Addressing Uncertainty in Fire Modeling of MCC Fire in a Switchgear Room

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1. Introduction

Detail analysis of fire areas is a key element of performance-based fire protection programs for operating nuclear power plants and is performed to find out the fire area vulnerability including target elements.

NFPA 805 requires fire modeling and uncertainty analysis to develop the fire scenario in nuclear power plants [1]. Uncertainty analysis provides assurance that the performance criteria have been met in the fire protection program and produces a probability distribution for target failure time..

Sample calculations using FDS5 are performed to predict the potential damage to the cables within trays for the Motor Control Center (MCC) fire scenario in a switchgear room. This study is to demonstrate that the combination of FDS5 model and the limited number of fire scenario with Latin Hypercube Sampling (LHS) techniques leads to a practical approach to meet NFPA 805 requirements.

2. FDS5 simulation of Switchgear Room Fire

FDS5 is the most widely used computer code to simulate a compartment fire. FDS5 simulates the computational regime with a numerical form of the Navier-Stokes equations, which are appropriate for the low speed and thermally-driven buoyant flow with an emphasis on smoke and heat transport from a fire [2]. LES turbulent model is used in combination with the Smagorinsky sub grid model.

Total volume of compartment is 17.1x8.5x9.0 (m^3) and the geometry of compartment is nodalized with cell number of 80x40x45 with each cell size of 0.2 m. Fig 1 shows the FDS5 modeling results of switchgear room with the significant elevation change between “high” and “low” ceilings.

Three cable trays filled with cross-linked polyethylene (XLPE) cables are located near the ceilings as shown in Fig. 1.

2.1 Fire Scenario

A fire is assumed to start within a motor control center cabinet with a maximum value of 702 kW in 12 min and remains steady for 8 additional minutes for a cabinet with more than one cable bundle of qualified cable. After 20 min, heat release rate (HRR) is assumed to reduce linearly to zero in 12 min. HRR per unit area is calculated as a 3900 kW/m^2 using the thermal properties in Table 1.

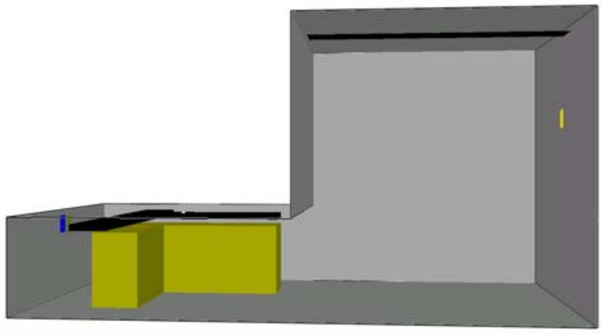

Fig. 1. FDS5 modeling of a switchgear room

The air vent dimensions are 0.6 m wide and 0.3 m long. The cabinet is 2.4 m tall. The fire is assumed to burn within the interior of the cabinet, and the smoke, heat, and possibly flames are assumed to exhaust from the air vent at the top of the cabinet.

The cables within trays are modeled as 1.5 cm cylinders with uniform thermal properties given Table 1.

Table 2 shows the sensitive variables selected in this study according to the uncertainty and sensitivity study on PRISME pool fire experiment [3].

MOSAIQUE [4] is used to performe a set of 60 LHS sample calculations including the base case run by varying the sensitive variables according to their uncertainty distribution in Table 2. 60 sample calculations represent the 95% probability with 95% confidence limit [5].

Table 1. Material Properties of a Switchgear Room

Material	Thermal Conductivity, (W/m/K)	Density, (kg/m^3)	Specific Heat, (kJ/kg/K)	Reference
Concrete	1.6	2400	0.75	NUREG-1805
Steel	54	7850	0.465	NUREG-1805
XLPE Cables	0.235	0.235	1.39	NUREG/CR-6850

Table 2. Sensitive variables in this study

Variables	Mean Values	Uncertainty distribution	Reference
HRR	702 kW	Uniform	NUREG-1934
Emissivity	0.95	Uniform	NUREG-1934
Air flow rate	0.735 m^3/s	Uniform	NUREG-1934

2.2 Target Damage Criteria

This study is focused on a target consisting of cables in tray and considers damage of target due to thermal impact only. XLPE cables are assumed to be damaged when the cable temperature reaches 320℃ or the exposure heat flux reaches 11 kW/m^2 [6].

A FDS V&V effort concluded that FDS can reliably predict heat flux and surface temperature within about 25% [7]. Thus, the lower bound failure criteria used in this study are 240℃ and 8.25 kW/m^2.

2.3 Sample Calculation Results

Fig. 2 shows the cable temperatures in each trays for the base case calculation using mean values. Cable temperatures in tray A and B are well above the damage criteria and cable temperatures in tray C are below the damage criteria. It means cables in tray A and B are like to be damaged.

With 60 sample calculation, average time of cable damage is 205 second for the cables within tray A and 769 second for the cables within tray B.

Fig. 3 and Fig. 4 show the probability histogram of the cable failure time based on the damage criterion for the cables within tray A and tray B respectively. The probability histograms show that the majority of cable failures occur in the 190 to 210 second for tray A and the 700 to 800 second for tray B.

3. Conclusions

The case study of a switchgear room fire using FDS5 is performed to address uncertainty in detail fire modeling. This study demonstrates the applicability that addresses uncertainty to satisfy NFPA 805 requirement

The method in this study is useful to demonstrate that the combination of fire modeling code and the limited number of fire scenario with LHS techniques leads to a practical approach for detail fire modeling required by NFPA 805.

Acknowledgement

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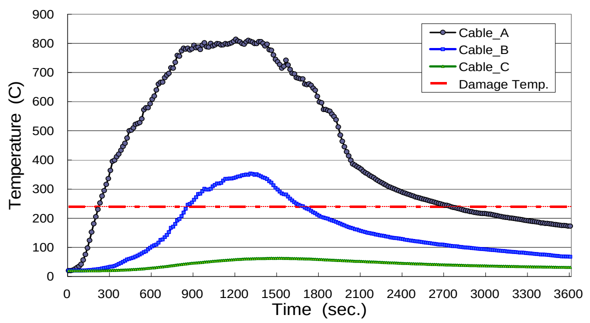

Fig. 2. Cable Temperatures in the Tray

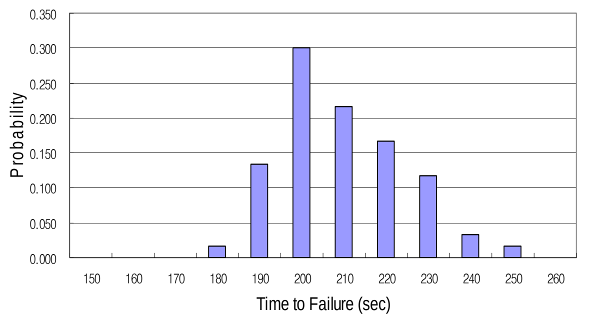

Fig. 3. Failure Probability of Cables in Tray A based on Damage Criterion (240C)

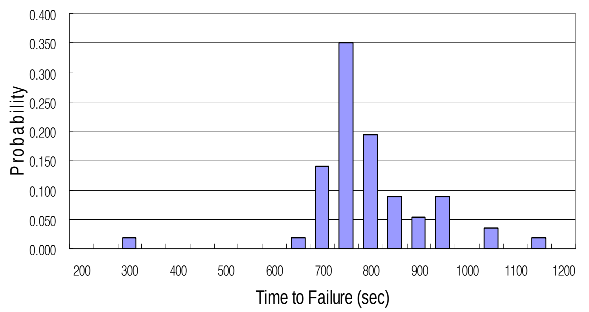

Fig. 4. Failure Probability of Cables in Tray B based on Damage Criterion (240C)

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