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MEMORANDUM FOR: Thomas Murley, Director
Office of Nuclear Reactor Regulation

FROM: Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 159: "NUCLEAR PLANT AGING RESEARCH: SAFETY-RELATED INVERTERS"

The purpose of this memorandum is to transmit the results of aging research performed on safety-related inverters. This research was performed by Brookhaven National Laboratory (BNL), under the Nuclear Plant Aging Research (NPAR) program. This research evaluated 12 years of operating experience data, nuclear plant maintenance practices, and plant design information to determine the impact of inverter aging on safety and the methods that should be employed by nuclear power plants to detect aging degradation and mitigate its effects. The research also included testing of a naturally aged inverter.

The results of this research are reported in full in NUREG/CR-5051, "Detecting and Mitigating Battery Charger and Inverter Aging." The NUREG discusses the cost-effective methods for detecting and mitigating inverter aging and provides maintenance program guidelines for achieving a high degree of reliability necessary for this important safety-related equipment. The program encompasses four areas: inspection, testing, predictive maintenance, and corrective maintenance.

Recommendations are made regarding vital bus configurations and personnel training and procedures. Specifically, the NUREG recommends addition of an automatic transfer switch for those plants susceptible to plant transients due to an inverter failure. Procedures should exist to provide maintenance guidance and to alert plant operators to the expected plant response resulting from an inverter failure.

Background

A typical nuclear power plant design requires at least two inverters to supply power to instrumentation, controls, and other safety-related equipment vital to power and safe shutdown operation. During power operation, the inverter is generally supplied by the dc bus (battery charger) and provides power to important 120 volt ac loads. These loads are both safety- and non-safety-related and include such items as emergency core cooling instrumentation and logic, feedwater controls, reactor protection system, annunciators, and emergency diesel generator auxiliaries.

Despite recent equipment improvements, failures have continued to occur due to malfunction or age-related degradation of components such as capacitors, fuses, semiconductors, and magnetic devices. Because of the effects on safety systems with inverter performance, it is necessary to detect degradation prior to catastrophic failure.

To determine how inverter aging effects can be detected and mitigated, several activities were conducted. Sources of information included manufacturers of equipment, utilities, suppliers of components, technical reports, text books, and testing. These activities are briefly described below:

1. Data review: The LER and NPRDS data from 1974 to 1986 were reviewed and analyzed to determine the operating experience of inverters.

2. Testing: Inverters obtained from the Shippingport facility were tested at BNL to evaluate their naturally aged condition, to determine the effectiveness of condition monitoring techniques, and to obtain insight into the practicality of these methods.

3. Current maintenance practices: A survey was conducted of commercial nuclear power plants to obtain information related to inverter performance. Corrective and preventive maintenance practices were evaluated for their ability to detect aging and their effectiveness in mitigating aging effects.

4. Vendor-recommended maintenance: The manufacturers of inverters outline the basic maintenance required to maintain equipment reliability. This input is necessary when evaluating the effectiveness of storage, maintenance, or replacement practices.

5. Advanced technologies and techniques: The design, operation, and monitoring of inverters in computer and military applications were reviewed to determine the feasibility of applying advances made in these areas to the electrical distribution systems in nuclear power plants.

The operating experience data have demonstrated that inverter failures can impact plant safety and availability. One of the most visible and dramatic effects of an inverter failure is reactor trip. In the nine years from 1976 to 1984, 42 reactor trips were cited from inverter failures in the LER data base. From 1984 to 1986, 57 reactor trips resulted from an inverter failure. As illustrated in Fig. 1, in addition to 57 reactor trips (44 of which occurred during power operation), containment isolations, safety injection (SI) actuations, and safety system (HPCI & RCIC) inoperability directly resulted from inverter failures.

Each reactor trip has the potential for impacting safety because of the additional equipment and operator actions generally needed to bring the plant to a safe and controlled condition. The plant effects associated with inverter failures can challenge safety systems, place the plant in an abnormal transient condition, and hinder operator response by providing misleading information or limited control capabilities.

This research supports a recent AEOD case study report (C605), which concluded that a high percentage of inverter failures were due to hardware failures. In addition, the analysis performed by BNL on operating data accumulated over the last 12 years indicates that electrical transfers, overheating, and personnel errors are the three leading causes of inverter failures (Fig. 2). In many cases, the stresses resulting from these occurrences result in an accelerated aging of critical components. This is also supportive of the conclusions reached by AEOD based on a more limited data evaluation.

Discussion

One of the goals of the aging research work associated with inverters was to identify methods of inspection, surveillance, and monitoring that will ensure timely detection of aging effects prior to the loss of safety function. For inverters, several viable methods were found for detecting degradation, including inspection, temperature monitoring, and component parameter measurements.

The inspection of an inverter by experienced personnel can provide a great deal of information about the equipment's overall condition. Observation of meter oscillation, cyclical electrical hum, or cooling fan noise while the inverter is operating can indicate an impending failure. The monitoring of circuit voltage and current waveforms using standard nuclear power plant test instruments also yields pertinent information regarding the inverter's operational readiness. Similarly, a careful inspection of the inverter while it is de-energized can detect component degradation due to overheating and loose electrical and mechanical connections. Signs of capacitor pressurization, such as the presence of electrolyte fluid or bulging of the casing itself, also can be observed during inspection.

Overheating is an important cause of stress that can result in failure of the inverter. In particular, the expected life of electrolytic capacitors, magnetic devices, and semiconductors such as silicon controlled rectifiers (SCRs) are directly affected by temperature. Therefore, it is prudent to monitor them periodically to detect any temperature increase. The use of forced air cooling should be considered to reduce the stress on components due to high temperature.

The testing of a naturally aged inverter indicated that monitoring its temperature can be an effective technique. The installation of thermocouples on component surfaces and inside the panel offers insight into component operation. For example, SCR heat transfer degradation can be detected by monitoring its case temperature, and electrolytic capacitor degradation, as reflected by the increase in internal resistance, may be indicated by an increase in the temperature of its casing.

Component performance data may change with time and can indicate degradation that will eventually lead to an inverter failure. Two parameters associated with electrolytic capacitors are recommended for detecting aging degradation, equivalent series resistance (ESR) and capacitance value.

The second research goal as reported in NUREG/CR-5051 was the evaluation of the effectiveness of storage, maintenance, repair, and replacement practices in mitigating the effects of aging. To mitigate inverter aging effects, maintenance must be performed periodically to refurbish and replace those components that exhibit aging. In addition to discrete components such as capacitors, transformers, and semiconductors, the integrity of other entities such as cable connectors, wiring, and structural fasteners also must be maintained to ensure proper performance of the equipment under normal operating and postulated accident conditions.

The type of maintenance recommended for mitigating inverter aging can be categorized under four headings: cleaning, component replacement, test/check, and calibration.

1. Cleaning: Overheating is a contributor to degradation of the inverter's components. Cleaning can minimize the risk of overheating, and it is commonly performed by utilities but with different levels of detail. The cleaning, especially of SCR heat sinks and ventilation flow paths, improves heat transfer away from temperature-sensitive components.

2. Component Replacement: Equipment qualification (EQ) requirements for component replacements should be incorporated into the preventive maintenance program to maintain the qualifications for inverters. The vendor maintenance recommendations should also be considered.

3. Tests/Checks: A number of inverter tests and circuitry checks can be performed to ensure the operational readiness of equipment. A survey of nuclear utilities indicated that testing and circuitry checks are conducted on a limited basis only, as summarized in Table 1.

   The limited amount of periodic testing performed on inverters indicates that here lies the greatest potential for enhancing inverter preventive maintenance to detect and mitigate aging effects. The benefit of conducting several of these tests is described in NUREG/CR-5051.

4. Calibration: External metering of the inverter typically consists of indicators that monitor the output voltage, current, and frequency. Internally, relays may be provided for sensing high voltage, high temperature, or other abnormal conditions. These devices should be calibrated periodically to mitigate the effects of "setpoint drift."

Current maintenance practices at nuclear power plants were evaluated to assess the utilities' programs for addressing inverter aging. The fact that inverter maintenance activities are specified at all of the plants responding to the survey indicates that utilities are cognizant of the inverter's importance to safety and availability. However, the wide range in the type of maintenance performed could reflect inadequacies at some plants.

Table 1: Types of Inverter Testing Conducted
(Survey of 23 Nuclear Power Plants)

Test/Check Activity	# of Plants
Cable Megger Test	1
Load Capacity Test	1
Static Transfer Switch Check	2
Output Electrical Parameter Check	3
Circuitry Waveform Check	2
Component Check (Fuses, Diodes)	2
Check Annunciators/Status Lights	1

Regulatory Applications

The results of this research are being reflected in IEEE Std 650, "Qualifications of Class 1E Static Battery Chargers and Inverters for Nuclear Plant Generating Stations," and other appropriate IEEE guidelines.

The "Maintenance Rule" now under consideration by NRC, is expected to incorporate the research results in appropriate regulatory guides.

Recommendations and Conclusions

A review of the operating experience data indicated that component (electrolytic capacitors, fuses, inductors, and silicon-controlled rectifiers) failures were responsible for a high number of inverter failures, and that overheating, electrical transients, and personnel errors were the dominant failure causes.

Based on research conducted, including testing of a naturally-aged inverter and evaluation of nuclear power plant maintenance practices, it is recommended that a comprehensive maintenance program be established for safety-related inverters. To detect and mitigate the effects of aging on inverters, this program should encompass four areas: inspection, testing, predictive maintenance, and corrective maintenance. Guidelines for each of these areas are provided in the NUREG. These guidelines are a means of counteracting degradation mechanisms that will increase inverter failure rates as plants age.

While emphasis has been placed on maintenance practices for mitigating plant aging, the potential improvement in vital bus reliability through the use of an automatic transfer switch should not be overlooked. The automatic transfer switch reduces the impact of inverter degradation by sensing the failure and switching the vital bus to an alternate electrical source without interrupting power to safety-related instrumentation, controls, and equipment. Other recommended design improvements discussed in the NUREG include the use of equipment for detecting and suppressing electrical bus transients regularly experienced in power plants, the use of higher voltage and temperature-related components in the inverter circuitry, and the addition of forced air cooling to reduce the overheating problems that have been experienced.

With personnel-induced stresses accounting for approximately 15% of the inverter failures, it is recommended that training be provided and procedures established for the operation and maintenance of this complex electric equipment.

Eric S. Beckjord, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Figures 1 and 2
2. List of References

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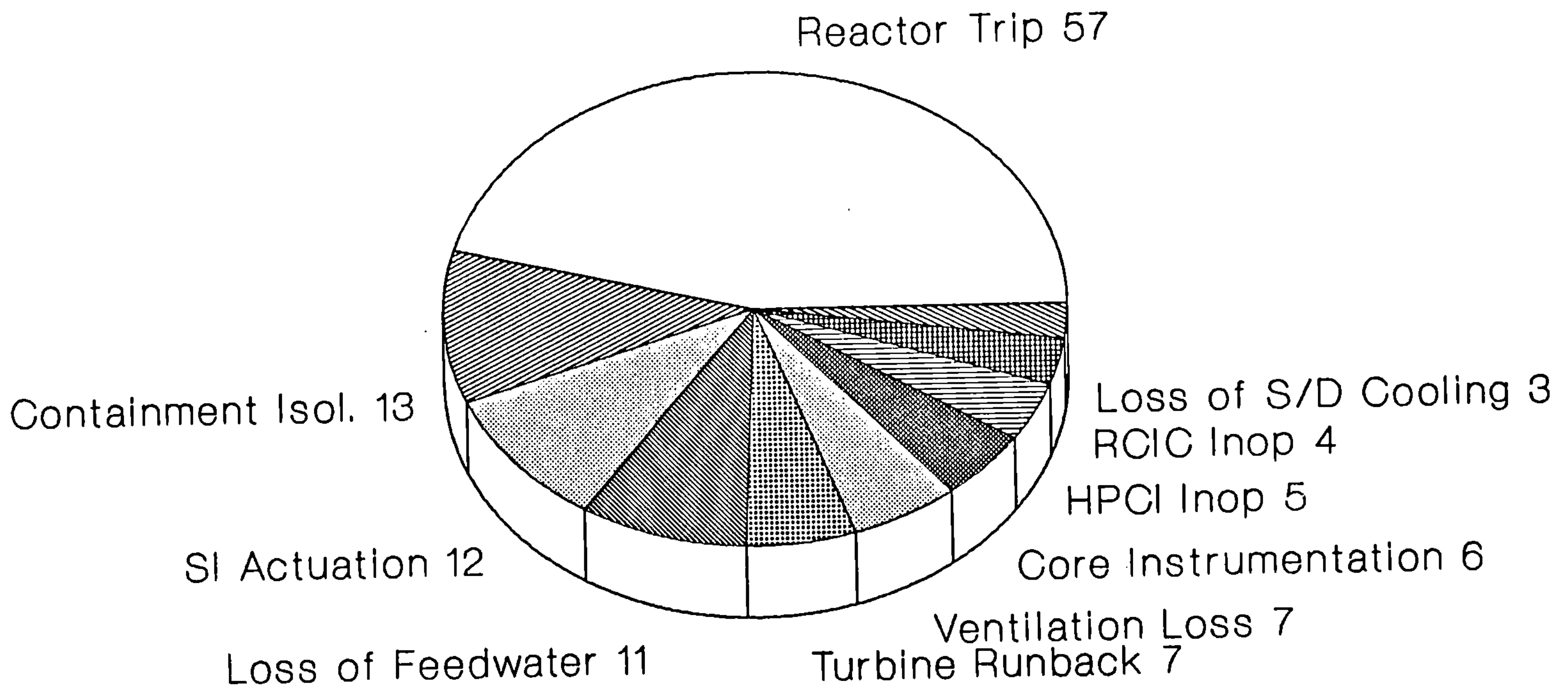
REFERENCES

1. USNRC, AEOD Case Study Report C605, "Operational Experience Involving Losses of Electrical Inverters," December 1986.

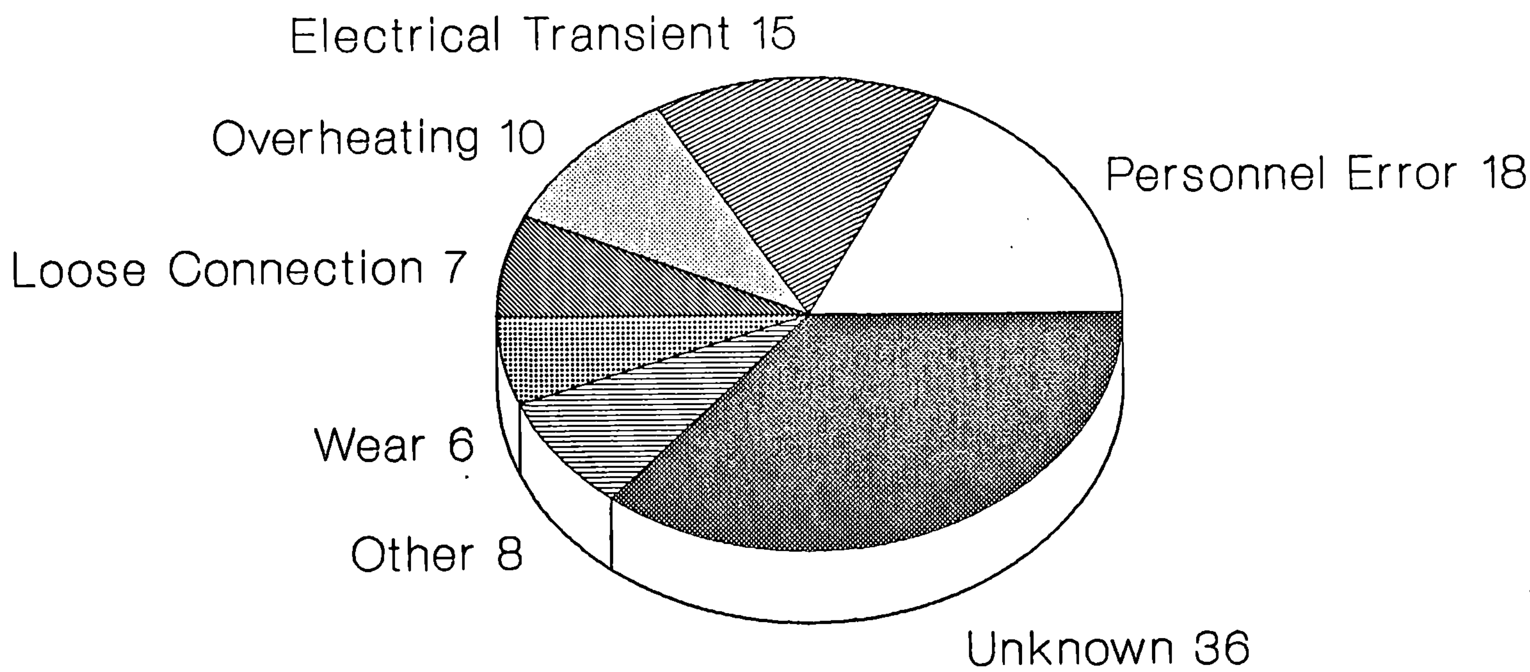
2. W. GUNTHER et al., "Operating Experience and Aging-Seismic Assessment of Battery Chargers and Inverters," NUREG/CR-4564, June 1986.

3. W. GUNTHER et al., "Detecting and Mitigating Battery Charger and Inverter Aging," NUREG/CR-5051, September 1988.



Number of Events

FIGURE 1



Percent of Failures

FIGURE 2