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INSIGHTS FROM THE ANALYSES OF RISK-INFORMED EXTENSION OF DIESEL GENERATOR ALLOWED OUTAGE TIME

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ABSTRACT

In recent years, many U.S. nuclear plants have applied and received approval for the risk-informed extension of the Allowed Outage Time (AOT) for Emergency Diesel Generators (EDGs). These risk-informed applications need to meet the regulatory guidance on the risk criteria. This paper discusses in detail insights derived from the risk-informed analyses performed to support these applications.

The risk criteria on ΔCDF/ΔLERF evaluate the increase in average risk by extending the AOT for EDGs, induced primarily by an increase in EDG maintenance unavailability due to the introduction of additional EDG preventive maintenance. By performing this preventive maintenance work on-line, the outage duration can be shortened. With proper refinement of the risk model, most plants can meet the ΔCDF/ΔLERF criteria for extending the EDGAOT from, for example, 3 days to 14 days. The key areas for model enhancements to meet these criteria include offsite/onsite power recovery, LERF modeling, etc. The most important LERF model enhancements consist of refinement of the penetrations included in the containment isolation model for the consideration of a large release, and taking credit for operator vessel depressurization during the time period between core damage and vessel failure. A recent study showed that although the frequency of loss of offsite power (LOSP) has decreased, the duration of offsite power recovery has actually increased. However, many of the events used to derive this conclusion may not be applicable to PRAs. One approach develops the offsite power non-recovery factor by first screening the LOSP events for applicability to the plant being analyzed, power operation, and LOSP initiating event, then using the remaining events data for the derivation based on the fraction of events with recovery duration longer than the time window allowed.

The risk criteria on ICCDP/ICLERP examine the increase in risk from the average CDF/LERF, based on the increased maintenance unavailability, to the instantaneous CDF/LERF caused by the removal of an EDG from service. Some plants have implemented a requirement to disallow any planned maintenance on other accident initiation/mitigation equipment during the time period when an EDG is out of service (OOS) for maintenance. Nevertheless, emergent failures may still occur during the time when an EDG is removed from service. Another risk management strategy that some plants have adopted is to require a specific set of electrical and system alignments be implemented during the time when each EDG is OOS. These are the alignments that would yield the lowest risk when a particular EDG is unavailable.

The risk-informed application for EDGAOT extension must also address risks associated with external events. Fires and seismic events are the most important events to evaluate. For the fire events, only plant locations that, due to fire damage, could result in an LOSP are critical. These generally include switchgear rooms, cable spreading room, control room, etc. The likelihood of a fire-induced LOSP event in the control room and cable spreading room is significantly less than that in the 4kV switchgear rooms because at least two separate circuit shorts are required. For the seismic events, offsite power usually is the weakest link from the fragility standpoint. Seismic risk is therefore generally sensitive to the increase in EDG maintenance unavailability as long as the seismic risk is a significant contributor to the total risk.

Keywords: Diesel Generator, Allowed Outage Time, Risk-Informed Analysis, PRA, PSA.

1. INTRODUCTION

In recent years, many U.S. nuclear plants have applied and received approval for the risk-informed extension of the Allowed Outage Time (AOT) for Emergency Diesel Generators (EDGs). Since the issuance of Regulatory Guide 1.174 and 1.177, these risk-informed applications need to meet the regulatory guidance on the risk criteria for Increase in Core Damage Frequency (ΔCDF), Increase in Large Early Release Frequency (ΔLERF), Incremental Conditional Core Damage Probability (ICCDP), and Incremental Conditional Large Early Release Probability (ICLERP). This paper discusses in detail insights derived from the risk-informed analyses performed to support these applications.

2. CHANGE IN AVERAGE RISK

The risk criteria on ΔCDF and ΔLERF as applied to the evaluation of risk impact for the extension of AOT associated with EDGs are meant to evaluate the increase in annual average risk in CDF and LERF by extending the AOT for EDGs. This is primarily induced by an increase in the EDG maintenance unavailability due to the introduction of additional EDG preventive maintenance, previously performed during outage, to be now performed during power operation. By performing this preventive maintenance work on-line, the outage duration can certainly be shortened. This is the main benefit motivating the U.S. utilities to apply for the extension of AOT for EDGs.

There are two frequently used methods for estimating the unavailability contribution from the additional EDG preventive maintenance during online operation. One method simply identifies the specific work items that would be shifted from outage to online. The duration required for completing these additional work items online is then estimated. Oftentimes, this incremental duration is estimated by such broad categories as electrical maintenance, mechanical maintenance, I&C maintenance, etc. The second method assumes that the amount of time for servicing the EDGs online would be approximately the same as how long it currently takes to complete the EDG work while it is being performed during outage. Typically, the duration scheduled for the EDG work during the outage is used as the best estimate for the out of service duration for performing the same EDG work online. To calculate the maintenance unavailability, the average total power operation time in each cycle is also needed. This can be estimated by subtracting the total outage duration, including refueling and forced outages, from the total cycle time. Two parameters that may significantly affect the resulting change in the average risk include the duration of the planned EDG online maintenance and the total unit outage duration. Sensitivity analysis should therefore be performed for the values used for these parameters since they are the estimated future performance and the actual values would not be known until some time after implementation of the extended AOT.

Besides the additional EDG preventive maintenance, there are other contributors to the increase in the average risk. The most likely one is the extended EDG restoration time following emergent EDG failures. In the past, most plants would work expeditiously to return the failed EDG to service within the original, shorter AOT. Occasionally, a Notice for Enforcement Discretion (NOED) may be submitted and approved, if the risk exposure is sufficiently low. With the extended AOT, however, EDG NOED applications are no longer needed. The priority for restoring the failed EDG may not be as high as it used to be, considering that much more time is available for completing the repair work. This potential increase in risk is nonetheless partially offset by a decrease in the mode transition risk due to less frequent shutdowns resulting from expiration of the AOT time limit, and a decrease in the shutdown operation risk since most of the EDG preventive maintenance would be moved from outage to online thus reducing the outage duration. The net effect of these causes for increase and decrease in risk is, however, believed to be relatively small in relation to the contribution from the additional EDG preventive maintenance.

A simplification often used in the risk impact analysis for EDG AOT extension is to assume that the existing EDG maintenance unavailability is exclusively corrective maintenance. One approach is to also assume that the maintenance unavailability attributed from corrective maintenance remains roughly the same with the extended AOT. This is valid so long as most of the increase in corrective maintenance is offset by the decrease in risk due to reduction in the shutdown risks. This EDG unavailability contribution can be estimated from the out of service duration data recorded in the Maintenance Rule program and the critical hours data documented in the USNRC monthly operating reports. Due to significant differences in the performance of EDGs between different divisions at some plants, a separate corrective maintenance unavailability value may need to be estimated for each EDG. Another method for the treatment of corrective maintenance is to increase its contribution proportional to the increase in AOT. In this approach, the mode transition and shutdown risks are conservatively neglected. This corrective maintenance contribution is then summed with the additional EDG preventive maintenance contribution to obtain the new, total maintenance unavailability. Due to this increase in the total EDG maintenance unavailability, the average risk in terms of CDF and LERF would also increase.

Since most of the core damage and large early release models were not originally developed with this specific risk-informed application in mind. The primary objectives of the model development and evaluations were to ensure that the total risk level estimated was acceptable and the top contributors were realistic. As a result, much conservatism may still exist in these models, which affects the results of the risk impact evaluation for the extension of EDG AOT, especially when the importance of the plant's coping capability without an EDG is magnified. However, with proper refinement of the risk model, most plants can meet the risk criteria on ΔCDF/ΔLERF for extending the EDG AOT from, for example, 3 days to 14 days.

3. MODEL ENHANCEMENTS AND PRA QUALITY

3.1 General Model Enhancements

To ensure the risk impact evaluation is realistic, most plants need to revise the PRA model to remove conservatisms. Engineering analyses may need to be performed to support PRA model changes. For the EDG AOT extension, some of the typical model enhancements may include:

- Update of the EDG failure rate. More recent plant and Maintenance Rule data may be incorporated to better reflect the actual performance of EDGs. In most cases, the data shows a more reliable performance and lower EDG failure rate.
- Update of the EDG Common Cause Failure (CCF) probabilities. Many U.S. plants have adopted the generic CCF parameter values provided in NUREG/CR-5497. Due to the conservative nature of these generic values, the results of model evaluation using these values tend to be overly conservative; i.e., not realistic. It may be necessary to perform plant-specific screening of the generic CCF events included in the NUREG/CR-6268 database and re-develop the CCF parameter values based on the results of the plant-specific screening.
- Update of the loss of offsite power (LOSP) frequency. In recent years, the frequency of LOSP at U.S. plants has noticeably decreased. Using a two-stage Bayesian update approach will not only take advantage of the lower LOSP frequency in the industry, but also specifically account for the possible improved trend for the plant being evaluated. In addition, the two-stage Bayesian method can more appropriately assess the uncertainty involved in the estimate of the LOSP frequency which would be important for the analysis of uncertainty in the increased risk associated with the extended AOT.
- Realistic non-recovery probabilities for offsite power. Offsite power recovery analysis is one of the most important aspects in the evaluation of risk impact associated with the extension of EDG AOT. This is because EDGs are only challenged when the offsite power is lost. Further, the offsite power recovery analysis in most nuclear plant PRAs is still treated somewhat conservatively. As such, a more realistic analysis of the offsite power recovery analysis is imperative in yielding a more accurate assessment of the increased risk associated with the extended EDG AOT.
- Possible addition of recovery for EDG failures. Most plants do not take aggressive credit for the onsite power recovery. This results from two considerations. First, different from the offsite power restoration, recovery of EDG failures involves in-plant repair efforts which are typically not credited considerably in PRAs even for power recovery analysis. Second, the time window available for recovery from EDG failures is generally significantly less than that for the recovery of offsite power since the EDG recovery effort will not start until the EDG fails which may be some period of time after the loss of offsite power. As such, some plants only take credit for recovery from the DG starting failures, which have the same recovery time window as the offsite power recovery.
- LERF model enhancements. In most PRAs, the LERF model was only added in the last several years. Due to the unclear nature of the LERF definition, undue conservatisms, to some extent, may still exist in many LERF models, which could cause the LERF results unrealistic and may not even meet the risk criteria for LERF.
- Component cooling. This involves seal cooling and lube/gear oil cooling for the safeguard pumps. Seal cooling may not be required for the entire mission time during mitigation response to accident sequences. For example, during the injection phase, seal cooling for charging and safety injection pumps may not be needed from the Component Cooling Water (CCW) System as long as these pumps take suction from the Refueling Water Storage Tank (RWST) and the RWST water temperature is relatively cool. During the recirculation phase, however, seal cooling is typically required for these pumps. Following a loss of cooling water to the lube/gear oil coolers for the safeguard pumps, alternate cooling source may be aligned. For instance, alternate cooling from the Demineralized Water System may be provided to the lube/gear oil cooler for the charging pump to prevent Reactor Coolant Pump (RCP) seal Loss of Coolant Accident (LOCA) following a loss of the cooling water supply to the charging pump lube/gear oil coolers. Although it is an expensive hardware modification, one U.S. plant has also installed the capability to crosstie charging pumps from the adjacent unit to provide RCP seal cooling. The need for the alternate consideration of component cooling becomes more prominent when power supply to selected cooling water or safeguard pumps is lost; e.g., EDG failures following a LOSP event.
- Cooling for other selected heat loads. The Service Water or raw cooling water systems at some U.S. plants provide cooling to both essential and non-essential heat loads. To ensure risk model considers the operation procedure to provide sufficient cooling to the essential heat loads (e.g., room and other coolers for the safeguard

pumps), operator actions may be modeled for the isolation of the non-essentially heat loads, typically in the Turbine Building. This could then lessen the success criteria in terms of the number of pumps required to provide the cooling water. This action is in addition to any automatic isolation design that may exist, since the automatic isolation signal may not be generated for all event scenarios. Credit may be taken for both control room remote and local manual actions. Another recovery consideration is the modeling of the possible SWS crosstie from the adjacent unit for a twin unit plant.

- Alternate steam generator or vessel injection source. An example of this consideration involves the use of diesel-driven fire water pump for steam generator (PWR) or vessel (BWR) injection, which is especially useful for the station blackout scenarios if depressurization can be achieved.
- Power supply crossties and DC load shedding. This involves both AC and DC crossties. In some cases, new procedures and even new hardware may be needed. For AC power crosstie, usually alternate supply or maintenance crosstie may be available. An example is the power supply crosstie for the diesel fuel oil transfer pumps. The design of the fuel oil transfer system at some plants may involve two fuel oil transfer pumps supplying to three day tanks corresponding to three separate EDGs. Following failures of the two EDGs supplying the two fuel oil transfer pumps, the fuel oil transfer capability is then lost, even though the remaining EDG is still physically operable except for its fuel oil supply. With power cross-connected from the bus corresponding to the operable EDG, the fuel oil transfer function may be restored. Similarly, for plants with three DC buses and two Power Operated Relief Valves (PORVs), crosstie of DC power would be helpful when one or both buses supplying the two PORVs lost their AC supply due to EDG unavailability. Another consideration for making the risk model more realistic is the modeling of DC load shedding. During such scenarios as a station blackout, DC load shedding can extend the battery lifetime [to support the continued operation of such systems as Reactor Core Isolation Cooling (RCIC) and High Pressure Cooling Injection (HPCI) for BWR and the turbine-driven Auxiliary Feedwater (AFW) Pump for PWR] and thus power recovery time.
- Alternate fuel supply. An example of this is, after loss of the diesel fuel oil transfer pumps due to EDG unavailability and/or hardware failures, the supply of diesel fuel oil to the diesel day tanks may be provided by a fuel truck with hose connections following an LOSP event.
- HVAC. Due to the lack of or conservative nature of the original HVAC design calculations for room heatup, the success criteria in terms of the number of supply and/or exhaust fans required for the HVAC systems in many PRAs are often very conservative. New room heatup calculations may be performed to support a more realistic set of success criteria. In addition, more realistic calculations may also provide a longer heatup and equipment failure timing and therefore additional time for recovery actions. Typical recovery actions for failures of the HVAC systems include opening doors and use of portable fans.
- Local manual control. A PWR example for this consideration is the local, manual control of the turbine-driven AFW pump following DC battery depletion due to EDG unavailability during an LOSP event. Another example is the use of the remote shutdown panel for controlling the accident mitigation equipment when control room/cable spreading room is lost or instrument power supply to the control room instrumentation becomes unavailable.
- Other considerations. This may involve the use of plant-specific data, especially for the risk-significant accident mitigation equipment; e.g., SWS pumps, etc.

Although many of the above model enhancements may be needed to ensure that the risk calculation results (including the core damage and large early release sequences) are reasonable when power supplies to specific buses are lost due to unavailability of EDG(s) following an LOSP event, the most important areas for model enhancements to meet the risk acceptance criteria include offsite/onsite power recovery and LERF modeling refinements.

3.2 Refinement of Offsite and Onsite Power Recovery

A number of approaches have been used in the past for the incorporation of offsite power recovery. Some plants have used a surrogate (i.e., shortened) DG mission time for running failures in conjunction with application of a more accurate power non-recovery factor (see Eq. 1) for selected CDF/LERF cutsets. The use of a shortened DG mission time (e.g., 6 to 8 hours) is to take partial credit for offsite power recovery. The advantage of the using of a surrogate, shortened DG mission time is that the power non-recovery factor can be applied to fewer cutsets. However, this approach has misled many of the practitioners in its true meaning.

$$P(NR) = \frac{\int_{0}^{24} f(t) P_{NR,OP}[t + \tau(t)] dt}{\int_{0}^{6} f(t) dt} \qquad \text{(Eq. 1)}$$

Some plants have implemented a time-phased consideration of DG failure and offsite power recovery directly in the event tree model structure. The time intervals considered in this approach are generally much broader than the time intervals used for the determination of an accurate power non-recovery factor. Example time intervals are: power recovery by 30 minutes, 1 hour (based on steam generator dryout time), 5 hours, before core damage, etc. This approach does not provide the most accurate recovery factors and makes the event tree model much more complicated.

There are also plants that use a DG mission time consistent with the rest of the model (i.e., 24 hours) and incorporate a full-credit offsite power recovery consideration (i.e., not reduced to account for the shortened DG mission time). In this approach, the non-recovery factor is applied to more cutsets than the approach using a surrogate DG mission time. Generally, Monte Carlo simulation can be used to calculate the non-recovery factor, P(NR), considering the offsite and EDG recovery at the same time (see Eq. 2). This method of offsite power recovery is the most rigorously accurate approach.

$$P(NR) = \frac{\int_0^{24} f(t) P_{NR,\,OP}[t+\tau(t)] P_{NR,\,DG}[\tau(t)] dt}{\int_0^{24} f(t) dt} \qquad \text{(Eq. 2)}$$

The offsite power non-recovery factor is typically applied to such scenarios as a seal LOCA following a station blackout, station blackout with turbine-driven AFW failure, but no seal LOCA, etc.

Several sources of data have been used in the past to support the above offsite power recovery modeling:

- NUREG/CR-1032 offsite power recovery curve. This is one of the most dated sources of data for LOSP recovery modeling.
- NUREG/CR-5496 loss of offsite power event data. This study presents the results in terms of loss of offsite power frequency and duration by three categories of LOSP events: plant-centered, grid-related, and severe weather events. Due to the consideration of different recovery duration characteristics for these three categories of LOSP events, some PRAs use three sets of LOSP initiating event frequencies and developed three separate sets of offsite power recovery curves using the curve fitting method. Typically, this approach does not perform sufficient plant-specific screening of the LOSP events for applicability to the specific scenarios being modeled. However, this source of data is most widely used in the U.S. PRAs.
- Utility grid transmission line outage duration data. This approach derived separate offsite power recovery curves to envelop the uncertainty range. These separate recovery curves were sometimes developed by models assuming complete independence and complete dependence between transmission lines coming into the switchyard. This approach is highly judgmental due to the correlation involved between the multiple transmission lines that may be involved.
- Generation planning model and data. This approach is generally performed by the generation planning personnel. It is not clear how well the results benchmark with the actual data.

A recent U.S. NRC study showed that, in the U.S., although the frequency of loss of offsite power has decreased, the duration of offsite power recovery has actually increased. When the description of the raw events used to develop the LOSP statistics and this conclusion was examined closely, an important finding is that many of the events used to derive the LOSP statistics and this conclusion may not be applicable for PRAs. This is because some of these LOSP events occurred during outage and the plant response and urgency for response may be quite different. In addition, some events may have involved some degree of loss of power, but may not have caused an actual LOSP event. Another consideration is that, in some events, the plants were already being successfully supplied from one power source. As such, there were no urgent reasons for the plant to reconnect the offsite power, which resulted in a much longer offsite power restoration time.

One approach that has been used to resolve the above issue is to screen the raw LOSP event data for applicability to the plant being analyzed, applicability to power operation, and applicability to the LOSP initiating event. The recovery duration may also be adjusted if sufficient evidence is available to indicate that the offsite power could have been recovered sooner if there was such a need. The offsite power non-recovery probability can be developed using the remaining LOSP events data based on the fraction of events with recovery duration longer than the event scenario time window allowed. Since there are sufficient number of events that survive the screening and recovery duration for all three categories of LOSP events are included, the event data can be used directly without separating into the plant-centered, grid-related, and severe weather-related event categories or using the curve fitting method. Also, the long recovery duration associated with a recent U.S. loss of grid event is accounted for because all of the applicable LOSP events are used in the derivation of the non-recovery probability as a function of the duration. This approach can be similarly used to determine if the LOSP events would have precluded the use of alternate AC source connected to the switchyard (e.g., gas turbine) and derive the fraction of plant-centered LOSP events that would not permit the use of the alternate AC source. With a realistic screening and assessment of the recovery duration, a more robust offsite power non-recovery factor can be developed and applied to the loss of offsite power scenarios.

Many of the U.S. plants do not take credit for recovery of EDG failures. Selected plants credit EDG failure recovery using data from NUREG/CR-4550. Some plants only credit recovery of EDG starting failures since a longer and more definite recovery time window is available. For these plants, maintenance records for EDG starting and output breaker closing failures were reviewed to determine if, under emergency, the failure could be recovered within the time limit. In the U.S., very few plants take full recovery credit for EDG failures. To do this, the percentage breakdown of EDG failure causes based on the actual repair records must be developed. For each cause, the time required to recover under the emergency conditions must be judgmentally estimated. This time information is then convoluted with the thermal-hydraulic time window in accordance with the second equation presented previously to derive the EDG recovery/non-recovery probability data.

Regulatory Guide 1.200 requires that actual and/or realistic data must be used for any repair type of recovery analysis.

3.3 Refinement of LERF Model

Refinement of the LERF model generally includes enhancement of the containment isolation model and taking additional credit for operator actions to mitigate the severe accident. Usually, the containment isolation model was originally developed for all plant damage states (PDSs). As such, it consists of penetrations that, if remain open, may cause both small and large releases. For use in the LERF model, the containment isolation model should be revised to include only those lines that may result in large releases. Since the definition of large release is not completely clear, a release equivalent to expelling one entire volume of the containment atmosphere in an hour is sometimes used to represent a large release. Since multiple lines could fail open simultaneously, the combined total releases from all of the penetrations excluded from the LERF containment isolation model should not accumulate to more than this equivalent release. To screen the penetrations by line size, the total equivalent cross sectional flow area of containment penetrations screened out must be less than the penetration cross sectional flow area determined from a rate equivalent to releasing one containment volume in an hour. Lines up to and including 3” in diameter were calculated at one plant as can be excluded from the LERF containment isolation model. This calculation only considers those penetrations that are not screened out due to other considerations and applies only to penetrations that are open to the containment atmosphere because the containment pressure was used in this calculation. If the line is connected directly to the Reactor Coolant System (RCS), a higher pressure may cause a greater release flow.

Additional credit to mitigate a severe accident may include operator action for manual vessel depressurization during the time period between core damage and vessel failure, performing additional thermal-hydraulic calculations using such codes as MAAP or MELCOR to take credit for effects of containment spray and fan coolers, etc. Vessel depressurization during the period between core damage and vessel failure is one of the most important severe accident management actions that can reduce the likelihood of a large early release since it reduces the possibility of early containment failure resulting from high pressure melt ejection and direct containment heating.

3.4 PRA Scope and Quality

To support the risk-informed extension of AOT for EDGs, the PRA scope should include the following initiators:

- Internal events
- Internal fires
- Seismic events
- Internal floods
- Other external events, if significant

To ensure the quality of the PRA used to perform the risk impact of AOT extension, the PRA should have been peer-reviewed and resolved all significant comments from the peer review. In addition, it should meet at least the requirements for Capability Category II specified in the American Society of Mechanical Engineers (ASME) Standard for internal events, American Nuclear Society (ANS) Standard for seismic and other external events, and ANS Standard for fire PRA methodology (to be published). Furthermore, the requirements specified in Regulatory Guide 1.200, including Appendices A, B (to be published), and C (draft) should also be met.

4. INCREMENTAL RISK ASSOCIATED WITH EXTENDED AOT

The risk criteria on ICCDP and ICLERP are to examine the increase in risk from the new average CDF/LERF, based on the increased maintenance unavailability, to the instantaneous CDF/LERF caused by the removal of a particular EDG from service. Since the loads on the safety buses are generally not symmetrical, the ICCDP/ICLERP values calculated are different for each EDG. As part of the risk mitigation efforts, some plants have implemented a requirement to disallow any planned maintenance on other accident initiation and mitigation equipment during the time period when an EDG is out of service (OOS) for maintenance. Nevertheless, emergent failures may still occur during the time when an EDG is removed from service. To evaluate the risk exposed under this situation, calculations of the instantaneous risk associated with the simultaneous OOS of one EDG and failure of another piece of accident mitigation equipment with a relatively high failure rate is warranted.

For the calculation of the instantaneous risk associated with the removal of an EDG, the EDG removed from service is rendered unavailable in the risk model. In addition, most plants use the average or expected maintenance unavailability for equipment other than the EDG removed from service. This is to account for the likelihood of possible emergent failures. Some plants, however, have used zero maintenance to represent the maintenance unavailability of equipment other than the EDG removed from service in the calculation of the instantaneous risk. These plants essentially have made the commitments:

- No EDG maintenance is allowed when corrective or planned maintenance for other PRA equipment is in progress.
- Only one EDG is allowed to be in planned maintenance at a time.
- Planned maintenance of other PRA equipment is not allowed during the entire AOT OOS time for EDG maintenance.
- If emergent failures of other PRA equipment occur during the EDG planned maintenance, unit shutdown may be required depending on the risk level.

In the assessment of the instantaneous risk during unavailability of an EDG, the calculation of the CCF contribution is different depending on the cause of the EDG unavailability. If the EDG is removed from service for scheduled, planned maintenance, the loss of this EDG is not considered as part of the common cause failures. No change to the calculation of the probabilities of CCF basic events is involved. If the EDG is out of service due to a failure, the calculation of the probabilities for CCF basic events involving the failed EDG must be adjusted assuming one of the common cause failures has already occurred unless it is clear the EDG failure is not part of a common cause failure affecting the remaining EDGs. Most plants have requirements in the Technical Specifications to perform examination following an EDG failure to ensure that no common failure cause exists affecting the remaining EDGs.

Another risk management strategy that some plants have adopted to reduce the instantaneous risk is to require a specific set of electrical and system alignments be implemented during the time when each EDG is OOS. These are the alignments that would yield the lowest risk when a particular EDG is unavailable.

5. RISK ASSOCIATED WITH EXTERNAL EVENTS

As part of the risk-informed application for extension of AOT for EDGs, risks associated with the external events must also be addressed. Fires and seismic events are, by far, the most important external events to evaluate. For the fire events, only those plant locations that, due to fire damage, could result in a loss of offsite power are critical. Increase in EDG maintenance unavailability primarily affects fire risks in switchgear rooms, cable spreading room, control room, etc. The increase in core damage and large early release frequencies are also attributed to these locations only. Depending on the locations of the 4 kV switchgear rooms (e.g., DG Building, Turbine Building, Auxiliary Building, etc.), additional plant locations may also be involved. As such, tracing offsite power supply cables may be needed to identify these locations.

In the 4kV switchgear rooms at a few selected plants, offsite power supply cable from only one offsite source is present. As such, loss of offsite power may not occur due to damage from fires initiated in these rooms. At most plants, however, offsite power supply cables from two sources are connected to each 4kV emergency bus. Since only one source will be aligned following a plant trip, an LOSP event may occur if a fire-induced ground fault (i.e., short to ground) occurs to the connected offsite supply cable in one of the 4kV switchgear room causing the supply from this offsite source to all 4kV emergency buses to trip off (note that an LOSP event involves the loss of offsite power supply to all the 4kV emergency buses). Of course, this will only occur if there are no breakers between the offsite supply cables to the different 4kV emergency buses that would automatically actuate to isolate the fault.

Cable spreading room and control room are considered because fire damage to control cables could cause tripping of power supply breakers. Most of the cables in the cable spreading room and main control room are control cables and instrumentation cables. To cause an LOSP event due to fires in these locations, at least two separate fire-induced circuit shorts must occur. Since inter-cable shorts is much less likely than intra-cable shorts and shorts between cables located in different cable trays/conduits are even less likely, the probability of a fire-induced LOSP event due to fires in the cable spreading room and main control room is very small.

Therefore, the most important location that may cause an LOSP event due to fires is generally the 4kV switchgear rooms. In addition, no offsite power recovery is credited for fire-induced loss of offsite power scenarios.

For the seismic events, offsite power usually is the weakest link from the fragility standpoint. Any earthquakes with significant motion to cause damage to systems, structures, and components (SSCs) important to accident mitigation, offsite power would have been lost already. As such, the seismic risk should generally be somewhat sensitive to the effect of EDG unavailability increase as long as the seismic risk is a significant contributor to the total risk. However, the level of seismic risk and the corresponding level of detail for the seismic analysis may vary significantly due to the location of the plant (i.e., depending on the level of seismic hazard). Similar to the fire-induced LOSP, no credit for recovery of seismic-induced LOSP is taken in PRAs. However, recovery credit is usually taken for seismic-induced relay chatter since no actual equipment damage is involved and the operators just need to reset the breakers at the switchgear or MCC rooms.

6. RISK MANAGEMENT CONSIDERATIONS

Most U.S. plants manage risk with a procedurally controlled program that governs the scheduling of maintenance activities. This program involves review from a probabilistic and/or deterministic standpoint of all, planned and unplanned, maintenance activities. Maintenance is normally assessed from a probabilistic standpoint using a computerized On-Line Risk Monitor. In cases where quantitative solution is not possible because the functions or systems under consideration are not modeled, a qualitative assessment is used. Under certain risk significant conditions both quantitative and qualitative assessments may be required.

In order to manage the risk activities associated with the extension of the EDG AOT, selected risk management/reduction strategies may be used and incorporated into the configuration risk management procedure. These risk management/reduction strategies may include the following:

- Minimize the likelihood of loss of offsite power during the performance of EDG maintenance or surveillance tests. Typically, EDG planned maintenance will not be performed unless 1) no work on the high voltage switchyard is in progress, and 2) weather conditions will not increase the likelihood of loss of offsite power. Similarly, EDG surveillance tests will not be performed under the preceding conditions either. This is because EDG is normally in standby and only started for surveillance testing or emergency response. EDG corrective maintenance mostly results from equipment failures during surveillance testing.
- Reduce redundant component unavailability. All U.S. plants allow only one EDG removed from service for planned maintenance at a time. In addition, prior to removal of an EDG for planned maintenance and entry into an AOT, the redundant train is tested to demonstrate that the remaining EDGs are operable. In fact, the EDG online maintenance is usually performed following successful performance of the monthly surveillance test for the other EDGs. Most U.S. plants also attempt to limit the simultaneous testing and maintenance of the redundant or diverse accident mitigation systems. Additional protection for the train remaining in service may also be provided (e.g., posting signs, etc.).
- Reduce unavailability of other components. This may include: 1) risk management activities to control other equipment unavailability, operational activities (testing, load dispatching, etc.), and weather conditions, 2) EDG planned maintenance will not be performed if maintenance on other PRA equipment is in progress, 3) no additional, planned risk-significant activities or maintenance on other PRA equipment when EDG maintenance is in progress, 4) a special set of electrical, mechanical or system alignments (i.e., alignments that would yield the lowest risk when a particular EDG is unavailable; an example of a specific system alignment is to keep a standby pump running), and 5) special watch to reduce human error probabilities.
- Other compensatory measures. This may involve: 1) improve operating procedures and operator training to reduce impact of human errors, 2) improve system designs, which reduces overall system unavailability and plant risk, and 3) others.

The above risk management/reduction strategies are designed to control and minimize the risks involved with the extension of AOT for EDGs.

7. CONCLUSIONS

After implementing a significant set of model enhancements, the risk-informed assessments for most U.S. plants concluded that the increase in plant risk due to the extension of AOT for EDGs is small and consistent with the NRC "Safety Goals for the Operations of Nuclear Power Plants; Policy Statement," Federal Register, Vol. 51, p. 30028 (51 FR 30028), August 4, 1986, as further described by NRC Regulatory Guides 1.174 and 1.177. Regulatory Guide 1.174 ensures that the increase in average risk due to extension of the AOT associated with EDGs is relatively insignificant and Regulatory Guide 1.177 makes certain that the increase in instantaneous risk from the new average risk level during the period when an EDG is removed from service is small and within the risk acceptance limit. Using the risk criteria, these risk impact analyses help provide high assurance of the capability to provide power to the ESF buses during the extended AOT for EDGs.

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