The impact of seismically-induced relay chatter on nuclear plant risk

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1 INTRODUCTION

During an earthquake, relay chatter could impact the availability of components required to maintain the reactor in a safe shutdown condition. Additionally, chatter of relay contacts could lead to unusual equipment operating configurations as well as unusual, inconsistent, and erroneous indications on control panels--all of which could confuse plant operators, interfering with their ability to restore stable plant conditions.

For relay seismic qualification, fragility level has been defined in IEEE (1984) as the level of acceleration at a particular frequency that the relay can withstand and not have its contacts change state more than 2 milliseconds. This definition has been carried over without change into seismic probabilistic risk assessment (PRA), where relays have been assigned the lowest fragility values of any in-plant, seismically qualified equipment [Pickard, Lowe and Garrick, Inc., et al. (1981)]. Although most PRAs have assumed that equipment malfunction due to relay chatter will be fully recovered, Lambert (1984) and others have expressed concern that recovery of some circuits may require difficult diagnosis and that operator performance may be severely degraded by high stress levels following the earthquake. In response to these concerns, the Pacific Gas and Electric Company (PGandE) decided to analyze the contribution to risk from relay chatter in the ongoing Diablo Canyon PRA.

In the past few years, increasing knowledge in the geoscience field has broadened understanding that earthquake ground motion beyond design levels may be more likely than previously believed. Therefore the U.S. Nuclear Regulatory Commission, Budnitz (1985) and Prassinos (1986), and the Electric Power Research Institute (EPRI) have initiated studies to examine the seismic margin at nuclear plants; i.e., the ability of plants to withstand earthquakes somewhat higher than the design levels. Not surprisingly, concern here is also focusing on relay chatter. Given the thousands of relay contacts throughout the plant, even a small chance of chatter per relay might mean a significant chance for damage to the plant. Also the vast number of relays raises concern that analysis will be intractable.

This paper describes a systematic scheme for analyzing the impact of relay chatter that is amenable to both PRA analysis and seismic margins analysis. It uses knowledge of the systems engineering of the plant to bound the scope of the problem to a tractable size and has been applied

to both the Diablo Canyon PRA and the EPRI seismic margins program trial evaluation at the Catawba Nuclear Power Plant. It has also been coordinated with similar EPRI-sponsored work on relay functionality for the Seismic Qualification Utility Group.

2 METHODOLOGY

The approach outlined herein is one of setting up successive screens to remove as many components from detailed analysis as possible and then to examine all the remaining circuits in great detail to

- Determine the consequences, if any, of contact chatter.
- If contact chatter is a problem, determine how the operator can diagnose the problem.
- Given that the problem is diagnosed, determine the means available for the operator to correct the problem.

The analysis includes not only relay contacts, but also the following control devices:

- Control Switches (nonrotary)
- Pressure Switches
- Temperature Switches
- Flow Switches
- Circuit Breaker Auxiliary Contacts
- Contractor Auxiliary Contacts
- Overload Relay Trip Contacts

Our first step is to screen out unnecessary equipment and contacts not susceptible to chatter. Depending on the type of analysis (e.g., seismic margins or PRA), many components in the plant can be removed from consideration. This step, requiring detailed knowledge of plant design and safety system response, reduces the scope of the analysis from tens of thousands of components to, at most, several hundred.

The following is a sample compilation of classes of equipment that have been eliminated from further consideration by application of the screening criteria. Validity of these screening criteria must be verified for any particular plant to be analyzed.

- Circuit Breakers and Contactors. Circuit breakers, manual transfer switches, and contactor main contacts are designed to withstand the magnetic forces resulting from very high (short circuit) currents. Because of the large forces generated during these short circuit conditions, these contacts are not considered to be susceptible to chatter. Auxiliary contacts, however, are not designed to withstand the short circuit conditions and are therefore considered susceptible to chatter.
- Solenoid Valves. In safety applications, solenoid valves vent air from some other operator, thereby causing it to function. Since chatter of these valves would result in the safety function being accomplished, this chatter was not considered in these analyses.
- Transformer Cooling. Forced air (fan) cooling is required to extend large transformer ratings beyond the self-cooled (natural oil circulation) ratings. During plant shutdown conditions, transformer loads are normally within its self-cooled ratings. Therefore, forced air cooling fan control circuits are not considered in these analyses. In the worst case, exceeding the transformer's self-cooled rating without fans would not disable the transformer. The only consequence would be a slight reduction in transformer life.

- Reversing Starters. Closure of both sets of main contactors simultaneously would cause severe damage to the motor and its control circuits. However, safety-related motor starters are usually designed with a mechanical and electrical interlock which permits closure of both main contact sets simultaneously. Therefore, chatter in the control circuits of these starters is not considered.
- Timing Relays. Assuming a chatter duty cycle of 25%, most timing relays will be deenergized for sufficient time to reset the timing mechanism. Therefore, timing relays with settings greater than 1 second are not affected by chatter of upstream relays. However, this does not preclude the timing relay's contacts from chattering in response to the seismic input.
- Rotary Relays and Control Switches. Certain relays such as the Potter-Brumfield MDR, the Westinghouse W-2 control switch, and most lockout relays, have a rotary actuator. This type of actuator is immune to contact chatter because vertical or horizontal seismic motion cannot cause the contacts to rotate. However, the analyst must be aware that components inside disk-type relay packages may be subject to chatter; e.g., protective relays generally contain both rotary relays and armature-type, instantaneous action relays.

After screening is complete, the system piping, instrument, and electrical schematics are reviewed for the selected systems and major components to identify support systems and components that are required to function. Based on the component list, the appropriate electrical schematics are selected. The latest drawing revision in the key electrical drawings must be used. The schematics are reviewed to determine the initial component state and the state required to accomplish reactor shutdown or other safety functions. Where the components have multiple "safe" positions, the analysis considers all required states.

The contact paths are identified that cause the component to assume a undesirable position, prevent operation on demand, or cause degraded safety function. For example, if a valve is required to close to perform its safety function, only the "open" contact path will be evaluated. The relay models and types for the contacts to be evaluated are determined. Contacts not subject to chatter, such as rotary or disk-type relays, remain in their initial position. All other contacts are assumed to move to the position that causes the component to move to the nonsafe condition.

If the contact chatter results in the component reaching a nonsafe position, the circuit is analyzed to determine whether the condition is intermittent (i.e., the component returns to the initial state after the earthquake) or latched; i.e., requires automatic or operator intervention. If the component remains in an undesirable condition after the earthquake, the simplest means for reset is determined. Reset may be performed automatically (i.e., solid state protection system) or by operator intervention; i.e., resetting lockout or protective relays. The reset method and location are identified.

3 APPLICATION TO PRA AND SEISMIC MARGINS ANALYSES

The differences in relay chatter analysis to support PRA and that to support seismic margins analysis relate to screening procedures and to what further steps are required following the relay circuit analysis. In PRA, all earthquake levels are considered, higher accelerations are just less likely. The frequency of occurrence of each acceleration is

combined with the chance of chatter for all susceptible equipment in the PRA systems analysis at that level to determine the frequency of relay chatter problems. Then, human recovery scenarios are analyzed to calculate the likelihood of core damage.

For the Diablo Canyon PRA, the screening process and the relay circuit analysis were completed in early 1987. The results are most encouraging. The number of circuits to be analyzed was restricted to well under one thousand--a great deal of work, but not out of line with other work in the PRA. Although a substantial number of circuits would need to be reset for the associated equipment to operate, all of these can be reset simply, using normal reset operations. No difficult diagnoses or clever actions to reset circuits would be needed. These results are plant specific, and we must caution against drawing generic conclusions. Many special features of the PGandE electrical design and qualification program have minimized the chance for difficult circuit lock-up conditions. These include utility modifications to relay circuits and special attention to minimizing the chances for sneak circuit effects.

Seismic margins analyses, following the developing EPRI approach, are a much simpler process. The goal has been to develop a procedure that can be implemented by utilities with minimal outside assistance, as described by NTS, et al. (1987). For seismic margins work, because we are interested only in determining if the plant can survive the seismic margin earthquake (SME), only one success path need be analyzed. That means that we do not need to look at all plant equipment; we do not need to look at all safety equipment; we do not even need to look at all equipment relevant to risk as modeled in a PRA. Rather, a logic (block) diagram is constructed describing possible paths (of successfully operating systems) that will successfully bring the plant to stable, shutdown conditions and maintain it that way. Then, we need to show that at least one path will survive the earthquake.

Furthermore, because we restrict the earthquake ground motion to a specific SME, more screens can be applied than is possible in the PRA analysis. Figure 1 shows the screening steps in the seismic margins relay chatter analysis. Note that, during walkdowns, seismic structural mechanics analysts may screen or add components based on observations indicating special strength or weakness of specific components, mountings, or structures.

Application of the methodology to the Catawba plant is still in progress. Nevertheless, some general observations are appropriate. Only about 150 circuits were analyzed and that number would have been much smaller if the seismic screening had been accomplished first, as shown in Figure 1. In performing seismic margins evaluations, tradeoffs between system screening and seismic screening will always need to be done to maximize the efficiency of the overall effort. For Catawba, no problems in verifying a success path were encountered. However, the selection of a success path is very plant specific. Catawba has more shake table qualification data on relay cabinets and other equipment than other plants may have. If such data is not available at a particular plant, alternate means of success path selection can be used.

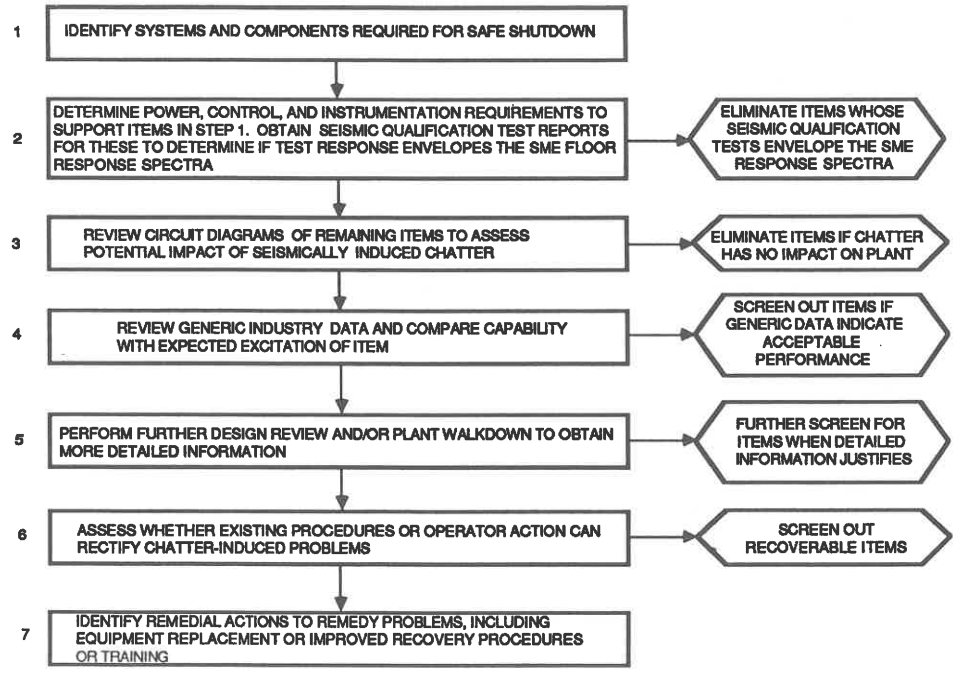

Figure 1. Steps in the assessment of the potential effects of electrical relay in seismic margins analyses.

4 RESEARCH NEEDS

If we consider the operational characteristics of relay circuits and the circuits they drive, it becomes clear that the fragility work available for relay chatter is generally very conservative. Hardy (1987) has found that experience with relays in severe earthquakes supports this contention.

The problem is that the 2-millisecond contact time on which fragility assessment is based is so short that, in most cases, it can have no effect on the circuits of interest. For example, even the fastest relays require more than 4 milliseconds to pick up their contacts (it takes time for the magnetic field to build up and more time to actually move the mechanism driving the contacts); most take much longer. Furthermore, in most control circuits, several additional relays or contactors must operate before the pump, valve, etc., of concern begins to be affected. All this requires even longer contact time. Finally, unless the actuation circuit is sealed in, the device of real interest requires hundreds of milliseconds or even seconds to operate. For example, a valve motor operator must take up any mechanical gear lash, then overcome inertia and any starting torque to even begin movement; to effectively open, it must move off its seat, but to close, it must travel through its entire motion.

Research is needed to determine the required contact time to actuate the various kinds of circuits in nuclear plants. Although analysis could address this issue, simple experiments are more appropriate because of the complexity of the causes of the various time delays. Research will then be needed to evaluate the fragility of contacts for

those varying times of contact duration. Extracting fragilities from experience data may be possible, with suitable accounting for the uncertainty in such a process.

5 SUMMARY AND CONCLUSIONS

Analysis of the impact of relay chatter is feasible and useful. Application to PRA analysis can lead to a better understanding of risk and the impact of relay chatter on operator performance. Application seismic margins analysis can be quite economical compared to PRA and answers the more restricted question: can the plant successfully withstand the SME. Both applications are plant specific, require solid knowledge of plant systems, systems interactions, and response to transients and accidents.

Development of fragility information for critical circuit operation as opposed to a 2-millisecond contact time for individual contacts could go a long way to alleviate concerns about the impact of relay chatter, probably putting it to rest on a generic basis for most types of relay circuits.

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