High Energy Arcing Fault Operating Experience Panel Discussion

October 20, 2021

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

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High Energy Arcing Faults and Their Significance for in Nuclear Installations – An International Perspective

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High Energy Arcing Faults (HEAF) - Public Workshop with NEI, EPRI, and Industry

October 20, 2021

Introduction and Background

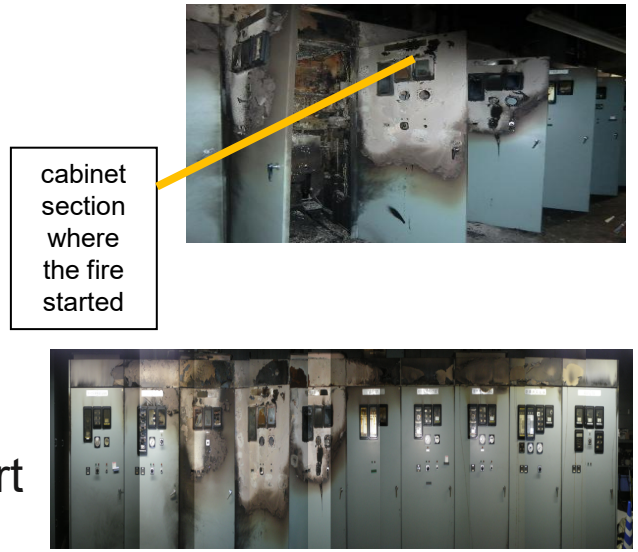
- HEAF events in nuclear installations were first observed to be significant in the early 2000s
  - Maanshan (Taiwan) event at 4.16 kV breaker in 2001
  - Onagawa (Japan) in two non-emergency switchgear cabinets in 2011
- First international investigations started in 2007/08 driven by Canada, France, Germany and the U.S.
  - OECD/NEA CSNI Task Report on HEAF OPEX and phenomena
  - German HEAF OPEX report in 2012
  - OECD/NEA FIRE Topical No. 1 on HEAF indicating a non-negligible number of fire events induced by HEAF in most FIRE member countries
- International OECD/NEA Experimental Research Project “HEAF” led by NRC as Operating Agent (meanwhile in Phase 2)

Maanshan HEAF Fire Event

- Event combination of sea fog salt deposit induced loss of offsite power (LOOP) with consequential HEAF at a feeder breaker (17 to 4160 V) essential bus A and ensuing fire
- Event sequence and consequences
  - Longer lasting (> 20 h) LOOP with the plant powered from 161 kV source not affected by salt deposits
  - During transfer of the reactor unit ck to preferred 345 kV source a HEAF with fire occurred in the feeder breaker, indicated open prior to the fault but providing voltage to breaker input side when 345 kV start-up transformer was energized
  - Propagation of HEAF and ensuing fire caused collateral damage to other switchgear compartments
  - Switchgear fire was extinguished by automatic CO_2 extinguishing system, offsite fire brigade was called as backup
  - Both of the two safety trains of the safety unavailable for > 2 h

Onagawa Seismically Induced HEAF Fire Event

- NPP under full power before the seismic event occurred
- Cause of the event combination:
  - Suspended breaker inside the high-voltage power distribution panel swinging widely due to the seismic vibration damaging disconnecting parts of the pertinent breaker
- Fire sequence and consequences
  - Fire detected by optical detector, although onsite fire brigade could first not identify fire location due to heavy smoke
  - Actuation of fixed CO_2 extinguishing system for some rooms after turbine building evacuation
  - External public fire brigade called could not support onsite resources because of blocked access ways
  - Fire duration of nearly 8 h, one safety train lost
  - All 10 cubicles completely damaged by fire, left 3rd one mostly damaged because high energy gas in the section where the fire started could propagate to other sections; aluminum involved (bus duct)



source: OECD/NEA FIRE Database

International Insights from HEAF OPEX (1)

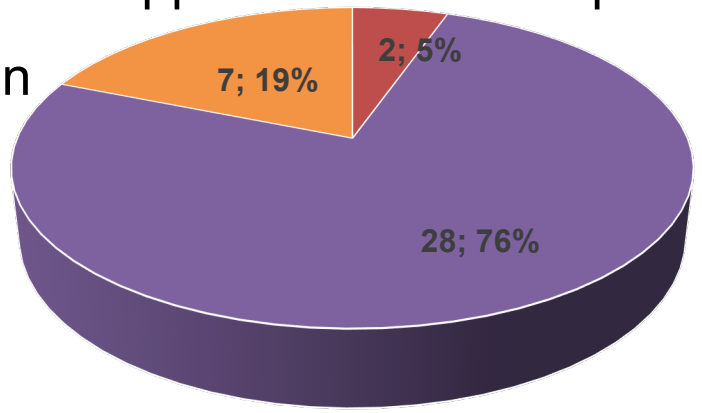
- FIRE Database is a collection of fire events in NPPs of 14 countries from Asia, Europe and North America
- Database covers up to end-2019 more than 550 fire events representative for 9.726,81 ry OPEX
  - 534 of these events not excluded from statistics
  - 340 during power operation, 153 during low power and shutdown modes, the rest during decommissioning or construction phases
- Non-negligible number of **65 HEAF induced fires** representing **~ 12 %**
  - More than one third of the events were safety significant
    - 12 HEAF fire events internationally reported to IRS
    - 7 HEAF fire events internationally reported to INES
  - > 30 % of the HEAF fire events occurred in FSSA rooms
  - HEAF fires occurred nearly in all FIRE member countries, highest numbers in the US, Germany, France and Sweden

International Insights from HEAF OPEX (2)

- OPEX indicates significance of HEAF as important phenomenon for causing ensuing fires at the component where the HEAF occurred, but also as event combination with other events
- 65 out of HEAF induced fire events (occurrence frequency ~ 6.7 E-03 /ry)
  - 37 of the HEAF induced fires are event combinations
  - Non-negligible contribution of HEAF induced fires to the overall fire risk, even if a nuclear reactor unit had stopped commercial operation

➢ HEAF needs to be considered in design and operation of nuclear installations

  - Some national and international standards and guidance take HEAF and HEAF induced fires already into account (e.g. German KTA standards)



fire and consequential HEAF	2.0 E-04 /ry
HEAF and consequential fire	2.9 E-03 /ry
event chain with fire and HEAF	7.0 E-04 /ry

Thank you for your attention

For further questions, please contact

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Aluminum High Energy Arcing Faults
OpE NRC (NRR/RES)

- Fort Calhoun, Unit 1
- Columbia
- Diablo Canyon, Unit 1
- Kewaunee, Unit 1
- Shearon Harris, Unit 1

Fort Calhoun, Unit 1, 2011

Bin 16.a | HEAF | 42* sec actual (WG designation)

- Event Description
  - Loss of power to six of nine safety-related 480 VAC electrical distribution buses, one of two safety-related 4160 VAC buses and one of two non-safety related 4160 VAC buses.
  - Significant unexpected system interactions also occurred. Specifically, conductive combustion products from the fire caused a fault across an open bus-tie breaker on an island bus; as a result a feeder breaker tripped unexpectedly resulting in loss of power to the opposite train bus.
  - The event resulted in grounds on both trains of safety-related direct current (DC) power used for breaker operation and electrical protection.
  - The maximum conditional core damage probability for the event was estimated to be 3.4 x 10-4.
- Staff Observation
  - It is unclear from the event description exactly what caused the conductive interaction or if aluminum had a role to play.
  - NRC Phase II testing has determined that air conductivity interactions should be implausible but has not ruled out surface conductivity interactions from aluminum impacts.
  - Similar cross train interactions due to heavy smoke is uncommon based on experience in the fire events database across all fire ignition bins. The AL HEAF program is investigating the possibility of conductive interactions given the OpE from events like this and from the testing observations.

Columbia, 2009

Columbia 2 | 8/5/2009 | Bin 16.1 | HEAF | est. 4-10 sec (WG designation)

- Event Description
  - The fault was located on the non-safety-related, non-segregated, 6900 VAC bus. The bus catastrophically failed, melting all three phases of conductor in the location of a flexible link. The bus bars are completely enclosed in aluminum ducts, with all three phases in the same duct (non-segregated).
  - The faulted bus section was located above the medium voltage switchgear and damage from the molten metal produced by the fault included another high voltage bus and other cables in the area of the switchgears below the initiation point
  - The explosion melted and removed approximately 1.2 m (4 ft.) of each of the three buses and 2.4 m (8 ft.) of the bus duct enclosure. Both the bus and the bus duct enclosure were made of aluminum.
  - The short destroyed the bus and the surrounding bus enclosure. The molten aluminum and copper splattered nearby switchgear cabinets but did not cause any internal damage.
- Staff Observation
  - The event vaporized 4ft of bus bar material and 8 ft. of the bus duct material. This is in excess of the current methodology developed in FAQ 07-0035 which states “Assume that molten metal material will also be ejected outwards and will spread within a sphere of 1.5-foot radius from the fault point. The fault point to be used when applying the 1.5-foot radial damage distance is the cross-sectional center of the bus duct.”
  - It is unclear what impact this event would have had on adjacent equipment. The nearest electrical enclosure was roughly 10ft below the origin point with no cable trays present.

Diablo Canyon, Unit 1, 2000

Diablo Canyon 1 | 5/15/2000 | Bin 16.1 | HEAF | est. 4-10 sec (WG Designation)

- Event Description
  - Phase-to-phase fault on the 12 kV bus in an overhead bus duct, supplied by Auxiliary Transformer.
  - The switchyard and main generator field breaker opened immediately following unit trip, however; coast down of the main generator continued to feed the arc fault. A 4 kV startup bus duct located immediately above the faulted 12 kV bus was damaged by the fault and subsequent arcing. Damage to the 4 kV bus induced a second arcing fault in the 4 kV bus duct resulting in a differential trip of Startup Transformer, 11 seconds after the initial fault.
  - 3 feet of the center 12 kV bus bar and 6–9 inches of the other two 12 kV bus bars had vaporized, several feet of the 12 kV bus duct had melted, and a one-square-foot hole was burned into the 4 kV bus duct.
  - The cause of the bus failure could not be conclusively determined due to the absence of physical evidence. The immediate cause is postulated to be a thermal failure of the bolted connection of the center conductor of the 12 kV bus.
- Staff Observation
  - This event is included in the data set which was used to create the NUREG/CR-6850 Supplement 1 ZOI methodology. The overhead bus duct was located 4 inches above the origination point of the fault and induced a secondary fault.
  - The proximity to adjacent targets or equipment was not available to determine if the NUREG/CR-6850 Supplement 1 ZOI methodology would have been challenged.

Kewaunee, Unit 1, 1987

Kewaunee | 7/10/1987 | Bin 16.1 | HEAF | est. 4-10 seconds (WG determination)

- Event Description
  - Phase-to-ground fault occurred on the flat aluminum bus bar rated at 3000 amps. The bus bar was routed from the main auxiliary transformer to three switchgear buses.
  - The root cause of the event was an insulation failure on the bus bar compounded by accumulation of particulate debris.
  - The phase-to-ground fault progressed to a phase-to-phase fault which accounted for the extensive bus damage. The event damaged a 9 meter (30 ft.) section of the bus bar from the main auxiliary transformer to buses.
  - A smaller fire occurred on a maintenance cart involving rags and rubber goods ignited by falling aluminum slag.
- Staff Observation
  - This event falls outside of the NUREG/CR-6850 Supplement 1 methodology. This event damaged 30 ft. of bus duct material and is well beyond the postulated 1.5 ft. It is unclear if other equipment was adjacent to the initiation point of this event or the impact that this event could have had on nearby equipment.

Shearon Harris, Unit 1, 2020

- Event Description
  - Ground fault occurred on the non-safety 22 kV/6.9 kV ‘B’ Unit Auxiliary Transformer (UAT) feeder to the 6.9 kV 'B' Auxiliary Bus.
  - Significant damage was found to all 3 phases of the B UAT feeder bus bar to the B Auxiliary Bus, which will not be repairable during the current forced outage. Ground fault origination appears to have occurred 5-10 feet below floor elevation from the B Auxiliary Bus where the bus bars (2 bars per phase, all enclosed in bus duct structure) make a 90 degree transition to a horizontal bus bar section that routes back to the B UAT located on the opposite side of the turbine building in the transformer yard.
  - B Auxiliary Bus was not significantly damaged beyond the incoming feeder breaker cubicle B UAT.
  - The Root cause was attributed to aging/heat degradation associated with Noryl insulation.

- Staff Observation
  - The cable tray was located ~2 feet away; cables were not damaged by the HEAF event.
  - The cables experienced insulation damage only and was attributed to molten aluminum slag falling into the cable tray.
  - Cables were still electrically functional.
  - This event included activation of a multi-cycle suppression system in the vicinity of the fault (fusible link sprinkler activation and thermal detection activation). It is currently unclear as to what role the sprinkler system played during the event or if the system extinguished an ensuing fire.