The Efficient Search Method for High Risk Events of Power Systems by Use of Knowledge Bases

TETSUSHI MIKI
Department of Electrical and Electronic Engineering
Anan National College of Technology
256 Aoki Minobayashi-Cho, Anan, 774-0017 Tokushima, JAPAN
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 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. This method gains the high search efficiency by use of knowledge bases. 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, Critical Fault Clearing Time, Simulation, Knowledge Bases

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 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, this paper presents the developed 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. This method gains the high search efficiency by use of knowledge bases. Because there are few researches about the search method for high risk events of power systems, the developed method is the innovative one in this field.

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) Selecting representative faults

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

1) All faults to be occurred in power systems are enumerated. Fault data base is made by classifying them based on kinds and locations of faults.

2) Faults which will cause high risk events are searched based on the following heuristic knowledge bases.

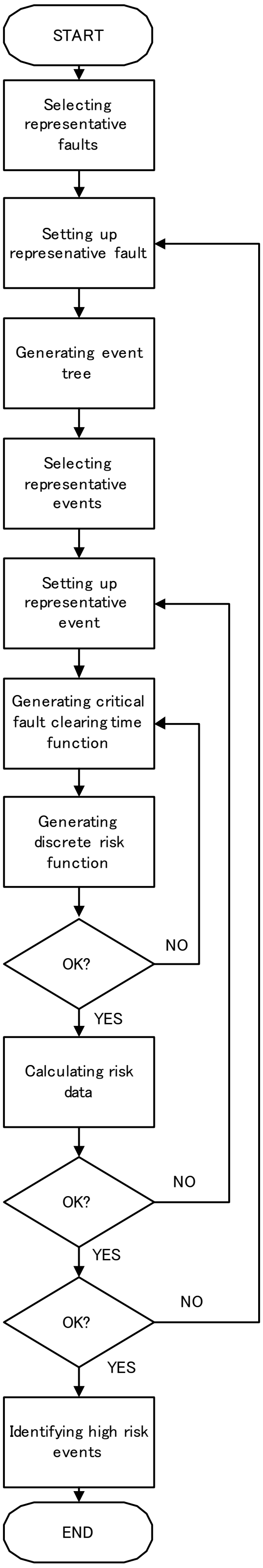

Fig. 1. Flowchart for efficient research method for high risk events of power systems.

a) Multi-phase-faults will cause high risk events with high probabilities.
b) Faults occurred in buses which connect many lines will cause high risk events with high probabilities.
c) Faults occurred in neighborhood of generators with small capacities will cause high risk events with high probabilities.
3) Transient phenomena of faults in border are simulated and representative faults are finally selected based on results of simulation.

(2) Setting up representative fault

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

(3) Generating event tree

Assuming that all protection systems act normally at first, event trees are generated. Next, the reliability of protection systems is analyzed and event trees in case of protection system failure are generated using analysis data. This new event trees are added to old ones [6]. These event trees are knowledge bases which express synthetically the states transition of power systems after faults.

Steps of generating event tree are shown as follows.

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

Assuming that all protection systems act normally, the event trees for the set up fault are generated using relational data between loads and action sequences of protection systems. Event trees are generated by only high risk events, cutting events with lower risk than standard value.

2) Reliability analysis of protection systems

The reliability of protection systems is expressed by average probabilities that they are in normal or ith failure mode state. These average probabilities are obtained as follows.

A. The failure of protection systems is analyzed and failure mode (no action, error action of ith type, etc.) are identified.

B. The transition rates among normal and ith failure modes are obtained as follows.

a) Failure rates are estimated based on past reliability data.

b) Repair rates are estimated based on maintenance methods (inspection frequency, automation inspection devices, etc.).

C. The state transition process of protection system is expressed by Markov model. Pj (average probability that the protection system is in state j) is obtained by solving probability differential equations. This probability is the branch probability of event tree.

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

Assuming that protection systems act in set up modes, event trees are generated using relational data between loads and action sequences of protection systems. These event trees are added to already generated event tree. Event trees are generated by only high risk events, cutting events with lower risk than standard value.

(4) Selecting representative events

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

(5) Setting up representative event

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

(6) 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 [7]. This function is knowledge base which expresses synthetically the transient stability of power systems after faults. Changing load roughly at first and finely later, representative events are simulated. Based on simulation data, critical fault clearing time functions is generated. The flowchart for generating critical fault clearing time functions is shown in Fig.2. The critical fault clearing time CCT is calculated using the bisection algorithm [8]. The steps of this flowchart are shown as follows.

1) Setting up load

The load W is set up.

2) Setting up initial fault clearing time CT1,CT2

The lower stability limit CT1 and upper stability limit CT2 is set up, considering that the finally calculated critical fault clearing time CCT will be between CT1 and CT2.

3) Calculating fault clearing time CT

The mid-point value CT which is fault clearing time in the next simulation is calculated by averaging stability limit CT1 and CT2.

4) Simulating transient phenomena caused by faults of power systems

At first, the load flows before the occurrence of fault are calculated based on the data about load and power system. Next, the transient phenomena after the occurrence of fault are calculated based on the data about fault, initial load flow and power system.

5) Check of system stability

The system stability is checked based on results of simulation. If it is found that the system is stable, then the lower stability limit CT1 of interval is replaced by the mid-point value CT. Otherwise, the upper value CT2 is replaced by the mid-point value CT. Because the critical fault clearing times of generators are generally different, they have different CCT functions classified into some modes. Therefore, the system stability must be checked in all modes.

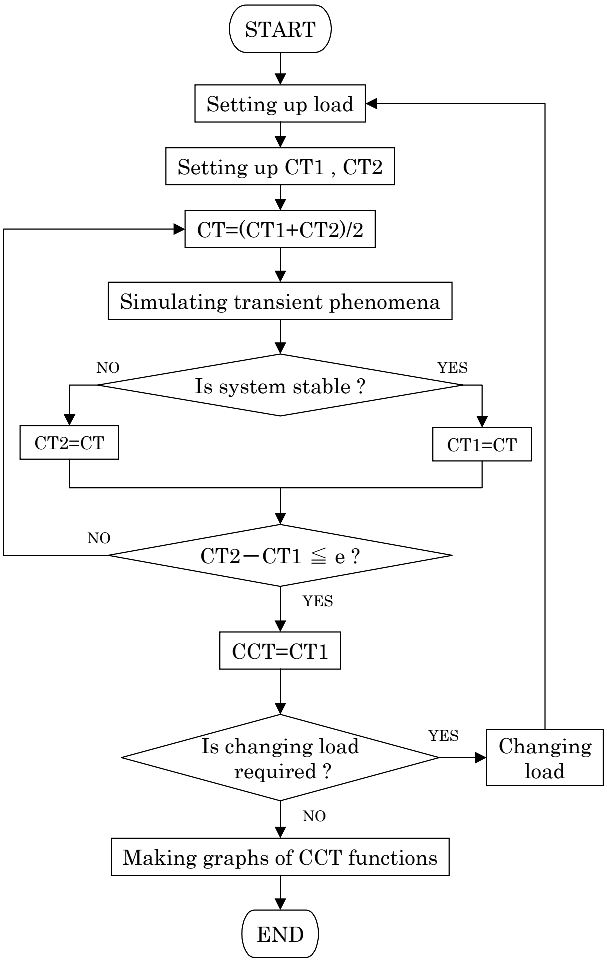

Fig. 2. Flowchart of generation of critical fault clearing time functions.

6) Check of calculation precision

The calculation precision is checked by comparing the difference between CT1 and CT2 with the required precision e. If the difference is smaller than e, then CCT equals CT1. Otherwise, step 3) is processed next.

7) Check of request of changing load

It is checked if changing load is required in order to make graphs of CCT functions. If it is found that changing load is required, then load is changed according to the algorithms previously developed in order to generate efficiently CCT functions and step 1) is processed next. [9] Otherwise, graphs of CCT functions expressed discretely are made based on CCT data in various loads.

(7) 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. This function is knowledge base which expresses synthetically the risk of power systems after faults.

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

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

(8) 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 (6) is processed next.

(9) Calculating risk data

The risk data Rijk of fault i, bottom event j, load k is calculated as follows.

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

Where

Wkb : bottom(minimum)value of load k

Wkt : top(maximum)value of load k

(10) Check of calculating representative events

If risk data of all representative events are calculated, the next step is processed. Otherwise, step (5) is processed next.

(11) Check of calculating representative faults

If risk data of all representative faults are calculated, the next step is processed. Otherwise, step (2) is processed next.

(12) 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

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

(1) A model power system is composed of 3 generators, 11 duplicate lines and 9 buses. Its constitution is shown in Fig.3. The capacities of generators are 247.5, 192 and 128MVA in order of numbers.

(2) Generators are expressed by the d-q axes model.

(3) Generators are controlled by AVR (automatic voltage regulators), PSS (power system stabilizers), and governors.

(4) Only the out of step due to the decrease of transient stability is simulated among fault cascading phenomena. Generators in out of step are isolated from the power system and cause energy loss. The average fault duration time is 1 hour.

(5) The probability density function of load is shown in Fig.4. All loads have similar change patterns with seasons, date and time.

3.2 Process of Search

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

(1) Selecting representative faults

The critical fault clearing time functions of LLL(three-phase-line-to-line-fault), LLG(two-phase-line-to-line-to-ground-fault), LL(two-phase-line-to-line-fault) and LG(one-phase-line-to-ground-fault) at bus 5 are shown in Fig.5. The unit of CCT is cycle and one cycle is 0.017 seconds. This graph makes it clear that CCT functions are not almost affected by kinds of faults. It is estimated that the reason why this characteristic is kept is that impedances between line and line or between line and ground are small. This characteristic is kept in other buses. Considering that faults in buses are the most severe, LLG in buses are selected as representative faults. This method can search high risk events more efficiently than exhaustive method.

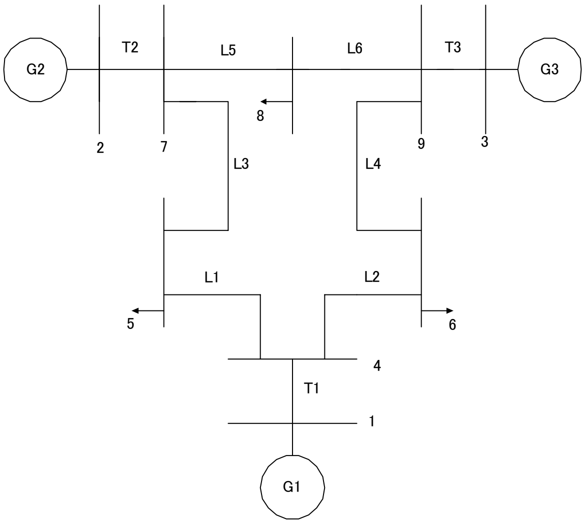

Fig. 3. Constitution of model power system.

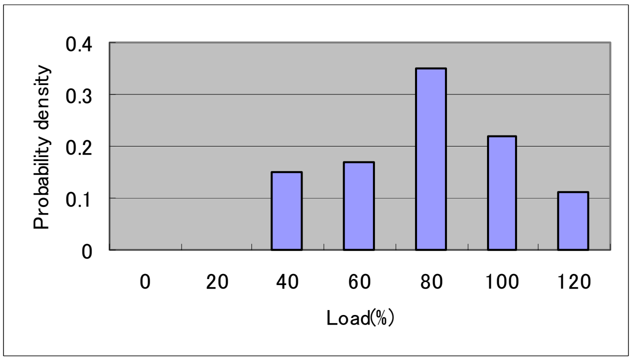

Fig. 4. Probability density function of load.

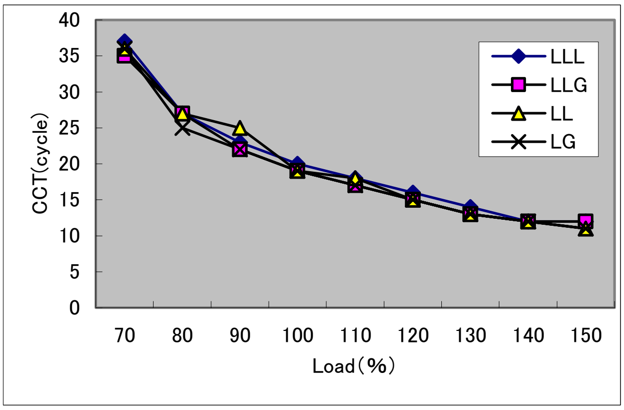

Fig. 5. Change of critical fault clearing time functions by kinds of faults.

(2) Generating event tree
When LLG occurs, large currents flow. The over-current-relays detect these currents and clear the fault. This protection actions are carried out in any load. If CT is smaller than CCT, the power system is stable, otherwise, it is unstable. If protection systems do not act by failures, the probability of energy loss will become high. But, the risk (the product of energy loss and its occurrence rate) will small, for the failure rate of no action is very small (about 1.0×10^{-5}). The event tree in case of no action is cut because of the above reason. The generated event tree is shown in Fig.6.

(3) 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.

(4) 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.7. This graph makes it clear that the event caused by the above fault occurred in the bus B7 has the highest risk.

(5) Generating discrete risk function and identifying high risk events
The discrete risk functions per one LLG occurred in the bus B7 in various CT are shown in Fig.8. Average energy loss is expressed by % (the relative value to the rated load). This graph makes it clear that the larger CT is, the higher the risk of the model power system is. When CT is 15 cycles, the highest risk event is occurred in the rated load. On the other hand, when CT is 20 or 25 cycles, the highest risk event is occurred in 80 % of the rated load.

3.3 Results of Application

The results of application have been clarified the following facts.

(1) The developed method can search accurately and efficiently high risk events of power systems by use of knowledge bases, for example, heuristic search knowledge, event trees, critical fault clearing time functions and discrete risk functions. These knowledge bases will be gradually improved by search experiences.

(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

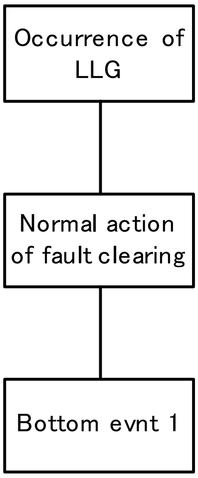

Fig. 6. Event tree caused by LLG.

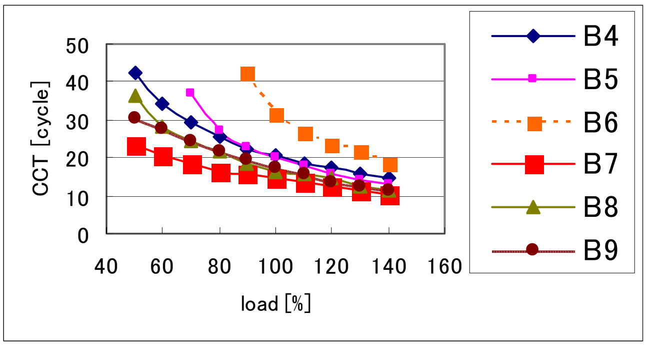

Fig. 7. Change of critical fault clearing time functions by fault locations.

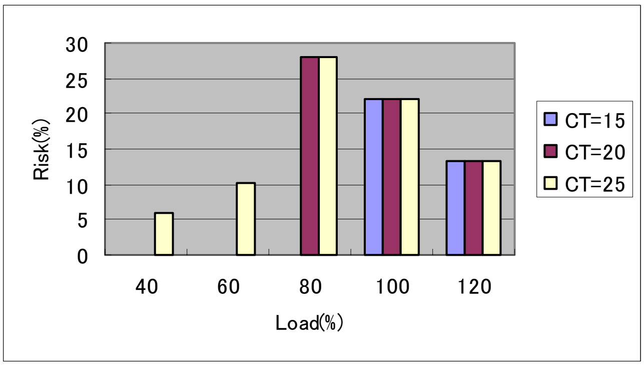

Fig. 8. Change of discrete risk functions by CT(fault clearing time).

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) It will be improved so as to enable to search accurately high risk events of power systems in case that loads have not similar change patterns with seasons, date and time.

(3) It will be extended to other fault cascading events except transient stability.

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