Failure Mode and Reliability Study for HTGR Electrical System: FMEA

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Introduction

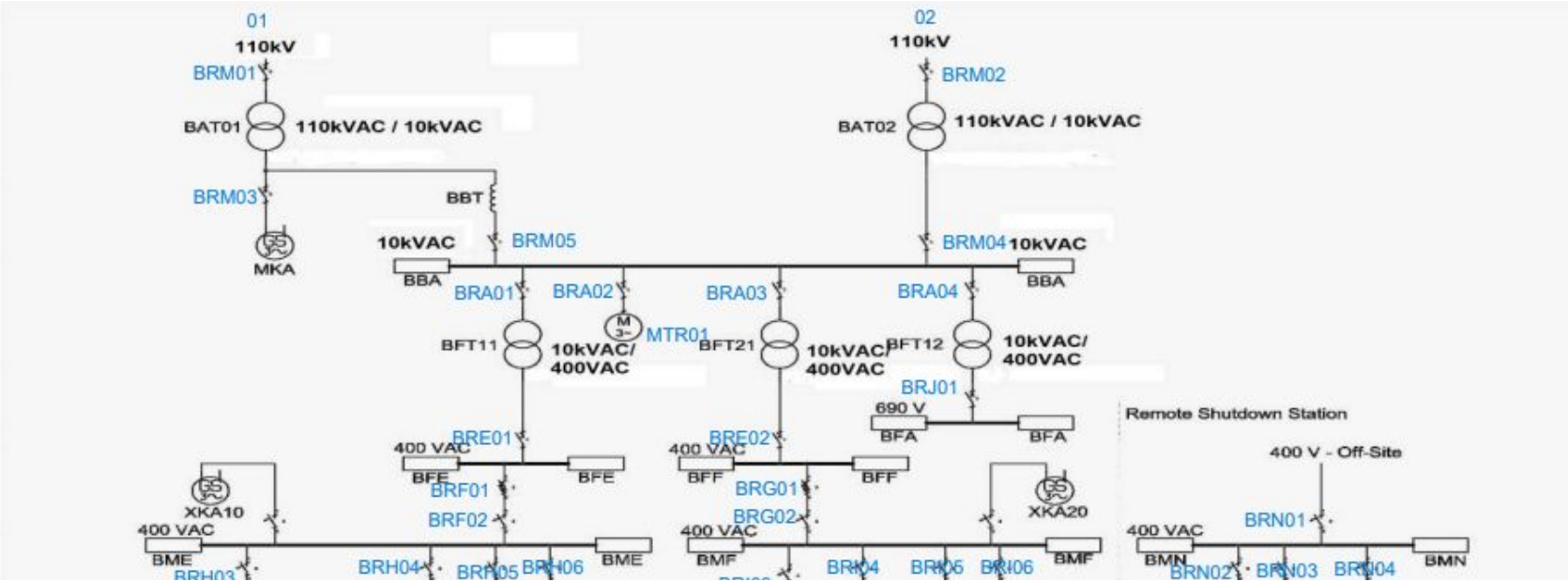
Reliability study of GEMINI+ Power Plant project

- **Methodology** : Karol Kowal, Mina Torabi,. "Failure Mode and Reliability Study for Electrical Facility of the High Temperature Engineering Test Reactor", Reliability Engineering and system safety, DOI: 10.1016/j.ress.2021.107529
- The Economic objective of the plant: A long term profitability needs to be ensured
- One of the severest Anticipated Operational Occurrences: Loss of Offsite (& Onsite) power which effects the profitability

The overall goals of this work:

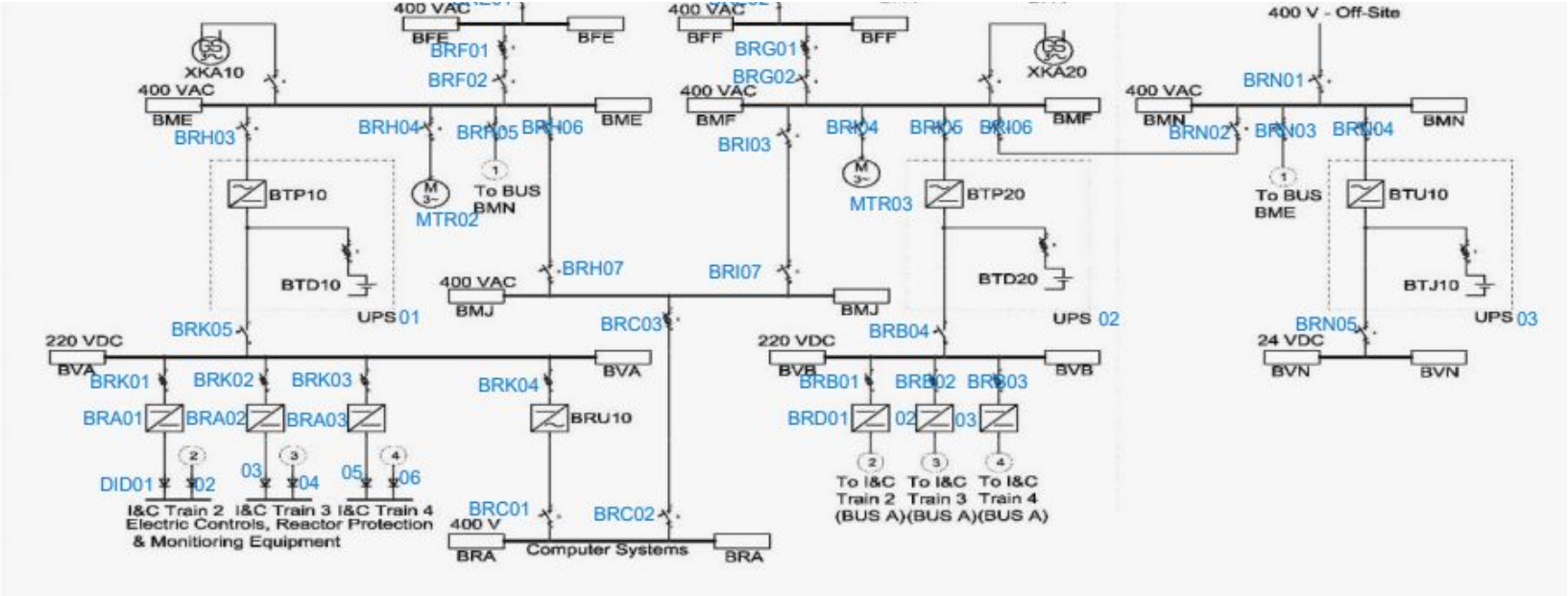
- Investigation of the system failure modes in terms of frequency and severity by the Failure Mode and Effect Analysis (FMEA) method
- Providing FMEA-based method for gradual screening of the failure modes aiming at selection of the most significant failures of high priority to be modelled with higher accuracy

Gemini+ Electrical System Diagram



Gemini+ Electrical System Diagram (Final GEMINI+ Safety Options Report)

Gemini+ Electrical System Diagram



Gemini+ Electrical System Diagram (Final GEMINI+ Safety Options Report)

Gospostrateg Electrical System Components Data Set

Electrical system components Data Set

No	Component type	Description	Unit	λ5%	λ50%	λmean	λ95%	Low	High	ecommend	Min	Max	Data Sources of Failure rates	Repair Time (hr)							Data Sources of Reapir Times
														_	Minimum	Mean	Maximum	5%	50%	95%	
1	Automatic Bus Transfer Switch	Automatic Power Transfer Switch Fails T	/d	4.19E-04	1.05E-03	1.13E-03	2.13E-03	_	_	_	_	_	NUREG/CR-6928	_	_	_	_	_	_	_	_
		Automatic Power Transfer Switch Trans	/h	3.89E-10	4.50E-08	9.90E-08	3.80E-07	_	_	_	_	_	NUREG/CR-6928	_	_	_	_	_	_	_	_
2	Battery Charger	Fails to Operate	/h	2.67E-07	2.00E-06	2.59E-06	6.93E-06	_	_	_	_	_	NUREG/CR-6928	_	_	_	_	_	_	_	Review of Maintenance and Repair Times for
		Fail During Operation	/h	_	_	5.50E-07	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	Review of Maintenance and Repair Times for
		Fails Shorted	/h	6.70E-09	2.00E-07	3.13E-07	1.00E-06	_	_	_	_	_	NUREG-75/014 (calc.)(USED IN OUR PAPER)	_	_	_	_	_	_	_	Review of Maintenance and Repair Times for
3	Battery Charger 120 V	Fail During Operation	/h	1.70E-06	_	6.70E-06	1.30E-05	_	_	_	_	_	IAEA-TECDOC-478	5.6 hours	_	_	_	_	_	_	IAEA-TECDOC-478
4	Battery Charger SCR Type	Operational Failure	/h	3.00E-07	_	5.00E-06	1.30E-05	_	_	_	_	_	IAEA-TECDOC-478	10.1 hours	_	_	_	_	_	_	IAEA-TECDOC-478
5	Battery Charger General	Hardware Failure	/d	_	_	4.00E-04	_	_	_	_	_	_	IAEA-TECDOC-478	18 hours	_	_	_	_	_	_	Review of Maintenance and Repair Times for
6	Battery Charger Rectifier	No Output	/h	_	_	_	_	6.00E-08	1.02E-05	4.90E-07	_	_	IAEA-TECDOC-478	18 hours	_	_	_	_	_	_	Review of Maintenance and Repair Times for
7	Battery Charger Solid State General	No Output	/h	_	_	_	_	1.40E-06	1.80E-05	5.50E-06	_	_	IAEA-TECDOC-478	5-10 hours	_	_	_	_	_	_	IAEA-TECDOC-478
8	Battery	Fails to Operate	/h	2.55E-07	3.67E-07	3.72E-07	5.06E-07	_	_	_	_	_	NUREG/CR-6928	_	_	_	_	_	_	_	_
		Fails Shorted	/h	6.70E-09	2.00E-07	3.13E-07	1.00E-06	_	_	_	_	_	NUREG-75/014 (calc.)(USED IN OUR PAPER)	_	_	_	_	_	_	_	_
		Inadequate Output	/h	_	_	_	_	4.90E-07	7.50E-06	3.20E-06	_	_	IAEA-TECDOC-478	_	_	_	_	_	4-7 hours	_	IAEA-TECDOC-478
		No Output	/h	_	_	_	_	3.00E-08	3.00E-06	6.40E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	4-7 hours	_	IAEA-TECDOC-478
		Operational Failure	/h	8.00E-10	_	8.20E-08	2.50E-07	_	_	_	_	_	IAEA-TECDOC-478	11.2 hours	_	_	_	_	_	_	IAEA-TECDOC-478
		Failed Effective Output	/d	_	_	1.30E-02	6.80E-02	_	_	_	_	_	IAEA-TECDOC-478	2 hours	_	_	_	_	_	_	IAEA-TECDOC-478
		Fail During Operation	/h	_	_	7.60E-08	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
9	Battery 125 V	Fail During Operation	/h	5.00E-08	_	5.20E-07	1.70E-06	_	_	_	_	_	IAEA-TECDOC-478	5 hours	_	_	_	_	_	_	IAEA-TECDOC-478
10	Battery General	Hardware Failure	/d	_	_	4.00E-04	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
11	Battery Lead Acid	Catastrophic (No Output Given Challeng	/cy	_	_	_	_	_	7.20E-06	4.60E-06	_	_	IAEA-TECDOC-478	19 hours	_	_	_	_	_	_	IAEA-TECDOC-478
12	Battery Lead Acid	Catastrophic (No Output Given Challeng	/h	_	_	_	_	0.00E+00	3.00E-08	2.00E-08	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
13	Battery Nickel Cadmium	All Failure Modes	/h	_	_	_	_	1.10E-07	9.90E-06	2.60E-07	_	_	IAEA-TECDOC-478	10.33 hours	_	_	_	_	_	_	NS ON INDUSTRY APPLICATIONS, VOL. 37, NO. 1, JANUARY/F
14	Battery (power system) Wet Cell	Failure to Provide Proper Output	/h	1.00E-06	3.00E-06	_	1.00E-05	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
15	Bus	All Failure Modes	/h	_	_	1.00E-08	_	_	_	_	6.00E-10	2.00E-07	IAEA-TECDOC-478	_	_	_	_	2 hours	4 hours	6 hours	Review of Maintenance and Repair Times for
16	Bus AC	Fails to Operate	/h	6.10E-08	6.81E-07	9.55E-07	2.75E-06	_	_	_	_	_	NUREG/CR-6928	_	_	_	_	_	_	_	_
		Fails Shorted	/h	2.00E-07	7.77E-07	8.96E-07	2.00E-06	_	_	_	_	_	NUREG-75/014 (calc.)(USED IN OUR PAPER)	_	_	_	_	_	_	_	_
17	Bus DC	Fails to Operate	/h	8.51E-10	9.85E-08	2.17E-07	8.31E-07	_	_	_	_	_	NUREG/CR-6928	10.8 hours	_	_	_	_	_	_	IAEA-TECDOC-478
		Fails Shorted	/h	2.00E-07	7.77E-07	8.96E-07	2.00E-06	_	_	_	_	_	NUREG-75/014 (calc.)(USED IN OUR PAPER)	_	_	_	_	_	_	_	_
18	Bus AC (120 V , 220 V)	Fail during operation	/h	6.30E-08	_	3.40E-07	6.80E-07	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_

Gospostrateg Electrical System Components Data Set

Electrical system components Data Set

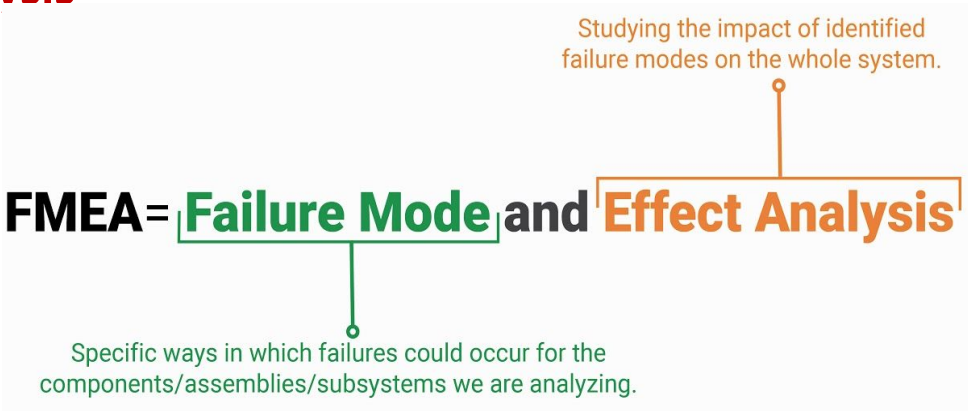
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
154	Transformer General	Open Circut, Primary To Secondary	/h	3.00E-07	1.00E-06	_	3.00E-06	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
		Fail During Operation	/h	_	_	1.70E-06	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
155	Transformer General Voltage <= 6 kv	Interruption	/h	_	_	7.90E-07	3.50E-06	_	_	_	_	_	IAEA-TECDOC-478	10 hours	_	_	_	_	_	_	IAEA-TECDOC-478
156	Transformer High Voltage Outdoor	Operational Failure	/h	1.50E-07	_	1.40E-06	3.50E-06	_	_	_	_	_	IAEA-TECDOC-478	10.8 hours	_	_	_	_	_	_	IAEA-TECDOC-478
157	Transformer Instrument Transformer C	No Output (Catastrophic)	/h	_	_	_	_	1.10E-07	4.90E-07	2.60E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
158	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	3.00E-08	1.80E-06	2.80E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
159	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	9.50E-08	3.90E-07	2.20E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
160	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	2.50E-07	6.20E-07	3.20E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
161	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	5.30E-07	1.90E-06	1.20E-06	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
162	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	1.00E-07	1.60E-06	5.80E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
163	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	5.00E-07	1.50E-06	1.10E-06	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
164	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	1.80E-07	5.10E-07	3.40E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
165	Transformer Main Power Generator or	No Output (Catastrophic)	/h	_	_	_	_	4.30E-07	1.40E-06	7.40E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
166	Transformer Main transformer Voltage	Interruption	/h	_	_	3.50E-06	1.80E-05	_	_	_	_	_	IAEA-TECDOC-478	38 hours	_	_	_	_	_	_	IAEA-TECDOC-478
167	Transformer regulating 120 V AC	Operational Failure	/h	4.40E-09	_	2.00E-06	4.20E-06	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
168	Transformer Station Service Including	No Output (Catastrophic)	/h	_	_	_	_	1.10E-07	1.40E-06	4.00E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
169	Transformer Station Service Including	No Output (Catastrophic)	/h	_	_	_	_	8.00E-08	2.30E-06	2.70E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
170	Transformer Station Service Including	No Output (Catastrophic)	/h	_	_	_	_	8.60E-08	1.10E-06	2.20E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
171	Transformer Station Service Including	No Output (Catastrophic)	/h	_	_	_	_	5.40E-08	8.10E-07	1.10E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
172	Transformer Station Start And Auxiliar	interruption	/h	_	_	2.00E-06	1.10E-05	_	_	_	_	_	IAEA-TECDOC-478	5 hours	_	_	_	_	_	_	IAEA-TECDOC-478
173	Transformer Substation Liquid Filled, S	No Output (Catastrophic)	/h	_	_	_	_	9.00E-08	2.60E-06	5.10E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
174	Transformer Substation Liquid Filled, T	No Output (Catastrophic)	/h	_	_	_	_	3.10E-07	1.90E-06	8.00E-07	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
175	Terminal board general	Short to adjacent circut	/h	1.00E-09	1.00E-08	_	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
		Open Circut	/h	_	_	3.00E-07	_	_	_	_	6.00E-09	2.00E-06	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
		Open connection	/h	1.00E-08	1.00E-07	_	_	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
176	Wire Control Circut Wire Typical Circu	Short to Ground	/h	3.00E-08	3.00E-07	_	3.00E-06	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
177	Wire Control Circut Wire Typical Circu	Short to Power	/h	1.00E-09	1.00E-08	_	1.00E-07	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
178	Wire Control Circut Wire Typical Circu	Open Circut	/h	1.00E-06	3.00E-06	_	3.00E-06	_	_	_	_	_	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
179	Wire General	Short to Ground	/h	_	_	1.00E-06	_	_	_	_	2.00E-08	5.00E-06	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
		Short to Power	/h	_	_	3.00E-08	_	_	_	_	6.00E-10	2.00E-07	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
		Open Circut	/h	_	_	1.00E-05	_	_	_	_	2.00E-07	5.00E-05	IAEA-TECDOC-478	_	_	_	_	_	_	_	_
180	Weather-related	Weather-related Loss of Offsite Power	/h	6.64E-07	8.76E-07	8.84E-07	1.13E-06	_	_	_	_	_	A. Volkanovski (calc.)	_	_	_	_	_	_	_	_

Gemini+ Electrical System Components Data Set

Gemini+ Electrical system components Data Set

No	Component type	Failure Mode	Unit	λmean	Data Sources of Failure rates
1	Transformer	Fails to Operate	/h	2.89E-06	NUREG/CR-6928
		Fails Shorted	/h	1.34E-06	NUREG-75/014 (calc.)(USED IN OUR PAPER)
2	Turbine Genertaor	Fails to run	/h	1.40E-04	NUREG/CR-6928
3	Emergency Diesel Generator	Fails To Start, Normally Stanc	/d	2.88E-03	NUREG/CR-6928
		Fails to Run	/h	4.50E-03	IAEA-TECDOC-478
		Spourious Stop	/h	5.50E-03	IAEA-TECDOC-478
4	High Voltage Circuit Breaker (110kV)	Spurious Operation	/h	4.83E-07	NUREG/CR-6928
		Fails Shorted	/h	3.14E-08	NUREG-75/014 (calc.)(USED IN OUR PAPER)
5	Medium Voltage Circuit Breaker (10KV)	Spurious Operation	/h	1.15E-07	NUREG/CR-6928
		Fails Shorted	/h	3.14E-08	NUREG-75/014 (calc.)(USED IN OUR PAPER)
6	Low Voltage Circuit Breaker (400,690, 220V)	Spurious Operation	/h	3.14E-08	NUREG-75/014 (calc.)(USED IN OUR PAPER)
		Fails Shorted	/h	9.97E-08	NUREG/CR-6928
7	Short-Circuit-Limiter (Inductor)	Fails to Operate	/h	4.50E-10	Reliability Evaluation of Conventional and Interleaved DC-DC Boost Converters
8	DC Bus	Fails to Operate	/h	2.17E-07	NUREG/CR-6928
		Fails Shorted	/h	8.96E-07	NUREG-75/014 (calc.)(USED IN OUR PAPER)
9	AC Bus	Fails to Operate	/h	9.55E-07	NUREG/CR-6928
		Fails Shorted	/h	8.96E-07	NUREG-75/014 (calc.)(USED IN OUR PAPER)
10	DC-AC Inverter	Inverter Fails Shorted	/h	3.40E-06	NUREG-75/014; TM 5-698-5 (calc.)
		Inverter Fails to Operate	/h	4.97E-06	NUREG/CR-6928
11	Battery	Battery Fails Shorted	/h	3.13E-07	NUREG-75/014; TM 5-698-5 (calc.)
		Battery Fails to Operate	/h	3.72E-07	NUREG/CR-6928
12	AC-DC Converter	Battery Charger Fails Shorted	/h	3.13E-07	NUREG/CR-6928
		Battery Charger Fails to Oper	/h	2.59E-06	NUREG-75/014 (calc.)
13	DC-DC Converter	Fails to Operate	/h	3.15E-05	ering application research on reliability prediction of the combined DC-DC powe
14	Isolating Diode	Fails to Operate	/h	3.70E-06	IAEA-TECDOC-478
15	Off-site Power	Switchyard-related Loss of O	/h	1.84E-06	A. Volkanovski (calc.)
		Weather-related Loss of Offs	/h	8.84E-07	A. Volkanovski (calc.)
		Grid-related Loss of Offsite I	/h	2.46E-06	A. Volkanovski (calc.)

FMEA Analysis



- A widely used analytical technique for risk assessment aiming at identification, prioritization, and mitigation of the potential failures of systems and processes
- Its first use was in the 1960s by the aerospace industry has been continually updating
- Risk Priority Number = Severity × Occurrence × Detection
- The Purpose of using FMEA in this work : identification and evaluation of possible ways in which an insufficient power of the Gemini+ Electrical Facility can occur

FMEA Analysis – Severity Rating

FMEA Severity ranking:

- The seriousness of single failure consequences

FMEA rating scale for severity (S)

No.	Description	Reactor shutdown	Emergency generator
1	Loss of redundancy of a Normal Power Distribution	Not needed	Not needed
2	Loss of redundant single load on an Accident Bus	Not needed	Not needed
3	Loss of redundancy of an Accident Power Distribution	Not needed	Not needed
4	Loss of redundancy of multiple Accident Power Distributions	Not needed	Not needed
5	Loss of single load on a Normal Bus	Needed	Not needed
6	Insufficient input power on a Normal Bus	Needed	Not needed
7	Insufficient input power on an Accident Bus	Needed	Not needed
8	Insufficient input power on an I&C Trains or Computer systems	Needed	Not needed
9	Loss of offsite and onsite power	Needed	Needed/Can be used
10	Loss of all loads on all Accident Buses	Needed	Cannot be used

1-4 Loss of redundancies which does not lead to the reactor shutdown

5-8 Loss of loads or power distribution which leads to the reactor shutdown; No Diesel Generator is needed

9-10 Loss of total offsite and onsite power and all loads which lead to the necessity of using Diesel Generator

FMEA Analysis – Occurrence rating

FMEA Occurrence ranking:

- Occurrence is a frequency of the failure mode. It corresponds to the expected number of a certain type of events that could occur for a given cause over the desired lifetime of the system being analysed
- Occurrence is usually estimated by the failure rate parameter

FMEA rating scale for Occurrence (O)

O	Description	Failure rate – λ [1/h]
1	Extremely Low	$\lambda \leq$ 1E-10
2	Very Low	1E-10 $< \lambda \leq$ 1E-09
3	Low	1E-09 $< \lambda \leq$ 1E-08
4	Moderately Low	1E-08 $< \lambda \leq$ 1E-07
5	Moderate	1E-07 $< \lambda \leq$ 1E-06
6	Increased	1E-06 $< \lambda \leq$ 1E-05
7	Moderately High	1E-05 $< \lambda \leq$ 1E-04
8	High	1E-04 $< \lambda \leq$ 1E-03
9	Very High	1E-03 $< \lambda \leq$ 1E-02
10	Extremely High	1E-02 $< \lambda$

FMEA Analysis – Detection rating

FMEA Detection ranking:

- Detection can be defined as the ability to identify the failure mode before it causes significant system performance deterioration.
- If the ability to detect the failure is unknown or the detection cannot be estimated, then according to the FMEA methodology, the detection rank should be set to 10.

FMEA Analysis

Gradual Screening Approach

1. Light Green Area: Failure modes of the lowest severity
2. Dark Green Area: Failure modes with relatively low impact on the reliability of entire system
3. Yellow Area: Failure modes with potentially significant impact on the system
4. Orange Area : Failure modes with significant contribution to the risk measures of the entire system
5. Red Area: Failure modes of the highest severity

Risk matrix of the Gemini+ Electrical Facility (the cells include the number of identified failures)

	S									
O	1	2	3	4	5	6	7	8	9	10
10										
9	1									
8										
7		7								
6	10	6	2			2	1			
5	11	26	10	5	1	10	5	2		
4	8	9	9	9		5	4			
3										
2										
1	1									
Σ										

9	Can be excluded from further reliability studies
90	Reliability models based on averaged λ values
35	Consideration of the λ uncertainty distribution
0	Consideration of the ageing effects, i.e. $\lambda = \lambda(t)$
0	Cannot be accepted (design changes required)

FMEA Analysis
Gradual Screening Approach

FMEA for High-Voltage Normal equipment of Gemini+ Electrical Facility

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	Turbine Generator	Failure to supply onsite power to MV Bus	Loss of redundant power supply line to Bus BBA	Fails to run	1	9	10	90
2	Commercial Offsite Power Lines	Failure to supply offsite power to MV Bus	Loss of redundant power supply line to Bus BBA	Grid-related	1	6	10	60
				Weather-related	1	5	10	50
				Grid-related	1	6	10	60
3	HV Breakers BRM 01/02	Failure to supply power to MV Bus	Loss of redundant power supply line to Bus BBA	Spurious Operation	1	5	10	50
				Fails Shorted	1	4	10	40

FMEA for Mean-Voltage Normal AC Power Center

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	Transformer BAT 01/02	Failure to supply redundant Power to the Bus BBA	Loss of redundant power supply line to Bus BBA	Fails to Operate	1	6	10	60
				Fails Shorted	1	6	10	60
2	Short Circuit Limiter	Failure to limit the short circuit current	Loss of redundant input power line to Bus BBA	Fails to Operate	1	1	10	10
4	AC Bus BBA	Failure to supply power to the MV loads	Loss of input power to Bus BFA	Fails to Operate	6	5	10	300
				Fails Shorted	6	5	10	300
3	MV Breakers BRM 03/04/05	Failure to supply power to Bus BBA	Loss of redundant power supply line to Bus BBA	Spurious Operation	1	5	10	50
				Fails Shorted	1	4	10	40
5	MV Breaker BRA 01	Failure to supply power to Bus BFE	Loss of redundant power supply line to Bus BFE	Spurious Operation	1	5	10	50
			Loss of input power to Bus BFA	Fails Shorted	6	4	10	240
6	MV Breaker BRA 02	Failure to supply power to the Motor MTR01	Loss of single MV load: Motor MTR01	Spurious Operation	5	5	10	250
			Loss of input power to Bus BFA	Fails Shorted	6	4	10	240
7	MV Breaker BRA 03	Failure to supply power to Bus BFF	Loss of redundant power supply line to Bus BFF	Spurious Operation	1	5	10	50
			Loss of input power to Bus BFA	Fails Shorted	6	4	10	240
8	MV Breaker BRA 04	Failure to supply power to Bus BFA	Loss of input power to Bus BFA	Spurious Operation	6	5	10	300
				Fails Shorted	6	4	10	240

FMEA Analysis

Gradual Screening Approach

FMEA for Low-Voltage Normal AC Power Centers (400V)

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	Transformer BFT 11/21	Failure to supply power to Bus BFE/BFF	Loss of redundant power supply line to Bus BFE/BFF	Fails to Operate	1	6	10	60
				Fails Shorted	1	6	10	60
2	AC Bus BFE/BFF	Failure to supply power to Bus BME/BMF	Insufficient power on Bus BFE/BFF	Fails to Operate	6	5	10	300
				Fails Shorted	6	5	10	300
3	AC Bus BFA	Failure to supply power to Bus BFA	Insufficient power on Bus BFA	Fails to Operate	6	5	10	300
				Fails Shorted	6	5	10	300
4	LV Breaker BRE 01/02	Failure to supply power to Bus BFE/BFF	Loss of redundant power supply line to Bus BFE/BFF	Spurious Operation	1	5	10	50
				Fails Shorted	1	4	10	40
5	LV Breaker BRF 01/02	Failure to supply power to Bus BME	Loss of redundant power supply line to Bus BME	Spurious Operation	2	5	10	100
				Fails Shorted	2	4	10	80
6	LV Breaker BRG 01/02	Failure to supply power to LV Bus BMF	Loss of redundant power supply line to Bus BMF	Spurious Operation	2	5	10	100
				Fails Shorted	2	4	10	80

FMEA for Low-Voltage Normal AC Power Centers (690V)

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	Transformer BFT12	Failure to supply power to the LV Bus BFA	Insufficient input power to the Bus BFA	Fails to Operate	6	6	10	360
				Fails Shorted	6	6	10	360
2	LV Breaker BRJ 01	Failure to supply power to LV Bus BFA	Loss of input power to the Bus BFA	Spurious Operation	6	5	10	300
				Fails Shorted	6	4	10	240

FMEA Analysis

Gradual Screening Approach

FMEA for Low-Voltage Accident AC Power Centers (400V)

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	LV Breaker BRN 01	Failure to supply offsite power to Bus BMN	Loss of redundant input power line to Bus BMN	Spurious Operation	1	5	10	50
				Fails Shorted	1	4	10	40
2	AC Bus BME	Failure to supply redundant power to 400V AC loads	Loss of input power to Bus BME and BVA	Fails to Operate	4	5	10	200
				Fails Shorted	4	5	10	200
3	AC Bus BMF	Failure to supply redundant power to 400V AC loads	Loss of input power to Bus BMF and BVB	Fails to Operate	4	5	10	200
				Fails Shorted	4	5	10	200
4	AC Bus BMN	Failure to supply redundant power to 400V AC loads	Loss of input power to Bus BVN	Fails to Operate	7	5	10	350
				Fails Shorted	7	5	10	350
5	LV Breaker BRH 03	Failure to supply power to UPS01	Loss of redundancy of input power in I&C Trains and Computer	Spurious Operation	3	5	10	150
			Loss of redundant Bus BME and BVA	Fails Shorted	4	4	10	160
6	LV Breaker BRH 04	Failure to supply power to Motor MTR 02	Loss of redundant single load: Motor MTR	Spurious Operation	2	5	10	100
			Loss of redundant Bus BME and BVA	Fails Shorted	4	4	10	160
7	LV Breaker BRH 05	Failure to supply redundant power to Bus BMN	Loss of redundant power supply line to Bus BMN	Spurious Operation	2	5	10	100
			Loss of redundant Bus BME and BVA	Fails Shorted	4	4	10	160
8	LV Breaker BRH 06	Failure to supply power to Bus BMJ	Loss of redundant power supply line to Bus BMJ	Spurious Operation	2	5	10	100
			Loss of redundant Bus BME and BVA	Fails Shorted	4	4	10	160
9	LV Breaker BRH 07, BRI 07	Failure to supply power to Bus BMJ	Loss of redundant power supply line to Bus BMJ	Spurious Operation	2	5	10	100
				Fails Shorted	2	4	10	80
10	LV Breaker BRI 03	Failure to supply power to Bus BMJ	Loss of redundant power supply line to Bus BMJ	Spurious Operation	2	5	10	100
			Loss of redundant Bus BMF & BVB	Fails Shorted	4	4	10	160

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11	LV Breaker BRI 04	Failure to supply power to Motor MTR 03	Loss of redundant single load: Motor MTR 03	Spurious Operation	2	5	10	100
			Loss of redundant Bus BMF & BVB	Fails Shorted	4	4	10	160
12	LV Breaker BRI 05	Failure to supply power to UPS02	Loss of redundancy of input power in I&C Trains	Spurious Operation	3	5	10	150
			Loss of redundant Bus BMF and BVB	Fails Shorted	4	4	10	160
13	LV Breaker BRI 06	Failure to supply power to Bus BMN	Loss of redundant power supply line to Bus BMN	Spurious Operation	2	5	10	100
			Loss of redundant Bus BMF and BVB	Fails Shorted	4	4	10	160
14	LV Breaker BRN 02	Failure to supply power to Bus BMN	Loss of redundant power supply line to Bus BMN	Spurious Operation	2	5	10	100
			Loss of input power to Bus BVN	Fails Shorted	7	4	10	280
15	LV Breaker BRN 03	Failure to supply redundant power to Bus BMN	Loss of redundant power supply line to Bus BMN	Spurious Operation	2	5	10	100
			Loss of input power to Bus BVN	Fails Shorted	7	4	10	280
16	LV Breaker BRN 04	Failure to supply power to UPS 03	Loss of input power to Bus BVN	Spurious Operation	7	5	10	350
				Fails Shorted	7	4	10	280

FMEA Analysis

Gradual Screening Approach

FMEA for Uninterrubtiple DC Power Centers (220V)

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	LV Breaker BRK 04/05	Failure to supply power to 220V DC Bus BVB/BVA	Loss of redundant Bus BVB/BVA	Spurious Operation	3	5	10	150
				Fails Shorted	3	4	10	120
2	AC-DC Converter BTP 10/20	Failure to supply DC Power to Bus BVA/BVB	Loss of redundant power lines to to Bus BVA/BVB	Fails Shorted	3	5	10	150
				Fails to Operate	3	6	10	180
3	DC Bus BVA	Failure to supply redundant power to DC/DC and DC/AC Inverters	Loss of all redundant loads on Bus BVA	Fails to Operate	3	5	10	150
				Fails Shorted	3	5	10	150
4	DC Bus BVB	Failure to supply power to DC/DC Inverters	Loss of all redundant loads on Bus BVB	Fails to Operate	3	5	10	150
				Fails Shorted	3	5	10	150
5	LV Breaker BRK 01/02/03	Failure to supply power to Converter BRA01/02/03	Loss of redundant power supply line to I&C Train 2/3/4	Spurious Operation	2	5	10	100
			Loss of all redundant loads on Bus BVA	Fails Shorted	3	4	10	120
6	LV Breaker BRK 04	Failure to supply power to Converter BRU10	Loss of redundant power supply line to Computer Systems	Spurious Operation	2	5	10	100
			Loss of all redundant loads on Bus BVA	Fails Shorted	3	4	10	120
7	LV Breaker BRB 01/02/03	Failure to supply power to Converter BRB 01/02/03	Loss of redundant power supply line to I&C Train 2/3/4	Spurious Operation	2	5	10	100
			Loss of all redundant loads on Bus BVB	Fails Shorted	3	4	10	120
8	DC-DC Converter BRA 01/02/03	Failure to supply DC Power to I&C Train 2/3/4	Loss of redundant power supply line to I&C Train 2/3/4	Fails to Operate	2	7	10	140
9	DC-DC Converter BRD 01/02/03	Failure to supply DC Power to I&C Train 2/3/4	Loss of redundant power supply line to I&C Train 2/3/4	Fails to Operate	2	7	10	140
10	DC-AC Inverter BRU10	Failure to supply AC Power to Computer Systems	Loss of redundant power supply line to Computer Systems	Fails to Operate	2	7	10	140
11	Isolating Diode DID 01/02	Failure to suppress the backward direction of the current on Train 2	Loss of redundant power line to the I&C Train 2	Fails to Operate	2	6	10	120
12	Isolating Diode DID 03/04	Failure to suppress the backward direction of the current on Train 3	Loss of redundant power line to Train 3	Fails to Operate	2	6	10	120
13	Isolating Diode DID 05/06	Failure to suppress the backward direction of the current on Train 4	Loss of redundant power line to Train 4	Fails to Operate	2	6	10	120

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14	LV Breakers BRK 04	Failure to supply power to Inverter BRU10	Loss of redundant power supply line for Inverter BRU 10	Spurious Operation	4	5	10	200
				Fails Shorted	4	4	10	160
15	LV Breaker BRC 01	Failure to supply power to Computer Systems	Loss of redundant power supply line to Computer Systems	Spurious Operation	2	5	10	100
				Fails Shorted	2	4	10	80
16	Computer AC Bus	Failure to supply power to Computer systems	Insufficient power on Computer Systems	Fails to Operate	8	5	10	400
				Fails Shorted	8	5	10	400
17	AC Bus BMJ	Failure to supply redundant power line to Computer AC Bus	Loss of redundant power supply line to Computer Systems	Fails to Operate	2	5	10	100
				Fails Shorted	2	5	10	100
18	LV Breaker BRC 02/03	Failure to supply redundant power line to Computer Systems	Loss of redundant power supply line to Computer Systems	Spurious Operation	2	5	10	100
				Fails Shorted	2	4	10	80

FMEA for Uninterrubtible DC Power Center (24V)

No.	Component	Function lost	The most sever effect	Causes	S	O	D	RPN
1	AC-DC Converter BTU 10	Failure to supply DC Power to Bus BVN	Insufficient input power to Bus BVN	Battery Charger	7	5	10	350
				Battery Charger	7	6	10	420
2	LV Breaker BRN 05	Failure to supply power to 24V DC Bus BVN	Loss of input power to the Bus BVN	Spurious Operation	7	5	10	350
				Fails Shorted	7	4	10	280

Conclusion

- ✔ FMEA analysis was performed to identify potential failure modes of Gemini+ electrical system
- ✔ The identified failures were categorized based on their initial frequency and severity. Based on this ranking a risk matrix was developed aiming at the failures categorization and gradual screening
- ✔ The results might be implemented for the future more advanced reliability study of the system

Thank you

for your attention

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