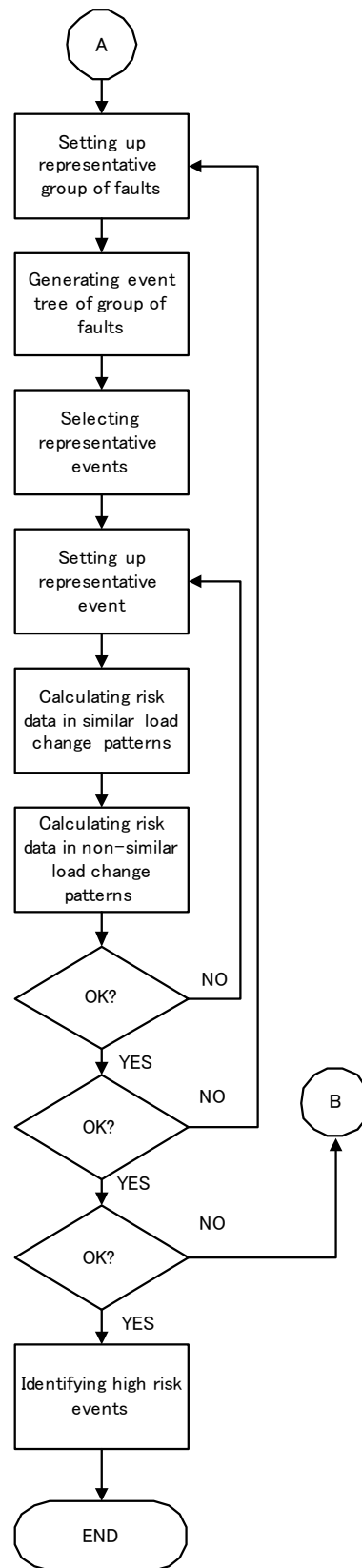


Fig. 1-(2/2). Flowchart for efficient research method for high risk events of power systems.

Where

W : load, Fi : occurrence rate of fault i, Pj : branch probability from top event to bottom event j, mt : total mode number of instability, PL(W) : probability density function of load, Cijm(W) : function for discriminating occurrence of instability defined as follows

$$CCTijm(W) - CT > 0$$

0 (stable)

$$CCTijm(W) - CT \leq 0$$

1 (unstable)

Where

CCTijm(W) : critical fault clearing time function of fault i, bottom event j, mode m, CT : fault clearing time, Rijm(W) : ratio of average energy loss of fault i, bottom event j, mode m to total average energy in normal state, Tijm(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 Rijm of fault i, bottom event j, load k is calculated as follows.

$$Rijk = \int_{Wkb}^{Wkt} Rij(W) dW \quad (2)$$

Where

Wkb : bottom(minimum)value of load k, Wkt : top(maximum)value of load k

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

The risk data is calculated by using the average energy loss calculated based on simulation results of transient phenomena.

- (12) Check of calculating representative events
- (13) Check of calculating representative group of faults
- (14) Check of calculating representative natural disasters
- (15) Identifying high risk events

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

3. Application to Model Power System

3.1. Condition 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) The average fault duration time of one fault is 1 hour.

3.2. Process of Search

The outline process of search for high risk events is shown as follows.

- (1) Generating probability density functions of loads

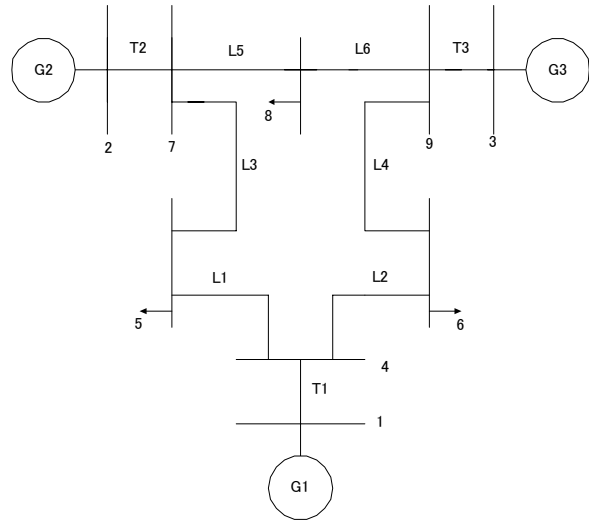


Fig. 2. Constitution of model power system

The total probability that the model power system is in non-similar load change patterns is 0.4. The probability density function of load with similar change patterns is shown in Fig.3.

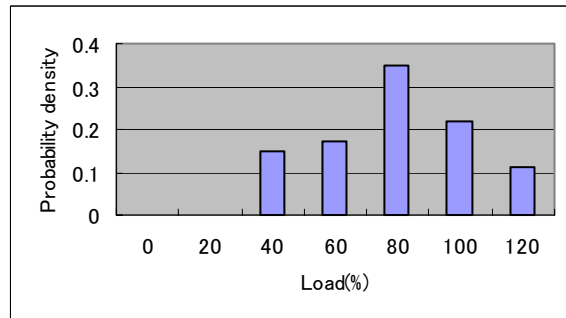


Fig.3 Probability density function of load

- (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 [5]. 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

The critical fault clearing time functions of events caused by LLG occurred in various buses are shown in Fig.4. The unit of CCT is cycle (0.017 seconds). This graph makes it clear that the event caused by the above fault occurred in the bus B7 has the highest risk.

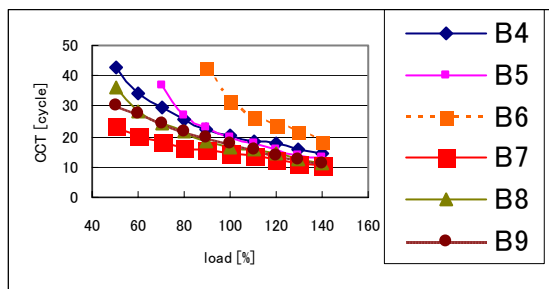


Fig. 4. Change of critical fault clearing time functions by fault locations.

2) Generating discrete risk function and calculating risk data

The discrete risk functions per one LLG occurred in the bus B7 in various CT are shown in Fig. 5. The total risk of all loads is defined as 100% in case that the average fault duration time is 1 hour and average power loss is the rated power.

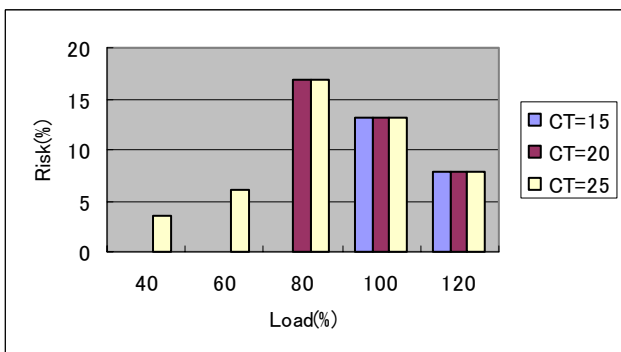


Fig.5. Change of discrete risk functions by CT (fault clearing time).

(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 and CT is 25 cycles, the high risk value per year in case of lightning is 0.043 (% / year)

3.3. Results of Application

The results of application have clarified the following facts.

- (1) The developed method can search accurately and efficiently high risk events of power systems caused by lightning.
- (2) The effect of fault clearing time on risk can easily assessed by using critical fault clearing time functions.

4. 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.

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