# Final Precursor Analysis

**Accident Sequence Precursor Program – Office of Nuclear Regulatory Research**

| | | |
|---|---|---|
| **Arkansas Nuclear One, Unit 2** | Fault in Unit Auxiliary Transformer Leads to Reactor Trip and Partial Loss of Offsite Power | |
| **Event Date:** 12/09/2013 | **LER:** 368/13-004<br>**IR:** 50-368/14-02 | **CCDP =** $2\times10^{-6}$ |
| **Plant Type:** Pressurized-Water Reactor (PWR) with a Dry, Ambient Pressure Containment | | |
| **Plant Operating Mode (Reactor Power Level):** Mode 1 (100 Percent Reactor Power) | | |
| **Analyst:** Michelle Kichline | **Reviewer:** Keith Tetter | **Contributors:** N/A |

## EXECUTIVE SUMMARY

On December 9, 2013, at approximately 7:47 am, an electrical fault on the Unit Auxiliary Transformer (UAT) resulted in a fire and catastrophic failure of the transformer. This caused an automatic reactor and main turbine trip, lockout of the Switchyard Auto Transformer (SAT), loss of power to Startup Transformer (SUT) 1, and a lockout of SUT 3 when voltage degraded on the non-vital 6900V buses supplied by the UAT. These conditions caused a loss of one of the two available offsite power sources for Unit 2 that resulted in an auto-start of the Unit 2 Emergency Diesel Generator B to supply Safety Bus 2A4. When the 6900V buses supplied by the UAT de-energized, loss of the main feedwater system occurred and the emergency feedwater (EFW) system automatically actuated.

The root cause of the UAT catastrophic failure was failure of its protective relays to isolate a bus fault due to improper installation of a differential current relay output wire. The root cause of the bus fault was improper installation of the 6900V Phase C flexible link bolted connection that led to insulation breakdown. The lockout of the SAT occurred due to an overcurrent protective relay initiated trip that is suspected to have been caused by a fault at the 22kV structure that supplies SUT 3. Lockout of the SAT, which supplies one source of offsite power to SUTs 1 and 3, is designed to initiate a lockout of both transformers, however only a SUT 3 lockout occurred.

According to the risk analysis modeling assumptions used in this Accident Sequence Precursor (ASP) analysis, the most likely core damage sequence is a loss of main feedwater (LOMFW) followed by failures of the EFW system and once-through cooling. This accident sequence accounts for approximately 79 percent of the conditional core damage probability (CCDP) for the event. In general, these results are consistent with at-power LOMFW events previously analyzed by the ASP Program at other PWRs. This event was determined to be a precursor with the CCDP for this event being $2\times10^{-6}$.

## EVENT DETAILS

**Event Description.** On December 9, 2013, at approximately 7:47 am, an electrical fault on the UAT buses resulted in a fire and catastrophic failure of the transformer. The UAT is the normal power supply for in-house loads for Unit 2 when the main generator is online. Loss of power to the non-vital 6900V buses supplied by the UAT caused an automatic reactor and main turbine

trip, lockout of the SAT, loss of power to SUT 1, and a lockout of SUT 3. Since SUT 3 had a lockout, the system fast-transferred one train of house loads to SUT 2. Loss of power to the other train of house loads resulted in the automatic start of the Unit 2 EDG B to supply Safety Bus 2A4.

When the 6900V buses supplied by the UAT de-energized, a loss of condenser vacuum occurred due to unavailability of the circulating water system. The EFW system automatically actuated upon loss of the normal MFW system. Additional information is provided in Licensee Event Report (LER) 368/13-004 (Reference 1) and NRC Inspection Report (IR) 50-368/14-02 (Reference 2).

**Electrical Distribution Information.** A simplified diagram of the station electrical system configuration is shown in Figure 1 below. The SAT supplies one source of offsite power to SUTs 1 and 3. When the main generator is offline, SUT 1 is the preferred offsite power source for Unit 1, while SUT 3 is the preferred offsite power source for Unit 2. SUT 2 is shared between Units 1 and 2. Unit 2 house loads are normally fast-transferred from the UAT to SUT 3 after a reactor and turbine trip.

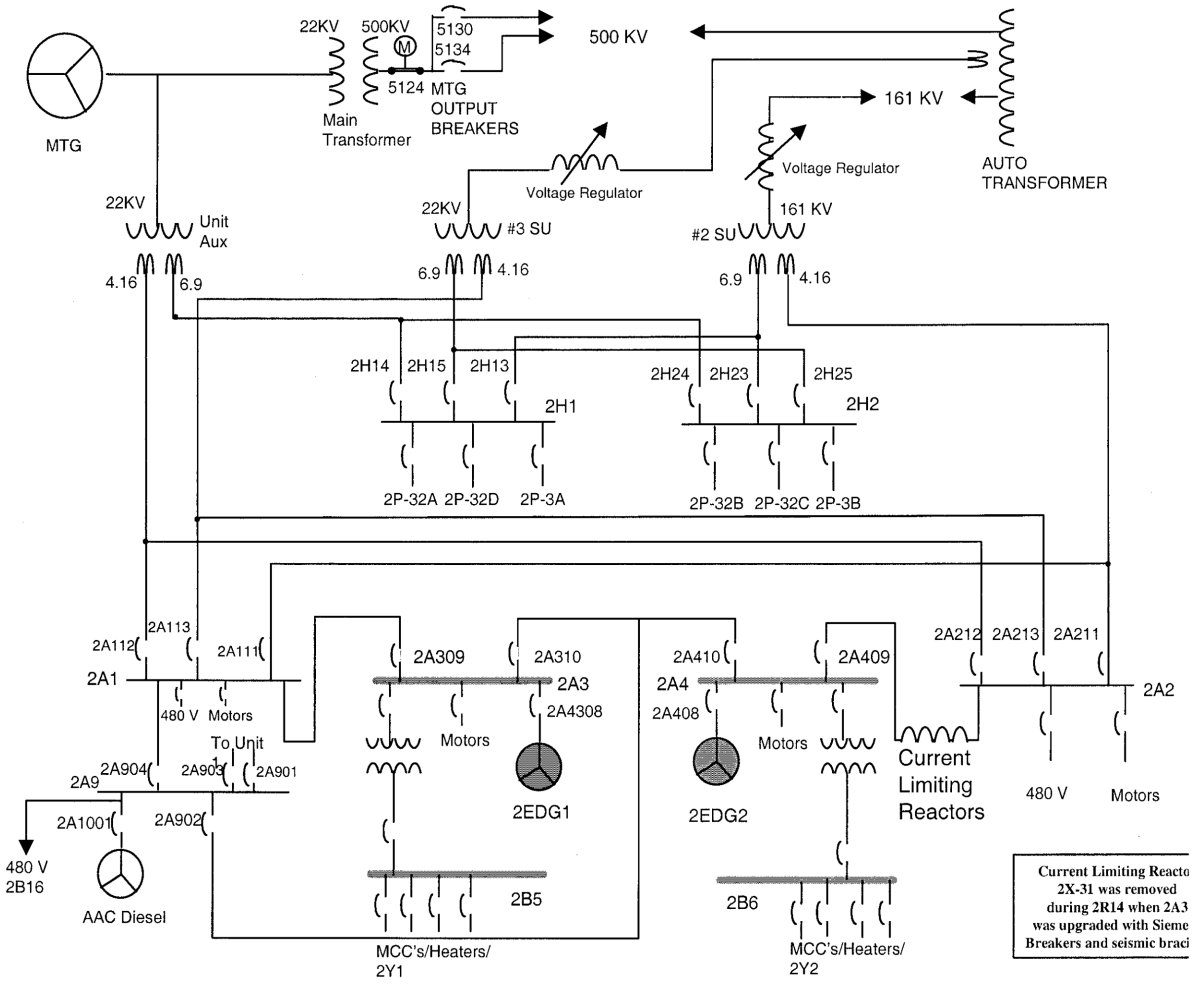


**Figure 1: Simplified Electrical System Diagram**

**Cause.** The initial fault on Phase C of the 6900V bus was due to improper construction of the flexible link bolted connection that led to insulation breakdown. The UAT failed catastrophically because the differential current relay output wire was not properly connected due to a human performance error. The differential current relay failed to operate to lockout the main generator to isolate the bus fault as designed.

Lockout of the SAT occurred due to an over-current protective relay initiated trip that was suspected to have been caused by a fault on the 22kV structure that supplies SUT 3. Lockout of the SAT is designed to initiate a lockout of both SUTs 1 and 3, however only a lockout of SUT 3 occurred. Lockout of the SAT resulted in loss of one of the two offsite power sources that are required by the units' Technical Specifications.

## MODELING ASSUMPTIONS

**Analysis Type.** The Arkansas Nuclear One Unit 2 (ANO-2) Standardized Plant Analysis Risk (SPAR) Model, Revision 8.26 created in May 2014, was used for this event analysis. This event was modeled as an LOMFW initiating event. The LOMFW initiating event was used because all MFW was unavailable due to the loss of power to the 6900kV buses and the EFW system automatically actuated during the event. Loss of condenser vacuum occurred during the event, however the loss of condenser heat sink initiating event tree for ANO-2 does not assume all MFW is unavailable. The LOMFW event tree is shown in Figure B-1 in Appendix B.

**Significance Determination Process (SDP) Results/Basis for ASP Analysis.** The inspectors reviewed this issue and two Green findings were identified, as discussed in Reference 2. One finding was for the failure to correctly install the flexible link bolted connection on Phase C of the UAT. The other finding was for the failure to correctly land the signal wire from the UAT differential current relay output contacts to the main generator lockout relay.

The SDP assesses the risk significance of individual inspection findings considering only those systems, structures, and components (SSCs) directly associated with the licensee performance deficiency. The ASP Program assesses the risk significance of operational events considering all SSC failures and unavailabilities (e.g., equipment out for test and maintenance), regardless of whether performance deficiencies were identified. The ASP Program uses SDP results for degraded conditions when possible; however, an independent ASP analysis is performed for initiating events. Therefore, an ASP analysis was performed for this initiating event.

**SPAR Model Modifications.** The Offsite Electrical Power (OEP) Fault Tree was modified to require failure of both Division A and Division B AC power in order for a subsequent loss of offsite power (LOOP) to occur. Specifically, Transfer Gates OEP-2A1 (*Failure of AC Power from SWGR 2A1*) and OEP-2A2 (*Failure of AC Power from SWGR 2A2*) were moved under a new AND gate labeled OEP-3 (*Failure of SWGRS 2A1 and 2A2*). The modified fault tree is shown in Figure B-2 in Appendix B.

Since a LOOP must occur before Buses 2A3 and 2A4 compete for the Station Blackout (SBO) diesel generator, the fault trees for Division A (*EPS-SBO-A*) and Division B (*EPS-SBO-B*) were modified. Specifically, for fault tree EPS-SBO-A, a new OR gate named NEW-EPS-SBO-HE-A was added to gate EPS-SBO-B4 (*SBO DGN unavailable to Bus 2A4 due to alignment to Bus 2A3*). House events for all of the Division B LOOP events were added to the new gate NEW-EPS-SBO-HE-A. For fault tree EPS-SBO-B, a new OR gate named NEW-EPS-SBO-HE-B was added to gate EP-SBO-A4 (*SBO DGN unavailable to Bus 2A3 due to alignment to Bus 2A4*). House events for all of the Division A LOOP events were added to the new gate, NEW-EPS-

SBO-HE-B. The modified Division A and Division B fault trees are shown in Appendix B as Figures B-3 and B-4, respectively.

**Key Modeling Assumptions.** The following modeling assumptions were determined to be significant to the modeling of this event analysis:

- The probability of an LOMFW initiating event (*IE-LOMFW*) was set to 1.0. All other initiating event probabilities were set to zero. The LOMFW initiating event was used because the loss of condenser heat sink initiating event tree for ANO-2 does not assume all MFW is unavailable.
- House events for loss of condenser vacuum (*HE-LOCONVAC*) and loss of the power conversion system (*HE-LOPCS*) were set to TRUE because the main condenser was not available during the event.
- Basic Event ACP-BAC-LP-2A2 (*Division B AC Power 4160V Bus 2A2 Fails*) was set to TRUE as a surrogate for the loss of offsite power to Bus 2A2 due to the failure of UAT and the lockout of SUT 3. Bus 2A2 did not fail during the event, but it was de-energized.
- Basic Event OEP-VCF-LP-SNGLAV (*Single Unit LOOP (Weighted Average)*) was set to TRUE and basic event OEP-VCF-LP-SITEAV (*Site LOOP Given Plant LOOP (Weighted Average, Critical Operation)*) was set to FALSE to turn off the logic corresponding to the competing effects for the SBO diesel generator between the units. Since the event being analyzed was an initiating event for Unit 2 (Unit 1 did not experience a reactor trip), the potential for a dual-unit LOOP is not considered.

## ANALYSIS RESULTS

**CCDP.** The point estimate CCDP for this event is $1.8\times10^{-6}$. The ASP acceptance threshold is a CCDP of $1\times10^{-6}$ or the CCDP equivalent of an uncomplicated reactor trip with a non-recoverable loss of secondary plant systems (e.g., feed water and condensate), whichever is greater. This CCDP equivalent for ANO-2 is $1.0\times10^{-6}$; therefore, this event is a precursor.

**Dominant Sequence.** The dominant accident sequence is LOMFW Sequence 14 (CCDP = $1.4\times10^{-6}$) which contributes approximately 79 percent of the total internal events CCDP for Unit 2. The cut sets/sequences that contribute to the top 95 percent and/or at least 1 percent of the total internal events CCDP are provided in Appendix A.

The events and important component failures in LOMFW Sequence 14 are:

- LOMFW occurs
- Reactor scram succeeds
- OEP succeeds
- EFW fails
- Once-through cooling fails

## REFERENCES

1. Arkansas Nuclear One – Unit 2, LER 368/13-004, “Fire and Explosion of the Unit Auxiliary Transformer resulted in an Automatic Reactor Scram and Initiation of the Emergency Feedwater System,” dated February 5, 2014 (ML14037A205).

2. U.S. Nuclear Regulatory Commission, “Arkansas Nuclear One - NRC Integrated Inspection Report 05000368/2014002,” dated May 9, 2014 (ML14132A255).

# Appendix A: Analysis Results

### Summary of Conditional Event Changes

| Event | Description | Cond. Value | Nominal Value |
|---|---|---|---|
| ACP-BAC-LP-2A2 | DIVISION B AC POWER 4160V BUS 2A2 FAILS | TRUE | 3.33E-5 |
| IE-LOMFW | LOSS OF MAIN FEEDWATER | 1.0[a] | 5.86E-2 |
| OEP-VCF-LP-SITEAV | SITE LOOP GIVEN PLANT LOOP (WEIGHTED AVERAGE, CRITICAL OPERATION) | FALSE | 1.45E-1 |
| OEP-VCF-LP-SNGLAV | SINGLE UNIT LOOP (WEIGHTED AVERAGE) | TRUE | 8.55E-1 |
| HE-LOCONDVAC | LOSS OF CONDENSOR VACUUM HOUSE EVENT | TRUE | FALSE |
| HE-LOPCS | LOSS OF PCS HOUSE EVENT | TRUE | FALSE |

a. All other initiating event probabilities were set to zero.

### Dominant Sequence Results

Only items contributing at least 1.0% to the total CCDP are displayed.

| Event Tree | Sequence | CCDP | % Contribution | Description |
|---|---|---|---|---|
| LOMFW | 14 | 1.38E-6 | 78.7% | /RPS, /OEP, FW, OTC |
| LOMFW | 16-10 | 1.23E-7 | 7.0% | RPS, /OEP, /RCSPRESS, FW-ATWS |
| LOMFW | 15-19 | 1.02E-7 | 5.8% | /RPS, OEP, /EPS, EFW-L, OTC-L |
| LOMFW | 16-11 | 3.99E-8 | 2.3% | RPS, /OEP, RCSPRESS |
| LOMFW | 16-09 | 3.79E-8 | 2.2% | RPS, /OEP, /RCSPRESS, /FW-ATWS, BORATION |
| LOMFW | 15-20-28-4 | 3.44E-8 | 2.0% | /RPS, OEP, EPS, EFW-B, /OPR-01H, OTC |
| Total | | 1.75E-6 | 100.0% | |

### Referenced Fault Trees

| Fault Tree | Description |
|---|---|
| BORATION | EMERGENCY BORATION |
| EFW-B | EMERGENCY FEEDWATER DURING SBO |
| EFW-L | EMERGENCY FEEDWATER DURING LOOP |
| EPS | EMERGENCY POWER |
| FW | FEEDWATER SYSTEM (MFW & EFW) |
| FW-ATWS | FEEDWATER SYSTEM - ATWS (MFW & EFW) |
| OEP | OFFSITE ELECTRICAL POWER |
| OTC | ONCE THROUGH COOLING |
| OTC-L | ONCE THROUGH COOLING DURING LOOP |
| RCSPRESS | RCS PRESSURE LIMITED |
| RPS | REACTOR PROTECTION SYSTEM |

**Cut Set Report - LOMFW 14**

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 1.38E-6 | 100 | Displaying 590 Cut Sets. (590 Original) |
| 1 | 2.50E-7 | 18.10 | IE-LOMFW,ACP-CRB-OO-2A409,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XM-ACBCH32B,EFW-XHE-XM-CNTRLD,MFW-XHE-XL-NOREC |
| 2 | 2.50E-7 | 18.10 | IE-LOMFW,ACP-CRB-OO-2A409,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XA-BCH32B,EFW-XHE-XM-CNTRLD,MFW-XHE-XL-NOREC |
| 3 | 9.45E-8 | 6.85 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XA-BCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO,MFW-XHE-XL-NOREC |
| 4 | 9.45E-8 | 6.85 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XM-ACBCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO,MFW-XHE-XL-NOREC |
| 5 | 6.00E-8 | 4.35 | IE-LOMFW,EFW-MOV-CF-CV102756,HPI-XHE-XM-FB,MFW-XHE-XL-NOREC |
| 6 | 4.66E-8 | 3.37 | IE-LOMFW,EFW-MOV-CF-CV1036789,HPI-XHE-XM-FB,MFW-XHE-XL-NOREC |
| 7 | 4.51E-8 | 3.27 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XM-ACBCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-SBO,EPS-DGN-TM-2DG2,MFW-XHE-XL-NOREC |
| 8 | 4.51E-8 | 3.27 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XA-BCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-2DG2,EPS-DGN-TM-SBO,MFW-XHE-XL-NOREC |
| 9 | 4.51E-8 | 3.27 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XA-BCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-SBO,EPS-DGN-TM-2DG2,MFW-XHE-XL-NOREC |
| 10 | 4.51E-8 | 3.27 | IE-LOMFW,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XM-ACBCH32B,EFW-XHE-XM-CNTRLD,EPS-DGN-FR-2DG2,EPS-DGN-TM-SBO,MFW-XHE-XL-NOREC |
| 11 | 3.95E-8 | 2.86 | IE-LOMFW,AFW-XHE-XM-2P75,EFW-MDP-TM-2P7B,EFW-TDP-FR-2P7A,HPI-XHE-XM-FBD |

**Cut Set Report - LOMFW 16-10**

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 1.23E-7 | 100 | Displaying 67 Cut Sets. (67 Original) |
| 1 | 3.94E-8 | 31.96 | IE-LOMFW,EFW-TDP-FR-2P7A,RPS-BME-CF-TB2OF8 |
| 2 | 3.32E-8 | 26.93 | IE-LOMFW,EFW-TDP-FR-2P7A,RPS-ROD-CF-RODS |
| 3 | 6.47E-9 | 5.25 | IE-LOMFW,EFW-TDP-FS-2P7A,RPS-BME-CF-TB2OF8 |
| 4 | 5.45E-9 | 4.43 | IE-LOMFW,EFW-TDP-FS-2P7A,RPS-ROD-CF-RODS |
| 5 | 5.31E-9 | 4.31 | IE-LOMFW,EFW-TDP-TM-2P7A,RPS-BME-CF-TB2OF8 |
| 6 | 4.47E-9 | 3.63 | IE-LOMFW,EFW-TDP-TM-2P7A,RPS-ROD-CF-RODS |
| 7 | 3.62E-9 | 2.93 | IE-LOMFW,EFW-MDP-TM-2P7B,RPS-BME-CF-TB2OF8 |
| 8 | 3.05E-9 | 2.47 | IE-LOMFW,EFW-MDP-TM-2P7B,RPS-ROD-CF-RODS |
| 9 | 1.89E-9 | 1.53 | IE-LOMFW,EFW-TDP-FR-2P7A,RPS-RYT-CF-20F4,RPS-XHE-XE-SGNL |

**Cut Set Report - LOMFW 15-19**

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 1.02E-7 | 100 | Displaying 596 Cut Sets. (596 Original) |
| 1 | 8.69E-9 | 8.51 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 2 | 6.85E-9 | 6.71 | IE-LOMFW,ACP-CRB-CC-152112,EFW-MDP-TM-2P7B,EFW-TDP-FR-2P7A,HPI-XHE-XM-FB |
| 3 | 4.15E-9 | 4.06 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-TM-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 4 | 3.92E-9 | 3.84 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB |
| 5 | 3.79E-9 | 3.71 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-SBO,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 6 | 3.79E-9 | 3.71 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT,SBO-DGN-XFER-BUS2A4 |
| 7 | 2.17E-9 | 2.12 | IE-LOMFW,ACP-CRB-CC-152112,EFW-PMP-CF-FSALL,HPI-XHE-XM-FB |
| 8 | 1.89E-9 | 1.85 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EFW-XHE-XR-2P7B,HPI-XHE-XM-FB |
| 9 | 1.87E-9 | 1.83 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-TM-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB |
| 10 | 1.81E-9 | 1.77 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-SBO,EPS-DGN-TM-2DG1,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 11 | 1.81E-9 | 1.77 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-TM-SBO,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 12 | 1.81E-9 | 1.77 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-TM-2DG2,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT,SBO-DGN-XFER-BUS2A4 |
| 13 | 1.81E-9 | 1.77 | IE-LOMFW,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG2,EPS-DGN-TM-2DG1,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT,SBO-DGN-XFER-BUS2A4 |
| 14 | 1.79E-9 | 1.75 | IE-LOMFW,ACP-CRB-CC-152112,EFW-MDP-FS-2P7B,EFW-TDP-FR-2P7A,HPI-XHE-XM-FB |
| 15 | 1.71E-9 | 1.67 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-SBO,HPI-XHE-XM-FB |
| 16 | 1.71E-9 | 1.67 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,HPI-XHE-XM-FB,SBO-DGN-XFER-BUS2A4 |
| 17 | 1.43E-9 | 1.40 | IE-LOMFW,EFW-TDP-FS-2P7A,EPS-DGN-FR-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 18 | 1.32E-9 | 1.30 | IE-LOMFW,ACP-CRB-OO-2A409,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XM-ACBCH32B,EFW-XHE-XM-CNTRLD,OEP-VCF-LP-CLOPT |
| 19 | 1.32E-9 | 1.30 | IE-LOMFW,ACP-CRB-OO-2A409,ACP-XHE-XM-B5ORB6D,DCP-BAT-FC-8HR,DCP-XHE-XA-BCH32B,EFW-XHE-XM-CNTRLD,OEP-VCF-LP-CLOPT |
| 20 | 1.17E-9 | 1.15 | IE-LOMFW,EFW-TDP-TM-2P7A,EPS-DGN-FR-2DG1,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |
| 21 | 1.13E-9 | 1.10 | IE-LOMFW,ACP-CRB-CC-152112,EFW-MDP-TM-2P7B,EFW-TDP-FS-2P7A,HPI-XHE-XM-FB |
| 22 | 1.05E-9 | 1.03 | IE-LOMFW,EFW-MDP-TM-2P7B,EFW-TDP-FR-2P7A,EPS-XHE-XM-SBOD,HPI-XHE-XM-FB,OEP-VCF-LP-CLOPT |

### Cut Set Report - LOMFW 16-11

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 3.99E-8 | 100 | Displaying 12 Cut Sets. (12 Original) |
| 1 | 1.40E-8 | 34.99 | IE-LOMFW,RCS-PHN-MODPOOR,RPS-BME-CF-TB2OF8 |
| 2 | 1.18E-8 | 29.48 | IE-LOMFW,RCS-PHN-MODPOOR,RPS-ROD-CF-RODS |
| 3 | 3.53E-9 | 8.85 | IE-LOMFW,PPR-SRV-CC-PSV4732,RPS-BME-CF-TB2OF8 |
| 4 | 3.53E-9 | 8.85 | IE-LOMFW,PPR-SRV-CC-PSV4742,RPS-BME-CF-TB2OF8 |
| 5 | 2.97E-9 | 7.45 | IE-LOMFW,PPR-SRV-CC-PSV4732,RPS-ROD-CF-RODS |
| 6 | 2.97E-9 | 7.45 | IE-LOMFW,PPR-SRV-CC-PSV4742,RPS-ROD-CF-RODS |
| 7 | 6.69E-10 | 1.68 | IE-LOMFW,RCS-PHN-MODPOOR,RPS-RYT-CF-20F4,RPS-XHE-XE-SGNL |

### Cut Set Report - LOMFW 16-09

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 3.79E-8 | 100 | Displaying 5 Cut Sets. (5 Original) |
| 1 | 1.99E-8 | 52.67 | IE-LOMFW,CVC-XHE-XM-BOR,RPS-BME-CF-TB2OF8 |
| 2 | 1.68E-8 | 44.38 | IE-LOMFW,CVC-XHE-XM-BOR,RPS-ROD-CF-RODS |
| 3 | 9.56E-10 | 2.53 | IE-LOMFW,CVC-XHE-XM-BOR,RPS-RYT-CF-20F4,RPS-XHE-XE-SGNL |

### Cut Set Report - LOMFW 15-20-28-4

Only items contributing at least 1% to the total are displayed.

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | 3.44E-8 | 100 | Displaying 259 Cut Sets. (259 Original) |
| 1 | 7.37E-9 | 21.44 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-CF-RUN |
| 2 | 2.57E-9 | 7.48 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO |
| 3 | 1.71E-9 | 4.97 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,EPS-XHE-XM-SBO |
| 4 | 1.23E-9 | 3.57 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO,EPS-DGN-TM-2DG1 |
| 5 | 1.23E-9 | 3.57 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-SBO,EPS-DGN-TM-2DG2 |
| 6 | 1.23E-9 | 3.57 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,EPS-DGN-TM-SBO |
| 7 | 1.21E-9 | 3.52 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FS-2P7A,EPS-DGN-CF-RUN |
| 8 | 1.08E-9 | 3.13 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-CF-STRT |
| 9 | 9.94E-10 | 2.89 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-TM-2P7A,EPS-DGN-CF-RUN |
| 10 | 8.16E-10 | 2.37 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG2,EPS-DGN-TM-2DG1,EPS-XHE-XM-SBO |
| 11 | 8.16E-10 | 2.37 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-TM-2DG2,EPS-XHE-XM-SBO |
| 12 | 6.79E-10 | 1.97 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-CF- |

| # ↑ | CCDP | Total% | Cut Set |
|---|---|---|---|
| | | | FRDG12,EPS-DGN-FR-SBO |
| 13 | 4.51E-10 | 1.31 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FR-2P7A,EPS-DGN-CF-FRDG12,EPS-XHE-XM-SBO |
| 14 | 4.23E-10 | 1.23 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-FS-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO |
| 15 | 3.47E-10 | 1.01 | IE-LOMFW,ACP-CRB-CC-152112,EFW-TDP-TM-2P7A,EPS-DGN-FR-2DG1,EPS-DGN-FR-2DG2,EPS-DGN-FR-SBO |

**Referenced Events**

| Event | Description | Probability |
|---|---|---|
| ACP-CRB-CC-152112 | FAILURE OF CRB 152-112 TO OPEN | 2.39E-3 |
| ACP-CRB-OO-2A409 | FAILURE OF CIRCUIT BREAKER 2A409 TO OPEN | 2.39E-3 |
| ACP-XHE-XM-B5ORB6D | OPERATOR FAILS TO CROSS-TIE 480V AC POWER (dependent) | 6.90E-2 |
| AFW-XHE-XM-2P75 | OPERATOR FAILS TO ALIGN AND START AFW PUMP | 4.00E-3 |
| CVC-XHE-XM-BOR | OPERATOR FAILS TO INITIATE EMERGENCY BORATION | 2.00E-2 |
| DCP-BAT-FC-8HR | BATTERY 2D11 OR 2D12 FAILS AFTER 8 HOUR DEPLETION | 1.00E+0 |
| DCP-XHE-XA-BCH32B | OPERATOR FAILS TO ALIGN STANDBY BCH TO BUS 2D02 | 1.00E-2 |
| DCP-XHE-XM-ACBCH32B | OPERATOR FAILS TO ALIGN ALTERNATE AC POWER TO BCH 2D32B | 1.00E-2 |
| EFW-MDP-FS-2P7B | EFW MDP 2P7B FAILS TO START | 9.47E-4 |
| EFW-MDP-TM-2P7B | EFW MDP 2P7B UNAVAILABLE DUE TO TEST AND MAINTENANCE | 3.63E-3 |
| EFW-MOV-CF-CV102756 | CCF OF SG INLET FLOW CONTROL MOVs CV-1025/26/1075/76 | 3.00E-6 |
| EFW-MOV-CF-CV1036789 | CCF OF SG INLET MOVs CV-1036/1037/ 1038/1039 | 2.33E-6 |
| EFW-PMP-CF-FSALL | CCF OF EFW PUMPS TO START (PSA) | 4.53E-5 |
| EFW-TDP-FR-2P7A | EFW TDP 2P7A FAILS TO RUN | 3.95E-2 |
| EFW-TDP-FS-2P7A | EFW TDP 2P7A FAILS TO START | 6.49E-3 |
| EFW-TDP-TM-2P7A | EFW TDP 2P7A UNAVAILABLE DUE TO TEST AND MAINTENANCE | 5.33E-3 |
| EFW-XHE-XM-CNTRLD | OPERATOR FAILS TO MANUALLY OPEN EFW DISCHARGE MOVs (LOSS OF POWER) (DEPENDENT) | 1.51E-1 |
| EFW-XHE-XR-2P7B | OPERATOR FAILS TO RESTORE EFW MDP 2P7B | 1.00E-3 |
| EPS-DGN-CF-FRDG12 | CCF OF DIESEL GENERATORS DG1/2 TO RUN | 2.39E-4 |
| EPS-DGN-CF-RUN | CCF OF DIESEL GENERATORS TO RUN | 7.80E-5 |
| EPS-DGN-CF-STRT | CCF OF DIESEL GENERATORS TO START | 1.14E-5 |
| EPS-DGN-FR-2DG1 | DIESEL GENERATOR 2DG1 FAILS TO RUN | 3.01E-2 |
| EPS-DGN-FR-2DG2 | DIESEL GENERATOR 2DG2 FAILS TO RUN | 3.01E-2 |
| EPS-DGN-FR-SBO | SBO DIESEL GENERATOR FAILS TO RUN | 3.01E-2 |
| EPS-DGN-TM-2DG1 | DIESEL GENERATOR 2A UNAVAILABLE DUE TO T&M | 1.43E-2 |
| EPS-DGN-TM-2DG2 | DIESEL GENERATOR 2B UNAVAILABLE DUE TO T&M | 1.43E-2 |

| Event | Description | Probability |
|---|---|---|
| EPS-DGN-TM-SBO | SBO DIESEL GENERATOR UNAVAILABLE DUE TO T&M | 1.43E-2 |
| EPS-XHE-XM-SBO | OPERATOR FAILS TO START SBO DIESEL GENERATOR | 2.00E-2 |
| EPS-XHE-XM-SBOD | OPERATOR FAILS TO START SBO DIESEL GENERATOR (DEPENDENT) | 6.90E-2 |
| HPI-XHE-XM-FB | OPERATOR FAILS TO INITIATE FEED AND BLEED COOLING | 2.00E-2 |
| HPI-XHE-XM-FBD | OPERATOR FAILS TO INITIATE FEED AND BLEED COOLING (dependent) | 6.90E-2 |
| IE-LOMFW | LOSS OF MAIN FEEDWATER | 1.00E+0 |
| MFW-XHE-XL-NOREC | OPERATOR FAILS TO RECOVER (RESTORE) MFW | 1.00E+0 |
| OEP-VCF-LP-CLOPT | LOSS OF OFFSITE POWER GIVEN TRANSIENT | 5.30E-3 |
| PPR-SRV-CC-PSV4732 | FAILURE OF SRV 2PSV-4732 TO OPEN | 3.54E-3 |
| PPR-SRV-CC-PSV4742 | FAILURE OF SRV 2PSV-4742 TO OPEN | 3.54E-3 |
| RCS-PHN-MODPOOR | MODERATOR TEMP COEFFICIENT NOT ENOUGH NEGATIVE | 1.40E-2 |
| RPS-BME-CF-TB2OF8 | CCF SPECIFIC 2 OF 8 TRIP CIRCUIT BREAKERS | 9.97E-7 |
| RPS-ROD-CF-RODS | CCF 20% OR MORE RODS FAIL TO DROP | 8.40E-7 |
| RPS-RYT-CF-20F4 | CCF 2 OF 4 (1 OUT-OF-2 TWICE) TRIP CONTACTORS | 4.78E-6 |
| RPS-XHE-XE-SGNL | OPERATOR FAILS TO RESPOND | 1.00E-2 |
| SBO-DGN-XFER-BUS2A4 | SUCCESSFUL ALIGNMENT OF SBO DG TO BUS 2A4 | 1.00E+0 |

# Appendix B: Key Event Tree and Modified Fault Trees

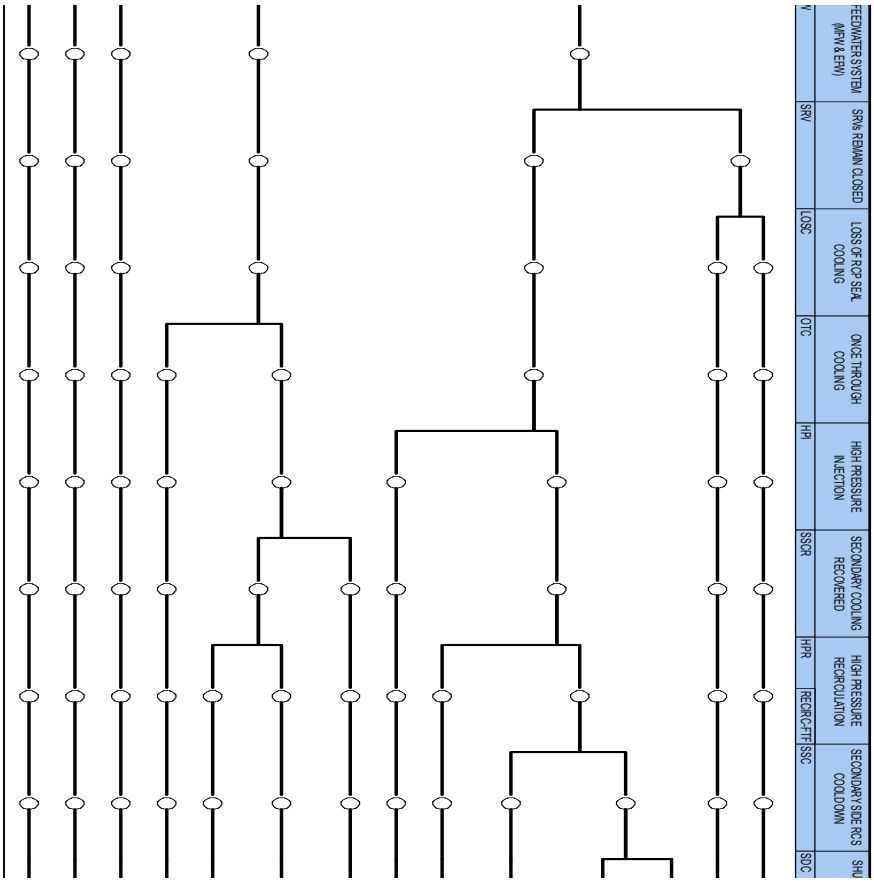


**Figure B-1: Loss of Main Feedwater Event Tree**

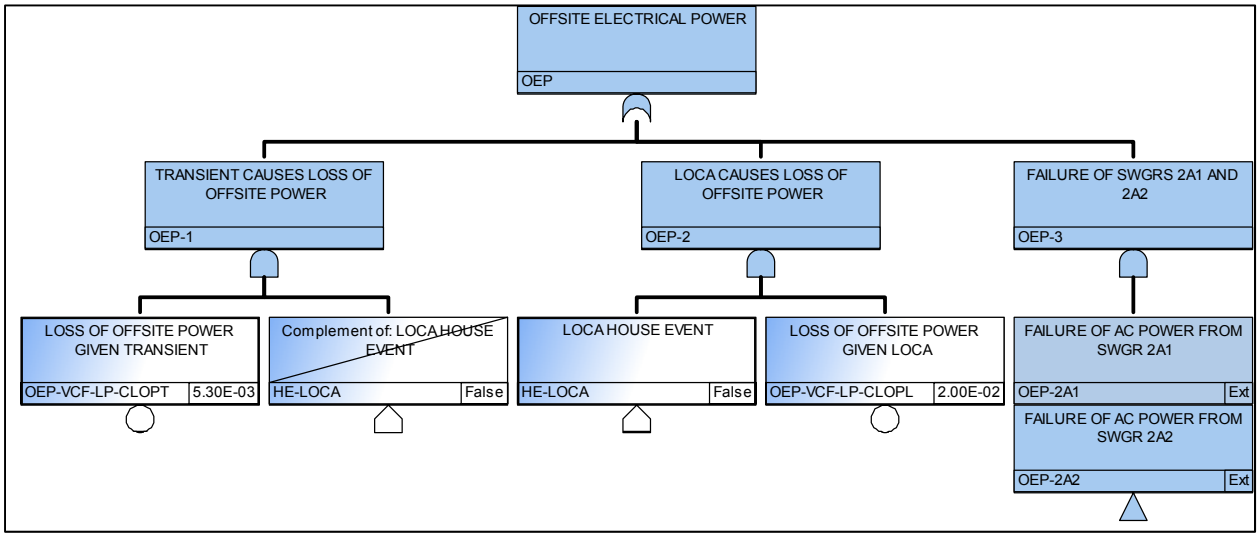


**Figure B-2: Modified OEP Fault Tree**

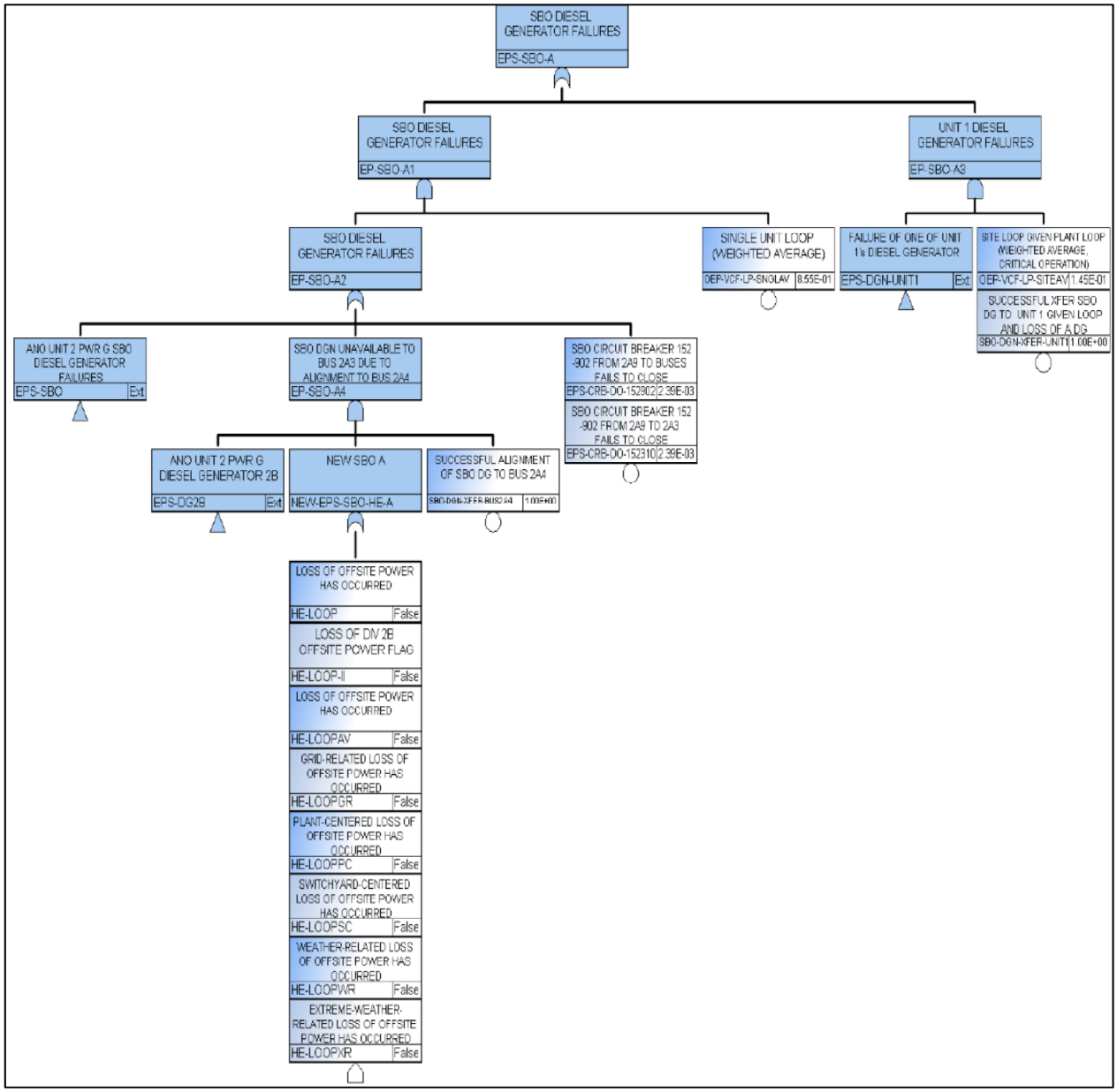


**Figure B-3: Modified EPS-SBO-A Fault Tree**

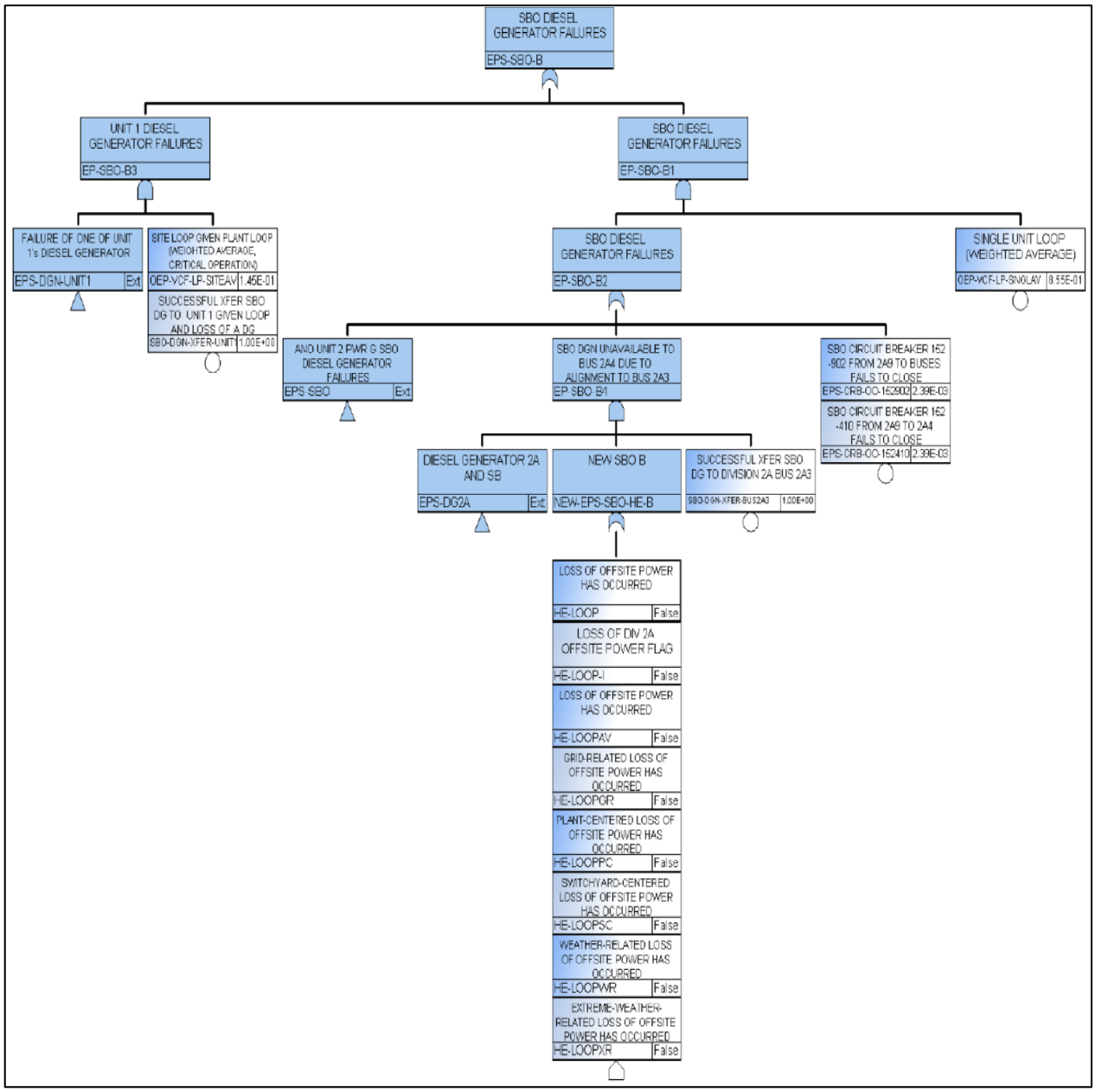


**Figure B-4: Modified EPS-SBO-B Fault Tree**