APPENDIX D

PLANT-SPECIFIC PROBABILITY OF A CONSEQUENTIAL LOOP: A METHOD OF ASSESSMENT

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

BNL	Brookhaven National Laboratory
CAO	Control Area Operator
CFR	Code of Federal Regulations
DBA	Design basis accident
ECCS	Emergency core-cooling system
EDG	Emergency diesel generator
FSAR	Final safety analysis report
GDC	General Design Criterion
IN	(NRC) Information Notice
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
ISO	Independent System Operator
LER	Licensee event report
LBLOCA	Large-break LOCA
LOCA	Loss of coolant accident
LOOP	Loss of offsite power
NERC	North American Electric Reliability Council
NPP	Nuclear power plant

D.1 INTRODUCTION

GDC 17 (Appendix A of 10 Code of Federal Regulations (CFR) 50) states, in part, “Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit...” Accordingly, licensees are required to demonstrate that their offsite power supplies are available after a unit trip or a design basis accident (DBA).

Operational data show that a loss of offsite power (LOOP) has occurred after events such as a unit trip. For example, the Salem Generating Station unit 2 had a LOOP after emergency core-cooling system (ECCS) actuations (and reactor trip) in 1986. This LOOP happened, in part, because since the completion of a transient study in 1981, additional electrical loads were added to the Salem Station electrical distribution system. When these loads were added, a static analysis of their effect on the system was performed which showed the system to be more than adequate to handle the additional load. However, the 1981 transient analysis for higher startup currents was never updated to account for the additional loads.

The objective of this report is to present a method to assess the plant-specific probability of consequential LOOP due to a loss-of-coolant accident (LOCA). The method is generic and can be applied to any size break of a LOCA. However, in this report this method is specifically applied to a large-break LOCA (LBLOCA) to support a voluntary risk-informed alternative to 10 CFR 50.46 and GDC 35. The considerations that make the method specific to this size of LOCA are clearly identified in subsequent sections. The reader who is interested in learning more about this risk-informed alternative is advised to read SECY-01-0133 [Ref. D.1] and a BNL report on the subject [Ref. D.2]. This method can be used by licensees to support requests to obtain relaxations allowed by this risk-informed alternative. In this section, an overview of the mechanisms that cause a LOOP after a LOCA are discussed, and subsequent sections present the method.

A LOCA causes the following electrical-related events in a nuclear power plant (NPP):

1. A reactor trip (loss of generation). The loss of a large amount of electric-power generation can cause instability in the offsite transmission-system grid.

2. The transfer of the power source of the plant loads from the main generator to offsite power. In many plants, the main generator normally feeds the plant loads through a unit auxiliary transformer. When the reactor trips, the main generator often remains connected to the plant’s electrical systems and high-voltage switchyard until protective relaying transfers the power source from the main generator to the offsite transmission-system grid.

3. Loading of safety loads to Class 1E buses[1]. The pumps of the ECCS are started and aligned. The AC-powered ECCS loads are powered from the Class 1E buses which, in turn, are fed from the offsite transmission-system grid.

---

[1] The term “Class 1E buses” is used to represent the safety buses that provide AC power to ECCS loads. These buses can be fed by offsite power and the EDGs.

The first event causes a sudden loss of a large amount of electric-power generation to the offsite transmission-system grid, and the last two events demand electric power from this grid to feed safety and non-safety loads. Starting of these loads requires motor-starting (inrush) current which, in turn, can cause undervoltage at the Class 1E buses. Thus, a LOCA can cause voltage instability in the offsite transmission-system grid due to the combined effect of losing electric-power generation and demanding electric power for safety and non-safety loads. This instability can degrade voltage at the unit switchyard, thereby actuating degraded voltage protection (relays) which, in turn, disconnect the Class 1E buses from the offsite grid. These buses subsequently are powered by the onsite emergency AC power sources, usually the emergency diesel generators (EDGs).

A LOOP occurs when the Class 1E buses are disconnected from the offsite transmission-system grid, so that the buses cannot meet the required success criteria to respond to a DBA, without the support of the onsite emergency-power system. The success criteria are stated in the final safety analysis report (FSAR). In many cases, this definition means that all Class 1E buses are disconnected from the offsite transmission-system grid. However, in some cases, a disconnection from the offsite grid of several Class 1E buses, but not all of them, also is considered a LOOP because those buses that remain powered from the offsite transmission-system grid cannot meet the success criteria required to respond to a DBA.

The electrical transient (disturbance) triggered by the LOCA due to a sudden loss of a large amount of electric-power generation and a demand to power safety and non-safety loads can be exacerbated by inadequate or degraded voltage conditions of the offsite transmission-system grid. NRC Information Notice (IN) 2000-06 [Ref. D.3] documents and discusses several events related to the voltage adequacy of offsite power sources, that is, power from the transmission grid to nuclear power plants. This IN identifies several factors that could result in inadequate offsite voltages, such as line outages, high system demand, and unavailability of other local voltage support.

One recent event at Callaway Unit 1 potentially tied the concern about inadequate voltage in the offsite system to industry deregulation. The licensee stated in the licensee event report (LER) 50-483/99-005 that such magnitude of power being transported across the grid during the period of the event had not been observed previously and was far in excess of typical levels. This LER also stated that the deregulated wholesale power market contributes to conditions in which higher grid power flows are likely to occur, and these large flows were observed at that time. This implies that in a deregulated environment, there may be a greater potential for experiencing degraded voltage conditions in the offsite transmission-system grid.

In summary, the electrical disturbance triggered by the LOCA, and the conditions of the offsite transmission-system grid, can contribute to the occurrence of a LOOP. The conditions of the offsite grid may be impacted by deregulation and other factors. Since this LOOP occurs as a consequence of the LOCA, it is called a consequential LOOP. Also, the LOOP does not occur simultaneously with the LOCA, but some time elapses during the electrical disturbance after the LOCA. For this reason, this LOOP also is called a delayed LOOP.

To simplify this discussion, the two factors identified above that contribute to the occurrence of a delayed LOOP, namely, the electrical disturbance triggered by the LOCA and the conditions of the offsite transmission-system grid, are called here “transient factors”.

In addition to the transient factors, a delayed LOOP can be caused by failures of the plant’s electrical equipment. For example, if the Class 1E buses are fed during power operation by the main generator, and are required to be transferred to an offsite source, but the transfer fails, then these buses will not be connected to the offsite source, and will effectively experience a LOOP.

Examples of a plant’s electrical equipment that are relevant to a delayed LOOP are the transfer schemes (mainly relays), undervoltage protective schemes (mainly relays), transformers, and circuit breakers. These components may fail to operate due to a hardware-related cause, or human error. Examples of human errors are failures during maintenance, testing, or calibration.

To simplify this discussion, the failures of the plant’s electrical equipment that contribute to a delayed LOOP are called here “plant-centered factors.” Strictly speaking, the electrical transient triggered by a LOCA also is “plant-centered,” but for convenience it is classified here as a “transient factor.”

Summarizing, a delayed LOOP can be caused by transient and/or plant-centered factors. Section D.2 discusses transient factors in more detail, and presents an approach to estimate their probability of occurrence. Section D.3 discusses plant-centered factors in more detail, and describes an approach to estimate their probability of occurrence. Section D.4 then advances a methodology for combining these two estimates to assess the plant-specific probability of delayed LOOP.

As presented in detail in the following sections, the method consists of assessing the plant-specific probability due to transient factors and plant-centered factors, and then combining these two estimates to assess the plant-specific probability of delayed LOOP. These methods are proposed to provide guidelines to licensees on one method for assessing this probability.

D.2 TRANSIENT FACTORS

This section presents a method to ascertain the contribution of electrical transients to the plant-specific probability of a consequential LOOP. The method is comprised of the following major steps:

1. Gather historical data on the voltage conditions at the plant's switchyard.

2. Perform voltage analyses of the plant's electrical system.

3. Assess the average time per year that the NPP is vulnerable to a LOOP condition.

4. Estimate the plant-specific probability of a LOOP due to transient factors.

5. Estimate the predicted performance of the offsite grid and conduct sensitivity studies.

Each of these steps is described in the following subsections.

D.2.1 Gather Historical Data on the Voltage Conditions at the Plant's Switchyard

The North American Electric Reliability Council (NERC) is a voluntary organization that promotes bulk electric system reliability and security. It has 10 regional councils, presented in Table D.1 and shown in Figure D.1.

Each regional council is composed, in turn, of 1 to 33 control areas. A control area is defined by NERC as "An electric system or systems, bounded by interconnection metering and telemetry, capable of controlling generation to maintain its interchange schedule with other Control Areas and contributing to frequency regulation of the Interconnection."

The operating data required by the method proposed in this appendix are the voltage conditions that would occur at the plant's switchyard immediately following trip of the plant with its resulting loss of generation to the grid. These data are not the voltages measured at the plant's switchyard or Class 1E buses during plant operation. A regional operator, such as the Control Area Operator (CAO) or an Independent System Operator (ISO), may be able to provide data or estimates of the post-trip voltage conditions. An ISO coordinates reliability over a large geographic region; for example, the California ISO is a nonprofit agency that coordinates operation of the California (and nearby) transmission systems. The California ISO is in the Western Systems Coordinating Council (WSCC) of NERC.

Table D.1 Member Councils of the North American Electric Reliability Council

Acronym	Name
ECAR	East Central Area Reliability Coordination Agreement
ERCOT	Electric Reliability Council of Texas
FRCC	Florida Reliability Coordinating Council
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP	Mid-Continent Area Power Pool
NPCC	Northeast Power Coordinating Council
SERC	Southeastern Electric Reliability Council
SPP	Southwest Power Pool
WSCC	Western Systems Coordinating Council

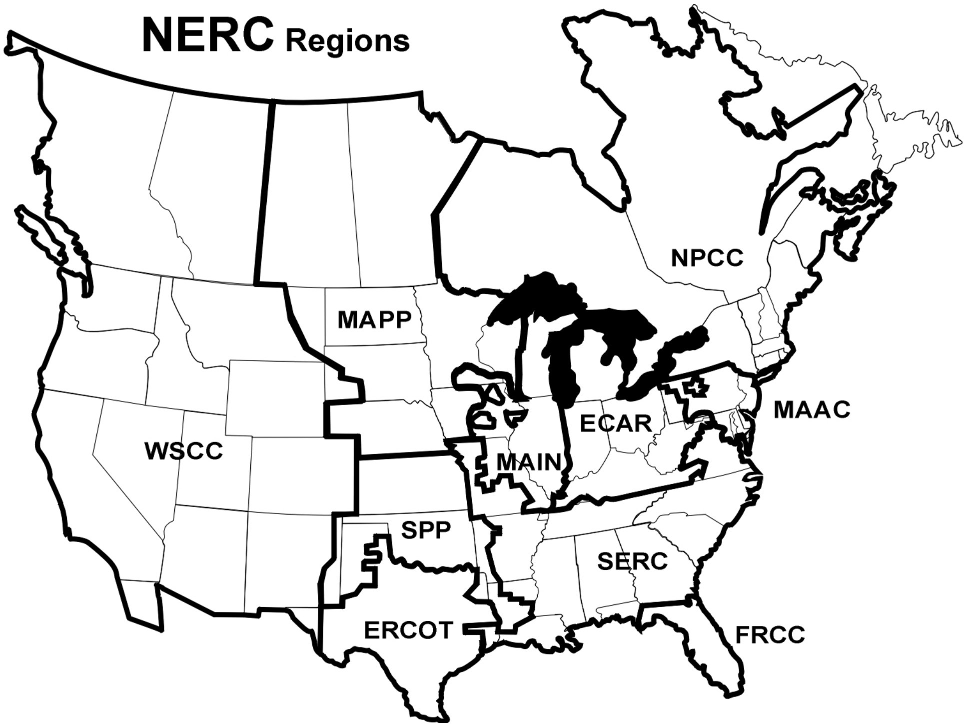


Figure D.1 North American Electric Reliability Councils

NERC periodically publishes forecasts of the generation and transmission system reliability. However, regional organizations, such as the CAOs and ISOs, conduct analyses of voltage adequacy and thus may be able to provide the necessary operational data on the voltage conditions that would occur at the plant's switchyard following trip of the plant. Ideally, these data would be available for several years. Using the data from regional organizations also helps to make the analysis more plant-specific.

The data on offsite network quality with respect to voltage stability can be partitioned into three categories:

1. The network is operating in a fashion where the NPP itself literally is the linchpin holding the network together,
2. The "gray area" between the previous and the next categories, and
3. The network is operating in a manner that provides a clear margin for maintaining the voltage stability of the grid given a reactor trip in the NPP.

These three categories represent a partitioning of a continuous spectrum of post-trip voltages, as shown in Figure D.2. Examining and partitioning past operating experience of the power system network in this way helps to ascertain the degree to which the transient response of the network will result in a consequential LOOP. For example, when a plant is connected to a network that has the characteristics of Category 1, the voltage is expected to be greatly deteriorated after a reactor trip, and the plant is very likely to lose offsite power after the reactor trip.

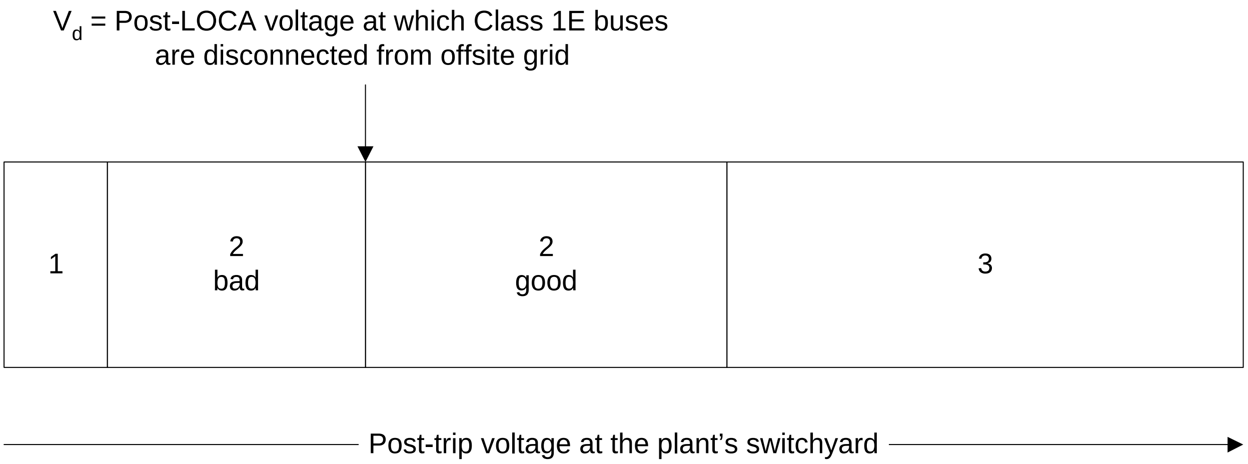


Figure D.2 Partitioning of a Continuous Spectrum of Post-LOCA Voltages

When a NPP is in the second category, grid transients that do not result in loss of the grid network, but do cause sufficiently low voltage to activate the undervoltage protection, also represent consequential LOOPs to the NPP. To make a realistic evaluation, Category 2, the “gray area” between the other two categories, has to be subdivided into at least two subcategories, shown in Figure D.2 as “bad” and “good.” The gray area is split into these subcategories by determining V_d, the post-LOCA voltage at the switchyard at which the Class 1E buses are disconnected from the offsite grid. The objective of the second step, described in the next subsection, is to assess this voltage.

For the third category, when the network is operating such that it provides a clear margin for maintaining the voltage stability of the grid given a reactor trip at the NPP, the value of the offsite power-supply voltage is the design value, which is likely to be 100% or better.

Each category and subcategory of the NPP’s post-trip voltage can be seen as a state of the NPP and the offsite grid or, to simplify, of the NPP. The time that a NPP spends in each state is called here “time of residence.”

As mentioned previously, the operational data on the voltage conditions that would occur at the plant’s switchyard following a reactor trip with its resulting loss of generation to the grid may be available from regional organizations, such as the CAOs or ISOs. These data consist of estimates of the periods of time that the subject NPP is exposed to each of the categories and subcategories per year.

Ideally, the data should be collected for at least five years prior to deregulation, and up to the current time afterwards. In this way, the data can be used for estimating the plant-specific probability of a consequential LOOP, and also can be analyzed statistically to identify any trends.

Operational data on the voltage conditions at the plant’s switchyard may not be available because there was no program in place to record or store it. In this case, the licensee may be able to use engineering judgment to estimate the periods of time that the subject NPP is exposed to each of the categories and subcategories per year, as discussed in Step 5 (Subsection D.2.5).

D.2.2 Voltage Analyses of the Plant’s Electrical System

The triggers for a consequential LOOP following a LOCA due to transient factors are the loss of the unit’s generation and the loading of non-safety and safety loads to offsite sources of power. Starting these loads requires a motor-starting (inrush) current that, in turn, can cause undervoltage at the Class 1E buses. Accordingly, the objective of this step is to use the plant’s accurate, up-to-date voltage analysis (transient and steady-state) to determine V_d, the post-LOCA voltage at the switchyard at which the Class 1E buses are disconnected from the offsite grid. Disconnection occurs when the post-LOCA voltage at the buses is at, or below, the settings of the undervoltage relays of these buses. These settings are expressed as pairs of voltage and time delays. A hypothetical example would be two pairs as follows: 90% for 30 seconds, and 65% for 1 second. This means that the Class 1E buses would be disconnected from the offsite sources if the post-LOCA voltage at these buses dropped to 90% for 30 seconds, or if it dropped to 65% for 1 second.

Assessing V_d, the post-LOCA voltage at the switchyard at which the Class 1E buses are disconnected from the offsite grid, requires evaluating the voltage at these buses as a function of the maximum expected plant loading during a DBA. The voltage analysis should include both transient- and steady-state responses to a LOCA, and should be undertaken as follows:

1. The post-LOCA grid-switchyard voltage has a nominal value of 1 per unit.
2. Assume the plant is initially operating and that the following events happen simultaneously or within a few seconds: large LOCA - reactor trip - turbine trip.
3. Model the plant's response to this sequence of events by keeping connected those loads that would not be tripped by design, tripping those loads that would be tripped, and starting those loads called upon for mitigation.
4. Record the voltage profiles at the Class 1E buses.
5. Determine if the plant's undervoltage schemes would have isolated the Class 1E buses from offsite power during the initial period (e.g., first 60 seconds).
6. If the plant's undervoltage-protection schemes did not isolate the Class 1E buses from offsite power in the previous step, repeat Steps 2-5 taking into account a successive drop of the grid-switchyard voltage in 3-5% increments until the Class 1E buses are isolated (i.e., a consequential LOOP occurs).

To ensure this analysis is acceptable, the following key elements should be included:

1. The model of the plant's distribution system, transfer/starting logic, protective relaying scheme, and loads should accurately represent the actual equipment under both transient and steady-state conditions.
2. A computer model of the plant's distribution system should be used. The software analysis package should be a verified and validated product.

The main outcome of these parametric studies is V_d, the post-LOCA voltage at the switchyard at which the Class 1E buses are disconnected from the offsite grid. This voltage is used in the next steps of the overall analysis, as discussed in the following sections.

D.2.3 Assess the Average Time per Year that the NPP is Vulnerable to a LOOP Condition

The objective of this step is to assess the average time per year that the NPP is vulnerable to a LOOP condition, that is, the average time that the post-trip conditions are such that the Class 1E buses would be disconnected from the offsite grid. This assessment can be divided into two substeps:

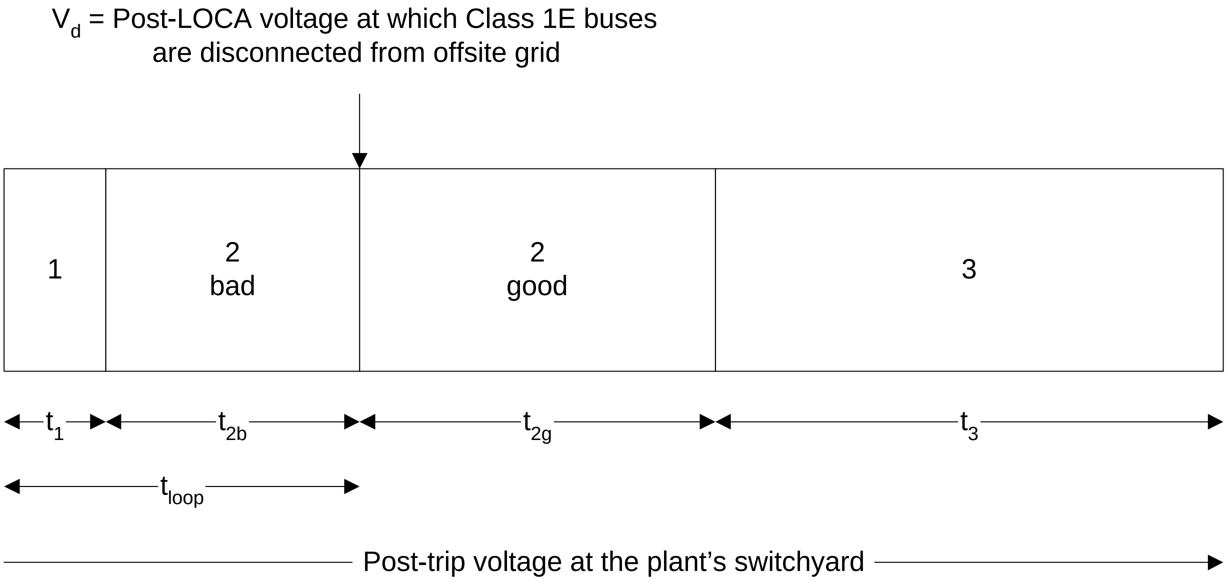
1. Using the operational data gathered previously, calculate the average time per year that the plant is exposed to each of the categories and subcategories of offsite-network quality. This step is accomplished by averaging the time of residence of the NPP in each state.

2. Using the average times of residence of the NPP in each state obtained in the previous substep, determine the total average time per year that the NPP is vulnerable to a LOOP condition.

This second substep is achieved by considering the illustration of the spectrum of post-trip voltages shown in Figure D.3. The NPP has an average time of residence in each of the categories and subcategories. For example, the average time that a plant spends in Subcategory “2 bad” is represented by t_{2b}. The total average time per year that the NPP is vulnerable to a LOOP condition, t_{loop}, is the sum of the average time that the NPP resides in Category 1 and Subcategory “2 bad”:

$$t_{loop} = t_1 + t_{2b}$$

The total average time per year that the NPP is vulnerable to a LOOP is used in the next step to estimate the plant-specific probability of a consequential LOOP. As shown in Figure D.3, the determination of the time of residence in each category and subcategory is not strictly necessary, as the main parameter required is the total average time per year that the NPP is vulnerable to a LOOP condition, t_{loop}. However, splitting the continuous spectrum of post-trip voltages into categories and subcategories helps to accurately assess the total average time per year that the NPP is vulnerable to a LOOP condition, and may provide insights into the conditions that a NPP has been exposed to, such as the average time of residence in Category 1.



$$T = t_1 + t_{2b} + t_{2g} + t_3$$

Figure D.3 Spectrum of Post-LOCA Voltages with Times of Residence

D.2.4 Estimate the Plant-Specific Probability of a LOOP Due to Transient Factors

The plant-specific probability of LOOP due to transient factors can be estimated as the following fraction:

$$\text{P(LOOP due to transient factors)} \sim \frac{\text{average time spent in configurations vulnerable to LOOP}}{\text{total time (in a year)}}$$

or,

$$\text{P(LOOP due to transient factors)} \sim t_{loop} / T$$

where T is one year, as shown in Figure D.3.

The average time spent in configurations vulnerable to a LOOP is obtained from the previous step. As an hypothetical example, suppose that in an average year, a plant spends one half day in Category 1 (when the network is operated such that the NPP itself is holding the network together), one and a half days in Subcategory “2 bad”, 100 days in Subcategory “2 good”, and 263 days in Category 3 (when the network is operating to provide a clear margin for maintaining the dynamic stability of the grid given the loss of the NPP).

Hence, for this hypothetical example,

$$t_{loop} \sim 0.5 + 1.5 = 2 \text{ days},$$

and the average time that the NPP is vulnerable to a LOOP is

$$\text{P(LOOP due to transient factors)} \sim 2 \text{ days} / 365 \text{ days} \sim 5.5\times10^{-3}.$$

As a second hypothetical example, suppose that in an average year, a plant spends one day in Category 1, nine days in Subcategory “2 bad”, 155 days in Subcategory “2 good”, and 200 days in Category 3 (when the network is operating to provide a clear margin for maintaining the dynamic stability of the grid given the loss of the NPP).

Hence, for this hypothetical example,

$$t_{loop} \sim 1 + 9 = 10 \text{ days},$$

and the average time that the NPP is vulnerable to a LOOP is

$$\text{P(LOOP due to transient factors)} \sim 10 \text{ days} / 365 \text{ days} \sim 2.7\times10^{-2}.$$

The average times of residence in each category and subcategory are expected to change over time, and they may show improving or deteriorating trends. In particular, deregulation may cause the times of residence in undesirable states to increase. For this reason, if the pre-deregulation data provide lower probabilities than those obtained using deregulation data, the former data should not be included in any aggregation. For example, if we assume that the hypothetical data of the first example corresponds to the pre-deregulated period, and the data of the second example corresponds to the deregulated period, then the data of the pre-deregulated period should not be aggregated with the data of the deregulated period. On the other hand, improving trends leading to reduced times of residence in undesirable states can be considered. The effect of deregulation on the offsite grid and the future performance of this grid is further analyzed in the next subsection.

D.2.5 Estimate the Predicted Performance of the Offsite Grid and Conduct Sensitivity Studies

As mentioned earlier in this section, regional organizations, such as the CAOs and ISOs, may be able to provide operational data on the voltage conditions that would occur at a plant switchyard following trip of the plant with its resulting loss of generation to the grid. These data essentially consist of estimates of the periods of time that an NPP is exposed to each of the previously identified categories and subcategories, per year. However, the operational data on the voltage conditions at the plant's switchyard may not be available because there was no program to record or store it. In this case, or to complement these sources, engineering judgment may be used, based on sound technical arguments, to estimate these periods. The estimates obtained this way should be complemented by estimating the predicted performance of the offsite grid, as described next.

The use of operational data to estimate the average time per year that the NPP is vulnerable to a LOOP condition, as explained in the previous major steps 1 to 4, may generate an unrealistic evaluation of the plant-specific probability of a LOOP due to transient factors. In essence, even if past operating experience is available, it may not be good enough to estimate (i.e., be representative of) the future performance of the offsite grid. This is true, for example, when a particular plant has not been exposed to the effect of deregulation because its impact has not reached the particular region where the plant is located. If the plant were to be exposed to a deregulated offsite grid starting this year, but was not exposed to such a grid in previous years, the operational data from previous years clearly may not be representative of the conditions to which the plant will be exposed from now onwards. Therefore, it is recommended to estimate the future performance of the offsite grid and conduct sensitivity studies of this performance.

Engineering judgment may be used to estimate the future performance of the offsite grid. Possibly, one or more different scenarios of future grid performance can be constructed, and different probabilities assigned to them. Once these scenarios of future grid performance are estimated, sensitivity studies can be carried out, using the same process described in this section (the four previous steps), to assess the plant-specific probability of consequential LOOP due to transient factors. The probabilities obtained from the sensitivity studies can then be used to estimate uncertainty bounds associated with the future performance of the offsite grid.

D.3 PLANT-CENTERED FACTORS

A delayed LOOP can be caused by failures of the plant’s electrical equipment. For example, if the Class 1E buses are fed during power operation by the main generator and are required to be transferred to an offsite source, but the transfer fails, these buses will not be connected to the offsite source and will effectively experience a LOOP even though an offsite source is available.

Examples of plant’s electrical equipment that can cause a delayed LOOP are the transfer schemes (mainly relays), undervoltage protective schemes (mainly relays), transformers, and circuit breakers. These components may have a pre-existing, latent failure that is not discovered until they are demanded to operate, or they may fail to operate on demand. These components may fail due to a hardware-related cause or due to human error. Examples of human error are failures during maintenance, testing, or calibration.

To assess the probability of consequential LOOP due to plant-centered factors, one possibility is to develop a PRA model (fault tree) of relevant components. The “top event” of the fault tree is LOOP occurs due to plant-centered factors after a LOCA. The LOOP is defined as in the Introduction, that is, a LOOP occurs when the Class 1E buses are disconnected from the offsite transmission system grid, such that they cannot meet the success criteria required to respond to a DBA, as stated in the FSAR, without the support of the onsite emergency power system.

The fault tree must contain all the relevant electrical components involved in powering the Class 1E buses, including the transfer of power sources, if applicable. Some components may be grouped and replaced by modules for which probabilistic data is available, as long as the dependencies between components or modules are preserved. The fault tree also must contain the important contributors to risk, such as human errors and common cause failures.

If a licensee developed fault trees of electrical systems as part of the Individual Plant Examination (IPE), Individual Plant Examination of External Events (IPEEE), or another effort, the licensee possibly can modify or expand these fault trees to model a plant-specific consequential LOOP due to the plant-centered factors. In this way, the effort invested by a licensee is reduced.

The probabilistic data, such as failure rates of electrical components, should be as plant-specific as possible to model as realistically as possible the reliability of the specific plant being analyzed.

GDC 17 requires, as a minimum, that there are two physically independent circuit paths from the offsite power network to the plant’s onsite power distribution system. Accordingly, there are two offsite power sources available to a plant. One of the offsite sources must be available within a few seconds after a LOCA. However, the other source may not be immediately available because some manual actions by the plant staff are required to make this power source available. For this reason, this source is called the delayed offsite source.

The time required for the operators to diagnose the cause of a LOOP and implement corrective actions is likely to be at least several minutes after the onset of the LOOP. Since a LBLOCA is the focus of this study, and mitigating this LOCA requires a fast response of the ECCS equipment, no credit should be given to the manual recovery of offsite power. Therefore, since the manual actions required to make the delayed offsite source available can take up to several minutes, this source should not be credited in evaluations related to a large-break LOCA.

After a plant trip and before a LOOP occurs, the electrical components are powered by offsite power. Accordingly, these components may be exposed to somewhat degraded voltages before a LOOP occurs because the offsite power will not be disconnected until the voltage at the Class 1E buses fulfills one of the settings of the undervoltage relays of these buses. Returning to the hypothetical example discussed in the previous section, if the settings of the undervoltage relays are 90% for 30 seconds and 65% for one second, the Class 1E buses would be disconnected from the offsite sources if the voltage at these buses dropped to 90% for 30 seconds, or if it dropped to 65% for one second. The electrical components, powered by offsite power, may be more susceptible to fail because they are exposed to the degraded voltages which, in turn, would be above the settings of the undervoltage relays of the Class 1E buses. It may not be possible to quantify the increase in probability failure of these components due to this exposure because models or data may not be available. However, sensitivity studies are recommended by assuming increases in the probability of failure of these components. The result of these sensitivity studies are updated plant-specific probabilities of consequential LOOP. The updated probabilities can then be compared with pre-defined thresholds to gain insights about the impact of these increases.

D.4 ASSESSING THE PLANT-SPECIFIC PROBABILITY OF A CONSEQUENTIAL LOOP

As discussed in the Section D.1, a delayed LOOP can be caused by transient and plant-centered factors. The transient factors are the electrical disturbance triggered by the LOCA and the conditions of the offsite transmission system grid. The plant-centered factors are failures of the plant’s electrical equipment, such as transfer schemes (mainly relays), undervoltage protective schemes (mainly relays), transformers, and circuit breakers.

Because a LOCA can cause an electrical disturbance in the offsite and onsite electrical systems, the transient factors and the plant-centered factors are not independent of each other. However, since either of the two factors (transient and plant-centered) can cause a delayed LOOP, an approximation of the plant-specific probability of a consequential LOOP given a LOCA can be obtained by adding the probability of LOOP due to transient factors and the probability of a LOOP due to plant-centered factors, as follows:

P(LOOP given a LOCA) ~ P(LOOP due to transient factors)
+ P(LOOP due to plant-centered factors)

This approximation only should be used when the individual probabilities on the right-hand side of the expression are less than 0.1.

Since the conditions of the offsite grid and the plant’s electrical systems evolve over time, it is recommended that the evaluation of the plant-specific probability of a consequential LOOP be revised periodically. The objective of the revisions is to confirm that changes in the offsite grid and in the plant’s electrical systems do not adversely affect this probability. The revisions would require updating the evaluations discussed in this report, which in turn would require gathering or estimating data reflecting the performance of the offsite grid, given that a reactor trip has occurred. As mentioned earlier, gathering of these data can help to identify trends in the performance of the offsite grid.

REFERENCES

D.1 Martinez-Guridi, G., “Conditional Probability of LOOP Given a LOCA: An Approach to Assessment Within the Framework of a Voluntary Risk-informed Alternative to 10 CFR 50.46 and GDC 35,” Brookhaven National Laboratory, Draft Technical Report, November 6, 2001.

D.2 Travers, W. D. to The Commissioners, “Status Report on Study of Risk-informed Changes to The Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria),” SECY-01-0133, July 23, 2001.

D.3 USNRC, “NRC Information Notice 2000-06: Offsite Power Voltage Inadequacies,” March 27, 2000.

Other relevant bibliography:

1. Kirby B.J., Kueck, J.D., and Poole A.B., “Evaluation of the Reliability of the Offsite Power Supply as a Contributor to Risk of Nuclear Plants,” Oak Ridge National Laboratory, ORNL/NRC/LTR/98-12, August 1998.

2. Kueck, J.D. (ORNL), Attarian, G.E. (CPL), Leake, H.C. (APS), and Sims, T.R. (SCS), “Risk Factors Regarding the Application of Degraded Voltage Relaying at Nuclear Generating Stations,” draft paper, no date.

3. Martinez-Guridi, G., Samanta, P.K., Chu, T.L., and Yang, J.W., “Evaluation of LOCA With Delayed LOOP and LOOP With Delayed LOCA Accident Scenarios,” NUREG/CR-6538, Brookhaven National Laboratory, July 1997.

4. Mazumdar, S., “Operational Experience on Bus Transfers,” AEOD/E90-05, June 1990.

5. Palo Verde Nuclear Power Plant, “Statistical Analysis of the 525 Kv Line Undervoltage Probability, Rev. 1,” Dec. 16, 1994.

6. Raughley, W. S., “The Effects of Deregulation of the Electric Power Industry on the Nuclear Plant Offsite Power System: An Evaluation,” Office of Nuclear Regulatory Research, NRC, submitted by cover memorandum dated June 30, 1999.