Technical Review of Justification for Eliminating Concerns of Multiple High Impedance Faults (MHIF) in Post Fire Safe Shutdown Analysis (PFSSA)

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1. Introduction

This study describes a review of the justification for eliminating the problem of multiple high impedance faults (MHIF) considered in post-fire safe shutdown analysis (PFSSA), which is part of a deterministic fire protection program in nuclear power plants (NPPs) [1].

The PFSSA evaluates the impact of a postulated fire event in each fire area on the safe shutdown function, to implement the defense-in-depth concept used in NPP fire protection [2]. In PFSSA, required safe shutdown cables are selected via detailed circuit analysis, which are essential for safe shutdown equipment to perform their shutdown functions [1]. The most important task in PFSSA is to ensure that the safe shutdown cables of the redundant train are properly separated by electrical raceway fire barrier system (ERFBS) or fire walls to meet 10 CFR 50 Appendix R [3].

In most operating NPPs, redundant trains of safety-related cables are electrically physically well separated in accordance with the latest electrical redundant separation requirements. However, in many NPPs, safe shutdown equipment is powered by a common power supply source that also supplies power to non-safe shutdown equipment.

A concern with common power associated circuits is the loss of a safe shutdown power source due to improper breaker or fuse coordination. A fire induced cable failure may occur in a non-safe shutdown load circuit powered by the safe shutdown power supply source. In this situation, if the coordination between the upstream feeding breakers and load breakers of the safe shutdown power supply is insufficient, the safe shutdown bus may be lost due to a fire induced fault in the non-safe shutdown circuit. As a result, the safe shutdown equipment cannot perform their safe shutdown functions due to the loss of power [2].

Previous analysis experiences showed in some NPPs, upstream feeding and downstream load circuit breakers for protection of safety and non-safety circuits connected to a common power supply source were not electrically coordinated well. This issue has been resolved in terms of common power source in the associated circuit analysis [2].

The U.S. Nuclear Safety Regulatory Commission (US NRC) pointed out that multiple high impedance faults (MHIF) can occur as a potential example of common power source associated circuit of concern [1]. However, NUREG-6850 addresses that the likelihood of MHIF occurrence is very low [4]. The MHIF did not need to be considered in the fire probabilistic risk assessment (PRA) [4].

In addition, Section 5.3.3 of staff regulatory guidance in NRC RG 1.189 (Revision.4), a deterministic fire protection regulatory guideline, addresses concerns about the MHIF [2]. The NRC RG 1.189 highlights the consensus of the expert panel for Phenomena Identification and Ranking Table (PIRT) of NUREG/CR-7150 [5]. If a potential MHIF phenomenon is assessed and certain criteria are met, MHIF no longer needs to be considered in the PFSSA. For this reason, licensees may use the guidance in Appendix B.1 of NEI 00-01 as a basis for removing the MHIF analysis from the PFSSA [1]. This study aimed to review in detail NEI 00-01 Appendix B.1, and to clarify the technical basis and reasons to determine if the MHIF analysis should be included in the PFSSA or removed.

2. Reviews and Results

2.1 Multiple High Impedance Faults (MHIF)

In a certain circuit failure mode, fire induced several hot shorts can be assumed to produce abnormally high currents below the trip point of individual overcurrent interrupting devices. This type of fault was defined as high impedance faults (HIFs) in Generic Letter 86-10. In addition, question and response about whether the HIFs should be considered in the circuit coordination studies or removed were addressed in Generic Letter 86-10 [6]. Under the assumed conditions, the circuit's overcurrent protective device does not detect or interrupt abnormal current flow. As a result, the fault current is assumed to continue indefinitely for a long time. In this condition, the HIFs will not be cleared quickly by the protective device. Thus, simultaneous HIFs should be considered in associated circuit analysis [6]. The cumulative fault current resulting from multiple simultaneous HIFs can exceed the trip point of the safe shutdown power supply incoming to the protective device. This can cause the safe shutdown power supply to be activated or de-energized before downstream load-side protection devices can correct the individual circuit fault [6].

Fig. 1 depicts the concept of MHIF [1]. In Fig.1, safe shutdown equipment A-1 and B-1, like A-2 and B-2, are equipment of redundant trains. Here, let's assume that a fire breaks out in fire area B. Due to the fire, safe shutdown equipment B-1 and B-2 are considered inoperable. However, even if a fire occurs in fire area B, safe shutdown equipment A-1 and A-2 can be used for safe shutdown because they are isolated by a 3-hour fire barrier. Circuit breakers 4 through 7 can provide power to non-safe shutdown equipment located in fire area B by circuits that traverse fire area B. However, let us assume here that a fire causes multiple, simultaneous high-impedance faults in several electrical circuits. At this time, the fault characteristic is that abnormal current is generated in each circuit, but in each case, the current is not sufficient to trip the affected branch feeder breakers 4 through 7. Due to the cumulative effect of the fault current flowing in each branch, circuit breaker 1, the incoming supply breaker, trips first, before downstream breakers 4 to 7 can isolate individual faults on each branch. When this happens, the power to the safe shutdown power supply is cut off, causing power loss to safe shutdown equipment A-1 and A-2. Therefore, neither the safe shutdown equipment A-1 and A-2 nor B-1 and B-2 can be used for safe shutdown.

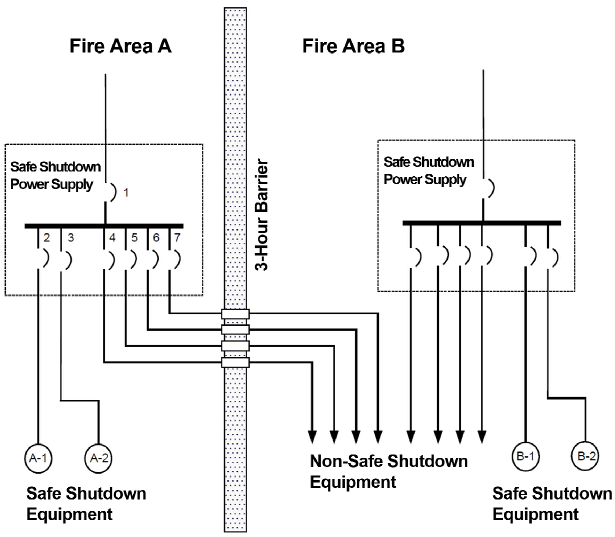

Fig. 1. A typical example of multiple high impedance faults (MHIFs) sequence, redrawn from Figure B.1-1 of NEI 00-01 (Rev.4) [1].

2.2 Review of NEI 00-01 Appendix B.1

NEI 00-01 Appendix B.1 summarizes the analysis and characterization of the behavior of fire-induced cable failures in relation to MHIF concerns [1]. NEI 00-01 Appendix B.1 explains what risks circuit failure modes causing MHIF pose to PFSSA and under what conditions these risks can occur. To ensure the capability of the PFSSA, a general analysis of a base case set of conditions related to the MHIF is needed. This analysis can be referred to as MHIF analysis. The base case approach can determine the applicability of MHIF to PFSSA and select specific boundary conditions. This base case approach is recognized as a viable means of maintaining the integrity of the MHIF.

However, because Kapton cables were excluded from the scope of NEI 00-01 Appendix B.1, plants using Kapton cables must consider MHIF in the PFSSA [1].

Table 1 shows the list of contents of NEI 00-01 (Rev.4) Appendix B.1 [1]. In each subsection, a considerable level of detailed analysis was performed. Through this analysis, it can be determined whether MHIF should be considered for PFSSA or should be removed.

Table I: A list of sub-section titles Appendix B.1 of NEI 00-01 (Rev.4) [1]

Section	Title
B.1-1	PURPOSE
B.1-2	INTRODUCTION
B.1-2.1	Overview
B.1-2.2	Defining the MHIF Concern
B.1-2.3	Framework for Resolution
B.1-3	ANALYSIS METHOD AND APPROACH
B.1-4	ANALYSIS CRITERIA AND PRINCIPLES
B.1-5	BASE CASE AND APPLICABILITY
B.1-6	CHARACTERIZATION OF FAULTS
B.1-6.1	Characterization of Fire-Induced Cable Faults for 120V Systems
B.1-6.1.1	EPRI/NEI Fire Test Results
B.1-6.1.1.2	Fault Clearing Times
B.1-6.1.1.3	Assessment of Probability
B.1-6.1.1.4	Uncertainty Analysis
B.1-6.1.1.5	Leakage Current for Non-Failures
B.1-6.1.2	NRC /SNL Fire Test Results
B.1-6.2	Characterization of Arcing Faults
B.1-6.2.1	Fire as an Initiator of Arcing Faults
B.1-6.2.3	Arc Voltage Drop and Wave-shape
B.1-6.2.4	Arc Fault Current
B.1-6.2.5	Arc Energy
B.1-7	ANALYSIS OF MHIFS
B.1-7.1	Medium Voltage Systems (2.3 kV and Above)
B.1-7.2	480 V – 600 V Low Voltage Systems
B.1-7.3	120 V and 208 V Systems
B.1-7.4	125 V and 250 V DC Systems
B.1-7.5	Failure Consequence Analysis
B.1-7.5.1	Loss of Safe Shutdown Power Supply
B.1-8	CONCLUSIONS

2.3 Process of MHIF analysis

Fig. 2 shows the MHIF analysis flow chart recommended in NEI 00-01 Appendix B.1 [1]. Step 1 is the step of establishing analysis standards and principles. Identify analysis criteria and relevant engineering principles. Describe the basis for the analysis criteria and document the engineering principles used to evaluate the results. In step 2, a set of conditions for the base case is defined. These conditions may set limits to the possibilities for the application of the analysis. Step 3 characterizes cable faults due to fire. By analyzing industry fire test data and engineering studies related to MHIF, cable faults that can cause fires are characterized. Step 4 analyzes MHIF's concerns. In the MHIF analysis, the characteristic behavior of cable failure due to fire is considered within the context of the concerns. At this stage, it is determined whether the MHIF poses a credible risk in the PFSSA for the defined base case condition and under what conditions it occurs. The evaluation includes uncertainty analysis.

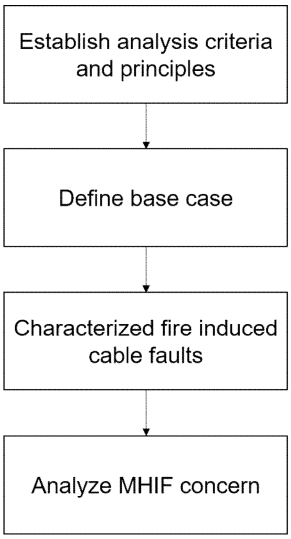

Fig. 2. Multiple high impedance faults (MHIFs) analysis flow chart, redrawn Figure B.1-2 from [1].

3. Conclusions

In nuclear power plants with deterministic fire protection programs, MHIF is a possible scenario and should be considered in the PFSSA. However, if certain criteria are met, it does not need to be considered in PFSSA. To support this, the licensee must ensure that the nuclear units under analysis meet the guidelines and requirements outlined in NEI 00-01 Appendix B.1. If the nuclear power plant being analyzed does not meet the requirements, the licensee must consider MHIF in the PFSSA. In particular, Kapton cables were not endorsed in NEI 00-01 Appendix B.1. Therefore, nuclear power plants using Kapton cables may require additional analysis of MHIF.

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