INDUSTRY REVIEW OF NRC PROPOSED DEGRADED VOLTAGE RELAY METHODOLOGY

NEI Task Force on Degraded Voltage Analysis

PURPOSE

The IEEE Nuclear Power Engineering Committee (NPEC) Working Group 4.7[1] and the Nuclear Energy Institute (NEI) have been working with the NRC staff to understand their current technical position related to degraded voltage relay (DVR) protection requirements for motor starting voltage as described in Regulatory Issue Summary 2011-12, "Adequacy of Station Electrical Distribution System Voltages". Specifically, there is an industry concern that the guidance in RIS 2011-12 is not being evaluated consistently at all Nuclear Power Generating Stations (NPGS) which could elevate the potential of a nuclear safety event such as a delayed loss of offsite power (LOOP) with double load sequencing effects as discussed in NRC GSI-171[2].

The purpose of this technical paper is to evaluate the technical merits of analytical methodologies proposed by the NRC regarding the starting voltage requirements of safety related equipment at the DVR setpoint.

Scope

The scope of this evaluation is to determine the potential impact of two NRC proposed methodologies on current NPGS DVR setpoints:

Method 1: Referred to as the "independent system method," determines the minimum voltage at the NPGS safety buses (i.e., "safety division") required to support both safety related equipment starting and running voltage limits. Safety related buses are not connected to the transmission system and do not credit the effects of the non-Class 1E system: such as upstream impedance, voltage control, load changes, etc. This results in a fixed voltage (i.e., infinite source bus) at the DVR-monitored buses during motor starting.

Method 2: Referred to as the "dependent system method," determines the minimum voltage that would be required at the NPGS safety buses prior to motor starting to support both safety related equipment starting and running voltage limits; thus accounting for the effects of the non-Class 1E system while connected to the transmission network. This results in a voltage at the DVR-monitored buses that dips during motor starting; however, for NPGS that utilize load sequencing, the pre-start bus voltage is readjusted between each load step to the original level.

In this evaluation, each of these methodologies is applied in actual power system analysis using the AC Auxiliary Power System model of several existing NPGS designs that are typical of the US nuclear industry. The impact on the DVR setpoints, as predicted by both these methodologies, is compared to existing setpoints.

It should be noted that neither method is capable of demonstrating voltage recovery above DVR reset in order to prevent transfer to the emergency onsite power source. In fact, voltage recovery must be shown to occur once loads have started and/or the transmission system has recovered using further analysis using the methodology presented in the "Offsite/Station Electrical Power System Design Calculation" section of RIS 2011-12 and IEEE Std 741-2007, Annex A.

It is not the intent of this paper to infer that degraded voltage protection is actually achieved during motor starting when the DVR minimum dropout voltage is set to correspond to the analytical value established by one or the other of these methodologies. In actuality, the very premise of using a voltage relay to protect a power system's capability (capacity) to start motors is technically inadequate. Since a voltage relay only measures voltage (and not power system capacity), any proposed analytical technique must assume some level of power system capacity, thereby violating the stated purpose of the protective function.

Background

The guidance for DVR protection has been developed through three primary NRC documents (1) NRC issued "Statement of Staff Positions Relative to Emergency Power Systems for Operating Reactors" - June 1977, (2) NUREG 0800 (Standard Review Plan) Appendix A, BTP PSB-1 Revision 0, "Adequacy of Station Electric Distribution System Voltages," dated July 1981, and (3) Generic Letter 79-36, August 8, 1979, "Adequacy of Station Electric Distribution Systems Voltages." NPGS have implemented specific designs and technical specifications to meet the intent of these NRC documents. In general, the NPGS licensing commitments are specific to the plant distribution system design and time frame in which the technical specifications were approved, based upon one or more of the three NRC documents listed above.

[1] Responsible for IEEE Std 741, "IEEE Standard Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations"

[2] NRC Generic Safety Issue 171, "Engineered Safety Features Failure from Loss-of-Offsite-Power subsequent to a Loss-of-Coolant Accident"

The recent Component Design Basis Inspections (CDBI) have resulted in NRC inspection findings that are requiring plants to perform DVR analyses that are not consistent with the plants licensing basis. The evaluations result in scenarios that may potentially lead to double sequencing of the NPGS engineering safety system loads.

NPGS have implemented the NRC DVR requirements based on the steady state equipment ratings and not on the starting voltage requirements of equipment. The current NRC staff position that degraded voltage protection includes motor starting at the DVR analytical minimum dropout is inconsistent with current industry practice in two respects:

- First, many NPGS have addressed the transient period of motor starting by demonstrating that the DVR time delay is long enough to prevent spurious tripping during the voltage transients.

- Second, NPGS that account for starting voltage transients typically use the DVR relay maximum reset voltage value as an analytical ending condition and establish an initial condition that will ensure that this criterion will be met. This initial condition is often the subject of positive administrative controls, alarms, and Technical Specification LCO action statements. The reset value is used because any transient that causes a voltage dip below the dropout setpoint must recover to the reset value in order for the electrical distribution system to stay connected to the grid. All transients that start below the reset value initiate the DVR, and if they exceed the relay time delay, will result in separation from the offsite source of power. Hence, analyses below the reset value are moot unless they also address the delayed LOOP and double sequencing effects as discussed in NRC GSI-171.

Approach

As previously identified, there are two NRC proposed methods that will be evaluated to determine the effect on the NPGS DVR setpoint. These methodologies are being considered to determine the impact to the current NPGS DVR setpoints when considering starting voltage adequacy, not to suggest changes to DVR protection.

The following items were applicable for both methods:

1. Determined an analytical limit for DVR setpoint (dropout) at the safety division measurement point.

2. Utilized the existing electrical model (i.e., ETAP model) used in current DVR analysis at each NPGS.

3. Determined the most limiting motor (defined as the one which received the lowest required percent of starting voltage, down to the NPGS 480V MCC) for the worst case design basis event (e.g., LOCA, Safety Injection, Containment Isolation, Load Rejection). Other components, such as static loads and MCC contactors, were assumed to be bounded by the current calculation of record.

Method 1, independent system, determines the DVR setpoint minimum voltage (analytical limit) without crediting the effects of the non-Class 1E system: upstream impedance of the non-Class1E plant or offsite electrical network, voltage control, load changes, etc. The intent of the independent system method is to bound any postulated transient condition and assure required starting voltages. To accomplish this, voltage is fixed at the safety division measurement point prior to the start of any motor start sequence (sequenced loading or block loading). This represents the voltage seen at the safety division at the moment of a motor start sequence, regardless of the upstream voltage response. Utilizing the existing methodology and loading for each NPGS, the constant voltage source was adjusted and a motor starting analysis was performed until the most limiting component received sufficient starting voltage (terminal voltage). This method provides the base minimum voltage required at the DVR to support starting equipment limits. This method cannot predict the required voltage at the DVR prior to the motor start sequence, it can only determine voltage adequacy during the sequence.

Key assumptions of Method 1 include:

1. The non-Class 1E system will maintain the voltage throughout the sequence (i.e., infinite source capacity).

2. Nominal load sequencing times are used, as applicable.

Method 2, dependent system, determines the DVR setpoint minimum voltage by accounting for the effects of the non-Class 1E system (e.g. non-Class 1E distribution elements, offsite power grid, etc.) and non-Class 1E load change (addition or removal). The intent of the dependent system method is to present the least conservative transient condition (using operable grid capacity) which would assure required motor starting voltages, given that this method is dependent on upstream conditions. Other upstream conditions (e.g., degraded grid capacity, negative operation of system voltage compensating equipment, spurious operation of any non-Class 1E component) would produce an even higher analytical limit. Utilizing the existing methodology and loading for each NPGS, the Transmission voltage source was adjusted and a motor starting analysis was performed until the most limiting component received sufficient starting voltage (terminal voltage). To accomplish this, the transmission system voltage was adjusted until the voltage at the DVR (prior to the motor starting sequence) was at the analytical limit. This method attempts to predict the minimum required voltage prior to the design basis event.

Key assumptions of Method 2 include:

1. Automatic On-Load Tap Changers did not actuate during the event (i.e. were locked in place).

2. The non-Class 1E systems were modeled per NPGS current analytical basis. Examples may include: the non-class 1E load shed schemes, bus transfers, load application, and all balance of plant automatic functions (including unit trip delay).

3. Typical transmission system impedance was not degraded below the operable impedance for the offsite transmission system. (Note: This is a non-conservative assumption with respect to capacity, since operable transmission system impedance doesn't represent a degraded grid.)

Utilizing the existing methodology and loading of each NPGS, the transmission system voltage source was adjusted and a motor starting analysis was performed until the most limiting component, down to the 480V MCC, received sufficient starting voltage (terminal voltage). Once sufficient starting voltage was achieved, the corresponding pre-event switchyard voltage was recorded. Once the analytical limits were established for each method, the required DVR settings were determined using tolerances and minimum ranges (between dropout and reset) applicable to the existing hardware for each NPGS. The resulting DVR dropout and reset settings for each NPGS are included in the results section for comparison to existing DVR settings.

Results

Impact on DVR Setpoints
Method 1 (Independent System)

Plant	NPGS 1	NPGS 2	NPGS 3	NPGS 4	NPGS 5	NPGS 6
ECCS Loading Type	Load Sequence	Block Start	Block Start	Block Start w/ Bus Xfer	Load Sequence	Load Sequence w/ Bus Xfer
DVR Dropout [1] (minimum)	91.4%	92.8%	91.9%	91.7%	88.7%	91.0%
DVR Reset [2] (maximum)	94.7%	95.0%	96.6%	94.2%	91.5%	93.6%
DVR Dropout [1] (minimum)	92.4%	93.8%	92.3%	91.7%	89.7%	91.7%
DVR Reset [2] (maximum)	95.7%	96.0%	97.0%	94.2%	92.5%	94.2%
DVR Setpoint [3] Change (+/-)	+1.0%	+1.0%	+0.4%	0.0%	+1.0%	+0.7%

Notes:
1) The DVR setpoint analytical limit that produces required voltage to all required loads. Actual DVR setpoint (dropout) will be slightly higher to account for tolerances.
2) The maximum DVR reset value, including tolerances.
3) The change in existing DVR dropout setpoint required to satisfy these criteria.

The independent system method shows an increase of the existing DVR setpoint from, 0.4% to 1.0% for five of the units while one plant showed no increase. Some of these NPGS may be successful in demonstrating reset of the relay, required for GDC-17 conformance (as historically interpreted); however, others may not have margin in the "Offsite/Station Electrical Power System Design Calculations" as discussed in the RIS. As a minimum, five of the NPGS would require licensing amendments to change the Technical Specifications, unless a more refined analysis can demonstrate lower motor starting voltage.

Impact on DVR Setpoints
Method 2 (Dependent System)

Plant	NPGS 1	NPGS 2	NPGS 3	NPGS 4	NPGS 5	NPGS 6
ECCS Loading Type	Load Sequence	Block Start	Block Start	Block Start w/ Bus Xfer	Load Sequence	Load Sequence w/ Bus Xfer
DVR Dropout [1] (minimum)	91.4%	92.8%	91.9%	91.7%	88.7%	91.0%
DVR Reset [2] (maximum)	94.7%	95.0%	96.6%	94.2%	91.5%	93.6%
DVR Dropout [1] (minimum)	98.7%	101.3%	102.5%	96.7%	92.7%	99.8%
DVR Reset [2] (maximum)	101.8%	103.9%	107.8%	101.4	95.5%	102.4%
DVR Setpoint [3] Change (+/-)	+7.3%	+8.5%	+10.6%	+5.0%	+4.0%	+8.8%
Switchyard [4] Voltage	104.0%	108.9%	104.9%	103.9%	104.8%	112.2%

Notes:
1) The DVR setpoint analytical limit that produces required voltage to all required loads. Actual DVR setpoint (dropout) will be slightly higher to account for tolerances.
2) The maximum DVR reset value, including tolerances.
3) The change in existing DVR dropout setpoint required to satisfy these criteria.
4) The switchyard voltage required to produce new DVR Reset (maximum).

All six NPGS show significant setpoint impact under the dependent system method (4 to 10.6% increases). All would require a minimum switchyard voltage greater than currently predicted by the transmission system provider and, in two cases, greater than the maximum voltage typically allowed by a transmission system (105%). The "Offsite/Station Electrical Power System Design Calculations" would not show acceptable results. Setpoints raised to these values would require operating the plant distribution at higher voltage than presently allowed by operating procedures. As an example under light loading conditions, there would be a significant concern of overvoltage conditions. This could result in overexcitation in motors and transformers in addition to other potential concerns such as circuit breaker interrupting ratings as well as bus withstand (close and latch).

Conclusion

A review of the results demonstrates that setting the DVR on the basis of providing motor starting protection will likely result in increased DVR setpoints. Either method is shown to potentially raise the DVR analytical limit, forcing an increase in the dropout setting and therefore the reset setting. This will reduce if not eliminate the margin between required switchyard operating voltage and anticipated post-accident voltage, increasing the probability of a LOOP from DVR timeout.

In the case of Method 2, the results demonstrate a significantly higher DVR setting will be required along with potential elimination of switchyard operating voltage margin. Operating in such a manner would be unreliable and would not reflect actual system conditions expected during a response to a design basis event. The resulting minimum switchyard voltages required for DVR reset are unrealistic if not unattainable and would be counter to Transmission Operator criteria.

Although each evaluated methodology is purported to demonstrate that DVRs would provide protection against all eventualities regarding the voltage response of the non-Class 1E electrical system, it fails to do so. To the contrary, each method makes many assumptions about the non-Class 1E system voltage response in an attempt to quantify the magnitude of voltage dip on the Class 1E system during motor starting. Making these assumptions violates the intended purpose of the DVR to provide a Class 1E protective function against all conditions.

Resetting DVRs in an attempt to provide perceived motor starting protection has no practical benefit and would have significant negative consequences for the following reasons:

- Increased DVR settings would significantly increase the probability of spurious LOOP and delayed LOOP with double sequencing effects as discussed in NRC GSI-171.

- Increased DVR settings would reduce or eliminate switchyard voltage operating bands for NPGS. If based on Method 2, this may result in a minimum switchyard voltage so high that it would result in overvoltages to plant equipment during light loading conditions.

- Since the DVRs provide no protective function while they are timing out, their voltage setting is not a factor in the voltages to which the plant equipment may be exposed during that period and increasing their voltage setpoint would have no benefit during this period.

- Each evaluated methodology analyzes a scenario that would be incredible at most plants (significant voltage degradation at the same instant as an accident signal) and fails to consider the credible scenario of a voltage change later into the event when the main generator trips.

- NRC GSI-171 concluded that a LOCA with delayed LOOP was an improbable event. Raising the DVR setpoint will negate this conclusion, leading to greater possibility of a delayed LOOP with double sequencing effects.

A more realistic scenario is to set the DVR to protect accident mitigating equipment from damage during steady state conditions (not motor starting), which is the current licensing basis for most plants. NPGS typically use the DVR maximum reset voltage value or “minimum anticipated voltage” as described in IEEE Std 741, as an ending condition following automatic load sequencing or block loading of safety related loads and establish an initial switchyard voltage to avoid DVR actuation. This ensures the grid provides sufficient capacity for starting required loads and for resetting the DVR; thus, ensuring continuity of a qualified offsite power source.

Setting the DVR dropout to protect accident mitigating equipment from damage during steady state conditions will avoid the risk of early offsite power separation associated with higher DVR settings based solely upon motor starting voltage demands.