

# Failure Mode and Reliability Study for HTGR Electrical System: FTA



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This work is one portion of the studies in the strategic Polish program of scientific research and development work "*Social and economic development of Poland in the conditions of globalizing markets GOSPOSTRATEG*" part of "*Preparation of legal, organizational and technical instruments for the HTR implementation*" financed by the National Centre for Research and Development (NCBiR) in Poland.

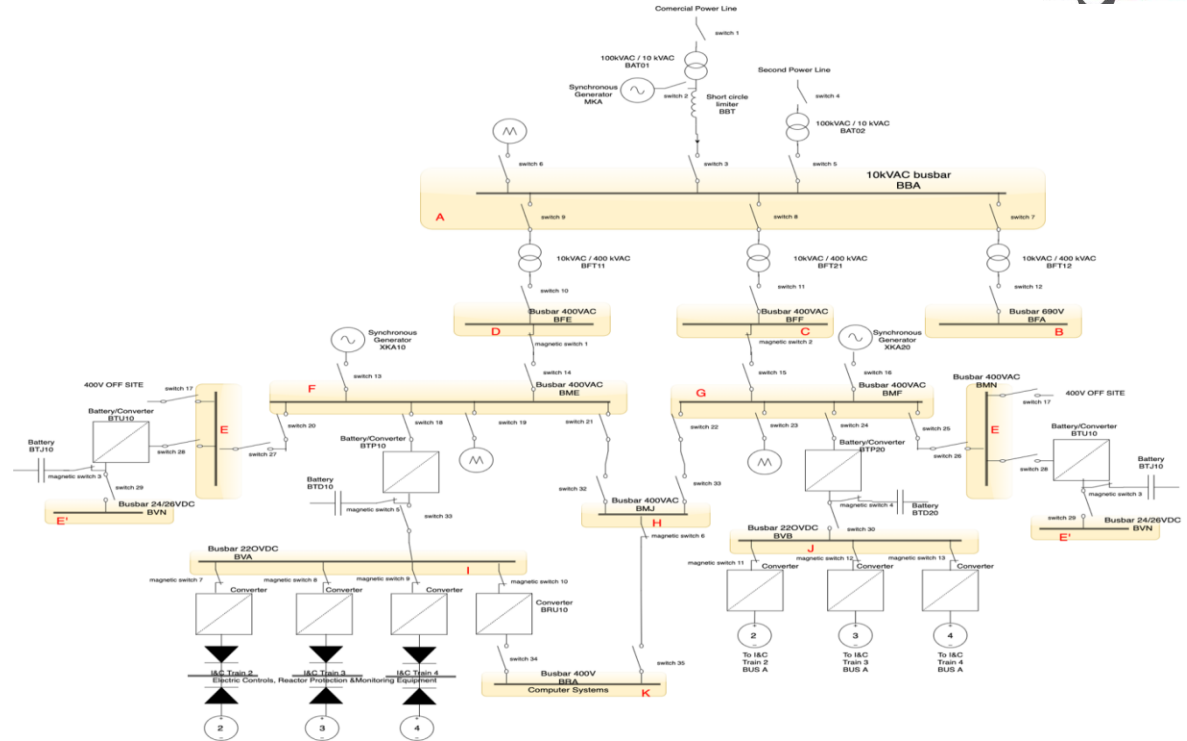
## □ The overall goals of this work:

- Develop a methodology and preliminary analysis of the reliability of the electrical system for the model that has been proposed for a high temperature nuclear reactor (HTR) under the Gemini + project of the EU H2020 program.
- Creating a reliability model in the SAPHIRE program
- Perform analysis for 2 case:
  - With grid connection
  - Without grid connection

# Gemini+ Electrical System Diagram

Schem of Electrical System  
contains :

- 12 Busbars
- 1 Synchronous Generator
- 2 Diesel Generator
- 35 Switches
- 13 Magnetic switches
- 1 Short circle Limiter
- 5 transformers
- 4 battery
- 4 baterii/conwerter
- 6 conwerters
- 3 Busbar of I&C systems
- 6 diod
- 3 power lines
- 2 diesel motor (not taking)



Gemini+ Electrical System Diagram [1]



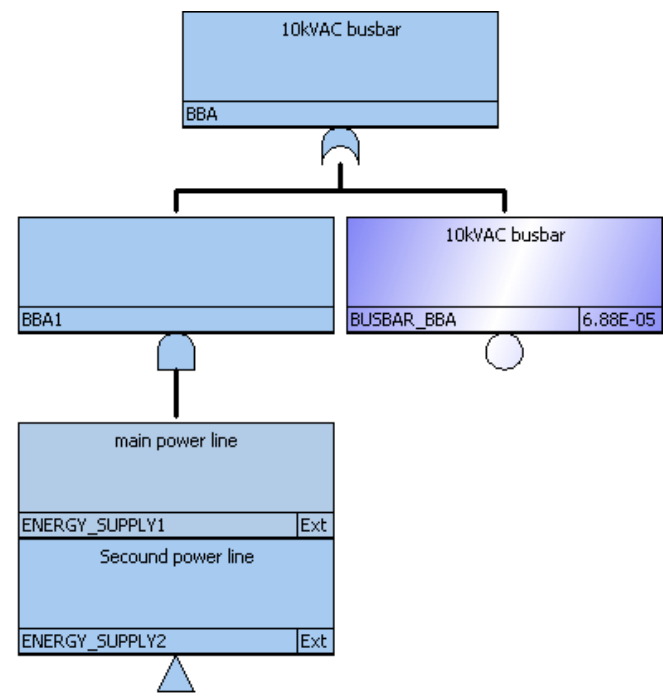
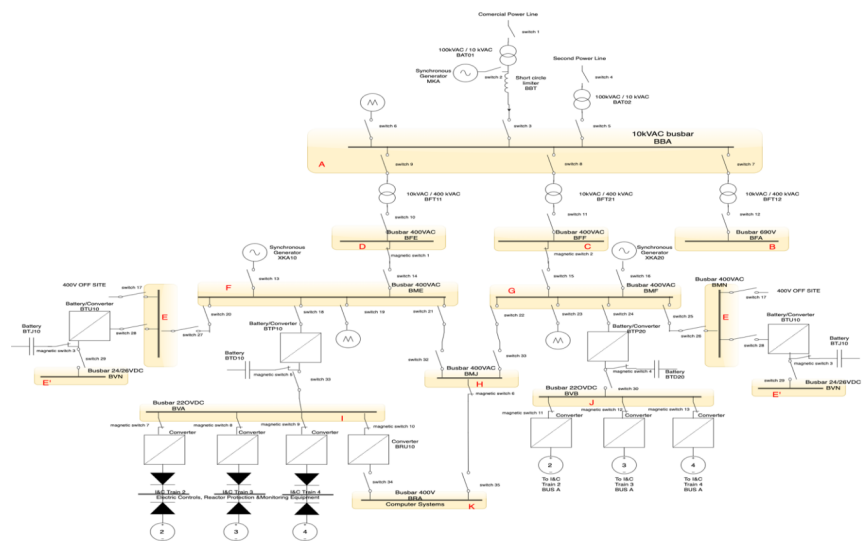
# NRC Electrical System Components Data Set

Equipment	Error	Names	Failure probability	Error factor	$\alpha$	$\beta$
Busbar	AC fails in operation	Others than BV...	9,55E-07	4	1,100	1,160E+06
	DC fails in operation	BV...	2,17E-07	8,4	0,500	2,310E+06
synchronous generator	Fail to run	MKA [Gospostrateg]	7,20E-07			
	Fail to start		4,50E-07			
main power sources	SBO Generator Fail to Start	XKA10, XKA 20	2,98E-02	1,5	12,500	4,080E+02
	SBO Generator Fail to Run		1,50E-03	2,5	2,500	1,670E+03
Circuit breaker (switches)	High Voltage (13.8 and 16 Kv) Circuit Breaker Fails To Open/Close	SWITCH:1,4	2,83E-03	6,2	0,659	2,320E+02
	High Voltage (13.8 and 16 Kv) Circuit Breaker Spurious Operation		4,83E-07	8,7	0,488	1,010E+06
	Medium Voltage (4160 v and 6.9 Kv) Circuit Breaker Fails To Open/Close	SWITCH:2,3,5,6,7,8,9	2,49E-03	6,3	0,644	2,580E+02
	Medium Voltage (4160 v and 6.9 Kv) Circuit Breaker Spurious Operation		1,15E-07	9,4	0,459	4,010E+06
	Low Voltage (480 v) Circuit Breaker Fails To Open/Close	SWITCH:10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,31,32,34,35	1,03E-03	1,2	56,500	5,500E+04
	Low Voltage (480 v) Circuit Breaker Spurious Operation		9,97E-08	1,3	39,500	3,960E+08
	DC Circuit Breaker Fails to Open/Close	SWITCH:29,30,33	4,33E-04	2,5	2,500	5,780E+03
	DC Circuit Breaker Spurious Operation		3,54E-08	3,3	1,500	4,230E+07
Magnetic Circuit breaker	DC Circuit Breaker Fails to Open/Close	SWITCH_:1,2,3,4,5,6,7,8,9,10,11,12,13	4,33E-04	2,5	2,500	5,780E+03
	DC Circuit Breaker Spurious Operation		3,54E-08	3,3	1,500	4,230E+07
short circle limiter [5]	Short ccircle limiter failure in operation	BBT	1,71E-7			
Transformers	Transformer Fail to Operate	BFT,BAT	2,89E-06	2,400	8,320E+05	2,6
batteries	Battery Fails to Operate	BTD,BTJ	3,72E-07	23,500	6,320E+07	1,4
Batteries system / converters	We assume failure of inverters and battery	BTP,BTU				
converters	Inverter Fails to Operate	CONVERTERS_I&C_	4,97E-06	1,130	2,270E+05	4
I&C trains	I&C FAILURE	I&C trains_2,3,4	1,00E-06	2,2		
Diodes [6]	Diodes fails in operatio	DIODES_	2,2E-9			
power supply (power lines)	Loss of offsite power, grid-related, power operation, per rcry	POWER SUPPLY	1,10E-02	6,7	0,6	55
	Loss of offsite power, plant-centered, power operation, per rcry		2,00E-03	2,2	3,5	1750
	Loss of offsite power, switchyard-centered, power operation, per rcry		1,34E-02	1,4	23,5	1750
	Loss of offsite power, weather-related, power operation, per rcry		5,99E-03	3,0	10,5	1750



# HTR with Grid Connection

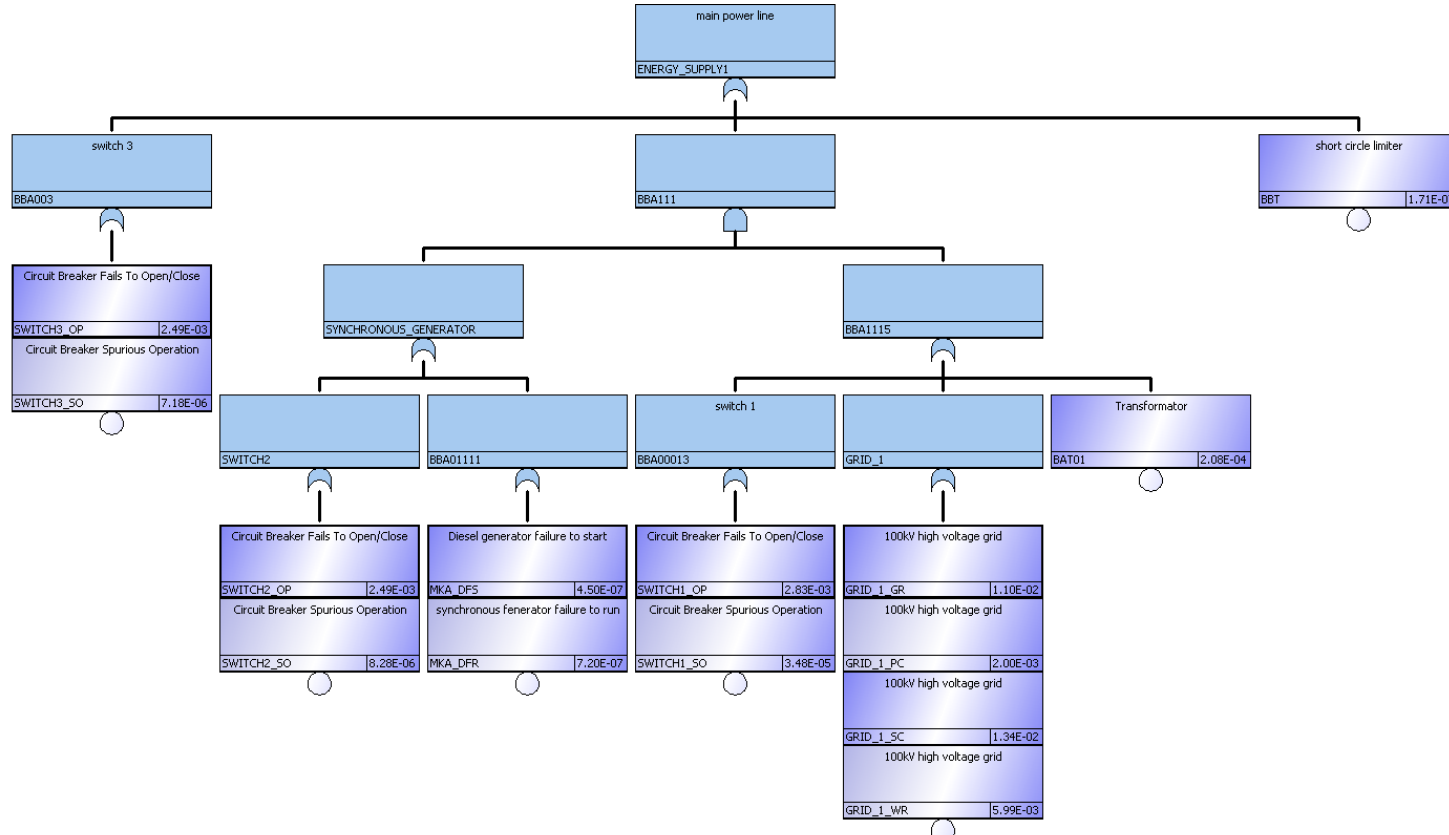
## FT BBA





# HTR with Grid Connection

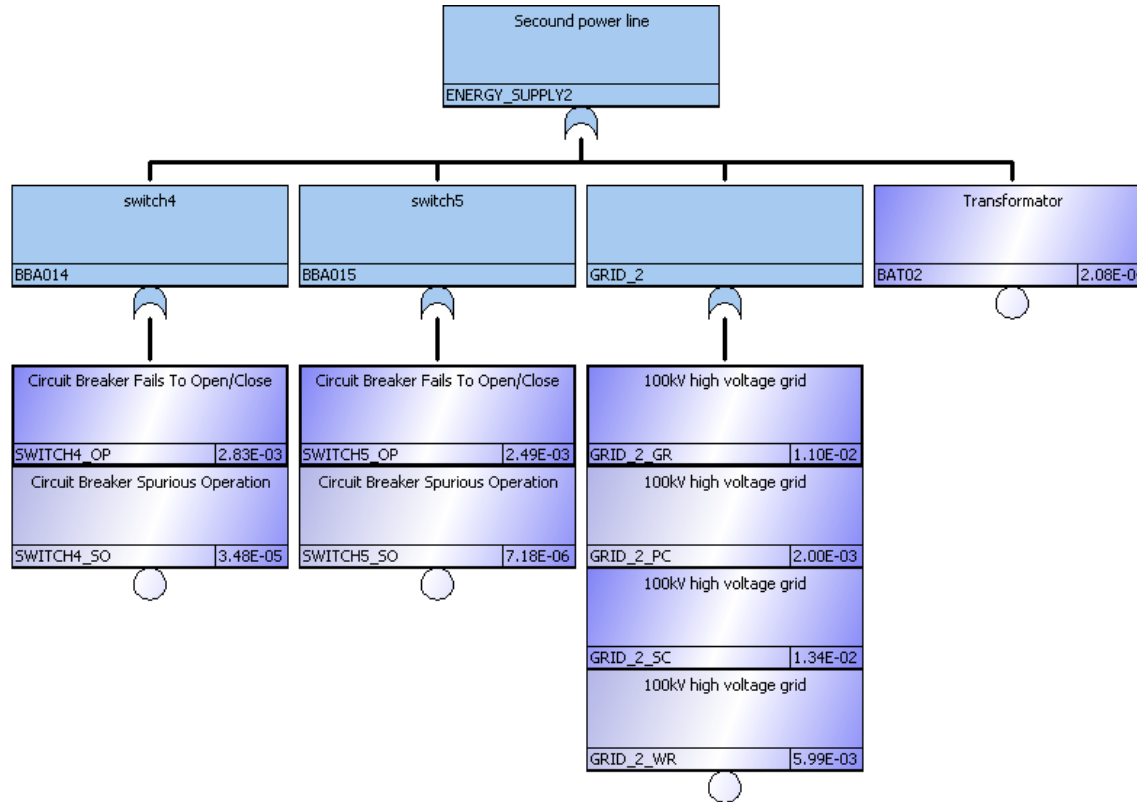
## FT Main Power Line





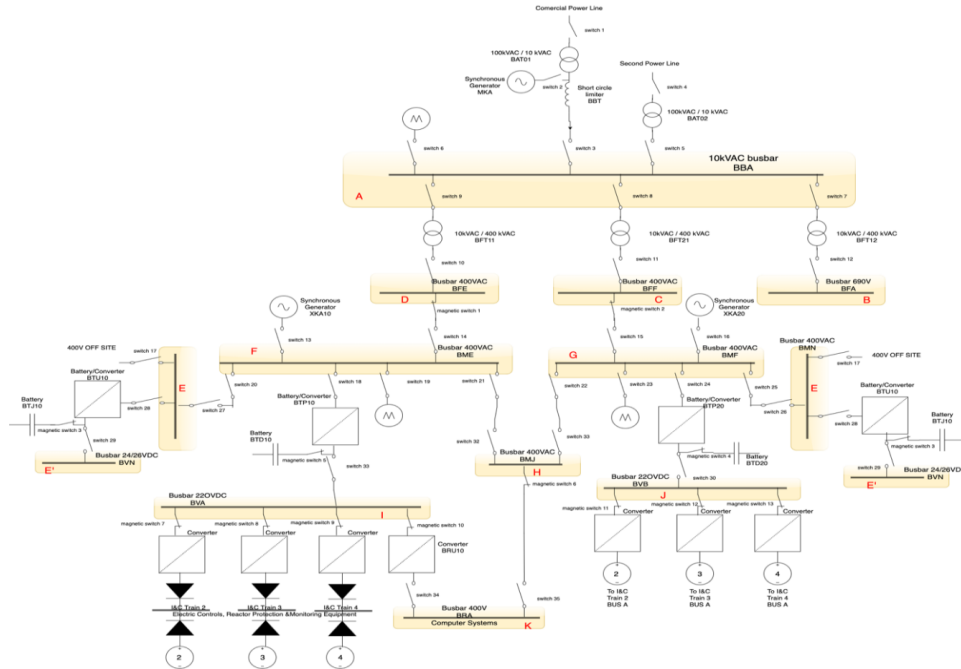
# HTR with Grid Connection

## FT Second Power Line

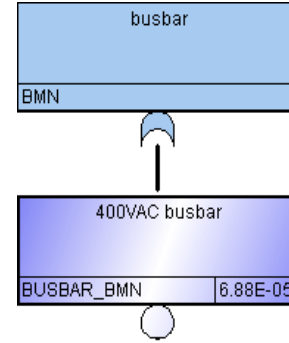




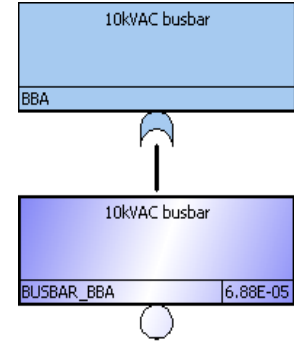
# HTR without Grid Connection



FT BMN

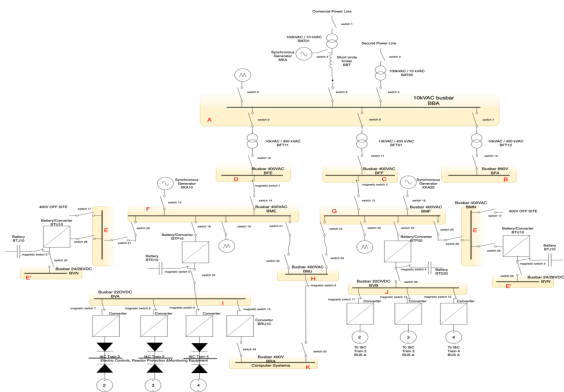


FT BBA





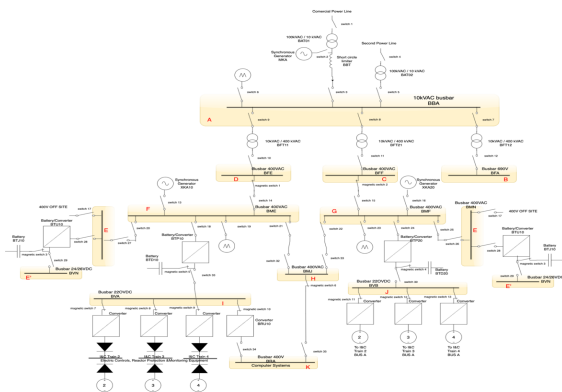
## Results of FT



Name of FT	Failure Probability	Cut sets	Cutoff
BBA	1.67E-04	280	-
BFA	3.97E-03	286	-
BFE	3.97E-03	286	-
BFF	3.97E-03	286	-
BME	9.46E-05	12761	-
BMF	9.46E-05	12761	-
BMJ	7.36E-05	223478	1e-25
BMN	3.31E-02	7	-
BRA	1.61E-03	223483	1e-25
BVA	1.71E-05	134786	1e-20
BVB	4.52E-04	9982	1e-20
BVN	4.67E-04	36	-
I&C_TRAIN_2	2.01E-06	97316	1e-20
I&C_TRAIN_3	2.01E-06	97316	1e-20
I&C_TRAIN_4	2.01E-06	97316	1e-20



## Results of FT I&C POWER

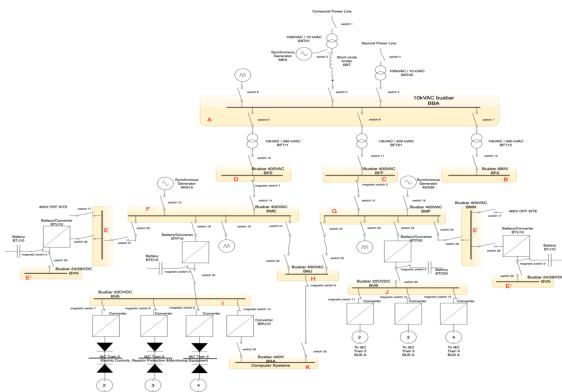


#	Failure Probability	#	Cut sets
<b>Total</b>	7.74E-9	100	50187
1	6.77E-9	87.4	BUSBAR_BVA, SWITCH30_OP 2
2	2.44E-10	3.15	BUSBAR_BVA, BUSBAR_BVB
3	1.93E-10	2.50	SWITCH30_OP, SWITCH33_OP, SWITCH34_OP
4	1.93E-10	2.50	SWITCH30_OP, SWITCH33_OP, SWITCH35_OP
5	8.12E-11	1.05	SWITCH30_OP, SWITCH33_OP, SWITCH_6_FTOC
6	8.12E-11	1.05	SWITCH30_OP, SWITCH33_OP, SWITCH_10_FTOC
7	6.71E-11	0.87	BRU10, SWITCH30_OP, SWITCH33_OP
8	3.98E-11	0.51	BUSBAR_BVA, SWITCH30_SO
9	1.29E-11	0.17	BUSBAR_BMJ, SWITCH30_OP, SWITCH33_OP
10	1.29E-11	0.17	BUSBAR_BRA, SWITCH30_OP, SWITCH33_OP
11	6.97E-12	0.09	BUSBAR_BVA, SWITCH24_OP, SWITCH_4_FTOC
12	6.97E-12	0.09	BUSBAR_BVB, SWITCH33_OP, SWITCH34_OP
13	6.97E-12	0.09	BUSBAR_BVB, SWITCH33_OP, SWITCH35_OP
14	2.93E-12	0.04	BUSBAR_BVB, SWITCH33_OP, SWITCH_6_FTOC
15	2.93E-12	0.04	BUSBAR_BVB, SWITCH33_OP, SWITCH_10_FTOC
16	2.42E-12	0.03	BRU10, BUSBAR_BVB, SWITCH33_OP
17	2.42E-12	0.03	BTP20_CONVERTER, BUSBAR_BVA, SWITCH_4_FTOC
18	1.35E-12	0.02	SWITCH30_OP, SWITCH33_OP, SWITCH34_SO
19	1.35E-12	0.02	SWITCH30_OP, SWITCH33_OP, SWITCH35_SO
20	1.14E-12	0.01	SWITCH30_SO, SWITCH33_OP, SWITCH34_OP



# HTR without Grid Connection

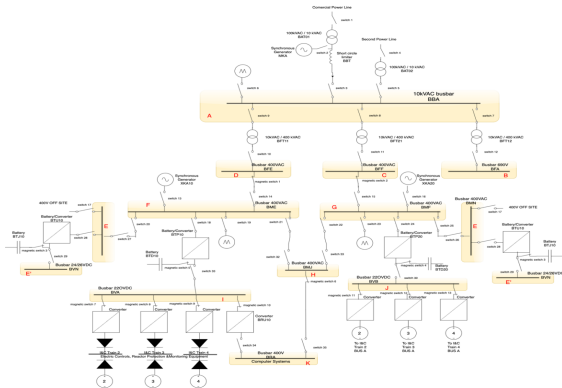
## Results of FT



Name of FT	Failure Probability	Cut sets	Cutoff
BBA	6.88E-05	1	-
BFA	3.88E-03	7	-
BFE	3.88E-03	7	-
BFF	3.88E-03	7	-
BME	7.03E-05	221	-
BMF	7.03E-05	221	-
BMJ	7.34E-05	29698	-
BMN	6.88E-05	1	-
BRA	1.61E-03	25832	1e-25
BVA	1.71E-05	80659	1e-25
BVB	4.52E-04	453	1e-25
BVN	4.52E-04	18	-
I&C_TRAIN_2	2.01e-06	196407	1e-25
I&C_TRAIN_3	2.01e-06	196407	1e-25
I&C_TRAIN_4	2.01e-06	196407	1e-25



## Results of FT I&C POWER



#	Failure Probability	%	Cut sets
<b>Total</b>	7.74E-9	100	134398
1	6.77E-9	87.42	BUSBAR_BVA,SWITCH30_OP
2	2.44E-10	3.15	BUSBAR_BVA,BUSBAR_BVB
3	1.93E-10	2.50	SWITCH30_OP,SWITCH33_OP,SWITCH34_OP
4	1.93E-10	2.50	SWITCH30_OP,SWITCH33_OP,SWITCH35_OP
5	8.12E-11	1.05	SWITCH30_OP,SWITCH33_OP,SWITCH_6_FTQC
6	8.12E-11	1.05	SWITCH30_OP,SWITCH33_OP,SWITCH_10_FTQC
7	6.71E-11	0.87	BRU10,SWITCH30_OP,SWITCH33_OP
8	3.98E-11	0.51	BUSBAR_BVA,SWITCH30_SO
9	1.29E-11	0.17	BUSBAR_BMJ,SWITCH30_OP,SWITCH33_OP
10	1.29E-11	0.17	BUSBAR_BRA,SWITCH30_OP,SWITCH33_OP
11	6.97E-12	0.09	BUSBAR_BVA,SWITCH24_OP,SWITCH_4_FTQC
12	6.97E-12	0.09	BUSBAR_BVB,SWITCH33_OP,SWITCH34_OP
13	6.97E-12	0.09	BUSBAR_BVB,SWITCH33_OP,SWITCH35_OP
14	2.93E-12	0.04	BUSBAR_BVB,SWITCH33_OP,SWITCH_6_FTQC
15	2.93E-12	0.04	BUSBAR_BVB,SWITCH33_OP,SWITCH_10_FTQC
16	2.42E-12	0.03	BRU10,BUSBAR_BVB,SWITCH33_OP
17	2.42E-12	0.03	BTP20_CONVERTER,BUSBAR_BVA,SWITCH_4_FTQC
18	1.35E-12	0.02	SWITCH30_OP,SWITCH33_OP,SWITCH34_SO
19	1.35E-12	0.02	SWITCH30_OP,SWITCH33_OP,SWITCH35_SO
20	1.14E-12	0.01	SWITCH30_SO,SWITCH33_OP,SWITCH34_OP

# Conclusion

- Based on the electrical system model proposed in the Gemini + project, a model of the system reliability in the form of fault trees was developed using the Sapphire program. The safety analysis of the electrical system shows the probability of failure at the level of  $7.74E-09$  both for the model with and without connection to the grid.
- The biggest difference is seen in BBA FT and BMN. The results for the BBA busbar are significantly different for both cases due to the removal of components from the fault tree. For BMN FT from the same reson.
- The fact that the obtained final probability values are the same for both cases is interesting and rather unexpected.

Name of FT	Results with grid connection	Results without grid connection
BBA	1.67E-04	6.88E-05
BFA	3.97E-03	3.88E-03
BFE	3.97E-03	3.88E-03
BFF	3.97E-03	3.88E-03
BME	9.46E-05	7.03E-05
BMF	9.46E-05	7.03E-05
BMJ	7.36E-05	7.34E-05
BMN	3.31E-02	6.88E-05
BRA	1.61E-03	1.61E-03
BVA	1.71E-05	1.71E-05
BVB	4.52E-04	4.52E-04
BVN	4.67E-04	4.52E-04
I&C_TRAIN_2	2.01E-06	2.01E-06
I&C_TRAIN_3	2.01E-06	2.01E-06
I&C_TRAIN_4	2.01E-06	2.01E-06
I&C POWER	7.74E-09	7.74E-09



# References

1. A Dr. Gerd BRINKMANN, Dieter Vanvor, Angela Jung, Final GEMINI + Safety Options Report, 2020, 141-152
2. Dr. Gerd BRINKMANN, Dieter Vanvor, Angela Jung, Final GEMINI + Safety Options Report, 2020, 395
3. Curtis Smith, James Knudsen, Kurt Vedros, Michael Calley, Kellie Kvarfordt, Ted Wood, SAPHIRE 8 Basics, Idaho National Laboratory, 109
4. NRC Data
5. Pankaj Yadov, Peter Watson, Mike Irwing, Gerasimos Doris, Respond Is Limiter Safet Justification, Manchester, 2019, 27
6. Mitsubishi High Power Semiconductors, Semiconductor Device Reliability, 1998

**Thank you**  
**for your attention**



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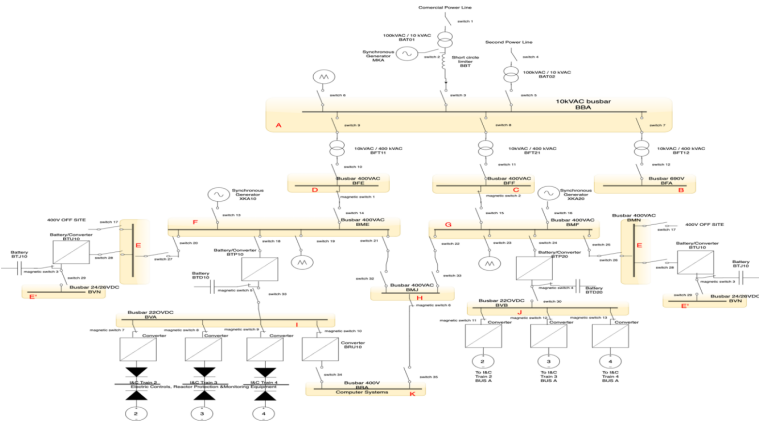
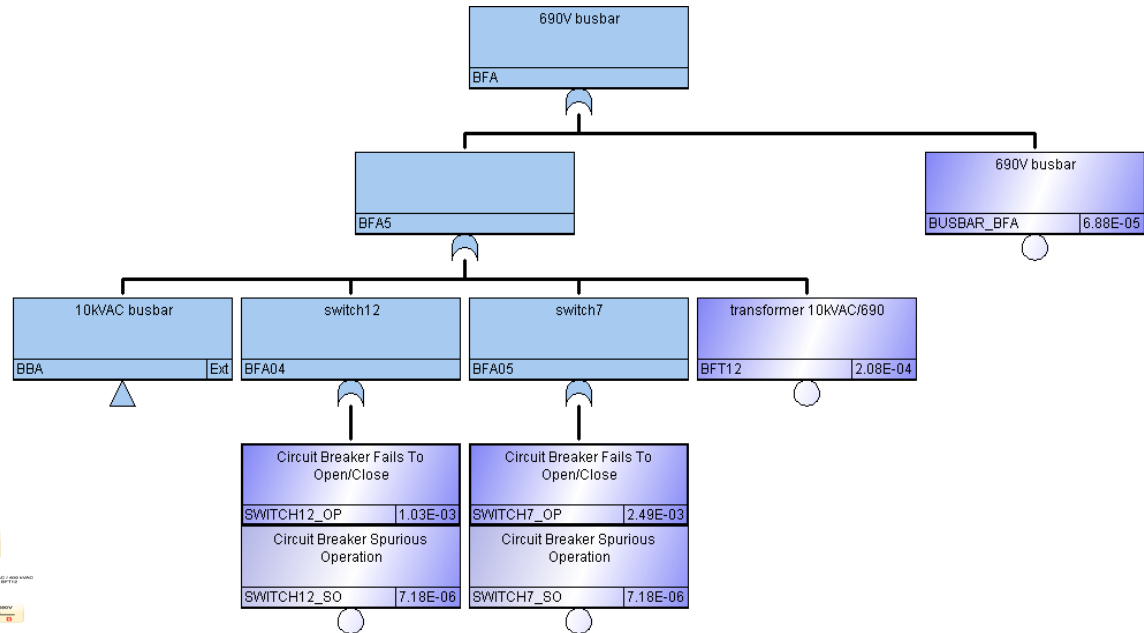
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# HTR with Grid Connection

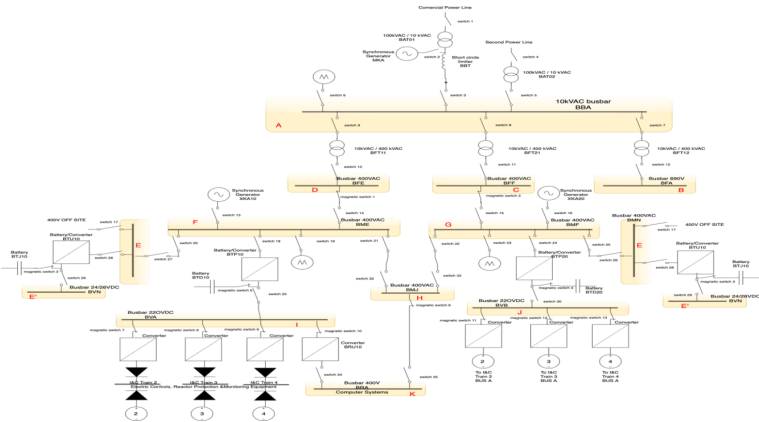
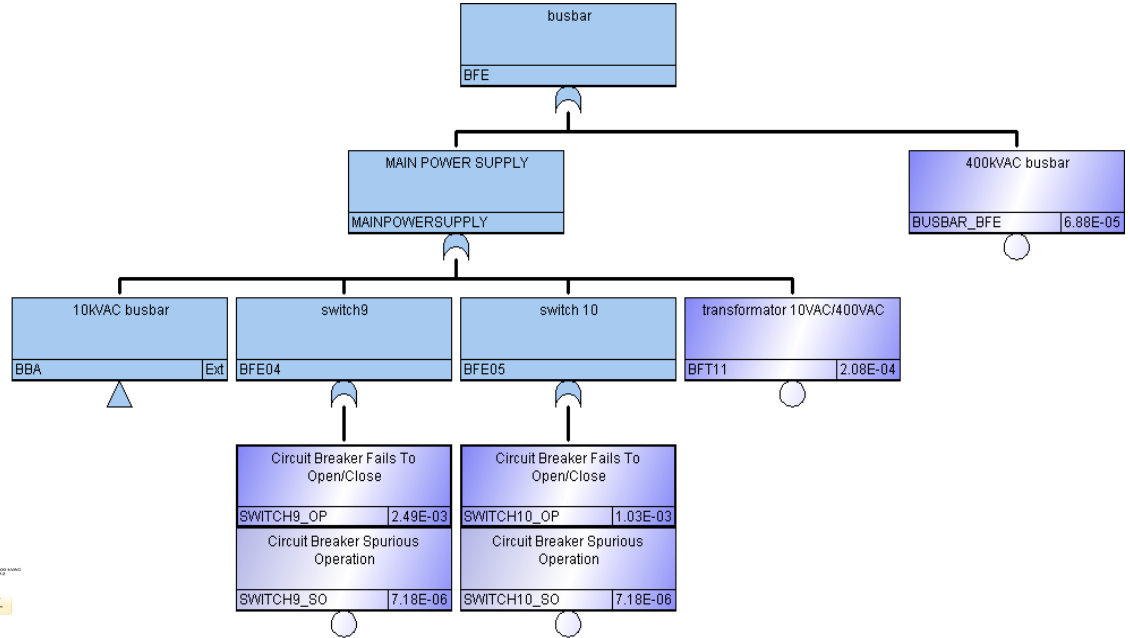
## FT BFA





# HTR with Grid Connection

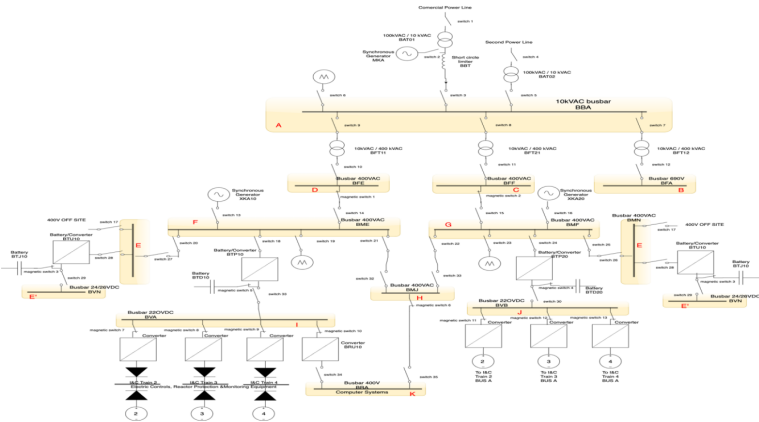
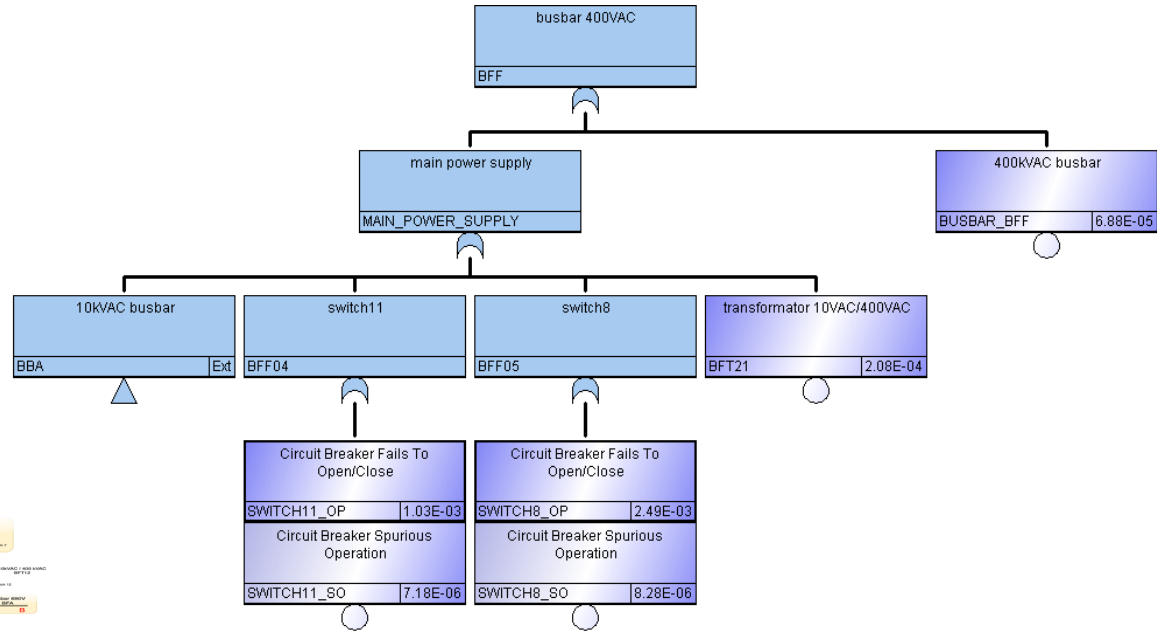
FT BFE





# HTR with Grid Connection

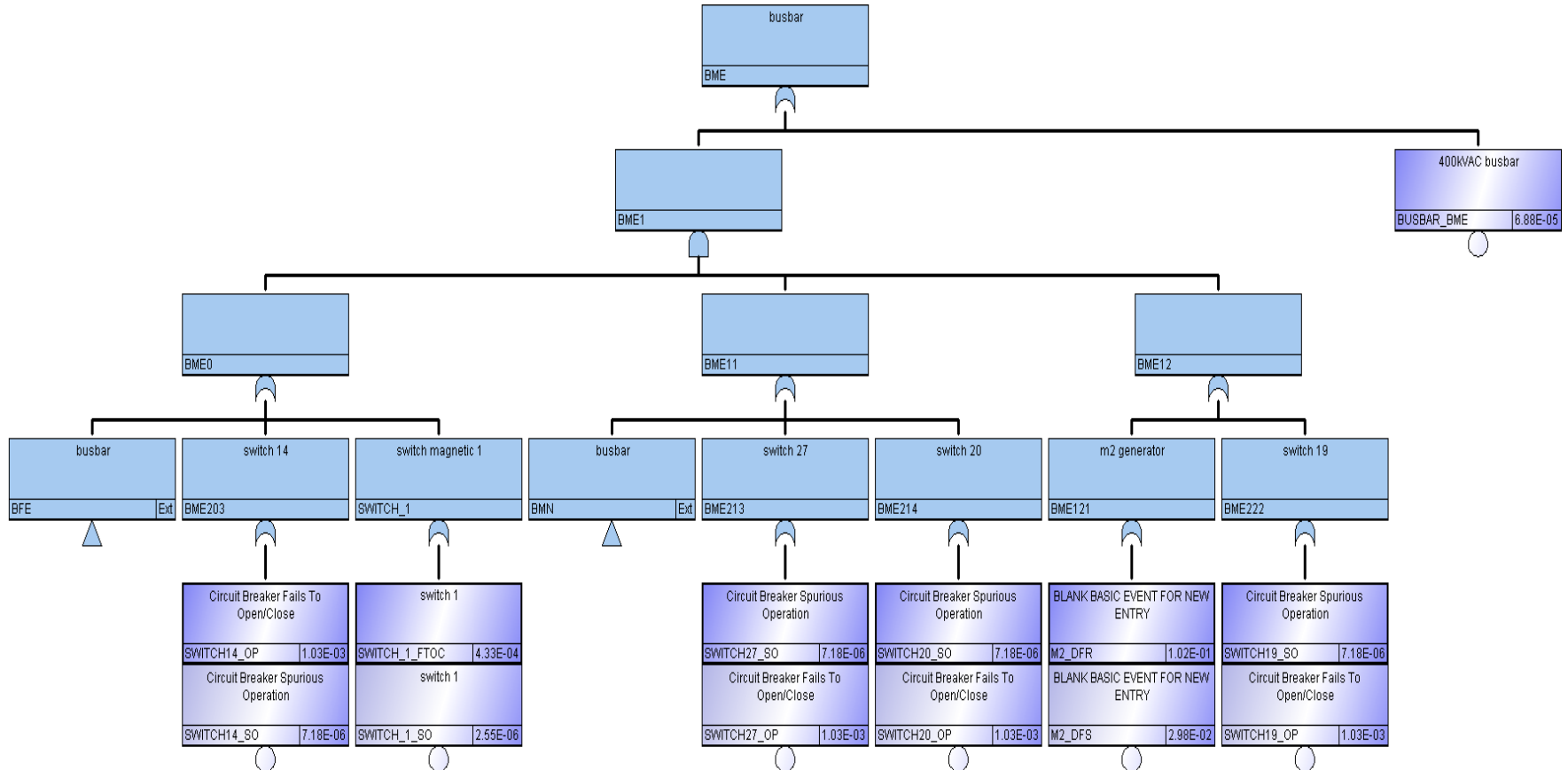
FT BFF





# HTR with Grid Connection

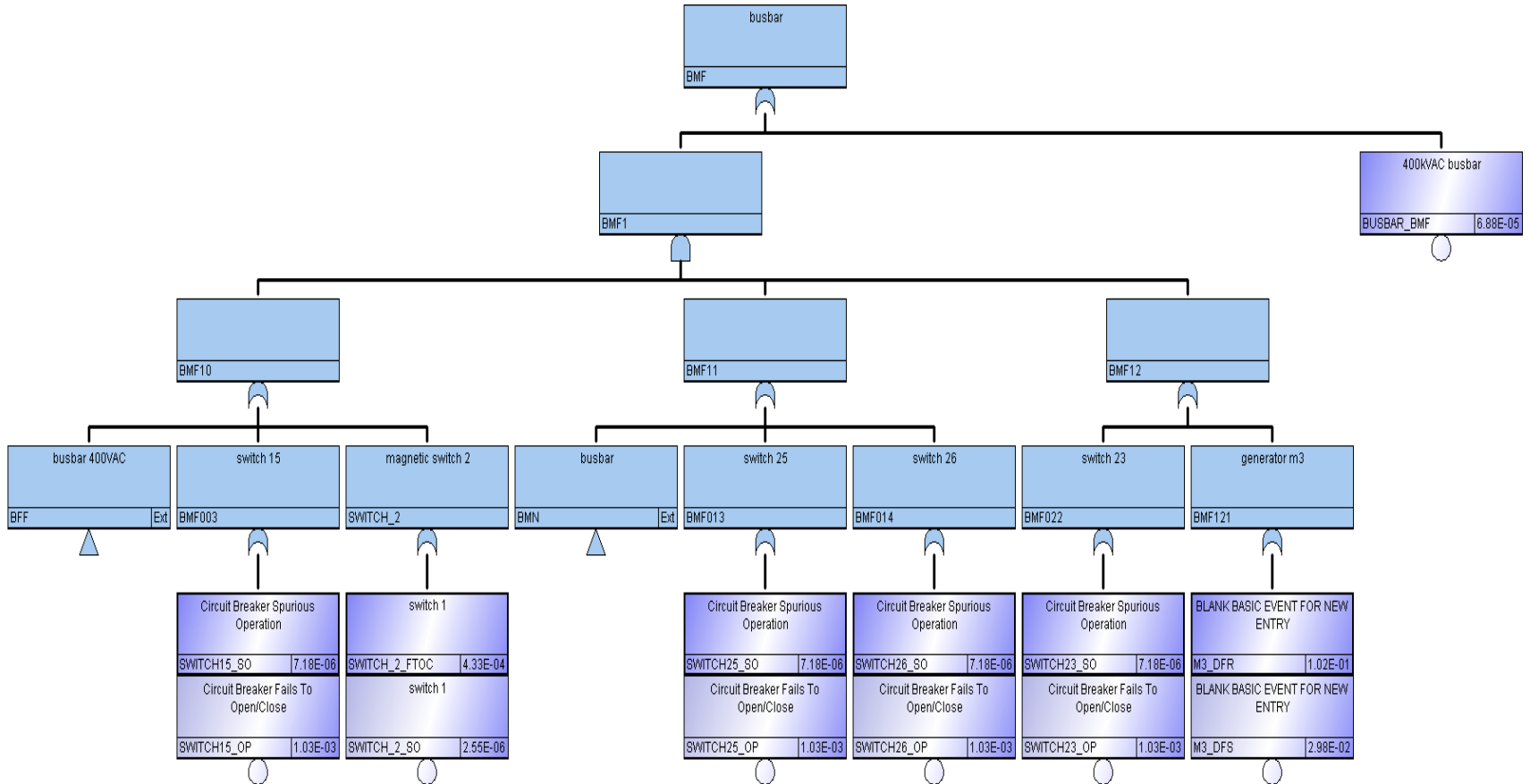
## FT BME





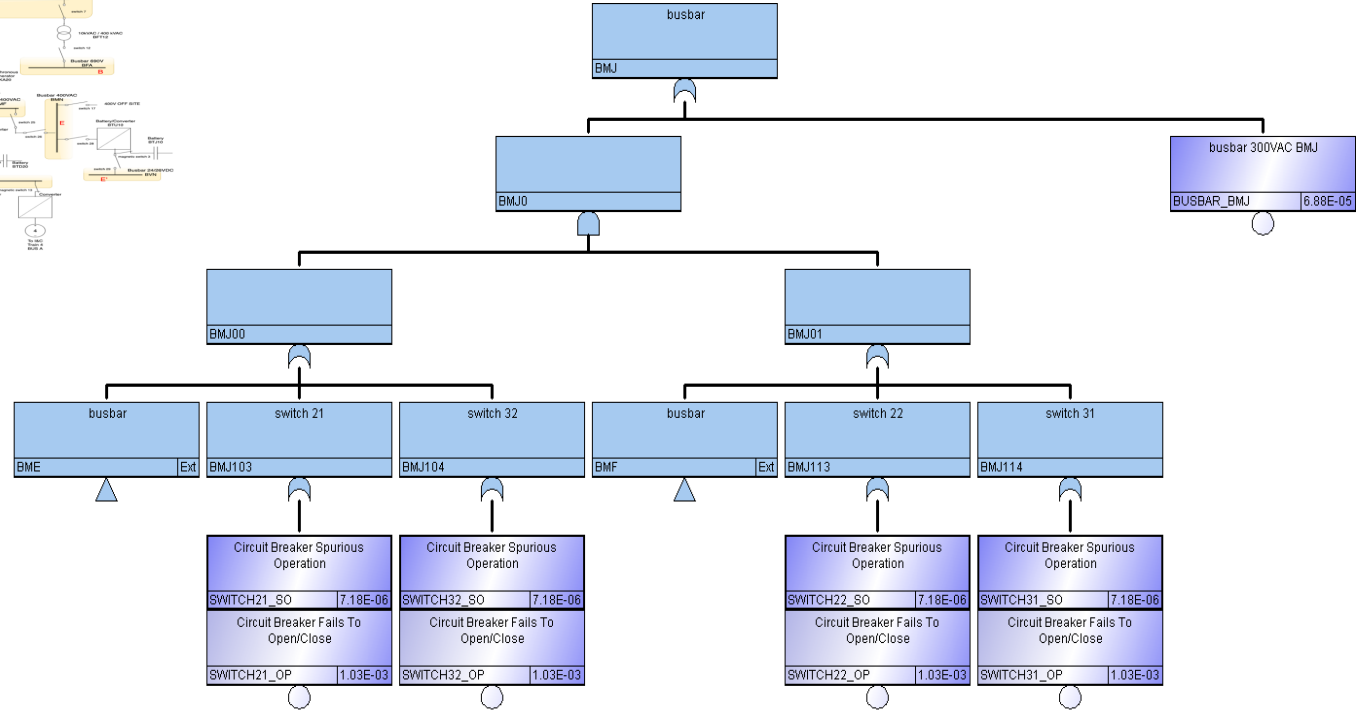
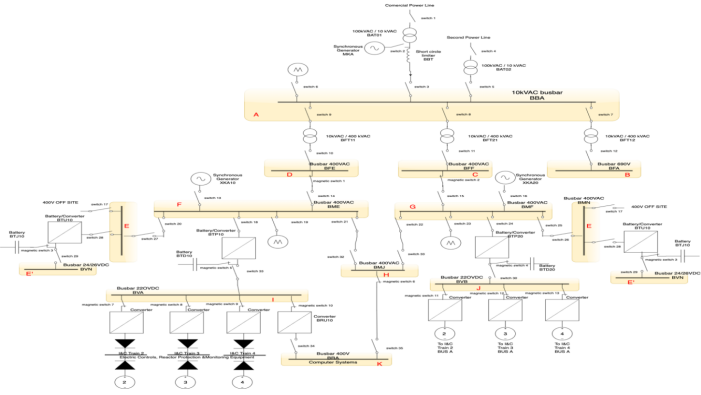
# HTR with Grid Connection

## FT BMF



# HTR with Grid Connection

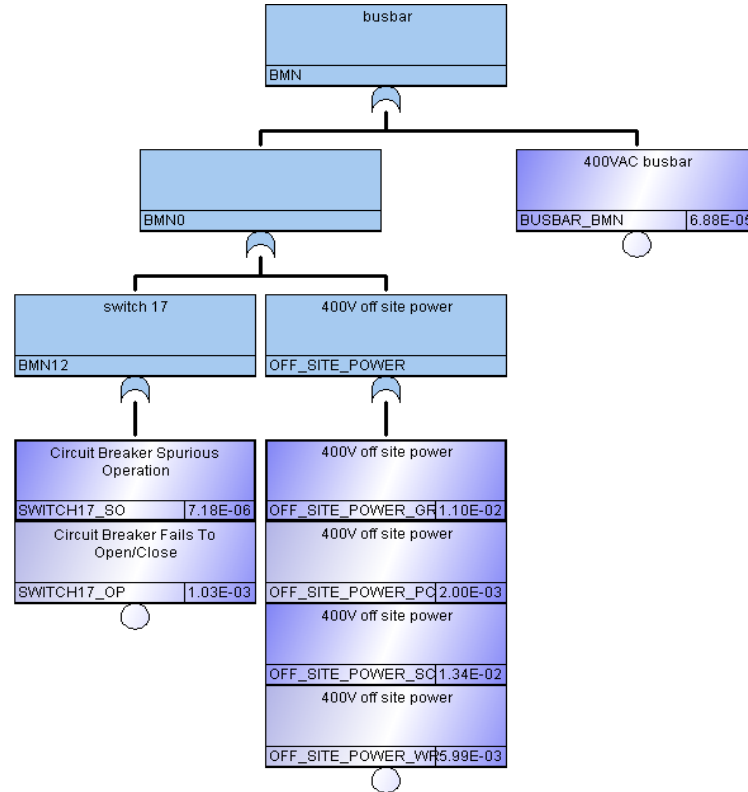
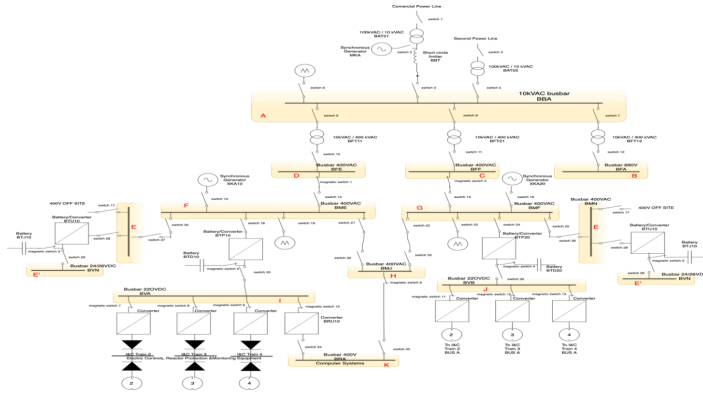
FT BMJ





# HTR with Grid Connection

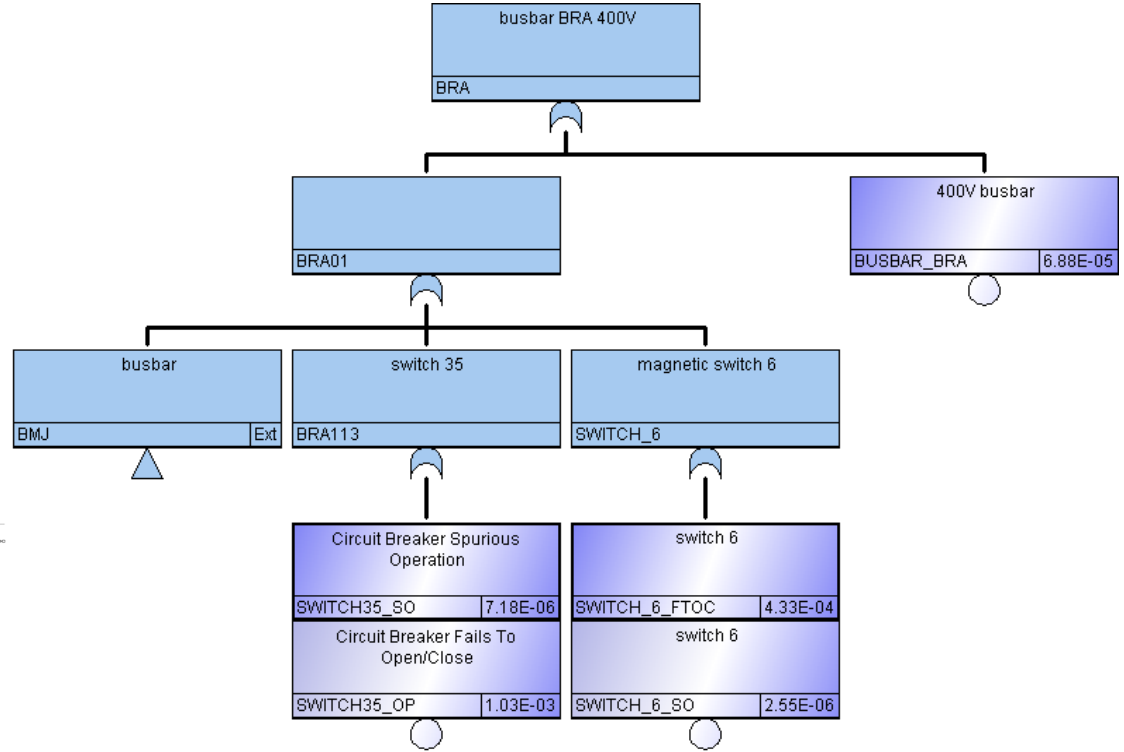
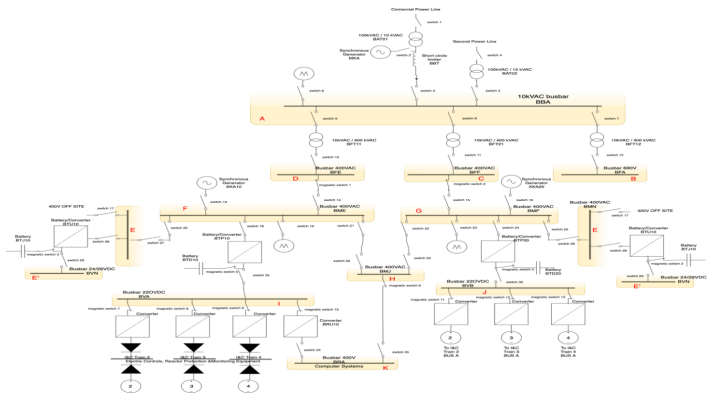
FT BMN





# HTR with Grid Connection

FT BRA

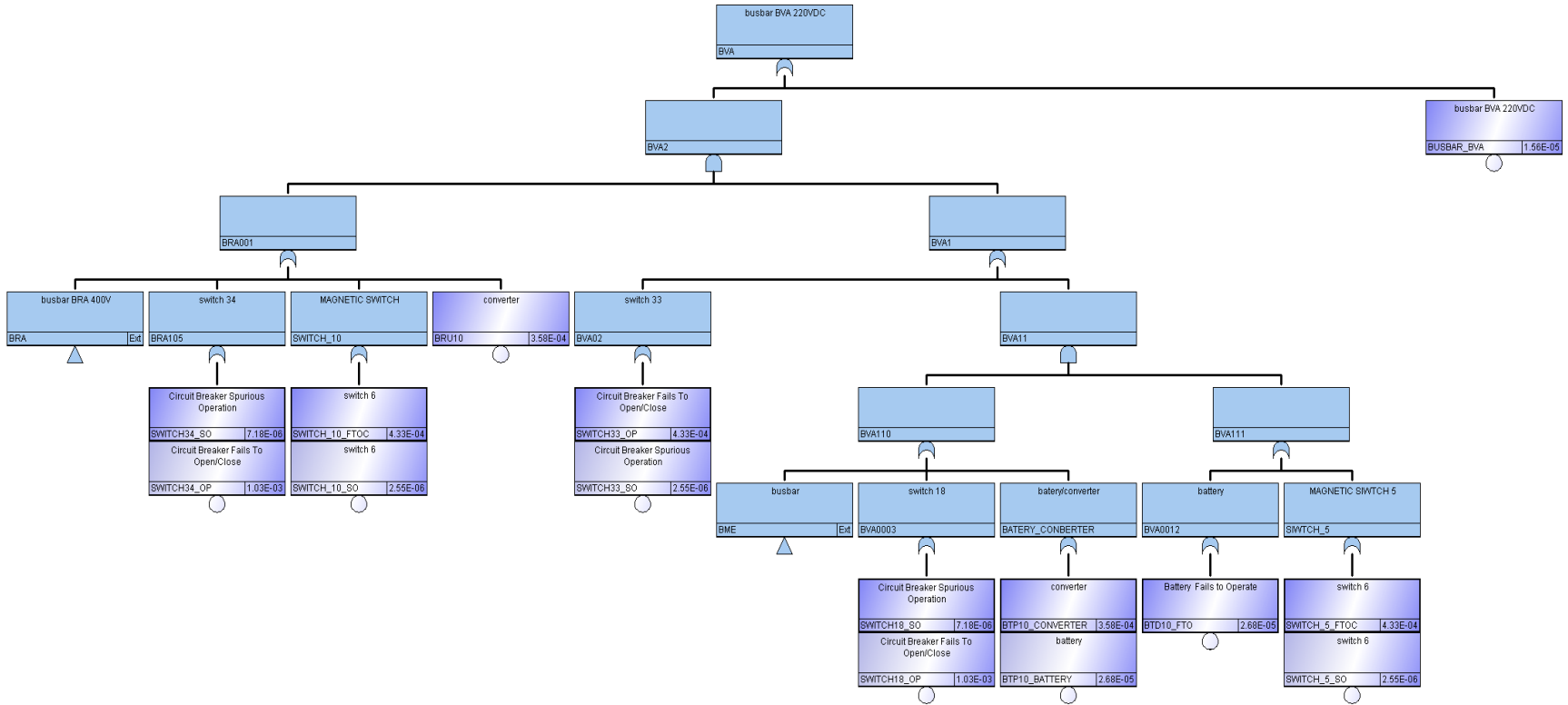






# HTR with Grid Connection

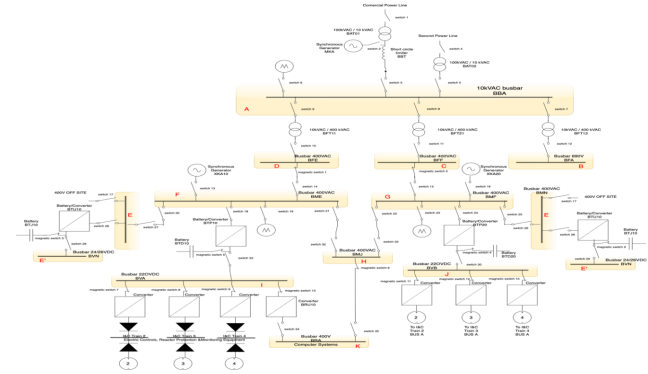
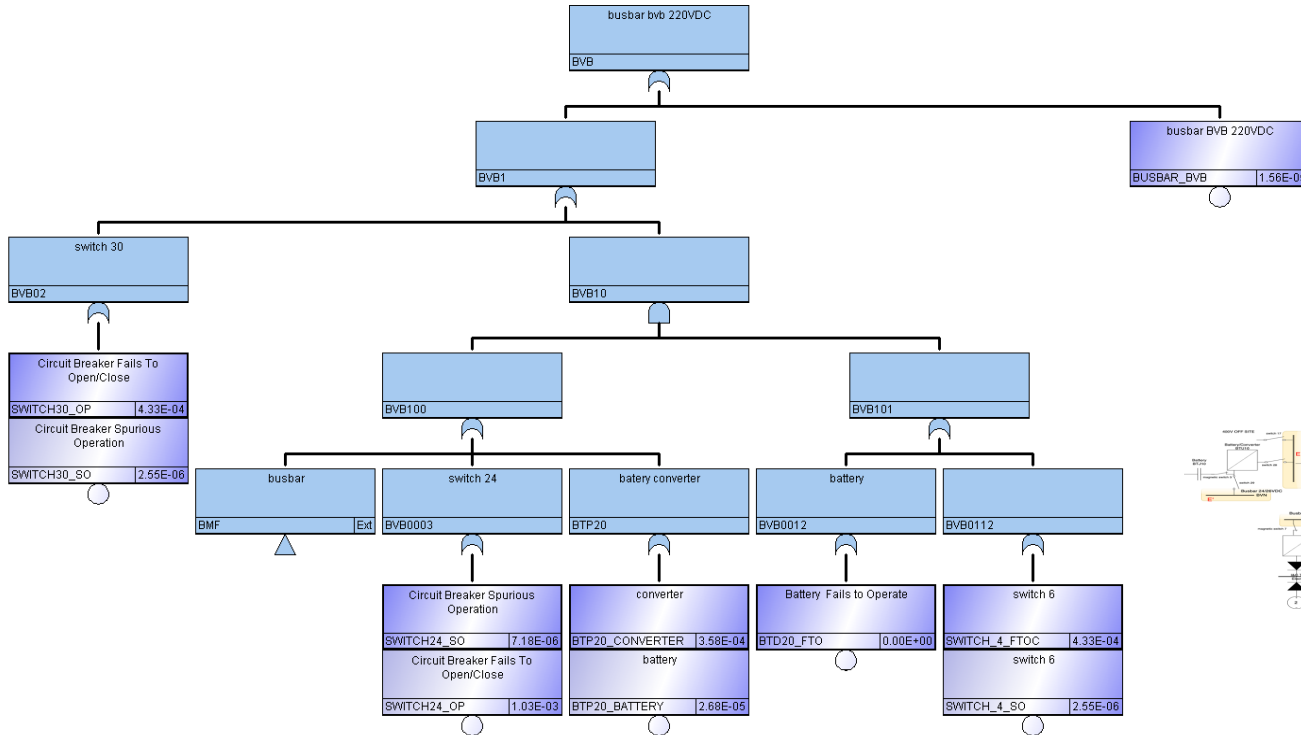
## FT BVA





# HTR with Grid Connection

FT BVB





# HTR with Grid Connection

FT BVN

