The Efficient Search Method for High Risk Events of Power Systems Caused by Natural Disasters

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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 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. 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 loss of transient stability which is the most important characteristic to assess in power systems [6]. 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. This paper presents the developed method which can search accurately and efficiently high risk events of power systems caused by natural disasters.

2 Efficient Search Method for High Risk Events of Power Systems

The flowchart of this method is shown in Fig.1. 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

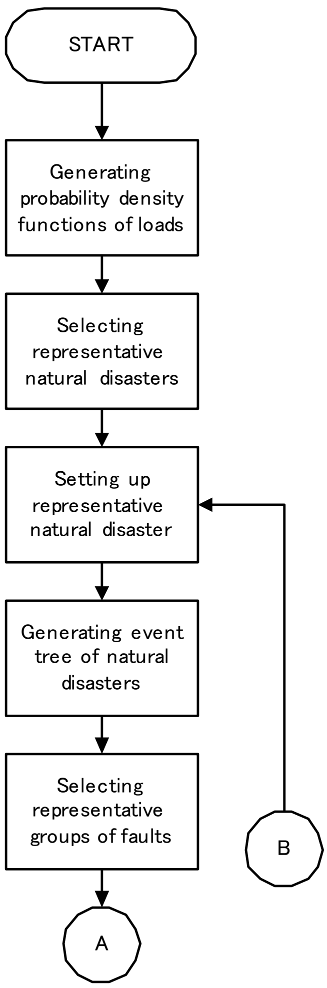

Fig. 1-(1/2). Flowchart for efficient research method for high risk events of power systems.

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 earthquake, typhoon, tornado, thunder, 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

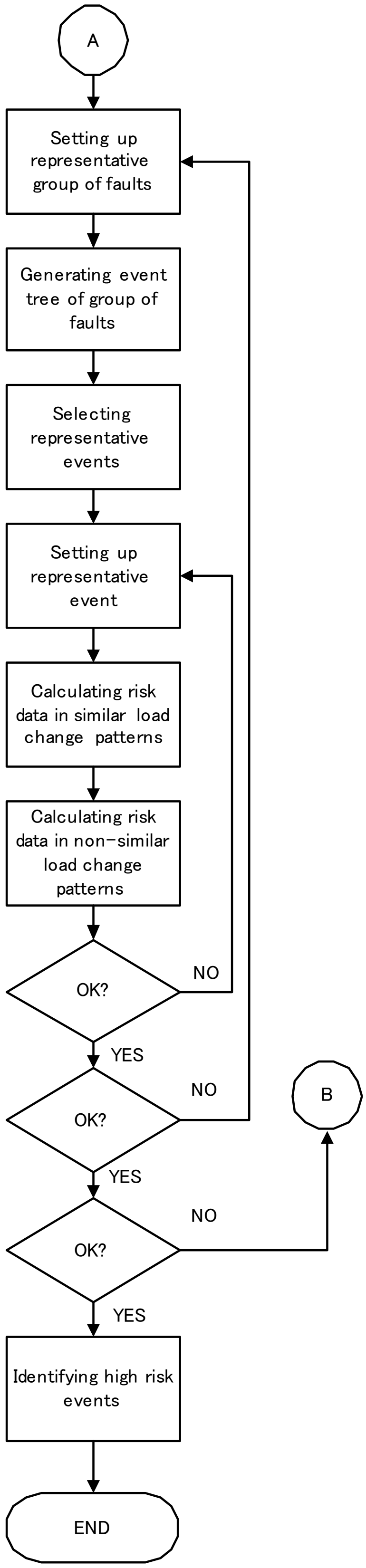

Fig. 1-(2/2). Flowchart for efficient research method for high risk events of power systems.

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 [7].

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 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

The flowchart for calculating risk data in similar load change patterns is shown in Fig.2. The steps of this flowchart are shown as follows.

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 [8].

2) Generating discrete risk function

The discrete risk function Rij(W) of fault i, bottom event j is generated as follows, cutting the low risk region of function.

$$Rij(W) = FiPj \times \sum_{m=1}^{m=mt} PL(W)Cijm(W)Rijm(W)Tijm(W)W \qquad (1)$$

Where

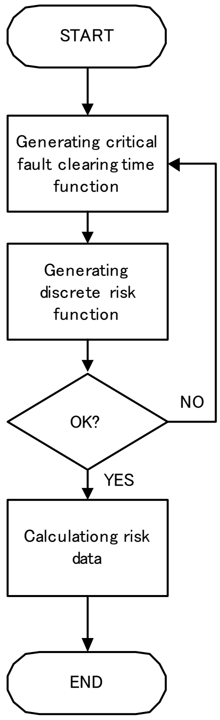

Fig. 2. Flowchart for calculating risk data in similar load change patterns.

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

The load region with high risk is identified by discrete risk function. If changing load is not required in order to calculate final risk data, the next step is processed. Otherwise, step 1) is processed next.

4) Calculating risk data

The risk data Rijk 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 flowchart for calculating risk data in non-similar load change patterns is shown in Fig.3. The steps of this flowchart are shown as follows.

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 WTAijl of fault i, bottom event j, non-similar load change pattern l is calculated based on simulation results of transient phenomena.

4) Check of calculating representative non-similar load change patterns

If average energy losses are calculated, the next step is processed. Otherwise, step 2) is processed next.

5) Calculating risk data

The risk data Rijl of fault i, bottom event j, non-similar load change pattern l is calculated as follows.

$$Rijl = FiPjWTAijl \quad (3)$$

Where

Fi : occurrence rate of fault i, Pj : branch probability from top event to bottom event j

(12) Check of calculating representative events

If risk data of all representative events are calculated, the next step is processed. Otherwise, step (9) is processed next.

(13) Check of calculating representative group of faults

If risk data of all representative faults are calculated, the next step is processed. Otherwise, step (6) is processed next.

(14) Check of calculating representative natural disasters

If risk data of all representative natural disasters are calculated, the next step is processed. Otherwise, step (3) is processed next.

(15) Identifying high risk events

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

3 Application to Model Power Systems

3.1 Conditions of Application

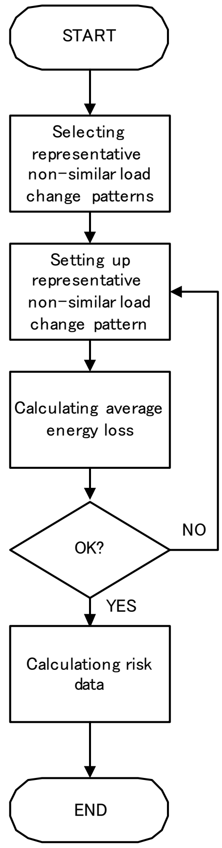

Fig. 3. Flowchart for calculating risk data in non-similar load change patterns.

In order to confirm the effectiveness of this 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.4. 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.

3.2 Process of Search

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

(1) Generating probability density functions of loads

The total probability that the model power system is in non-similar load change patterns is 0.4.

(2) Selecting representative natural disasters

(3) Generating event tree of natural disasters

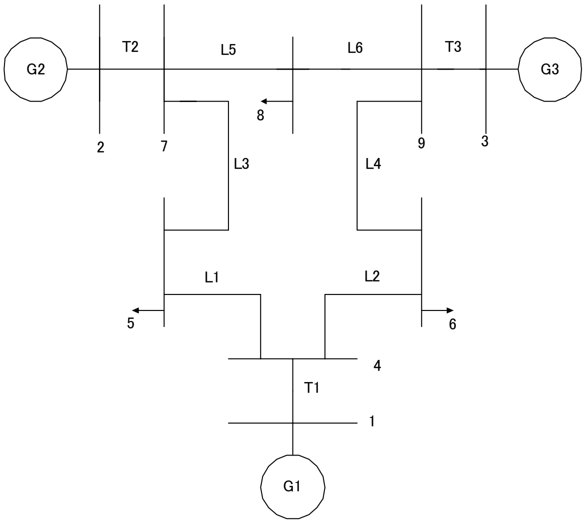

Fig. 4. Constitution of model power system.

Earthquakes are selected as representative natural disasters. The definition of level of earthquake and its occurrence rate is shown in Table 1.
Transition probability from top to bottom events in event tree of earthquake is shown in Table 2.
(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
The generated event tree is shown in Fig. 5.
(6) Selecting representative events
The events which satisfy the following conditions are selected as representative ones.
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 make it clear that the event caused by the above fault occurred in the bus B7 has the highest risk.
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. 6. 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.
(8) Calculating risk data in non-similar load patterns
When CT is 25 cycles, high risk data in non-similar

Table 1. Definition of level of earthquake and its occurrence rate.

Number of level	Seismic intensity x (Japanese scale)	Occurrence rate (time/year)
1	5.5≦x<6.0	0.1
2	6.0≦x<6.5	0.05
3	6.5≦x<∞	0.01

Table 2. Transition probability from top to bottom events in event tree of earthquake.

Number of level	No fault	One fault	Plural faults
1	0.95	0.05	0
2	0.1	0.8	0.1
3	0	0.2	0.8

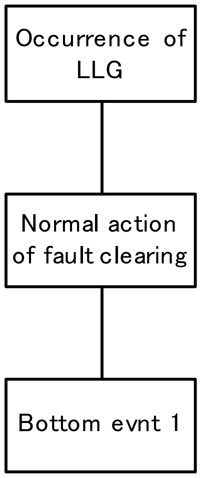

Fig. 5. Event tree caused by LLG.

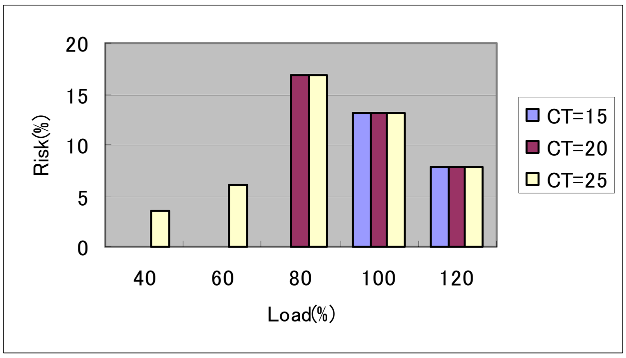

Fig. 6. Change of discrete risk functions by CT(fault clearing time).

load change patterns are calculated.
(9) Identifying high risk events
High risk data of one fault are shown in Table 3. The numbers of load change patterns are numbered according to values of risk. High risk data per year in each level of earthquake are shown in Table 4.

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 natural disasters.
(2) The effect of fault clearing time on risk can easily assessed by using critical fault clearing time functions.
(3) The accuracy and efficiency of search depends on the power system model of simulator and input data.

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 earthquake 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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Table 3. High risk data of one fault.

Number of load change pattern	Load of B5 (%)	Load of B6 (%)	Load of B8 (%)	Risk (%)
1	80	80	80	17
2	100	100	100	13
3	80	80	100	10

Table 4. High risk data per year in each level of earthquake.

Level of earthquake	Risk (%/year)
1	0.34
2	2.08
3	2.27