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Enhanced Understanding of High Energy Arcing Fault Phenomena in NPPs

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1. Introduction

High Energy Arcing Fault (HEAF) can occur in an electrical components or systems through an arc path to ground and has the potential to cause extensive damage to the equipment involved. The intense radiant heat produced by the arc can cause significant damage or even destructions of equipment and can injure people.

HEAF leads to the rapid release of significant electrical energy in the form of heat, vaporized copper, and mechanical force through the air which can act as an ignition source to other adjacent components. This phenomena has been underestimated in the past [1].

Affected components include a specific high-energy electrical devices, such as switchgears, load centers, bus bars/ducts, transformers, cables, etc., operating mainly on voltage levels of more than 380V [2] but the voltage levels in NUREG/CR-6580 is more than 440V [3].

This study reviews the recent HEAF events in nuclear power plants (NPPs) and investigates the HEAF phenomena with the experiment data performed at KEMA supported by OECD/NEA HEAF project.

2. Recent Events of HEAF

2.1 H.B Robinson NPPs, USA

On Mar. 28, 2010, H.B. Robinson NPP located near Hartsville, South Carolina had been experienced a HEAF event that involved fires in electrical equipment, a reactor trip and subsequent safety injection actuation, and an alert emergency declaration. During this event, two separate fires occurred approximately four hours apart.

The first fire was caused by a fault on a 4.16kV feeder cable between bus 4 and bus 5 led to an arc flash which caused internal damage to the unit auxiliary transformer and a subsequent fire within the conduit.

The second HEAF and fire occurred due to inappropriate recovery actions. Approximately four hours after the first fire, operators attempted to reset the generator lockout relay per plant procedures without first ensuring the cause of the lockout was cleared. This re-energized a bus damaged by the first fire and caused another electrical fault and fire, which resulted in significant damage to plant equipment.

Both HEAF events caused physical damage to the electrical components and associated cabinets, along with damaging materials in the near vicinity. In the first event, cables located in conduits exiting the top of a cabinet shorted together and damaged the conduit and potentially damaged electrical cables located in cable trays directly above the damaged conduit as shown in Figure 1.

A detailed evaluation in this event is described in the NRC augmented inspection report [4].

Figure 1. Damaged Electrical Cabinet and Conduits

2.2 Onagawa-1 NPP, Japan

On Mar. 11, 2011, the successive fire incident due to HEAF occurred in the electrical cabinet in which the overhang type high voltage breakers were used. The remarkable thermal and structural damage to the cables and equipment of the adjacent cabinets were recognized due to the release of the hot gas propagation and high inner pressure.

Fire took place due to short circuit inside MC 6-1A and subsequently spread to 10 other switch gear systems via power cable ducts. As a result, a pump in the residual heat removal system was inoperative for a short period. Fire could not be suppressed and was allowed to burn out almost 7 hours and electrical cabinets involved were heavily damaged and mostly burned as shown in Figure 2.

In 2012, Nuclear Regulation Authority (NRA) in Japan started HEAF tests at KEMA in USA to understand the HEAF phenomena involved, to develop models for damage prediction, to set zone of influence and to develop regulatory guides for fire hazard analysis for HEAF. Preliminary test results suggested an energy of 25 MJ was required for causing the arcing fire [5].

Figure 2. Damaged cabinets by HEAF incident

3. HEAF Experiments

3.1 Overview of Test Plan

The objective of OECD/NEA HEAF project is to perform the experiments to obtain scientific fire data on the HEAF phenomenon known to occur in NPPs through carefully designed experiments.

The blast effects including pressures, temperatures, and heat flux created within the equipment are important to understand the initial HEAF impact as well as the potential for equipment failure. Understanding the heat exposure effects is relevant to determining the zone of influence. Quantifying influenced zone from a HEAF is important when analyzing the arc effects on secondary combustible materials [6].

Under the agreement of OECD/NEA HEAF project, Korean consortium provided the four equipment to be tested such as class “M” metal-clad medium voltage air break switchgear (GEC_480V), type DS metal-enclosed low voltage power circuit breaker switchgear (DS 416 W 480V), class E7 & E8 high voltage air breaker switchgear (GEC_6.9kV), and porcel-line type DHP magnetic air circuit breaker (W 6.9kV).

HEAF test with above equipment had been conducted at KEMA in Chalfont, Pennsylvania, on June 2014 organized by USNRC. The test instruments are twelve slug calorimeters placed around the exterior of the equipment, two pressure sensors placed to measure the interior pressure of the equipment, and oxygen consumption calorimetry hood in place above the equipment that is intended to collect the products of combustion and exhaust the hot gases outside, since the arc may start a secondary fire that propagates in the cables and other combustibles in the cabinet.

A slug calorimeter determines heat flux by measuring the rate at which a slug of material heats up while subjected to a heat source. Slug calorimeters are used for calibration of arc-jet test conditions [7]. For arc-jet applications the slug is usually made of oxygen-free high conductivity (OFHC) copper. Figure 3 shows a typical assembly drawing of an arc-jet slug calorimeter [8].

The location of the slug calorimeters and the configuration of the calorimetry hood are shown in Figures 4 and Figure 5, respectively [9].

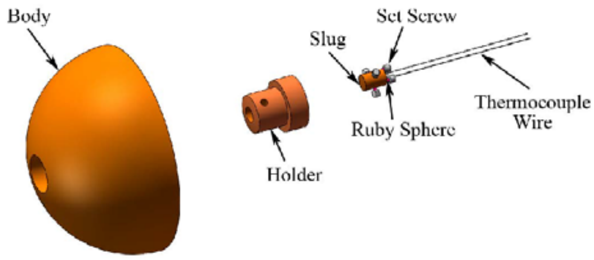

Figure 3. Typical assembly drawing for hemispherical slug calorimeter

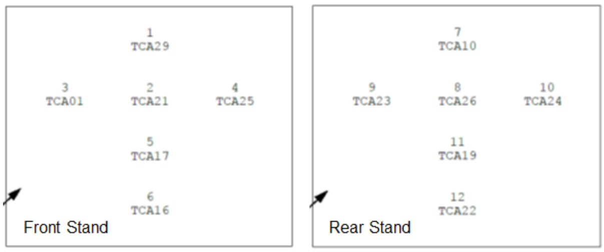

Figure 4. Slug Calorimeter Location

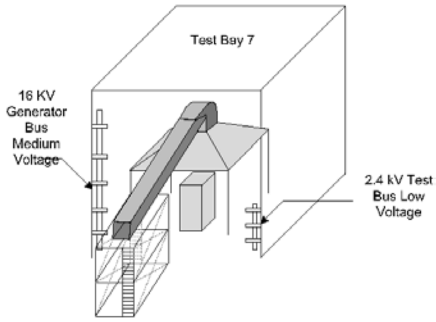

Figure 5. Hood Assembly in Test Bay 7

3.2 Draft Test Results

KEMA-Powertest, LLC provided the draft test results [9]. The test configuration is shown in Figure 5 and the test parameters are voltage, power level, damage zone, heat release rate, event duration.

The equipment subjected in the HEAF tests are two low voltage switchgear, i.e. Class “M” metal-clad air breaker switchgear (GEC_480V), and type DS metal-enclosed low voltage power circuit breaker switchgear (DS 416 W 480V). Reference standard used for the tests is IEEE C37.20.7-2007/2010 [10].

Total twelve tests were conducted; seven tests with the GEC_480V and five tests with DS 416 W 480V. Table 1 shows the slug calorimeter data obtained from one of the twelve tests.

Temperature rises in Table 1 do not indicated to characterize the HEAF phenomena enough to cause substantial damage to the equipment. The slug calorimeter used in the test is not familiar in general and there is no detail descriptions of slug calorimeter on draft test report. It is expected that a detail information of slug calorimeter and test data to show the HEAF characteristics will be given in the final test reports.

Date: 2014-6-17
Time: 9:30 AM
DAS Operator: Robert Probst

Data Channel	Avg Start Temperature (°C)	Maximum Temperature (°C)	Temperature Rise (K)	Maximum Heat Energy (cal/cm^2)	Time to Maximum Heat (s)
1	36.1	41.7	5.6	0.74	7.0
2	40.1	43.0	2.9	0.39	4.8
3	39.2	43.6	4.4	0.58	4.7
4	38.2	42.4	4.2	0.55	4.1
5	39.7	43.7	4.0	0.53	6.7
6	39.1	41.0	1.9	0.25	4.6
7	27.3	28.3	1.0	0.13	29.3
8	27.6	28.6	1.0	0.13	23.8
9	27.2	28.1	0.9	0.12	24.6
10	27.6	28.3	0.7	0.09	28.1
11	27.1	28.0	0.9	0.12	27.5
12	27.3	28.2	0.9	0.12	24.8

Remarks: Maximum Temperature, Maximum Heat Energy and Time to Maximum Heat are based on data from 30 seconds after test event.

Table 1. Calorimeter data

4. Conclusions and Further Study

As stated before, HEAF may cause the significant damage to adjacent facilities as well as the equipment involved. Quantitative estimation of the equipment damage, determining the damage area, and predicting the secondary fire after initiating HEAF event should be further studied in depth.

Draft test report produced by KEMA does not give comprehensive understanding of the HEAF phenomena. It is expected that a detail information of slug calorimeter and the test data to show the HEAF characteristics will be given in the final test reports. Analysis of test data and evaluation of slug calorimeter should be carried out to enhance the understanding of HEAF phenomena.

Acknowledgement

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