Methods for Frequency Gap Adjustment between Level 1 and PDS Sequences

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1. Introduction

To perform level 2 probabilistic safety assessment (PSA), level 1 event trees (ETs) are extended to incorporate the status of structure, system and components (SSCs) at the time of core damage which can impact severe accident progression. The extended ET is called plant damage state (PDS) ET or bridge ET. Example level 1 ET and PDS ET are shown on Fig. 1 and Fig. 2.

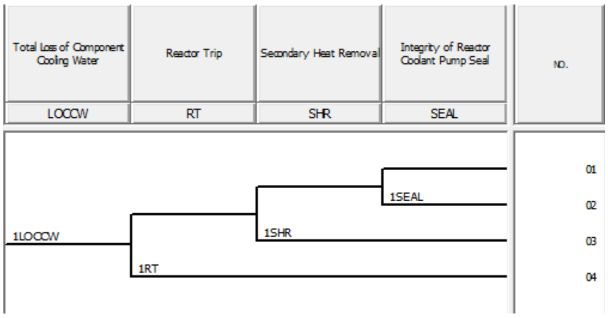

Fig. 1. Example level 1 ET.

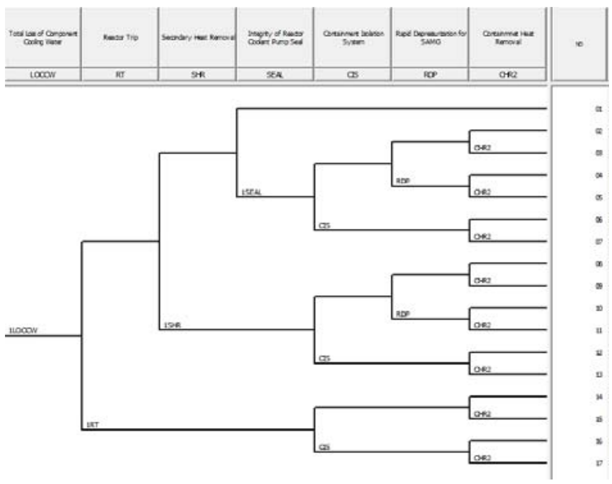

Fig. 2. Example PDS ET

As shown on Fig. 1 and Fig. 2, the sequences 2, 3, 4, 5, 6, and 7 of PDS ET stems from the sequence 2 of level 1 ET. Therefore, theoretically, the sum of the frequencies for PDS ET sequences 2, 3, 4, 5, 6, and 7 should be the same as the frequency of level 1 ET sequence 2 because each PDS ET sequence 2, 3, 4, 5, 6, and 7 is a fraction of level 1 ET sequence 2. However, due to the technical limitation of fault tree quantification at the present time, the sum of the frequencies for PDS ET sequences 2, 3, 4, 5, 6, and 7 is different from the frequency of level 1 ET sequence 2. The sum of PDS ET sequences frequencies can be bigger or smaller depending on the truncation limit and delete-term application (DTA) results.

2. Causes of the Frequency Gap

For the failure branches of additionally added heading in PDS ET, fault tree logics instead of numerical probabilities are linked. If a numerical probability is assigned to each branch, the PDS frequencies will be exactly the same as the level 1 frequency. However, the conditional failure probability of a specific branch for added ET heading is highly dependent on the sequence information determined by the failure and success combination of previous headings. Therefore, it is essential to use fault tree logic for the branches of the added heading to reflect the dependency among the functions in PDS ET branches

One of the causes for frequency gap between level 1 and PDS sequences is truncation limit used for minimal cut sets (MCSs) generation. As shown on Fig. 2, MCSs for PDS sequences 3, 4, 5, 6 and 7, require additional failure(s) given MCSs of level 1 sequence 2. Therefore, some MCSs for PDS sequences 3, 4, 5, 6 and 7 will be truncated and this will cause the PDS frequency to be lowed.

During the MCSs generation for ET sequences, DTA is applied to simulate negates. For example, PDS ET sequence 4 can be expressed as Eq. (1) which is the combination of success and failure of branch logics for the relevant headings.

Logic for PDS ET sequence 4
= LOCCW*/RT*/SHR*SEAL*/CIS*RDP*/CHR2 (1)

Due to the application of DTA to MCSs generation for each ET sequence, overestimation of sequence frequency can occur [1]. The negates in sequence 4 are /RT, /SHR, /CIS, and /CHR2. This is the main cause of PDS frequency overestimation compared to level 1 frequency.

The most important issue raised with regard to the frequency gap between level 1 and PDS sequences is excessive overestimation of PDS frequency caused by the DTA application to MCSs generation.

3. Methods to Adjust Frequency Gap between Level 1 and PDS Sequences

In this paper, three practical methods are suggested that can be used to adjust frequency gap between level 1 and PDS sequences for actual plant PSAs. The first method is to adjust PDS sequence frequency manually considering the dependency among fault tree logics for each branch. The second method is to adopt an FTREX [2] option of XNEG that can adjust PDS sequence frequency by adding an basic event for sequences with success branches under consideration. The third method is to apply probability subtraction method (PSM) [1] which is recently suggested and can calculate much more accurate sequence frequency with solid technical basis.

3.1 Manual Adjustment of PDS frequencies

As described in Section 2, the key issue of frequency gap between level 1 and PDS sequences is the significant overestimation of PDS frequency. This overestimation is mainly due to the DTA application in generating MCSs for PDS sequences.

For example, in Fig. 2, frequencies of PDS ET sequences 2, 3, 4, and 5 can be overestimated due to the DTA application to CIS branch. Frequencies of PDS ET sequences 2 and 3 can be overestimated due to the DTA application to RDP branch. Frequency of PDS ET sequence 2 can be overestimated due to the DTA application to CHR2 branch.

Therefore, it is possible to adjust frequency gap by identifying the contribution of added PDS ET branch failure probability which is independent of failures contributing to the other branches.

For example, if the contribution of CIS branch failure independent of the other branch logics is p1, the PDS sequences 2, 3, 4 and 5 can be adjusted by multiplying adjustment factor of 1-p1. If the contribution of RDP branch failure independent of the other branch logics is p2, the PDS sequences 2 and 3 can be adjusted by multiplying adjustment factor of 1-p2. Similarly, if the contribution of CHR2 branch failure independent of the other branch logics is p3, the PDS sequence 2 can be adjusted by multiplying adjustment factor of 1-p3.

If there is still considerable frequency gap between level 1 and PDS sequences after the application of the manual frequency adjustment described above, additional adjustment factor can be determined and applied. The additional frequency adjustment factor can be determined based on the review of (1) contribution of branch failure dependent on the previous branch logics in ET, (2) conditional failure probability of the branch in question given accident scenario before the branch, and (3) the DTA application effect to the success sequences of the branch in question for frequency adjustment. In the practical aspect, this additional frequency adjustment factor determination and application is not suggested because it take considerable amount of resources. In this occasion, PSM application is suggested instead because it is more efficient and has much more solid technical basis as described in Section 3.3.

The manual PDS sequence frequency adjustment can be generally performed by applying recovery process. Some domestic and overseas plants PSAs have already adopted manual PDS frequency adjustments.

3.2 Utilization of FTREX Option of XNEG

FTREX provides a number of quantification options which support various fault tree modeling techniques. XNEG is one of the FTREX options applicable during MCSs generation. FTREX option of XNEG was mainly designed for preventing sequence frequencies from overestimation caused by DTA application for MCSs generation in the ET sequences.

The principle of XNEG option application into PDS ET sequences quantification by FTREX is very simple. If a specific branch is selected for XNEG option application, FTREX quantifies the branch failure probability and add a dummy event to the sequences with the branch being successful. The probability of the dummy event is 1-p given the branch failure probability is p. If the fault tree of branch logic has initiating events, they should be treated very carefully. The manipulation of the initiating events in the branch logic for XNEG option by FTREX is explained in detail in FTREX manual as shown in Fig. 3.

Reflection of Negate Probability	
/XNEG=[XNEG prefix pattern]	Add XNEG event to final cutsets TOP = G1 * /G2 and /XNEG=G2 G1 = %I * A * B + %J * A * B + %K * A * B G2 = %I * C + %J * D + C * D + E After finishing delete-term approximation for TOP = G1 * /G2 XNEG events are attached to final cutsets depending on initiator. [%I * A * B * ~G2~%I~] where P(~G2~%I~) = 1.0 - P(C + E) [%J * A * B * ~G2~%J~] where P(~G2~%J~) = 1.0 - P(D + E) [%K * A * B * ~G2~] where P(~G2~) = 1.0 - P(C * D + E) If XNEG event name length exceeds 32, CRC16 hexa value of full name is attached to the truncated name as [~G2~%I~FFFF]

Fig. 3. FTREX option of XNEG for initiator manipulation

For external event analysis, generally more than hundreds of PDS ET quantifications are required. Therefore, it is almost impossible for analysts to adjust PDS sequence frequencies manually and the application of XNEG option of FTREX is inevitable.

However, when applying FTREX option of XNEG, dependency among branch fault tree logics cannot be reflected. This may lead to the underestimation of PDS sequence frequencies. Therefore, it is essential to examine dependency among branch fault tree logics before application of XNEG option to PDS ET quantification.

Some domestic and overseas plants PSAs have already adopted FTREX option of XNEG for PDS frequency adjustment.

3.3 PSM application to PDS Sequences Quantification

In this paper, a new method for PDS frequency adjustment is suggested. It is based on the new quantification method called PSM which evades negates during quantification. Therefore it can avoid overestimation caused by the application of the DTA. The new quantification method, PSM, is based on the probability equation, p(A/B) = p(A) – p(AB) from set theory. Using the equation, each PDS ET sequence frequency can be quantified without negates. For example, PDS ET sequence 4 in Fig. 2 can be quantified using the equation (2) below.

Frequency for PDS ET sequence 4 by PSM (2)
= p(LOCCW*SEAL*RDP)
- p[(LOCCW*SEAL*RDP)* (RT+SHR+CIS+CHR2)]

The calculated PDS ET sequence frequency by the application of PSM is much more accurate than that by the application of DTA.

However, at the present time, any PSA S/Ws don't provide functions that facilitate PSM for multiple PDS ET sequences quantification. Therefore, analyst should manually develop PDS ET logics for PSM application until PSA S/Ws provide functions to support PSM application. So, PSM can be applied to some selected PDS ET sequences which have big overestimation compared to level 1 frequency in the practical aspect.

4. Conclusions

In this paper, the causes of the frequency gap between level 1 and PDS ET sequences were explained. To overcome the frequency gap between level 1 and PDS ET sequences, three practical methods were introduced for actual plant PSA applications. They are manual adjustment, utilization of FTREX option of XNEG, and PSM application.

Manual PDS frequency adjustment is suggested for cases where the branch failure in question is mostly independent of the logics in the previous branches in the PDS ET. The adoption of FTREX quantification option of XNEG is suggested for cases where there are a number of PDS ET sequences for frequency adjustment. When applying FTREX option of XNEG, the dependency among branch logics should be well examined before application. PSM application is suggested for cases where the overestimation is very big and the number of sequences for quantification is limited. PSM application provides much more solid technical basis for accurate sequence quantification than DTA as has been used so far. Therefore, once PSA S/Ws provide the functions for PSM application in the future, frequency gap between level 1 and PDS ET sequences can be easily treated in the conventional PSA process.

REFERENCES

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[2] EPRI, FTREX 1.9 Software Manual, Product ID # 3002012968, 2018.