Ramifications of Modeling Impact On Regulatory Decision-making - A Practical Example

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Abstract: PRA models have been used for nuclear power plants in several areas including Maintenance Rule (MR) a(4), Reactor Oversight Process (ROP) and Mitigating System Performance Index (MSPI). As a part of the living PRA program, the PRA model has been updated to reflect operating experience, feedback from applications, and more recent PRA data and methodology.

PRA modeling detail which can affect the regulatory decision-making of Emergency Diesel Generator (EDG) MSPI (highlighting key PRA assumptions and design basis requirement under multi-unit accidents) and ROP process are discussed. Risk insights on the key assumptions in both deterministic and PRA modeling which may affect the MSPI program and ROP process are presented.

Areas of improvement to manage more effectively the living PRA program for regulatory decision-making as a result of the lessons learned from a practical example with several regulatory ramifications are summarized. These include the need of ralistic modeling of design features of interest, realistic success criteria for multi-unit accident scenarios and dependency treatment of human reliability analysis (HRA).

Keywords: PRA, Multi-unit accidents, MSPI, Parallel Function Of EDG, HRA.

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1. INTRODUCTION

The plant analyzed in this paper consists of three units. Eight diesel generators, (four for Units 1 and 2, and four for Unit 3) are provided as a standby power supply to be used on loss of the Normal Auxiliary Power System. Each of the diesel generators is assigned primarily to one 4.16-kV shutdown board. It is possible, through manual action of breaker ties to the shutdown buses, to make any diesel generator available to any 4.16-kV shutdown board. Four (4) diesel generators are in standby and aligned to automatically start when degraded voltage or under-voltage is sensed on the associated Unit 1 and 2 4-kV shutdown boards. Additionally, when a Loss of Coolant Accident (LOCA) occurs, the diesel generators are automatically started and remain in standby with their output circuit breakers open. When the transient is a loss of offsite power, the diesel generators will start and supply power to their associated 4-kV shutdown boards. Loads on the 4-kV shutdown boards will be shed and sequenced back on the boards as necessary by sequencing relays.

A test of the paralleling feature of the EDGs was performed. During the test, the Unit 1&2 A-train EDG was running and providing power to the safety-related board. The Unit 3A EDG was started and was placed in parallel operation with the running EDG. If the system had performed as designed, the 3A EDG would have picked up load and the 1&2 A EDG would have relieved load until they reached equilibrium and would have continued to run in parallel supplying the safety related load(s). During the test, the 3A EDG continued to pick up load and the 1&2A EDG continued to shed load until the 1&2A EDG tripped on a “reverse power” signal and power was lost to the associated safety-related board. A half- scram was created for Unit 1 due to the loss of a Reactor Protection System (RPS) power. An operator error (instead of restoring power to the de-energized RPS, the operator disabled the energized RPS train) caused a loss of both RPS trains, which resulted in a full scram and Main Steam Isolation Valve (MSIV) closure. No other mitigation systems failed. The MSIV was opened approximately 3 hours after the reactor scram. The test and subsequent plant response had two regulatory ramifications: MSPI of EDG failure and safety significance of the reactor scram with MSIV closure.

The 1&2A EDG tripped approximately 1 hour and 9 minutes after the closure of its output breaker (connecting it to the safety-related board) but less than an hour after the paralleling switch was manipulated to bring the 3A EDG into parallel operation. The root cause of the test failure indicated that the cause was faulty wiring in a transfer switch. The transfer switch in question is not within the boundary of the EDG, presumably because generic scope of EDG does not include this unique capability.

2. MSPI RAMIFICATIONS OF PARALLEL FUNCTION OF EDGs FOR MUTI-UNIT ACCIDENTS

The current safety analysis (current Licensing Basis) credits 2 residual heat removal (RHR) pumps for post design-basis RCS heat removal. One EDG cannot provide sufficient power to drive 2 RHR pumps, so two EDGs must run in parallel mode of operation to provide sufficient power.

Four (4) additional diesel generators power the Unit 3 4kV shutdown boards. Hardware capability exists to cross-tie the Unit 3 4kV shutdown boards to the Unit 1/2 shutdown boards.

However, the PRA model only credits this capability when Unit 1/2 diesels have failed independently or by common cause that is not applicable to Unit 3. The cross-tie capability is not credited for multi-unit initiators.

During a design basis loss of coolant accident (LOCA) on Unit 1 (2) concurrent with a LOOP on all three units, given a single active failure affecting a Unit 1/2 EDG or 4160V shutdown board, there could be insufficient power for two RHR pumps to provide suppression pool cooling on Unit 2 (1). Suppression pool cooling on the non-LOCA units will be required to maintain suppression pool temperature within acceptable limits during RCIC and/or HPCI operation during a LOOP.

The function monitored for the EDG system for MSPI is the ability to provide AC power to the class 1E boards following a loss of offsite power, per NEI 99-02 Appendix F (Reference 1). This function is listed in the Table 1:

Table 1
EDG MSPI Function Matrix

Scope	Risk Significant Function	System/Components
When the transient is a loss of offsite power, the diesel generators will start and supply power to their associated 4-kV shutdown boards.	Yes	Diesel Generators A, B, C and D

It is noted that the risk significant function of the EDGs based on the PRA model does not include the paralleling capability of the EDGs. However, the MSPI basis document states that the PRA success criteria are the same as the design basis success criteria, which requires two EDGs in parallel. Since the parallel feature requires the switch, failure of the switch would be included in the boundary of the EDG and count as a failure. However, upon further scrutiny, the PRA model implicitly assumes that the condition requiring the paralleling of the EDGs is highly unlikely and is not included in the PRA model. Under the existing PRA model, the switch is not required for the PRA function and would therefore be outside the scope of the EDG boundary and would NOT count as a failure.

The following questions were raised with respect to the unique feature for paralleling two EDGs for accidents involving one unit in LOCA while there is a loss of offsite power to all three units:

- Is Emergency Diesel Generator (EDG) paralleling modeled or taken credit for in the PRA?

The PRA model used for MSPI basis document does not include the component (key control switch for the parallel function) explicitly. In order to "estimate" the importance of this parallel function, the surrogate "EDG failure to start" or "EDG failure to run" is used, which overstates the importance of the unique design basis feature of EDG.

- Does the PRA require one or two RHR heat exchangers for successful decay heat removal?

The PRA model has a different success criterion for different accident conditions. For general transient scenarios, which include loss of offsite power initiators, 1 RHR pump and 1 RHR heat exchanger is required for successful decay heat removal. For ATWS and IORV (inadvertently open relief valve) scenarios, 2 RHR pumps and 2 RHR heat exchangers are required for success.

- What is the effect of including the failure to parallel the EDGs in the PRA model?

There are several ways to model the failure to parallel EDGs, varying from the explicit inclusion of the control circuits and switches to a higher level for function or a more coarse approximation by a "surrogate" basic event in the model. A more realistic modeling included more detailed scenario and timing, but require significant resource. A balanced approach was used to provide risk insights without unnecessary burden of creating excessively large number of cutsets involving subcomponents.

3. PRA LEVEL OF DETAIL FOR REGULATORY DECISION-MAKING

The following technical considerations were included to ensure a comprehensive coverage of factors which may facilitate regulatory decision-making. These were developed based on the review of current PRA model and ongoing effort including NFPA 805 and Fukushima NTTF responses.

3.1. Spatial Aspect of DG Parallel Feature

For internal events, the impact of the DG parallel feature is relevant only when two RHR pumps are required, mostly for LOCAs in which RHR service water cooling is required. The likelihood of having a loss of offsite power (as an initiator or consequential) in conjunction with failure of alternate decay heat removal is very small. For fire, the impact is heavily dependent on the data and assumptions of fire ignition frequency, the cable failure mode and its likelihood and the relative location and status of the alternative mitigation function; however, scoping estimate was performed and indicates that it is not significant if the same proposed modifications to improve the margin for fire-induced station blackout events are credited.

3.2. Temporal Aspect of EDG Parallel Feature

The paralleling feature of the EDGs is predominantly required for late (~ one hour or later after the accident) heat removal. For loss of offsite power only and small LOCAs caused by SRV cycling, the success criterion for the RHR system is less stringent both in capacity and timing than that for the design basis LOCA conditions. In addition, several alternate heat removal mechanisms are available (e.g., hardened wet well venting, continuous condensate injection, and drywell spray etc). The parallel function is not automatic and can be initiated at the discretion of the operator based on the plant conditions at the time. By properly including the applicable scenarios, the risk impact of including the failure of the parallel feature of EDGs was estimated to be negligible.

3.3. Risk Insights

The design basis function of the EDG parallel capability is placed in a holistic perspective with the detailed accident sequence scenario analysis by considering both the timing and relevant success criteria with additional procedural enhancement. Original design basis requirement does not consider the temporal aspects of the conditions and the likelihood of all mitigating factors such as the success criteria for the cooling capability (worst case scenarios require more RHR service water pumps for conservative design purposes), the operator action, and alternate decay heat removal capability. The PRA model provides a more realistic characterization of the importance of the parallel function. The MSPI importance of the function is explicitly estimated by the more detailed PRA model. The importance of the function is at least an order-of-magnitude lower than that of the EDG failure to start or failure to run due to the much lower likelihood of the need of the EDG parallel function.

3.4. Lessons Learned

Several areas of improvement for the PRA model to support regulatory decision-making are identified through the in-depth consideration of the design basis features for the EDGs. The likelihood of the hypothetical multi-unit event scenarios of interest is in general low. Improvement of the PRA modeling including scenario-based parallel function and associated success criteria and improved procedures yields a lower safety significance of the unique EDG parallel feature.

Another lesson learned is that there is a continuing interest in the PRA community for a more critical review of the current Risk Oversight Program dealing with a performance deficiency involving a reactor scram. The testing of the parallel feature of EDGs discussed in this paper involved an unexpected reactor scram due to a loose connection of a switch controlling the paralleling (which caused a half-scram) and an operator error (which created a full scram). Significant effort was involved in the Significant Determination Process associated with the reactor scram involving MSIV closure. Reference 2 provides an interim guidance for risk significance determination for events involving a reactor scram. The guidance does provide credit for all mitigating systems if available, However, PRA modeling with respect to HRA includes treatment of minimum failure probability of a single human action to be 1E-5 and 1E-6 for multiple human actions. Modeling of dependence of human actions is especially critical for accident scenarios in which many mitigation systems are available but require operator actions for which the level of the dependence and floor values of failure probability can vary by orders of magnitude due to different judgment assigned to performance shaping factors.

4. CONCLUSION

An integrated approach by realistically considering time-dependent accident scenarios (including success criterion), plant mitigating systems and procedural enhancement resulted in a more realistic risk significance of the EDG parallel function, which was deterministically based with significant conservatism. Additional details in the area of success criteria and operator actions which can be easily incorporated into the PRA model have provided insights which reduce the perceived risk significance of an unlikely demand for a required design basis function, while providing a defense-in-depth to enhance safety. The synergistic interaction of design engineers with PRA analysts indicates that PRA models can continue to provide risk insights by including explicitly components which may otherwise considered negligible until such circumstances when they become a focused issue with regulatory ramifications. Due to a high degree of redundancy and diversity of the mitigation systems for certain benign events, the SDP can be dominated by uncertainties in the treatment of HRA (both minimum value of a single human action and minimum dependency for multiple human actions).

References

[1] NEI 99-02, Revision 7, Regulatory Assessment Performance Indicator Guideline

[2] Interim Staff Guidance to Supplement RASP, (Revision 2.0), Volume 1, Section 8