Processing of Switching Events Sets in Reliability and Probabilistic Safety Assessment Program RiskA

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Abstract: Fault tree analysis and event tree analysis are the general methods for reliability and probabilistic safety assessment (PSA). In PSA programs, boundary conditions of analysis in fault tree and event tree can make convenience in the modeling and the analysis process. However, handling the logical value conflicts of the same events in different boundary conditions is one of the difficulties in the PSA programs. A new event type named Switching Event and processing method of Switching Events Set is introduced in this paper. The methods implemented in RiskA, which is a reliability and probabilistic safety assessment program developed by FDS Team, and their applications in real power plant model were also proposed and discussed in this paper.

Keywords: Probabilistic Safety Analysis, RiskA, House Event, Switching Events Set.

1. INTRODUCTION

Probabilistic safety analysis (PSA) programs are widely used in large complex system safety analysis and management [1-3]. Fault tree analysis and event tree analysis methods are mature technologies and generally used for reliability and probabilistic safety analysis. In order to avoid repetitions work in the PSA modeling and introduced convenience in the analysis progress, boundary conditions of analysis in fault tree and event tree are widely used in the PSA programs. One of the boundary conditions of analysis is house, which is a kind of special event with a logical value of TRUE or FALSE, but it is not convenient enough to only use house event.

In order to bring up more varieties and convenience, basic events and logical gates are also introduced in the boundary conditions of analysis in some PSA programs. However, handling the logical value conflicts of the same events in different boundary conditions is one of the difficulties in the probabilistic safety assessment programs. Different programs generally have various processing strategies in the boundary condition's construction and calculation, and even different definitions for the boundary conditions of analysis. Therefore, their methods for the handling of logical value conflicts of the same events will be generally different.

RiskA, which is a reliability and probabilistic safety assessment program developed by FDS Team[4-6], has been applied to Accelerator Driven Nuclear Waste Transmuter (ADS-CLEAR) PSA assessment, International Thermonuclear Experimental Reactor ITER-TBM's safety analysis[7], Experimental Advanced Superconducting Tokamak EAST's reliability analysis, Third Qinshan Nuclear Power Plant Risk Monitor (TQRM)[8-9], Design of FDS Series Fusion Reactors[10], Reliability Analysis of Laser Radar System, etc.

On the basis of switching event and the switching events sets in RiskA, not only the general house events but also basic events, logical gate events and function events in the event tree model are included in a boundary condition of analysis. A switching event set can be bound to every event of an event tree or analysis case in order to limit their analysis boundary conditions. Therefore, dynamic diversification can be conveniently introduced into a static structure model, such as: with different switching events set, a typical analysis case can be changed into some different cases in order to reduce the modeling work.

2. SWITCHING EVENTS SETS PROCESSING LOGIC

In order to expand the analysis boundary conditions from house event to various events, switching value is introduced through switching event to every object event that needs to be considered in the boundary conditions of analysis. Switching value is either TRUE or FALSE in RiskA.

Switching event is one kind of mapping event that relates the object event to a switching value in a switching events set. In order to bring up more flexibility, the switching values of switching events are neither set up in the fault tree nor in its properties, but in the switching events sets. This means that a switching event can be set up to more than one value if it appears in more than one switching events set. In the analysis process, the values chosen for a switching event in different calculation steps are decided by the connection of switching events sets in this analysis case. In order to avoid conflict, one object event can only be related to one switching event.

A switching events set is the collection of switching events that need to be considered as the boundary conditions of analysis. Every switching event is also designated to a switching value in this switching events set. In a single switching events set, a switching event can only be set to one value, i.e. TRUE or FALSE.

Switching events set can not only be bound to a function event or an initial event in an event tree model, but also be bound to an analysis case. Here attention should be paid to that one fault tree analysis case (or sequence or consequence analysis case) can only be provided with one switching events set, and this is also true for the function event or initial event in the event tree model.

When an analysis case needs to be calculated in RiskA, switching events sets can be used to limit the boundary conditions. For different analysis case, the strategy of handling the logical value conflicts in all the switching events sets that included in this case will have some differences. They are all described in details as bellow.

For a fault tree analysis case, the switching event set's working principle can be described as: the logical values in the switching events set have the priority higher than the values of house events in the fault tree model. This means that if a house event in the fault tree is related to a switching event which is included in the switching events set bounded to this fault tree analysis case, its value for this analysis is decided by the switching events set, other than decided by the original value of itself.

For a sequence analysis case, the situation is more complex as every function event and initial event in the event tree model can has one switching events set. Therefore, the sequence analysis process follows the rules bellow:

(a) All the switching events sets have higher priorities than the house events.
(b) A switching event will hold a same value in a whole case if no change is made to it.
(c) Generally, the switching events set bounded to the latter Initial or Function (I/F) event of the event tree model has a higher priority than the switching events set bounded to an anterior I/F Event of Event Tree. As shown in fig.1, IE1 is the first I/F Event of Event Tree in the event tree B, and FE1 is the second I/F Event of Event Tree, and FE2 is the third I/F Event of Event Tree, and so forth. Therefore, the switching event bounded to FE2 has a higher priority than the switching event bounded to FE1.
(d) The switching events set bounded to the sequence analysis case itself has the higher priority than any I/F Event of the Event Tree in this case.
(e) For the events in the fault tree model corresponding to each I/F Event of Event Tree, the switching events set of this I/F Event of Event Tree has the highest priority.
(f) Finally, if a function event is related to switching event, this switching event will has a higher priority than all other switching events. And this special event can only appear in the switching events set bounded to this function event.

For a consequence analysis case, the situation is similar to the sequence analysis case. Its process follows the rules bellow:

(a) The switching events sets in an event tree can not impact other event trees.
(b) In a single event tree, the rules are same as sequence analysis case.

Finally, there is still one thing needed to be noticed: after these conflicts process of the events value. That is in the general subsequent analysis, these different values are connected to a same event, how can we distinguish them? In RiskA, one event is divided into 3 different events: the original event which can hold the all original properties, the TRUE event whose value is 1, the FALSE event whose value is 0. These 3 events have different functional names, therefore, the logical value conflicts of the same events in different boundary conditions are thoroughly disposed.

For better comprehension, an example is given here: Fault tree A in fig.2 appears in all function events in event tree B in fig.1, i.e. appears in FE1, FE2 and FE3. Basic event BE1 is related to a switching event SE1. There are 3 switching events sets, SES1, SES2 and SES3, which are bounded to FE1, FE2 and FE3 respectively. The designated values of SE1 in 3 switching events sets are shown in table 1. According to the sequence analysis case rules, the values of BE1 are also shown in table 1. In FE2, the value of BE1 is hold as 1 because SES2 does not change it.

Table 1 The Values of SE1 and BE1

Switching Events Sets	Values of SE1	Values of BE1 in function events
SES1	TRUE	1 in FE1
SES2	—	1 in FE2
SES3	FALSE	0 in FE3

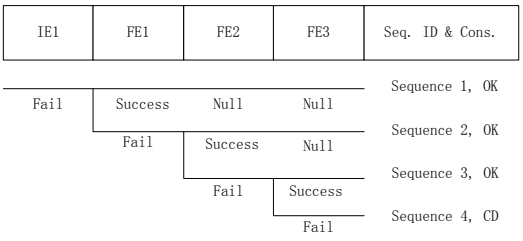

Fig.1 Event tree B

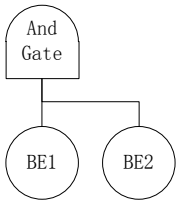

Fig.2 Fault tree A

3. BENCHMARKING

Three fault tree benchmark examples from OPEN-PSA[11-13] organization and 3 real nuclear power plant event tree examples from Third QinShan Nuclear Power Plant are tested. Testing environment is Inter(R) Core(TM)2 Quad CPU Q9500 @2.83GHz, 3.50GB EMS memory. The contrast PSA program Risk Spectrum is a widely used similar commercial program developed by Relcon AB[14]. For all the examples, the probability truncations are set to 1.0E-12. All the tests results are shown in table 2.

Table 2 includes 3 fault tree tests (marked by FT), 2 sequence tests (marked by SEQ) and 1 consequence test (marked by CON), their Minimal Cut Sets and Top Event Probabilities are all the same for RiskA and Risk Spectrum. The switching events and their values used in the analysis process are also shown in the table 2.

The checking of Minimal Cut Sets from both programs shows that they are consistent totally and thus confirm the correctness of the proposed methods.

Table 2 Validity Test Results

Benchmark Names (Case Type)	Switching Events(Value)	Risk Spectrum Results		RiskA Results	
		MCS No.	Prob.	MCS No.	Prob.
Baobab1(FT)	e1(0), e10(0), e11(0), e12(1), e13(1), e14(1)	307	6.68E-04	307	6.68E-04
Baobab2(FT)	e1(0), @g12(0), e11(1)	242	2.73E-02	242	2.73E-02
Chinese(FT)	e1(0), e10(0), e11(1)	160	3.26E-03	160	3.26E-03
FBIO-S55(SEQ)	0TCV6(1), 011B#1(1), 0HC11A(1), 120CP4(0), 12021C(0), 121AP3(0)	1832	4.85E-08	1832	4.85E-08
PCTR-S55(SEQ)	011B#2(0), 0HC11B(1), @4010LFU31(0), @3211-HG(0), @3620-SG1(1), @3432.EVN(1)	1830	4.85E-08	1830	4.85E-08
F-P-S-S55(CON)	SIG3C2(0), C11(1), @2SH1CB(0), @G440(0), @1SA1CB(1), @G513(1)	1316	3.67E-07	1316	3.67E-07

4. CONCLUSIONS

Construction and calculation strategies of the boundary conditions of analysis and the processing of logical value conflicts of the same events in different switching events sets in RiskA are proposed and their exactness and validity is approved by the benchmark models and examples from real nuclear power plant.

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Nomenclature

Analysis Case = Analysis object, such as: a fault tree, an event tree sequence or an event tree consequence, and its analysis settings/properties for the calculation process.

House Event = A special event, which is either TRUE or FALSE, generally used as an assistant in the fault tree modelling.

Boundary Conditions of Analysis = For RiskA, 4 kinds of events are included in the boundary conditions of analysis: house event, basic event, logical gate event, function event.

Switching Value = An logical value(i.e. TRUE or FALSE) for the events that are treated as a boundary condition of analysis in RiskA.

Switching Event = A special event that can be related to any house event, general basic event, logical gate event or function event, for a switching event set to embody it and set up its switching value.

Switching Events Set = A collection of Switching events and their designated switching values in this collection, which can be bound to every event of an event tree or analysis case.

I/F Event of Event Tree = Function event or initial event of the event tree model

MCS = Minimal Cut Set of a fault tree

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