
Alewijnse
Why DC grids?
Advantages
• Improved Efficiency
• Simplified Easy integration of energy storage and decentralized RE sources
• Reduced Electromagnetic Interference
AC VS DC
Challenges
DC-GRID MODELLING
DC grid modelling with short circuit analysis and protection study
Objectives
• Safety mechanisms of battery systems.
• Examine the impact of short circuits.
• Develop software models for key components such as generator, DC-DC converter, AFE rectifier, fuses, circuit breakers, battery systems, and link capacitors.
• Integrate these models into a simulation environment.
• Analyse DC grid dynamics and improved protection systems.
The ins and outs of DC grid
Simulink Model
Single line diagram of the DC grid
Simulink Model of the DC grid
Future Developments
• Verification and Validation
• Test Setup and Class Approval
• An extensive model of Solid-state circuit breaker (SSCB).
• Integration of SSCB model into the existing model
Example Projects
Simulations
DC Grid Protection
Fuse Model
DC CB Model
Simulink Model with protective devices

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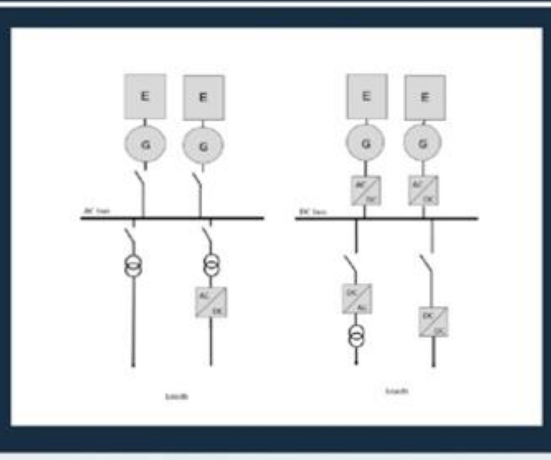
AC VS DC



Challenges

1. Absence of Natural zero-crossing
2. Arcing Issues
3. Fault Detection
4. Coordination of Protective Devices

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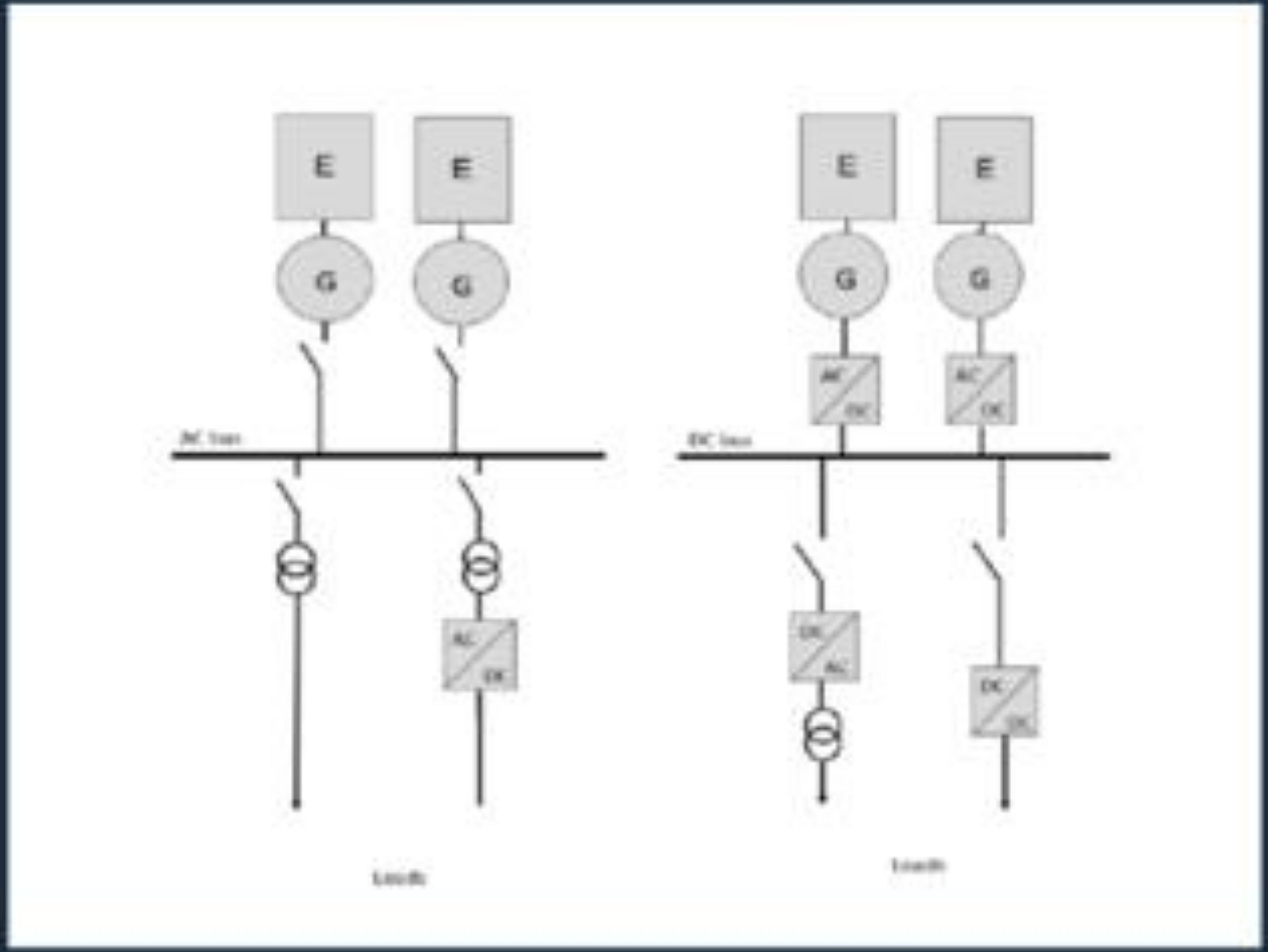

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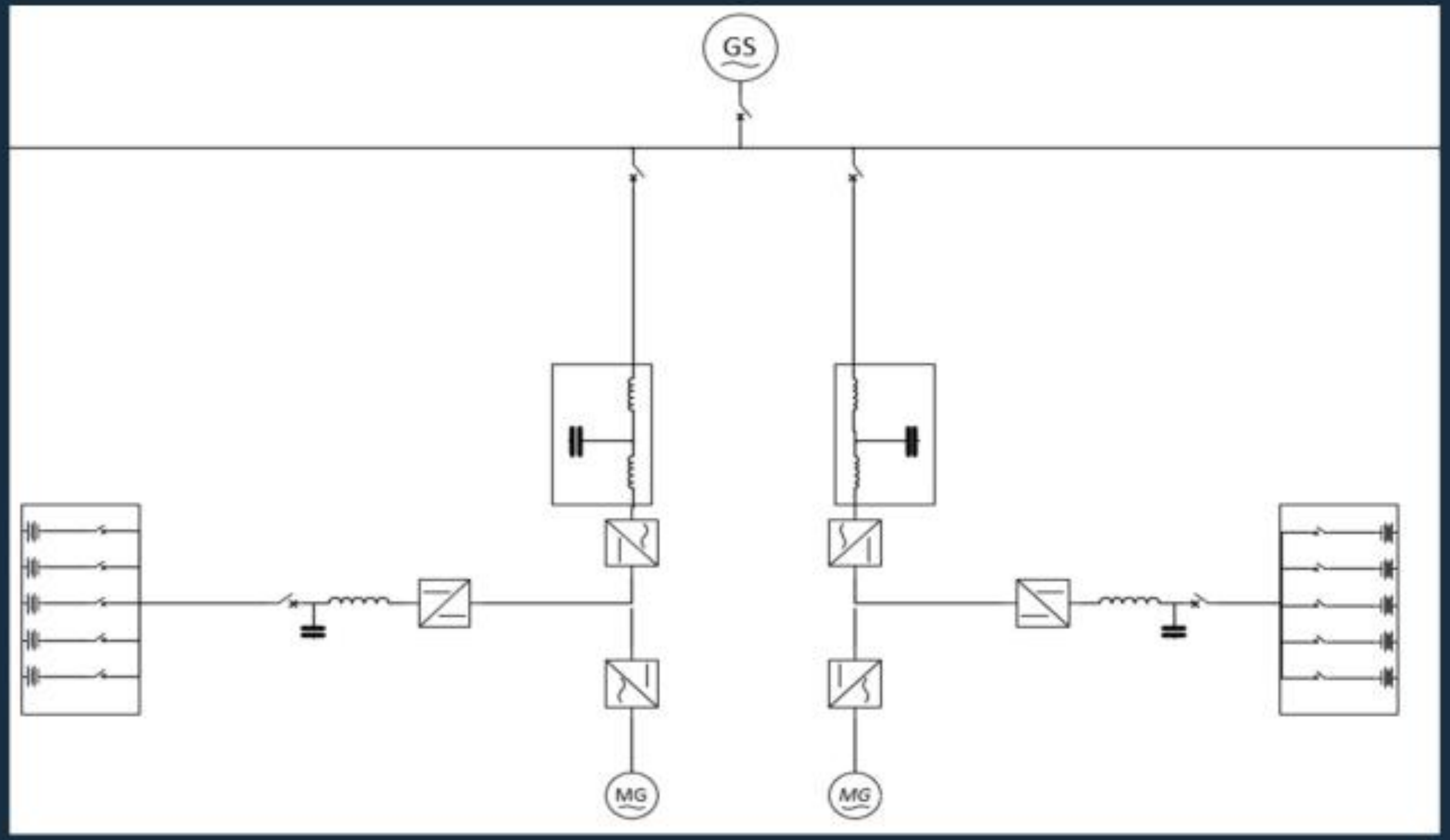
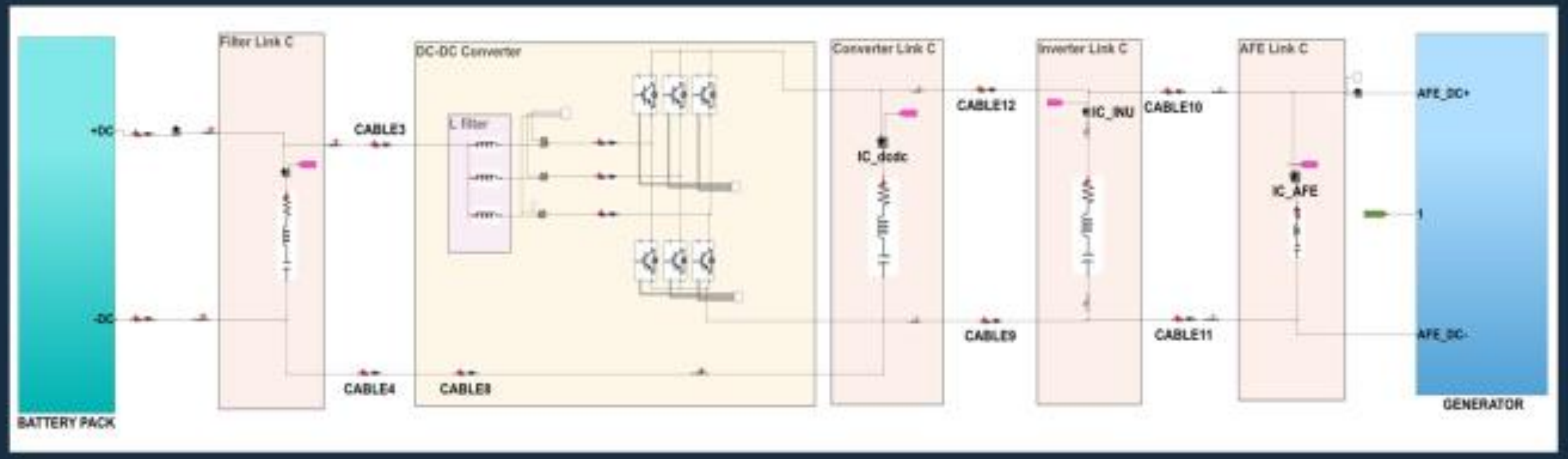
Simulink Model

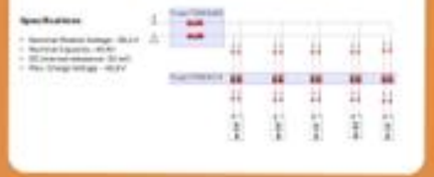
Single line diagram of the DC grid



Simulink Model of the DC grid



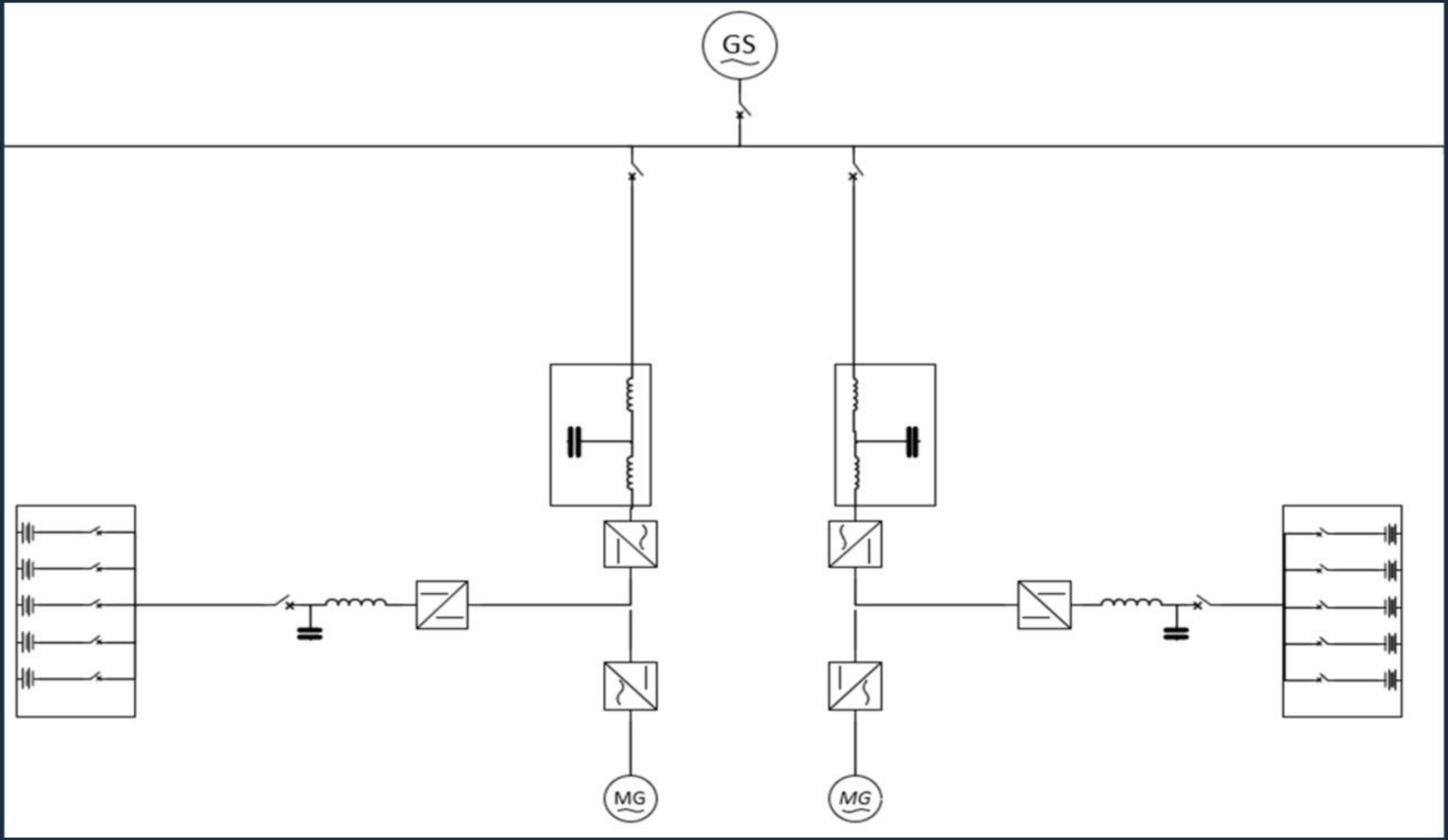
Battery system model



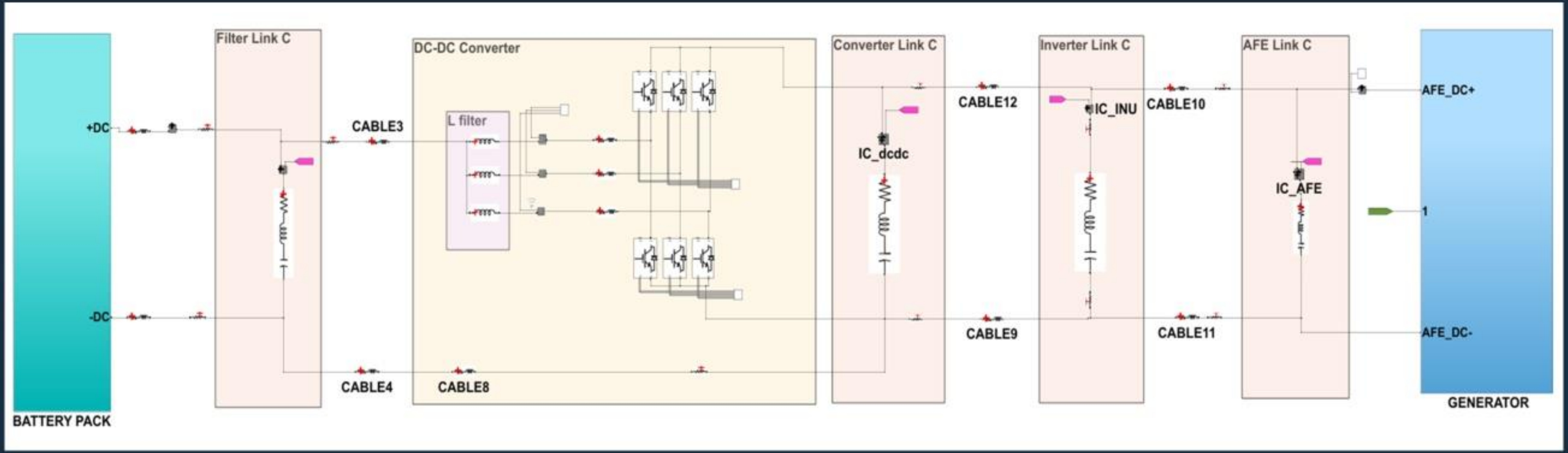
Electrical drives

Generator Subsystem

Single line diagram of the DC grid



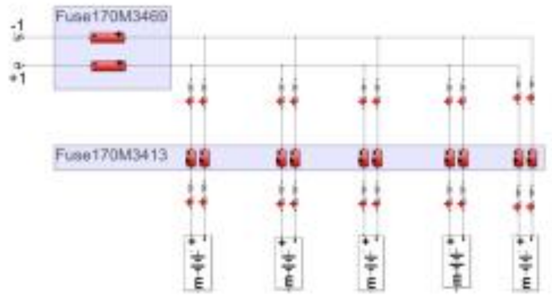
Simulink Model of the DC grid



Battery system model

Specifications

- Nominal Module Voltage – 38,4 V
- Nominal Capacity – 45 Ah
- DC internal resistance- 25 mΩ
- Max. Charge Voltage - 43,8 V



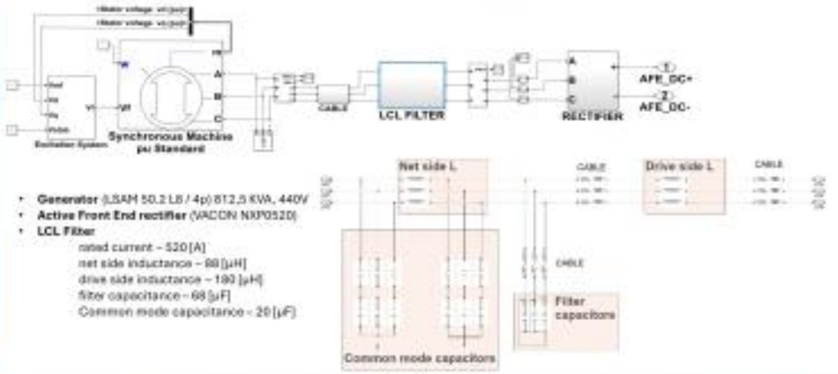
Electrical drives

Drive	DC voltage[V]	Capacitance [mF]	ESR [mΩ]	ESL [nH]
NXP0520 (AFE)	700	10.8	6.67	5.33
NXP0730 (INU)	700	10.8	6.67	5.33
NXP0168 (DC-DC)	700	7.2	10	8

IGBT's parameters :

- IGBT saturation voltage = 1.9V
- IGBT resistance = 3.7mΩ
- Diode threshold voltage = 1.5V
- Diode resistance = 2.7mΩ
- Inverse Diode I^2t = 93000A^2s
- Inverse Diode I_{fsm} = 4320A (10ms)

Generator Subsystem



- **Generator** (LSAM 50.2 L8 / 4p) 812,5 KVA, 440V
- **Active Front End rectifier** (VACON NXP0520)
- **LCL Filter**
  - rated current – 520 [A]
  - net side inductance – 88 [μH]
  - drive side inductance – 180 [μH]
  - filter capacitance – 68 [μF]
  - Common mode capacitance – 20 [μF]

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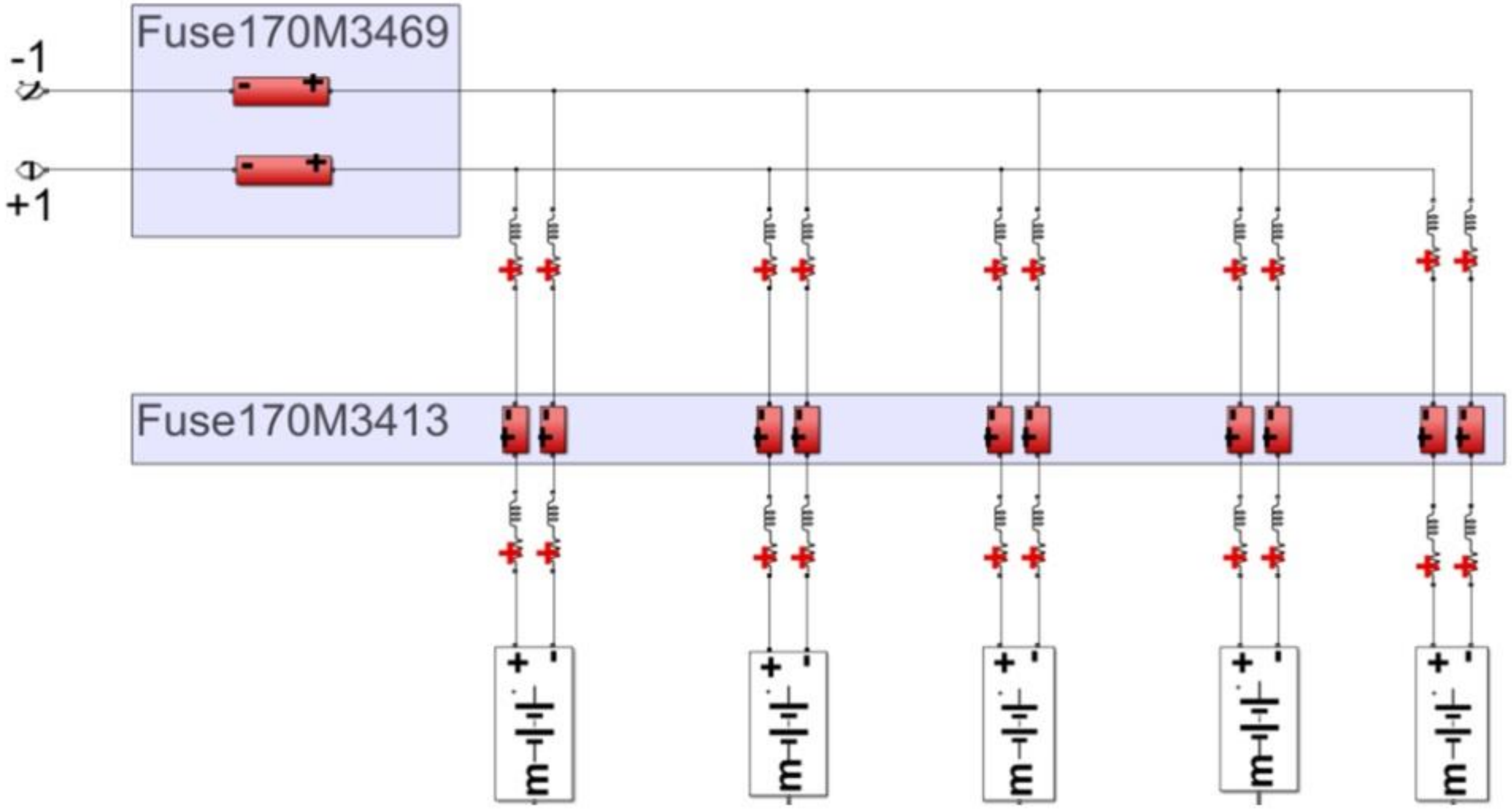

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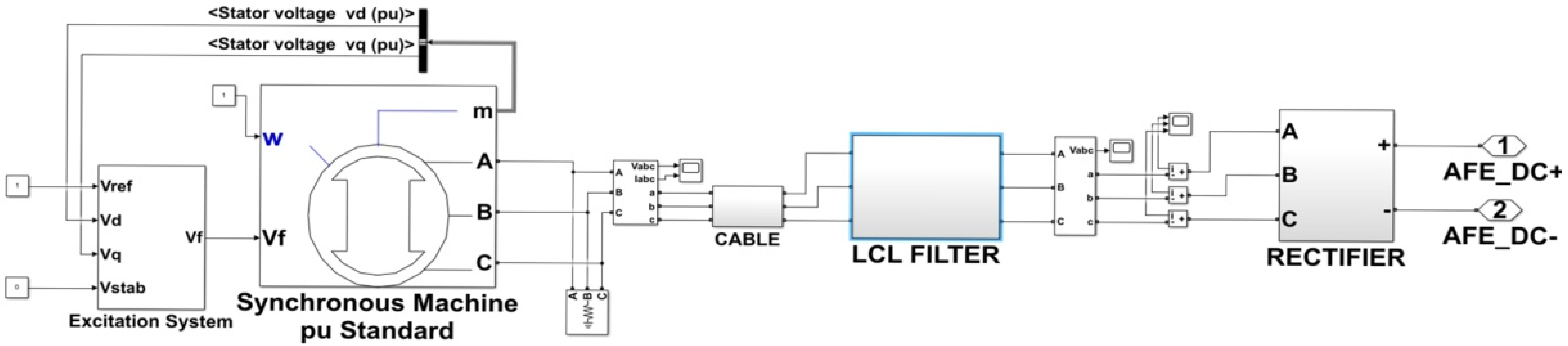

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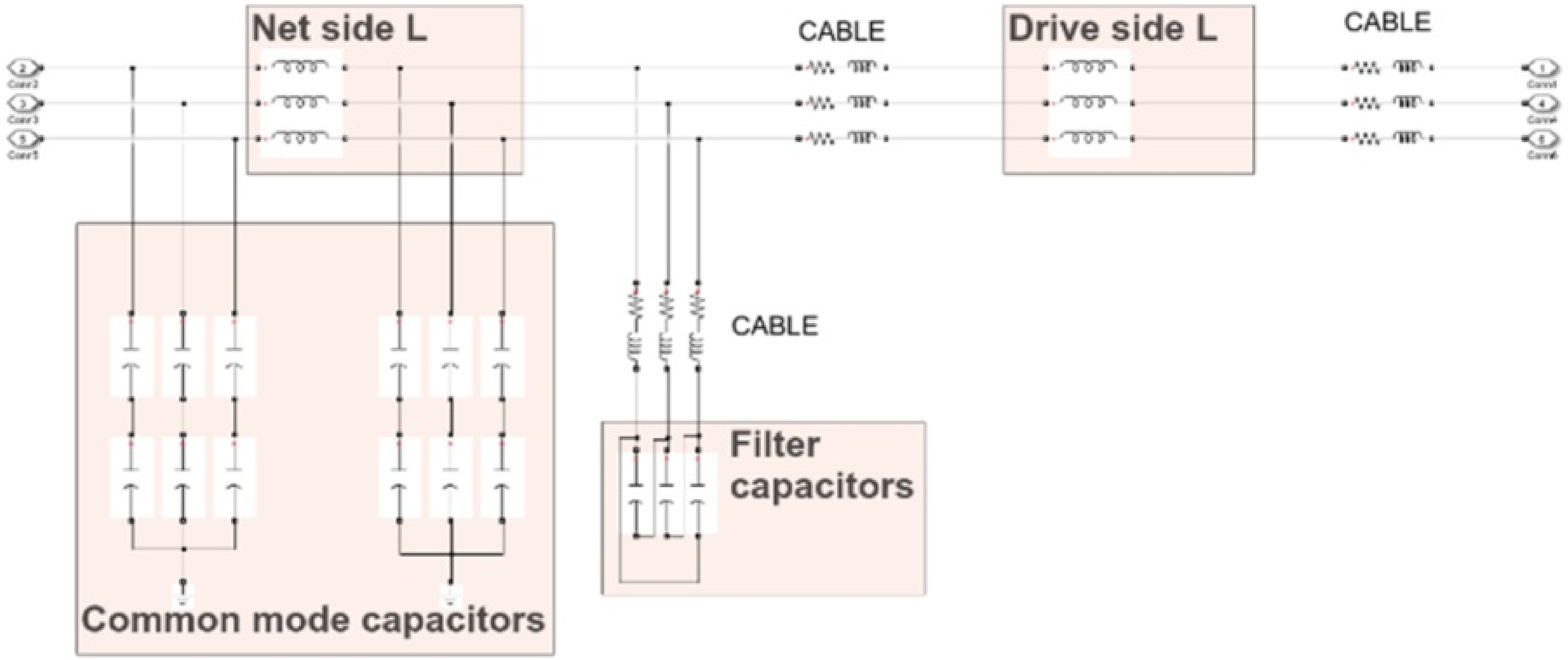
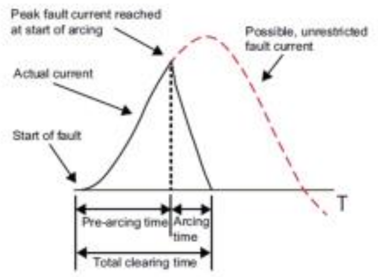


DC Grid Protection

Fuse Model

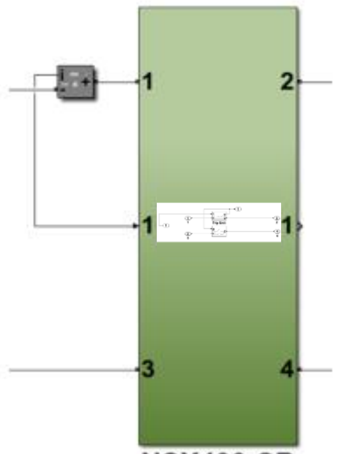
High speed fuses Bussman type are used, and the electrical characteristics are presented in the table below.

Type	Rated current [A]	Pre-arc [I^2t]	Clearing [I^2t]	Loss [W]
170M3469	400	15000	105000	60
170M6462	800	69500	465000	115
170M6464	1000	140000	945000	125



170M3469 FUSE2

DC CB Model



NSX400 CB

Simulink Model with protective devices

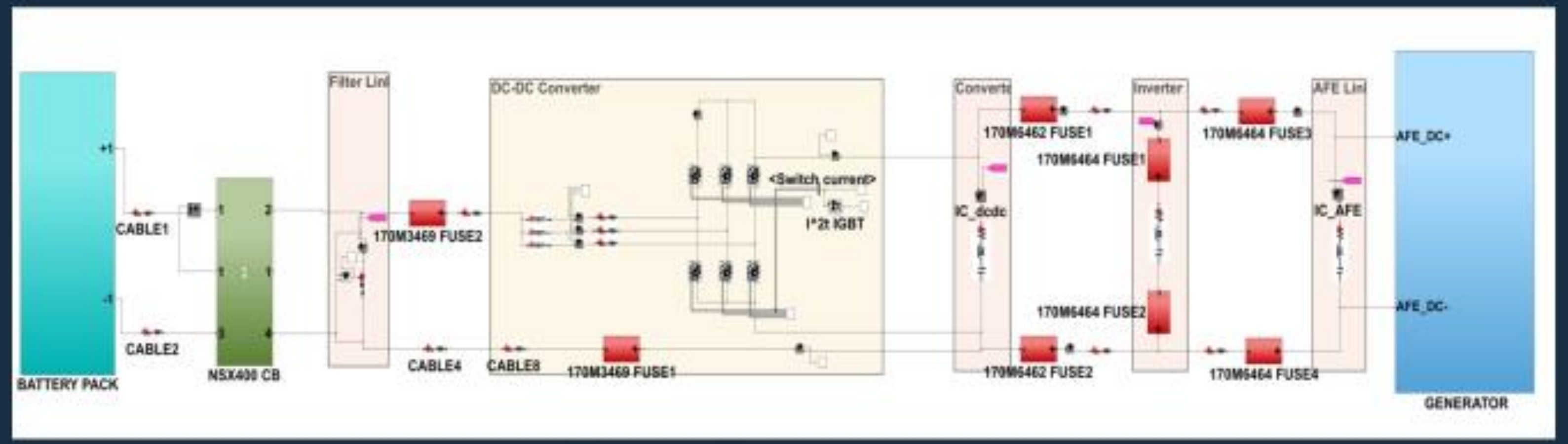


Figure: Model with fuses and circuit breakers

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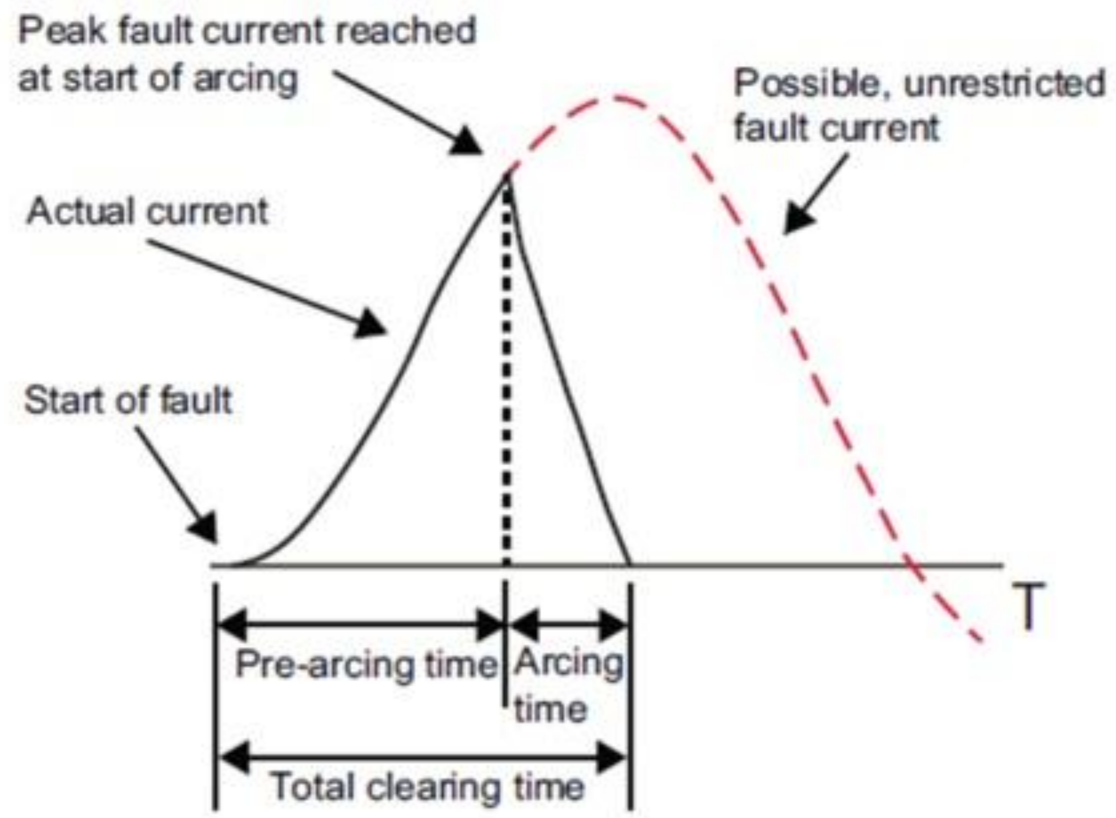
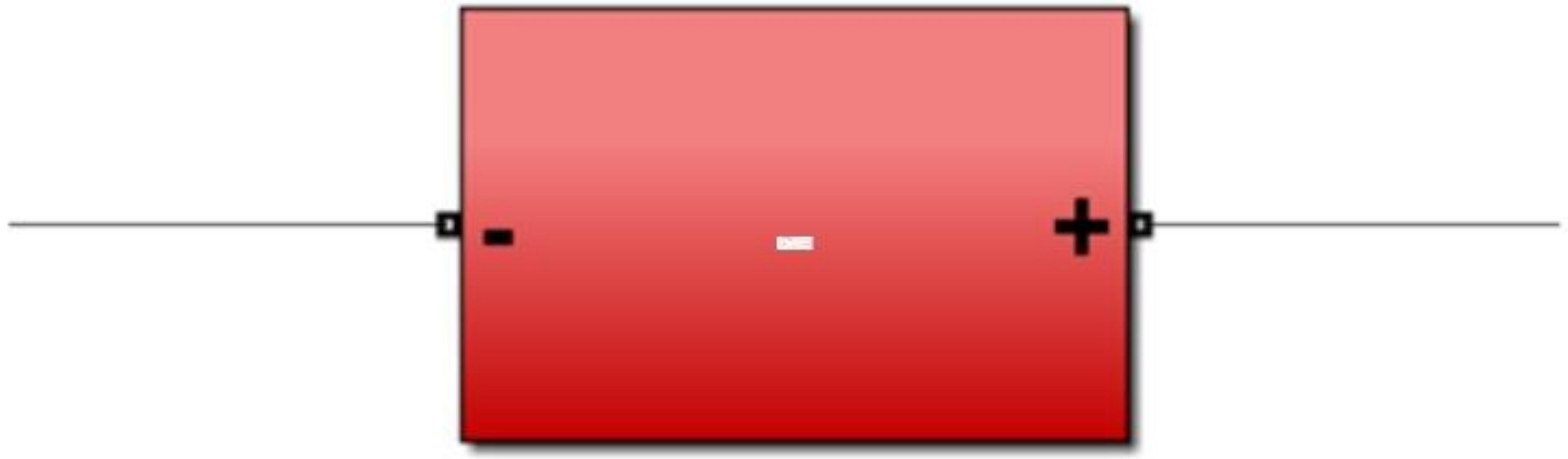
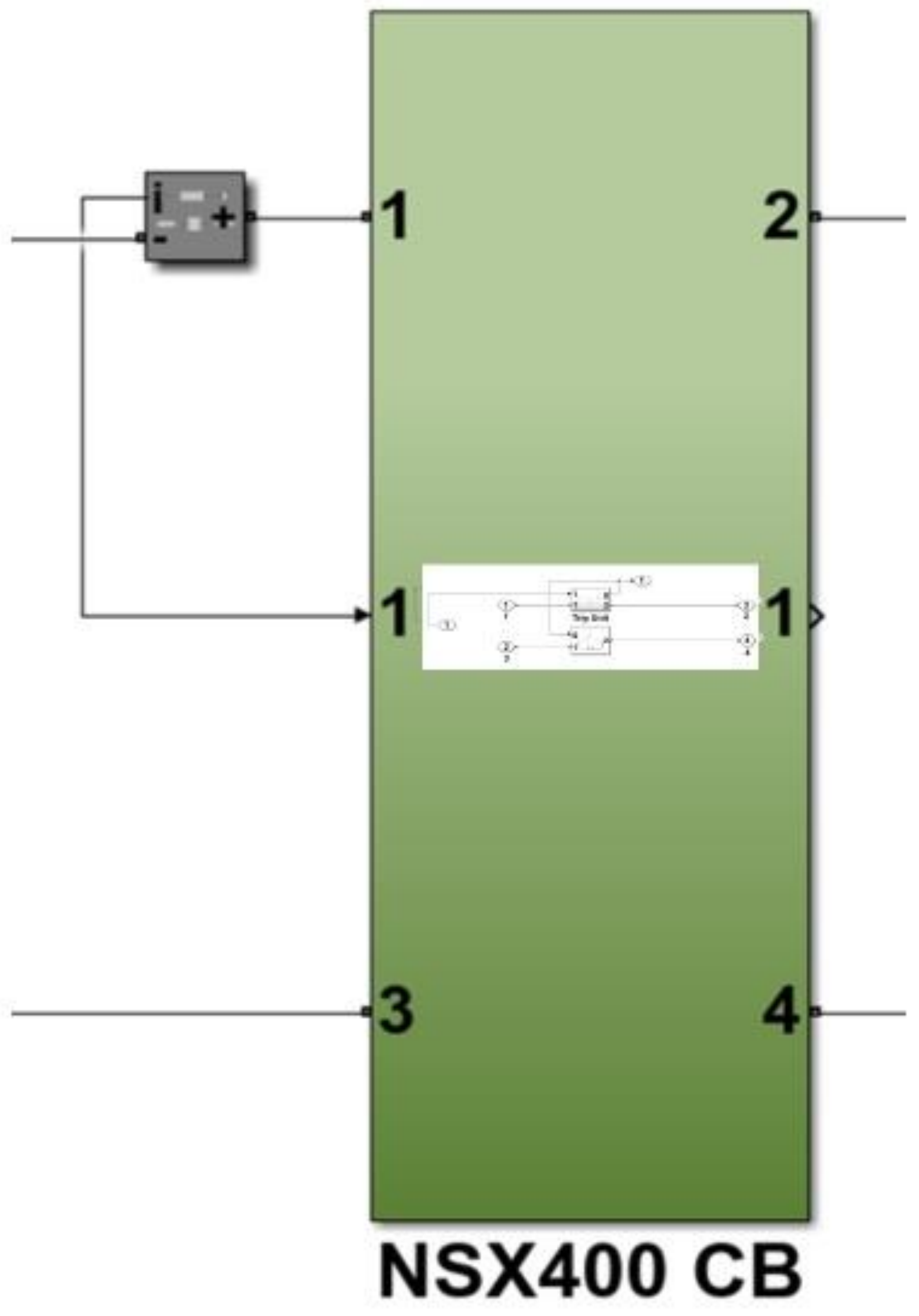




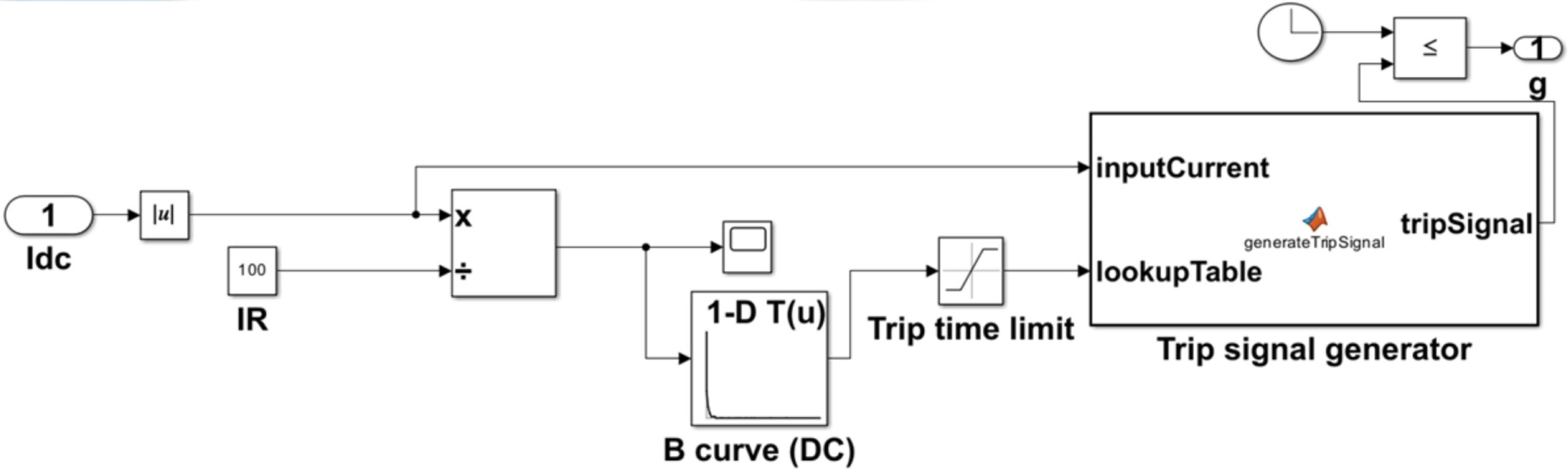
170M3469 FUSE2

-
1
|u|
400
15000
current
rated_current
i2t_threshold
checkCurrent
output_signal
i2t_value
g
1
2
x
data
current
zero_crossing
y
2
+

DC CB Model



1
1
1
1
1
g
2
Trip Unit
3
2
g
1
2
2
3
4
4


1
Idc
|u|
100
IR
x
÷
1-D T(u)
B curve (DC)
Trip time limit
inputCurrent
lookupTable
generateTripSignal
tripSignal
Trip signal generator
≤
1
g

Simulink Model with protective devices

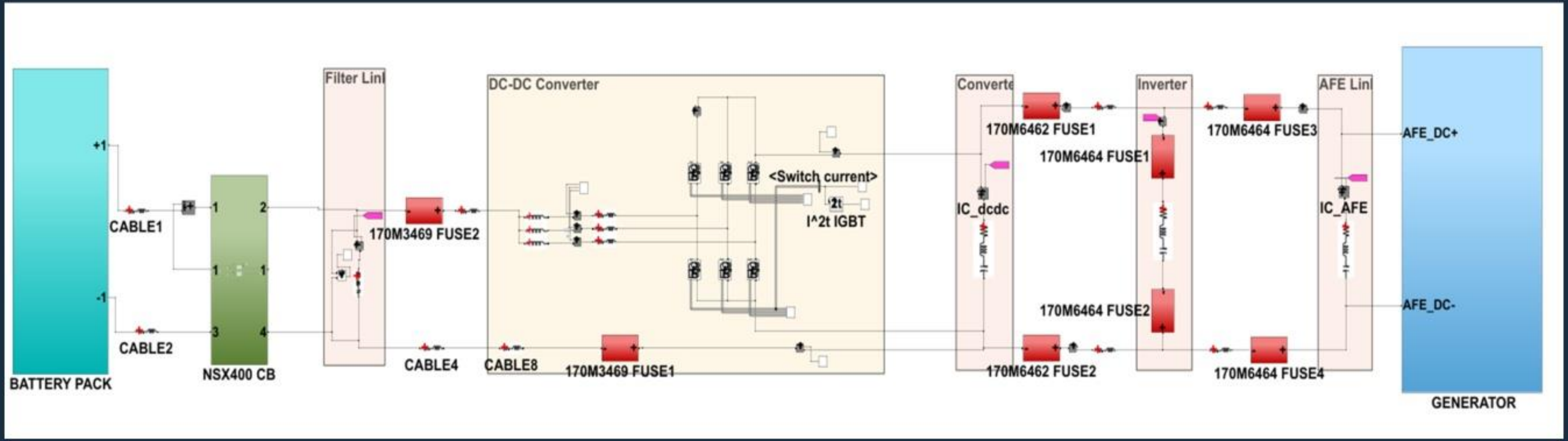
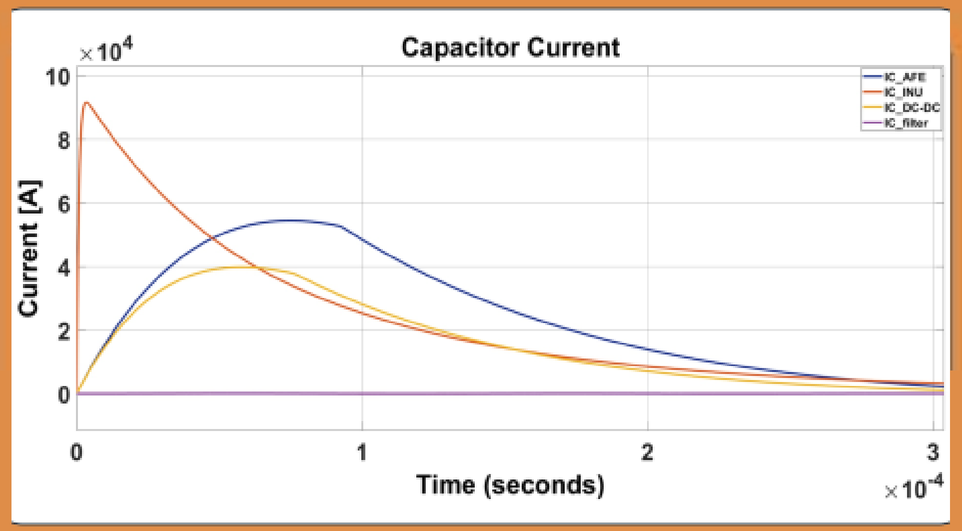
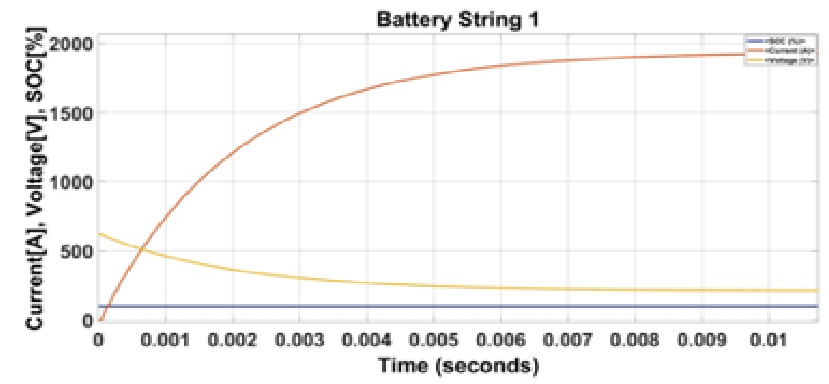
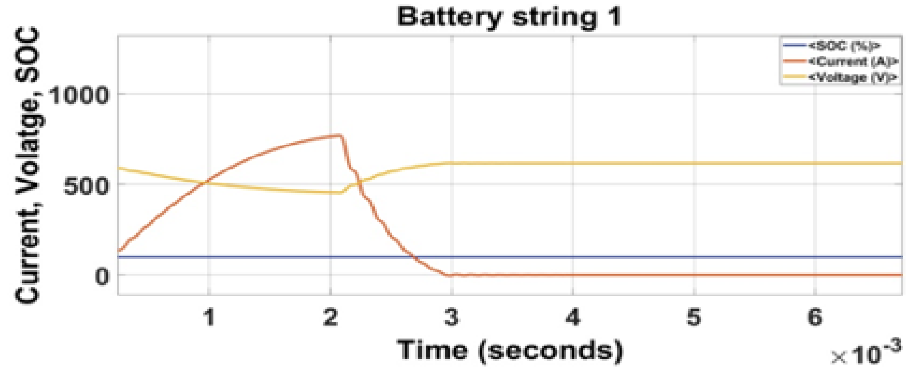


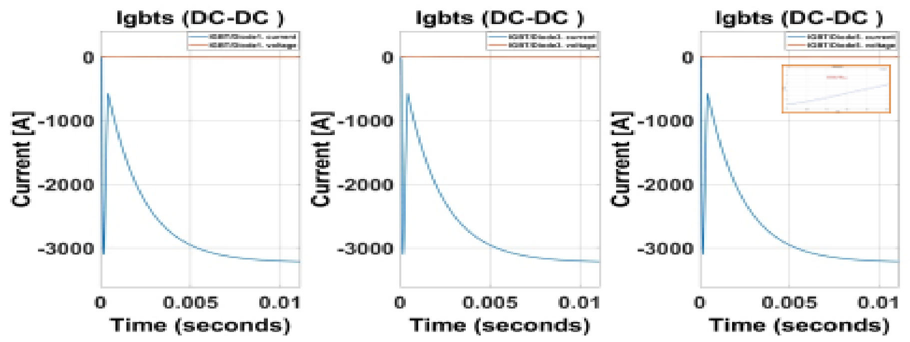
Figure: Model with fuses and circuit breakers

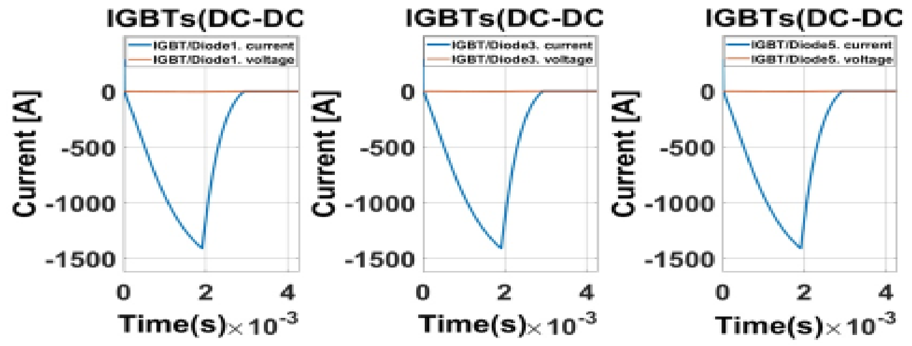
Simulations



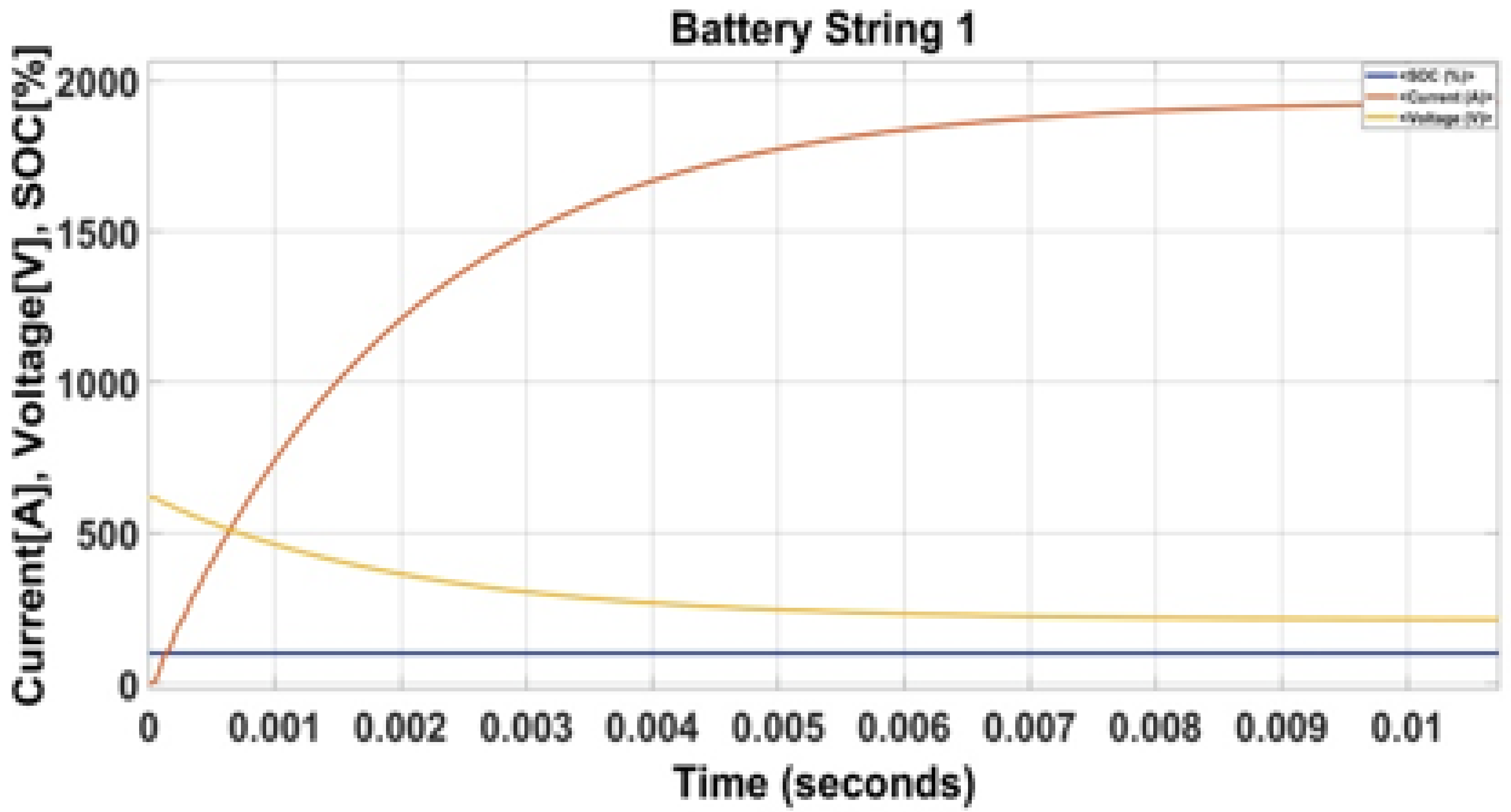


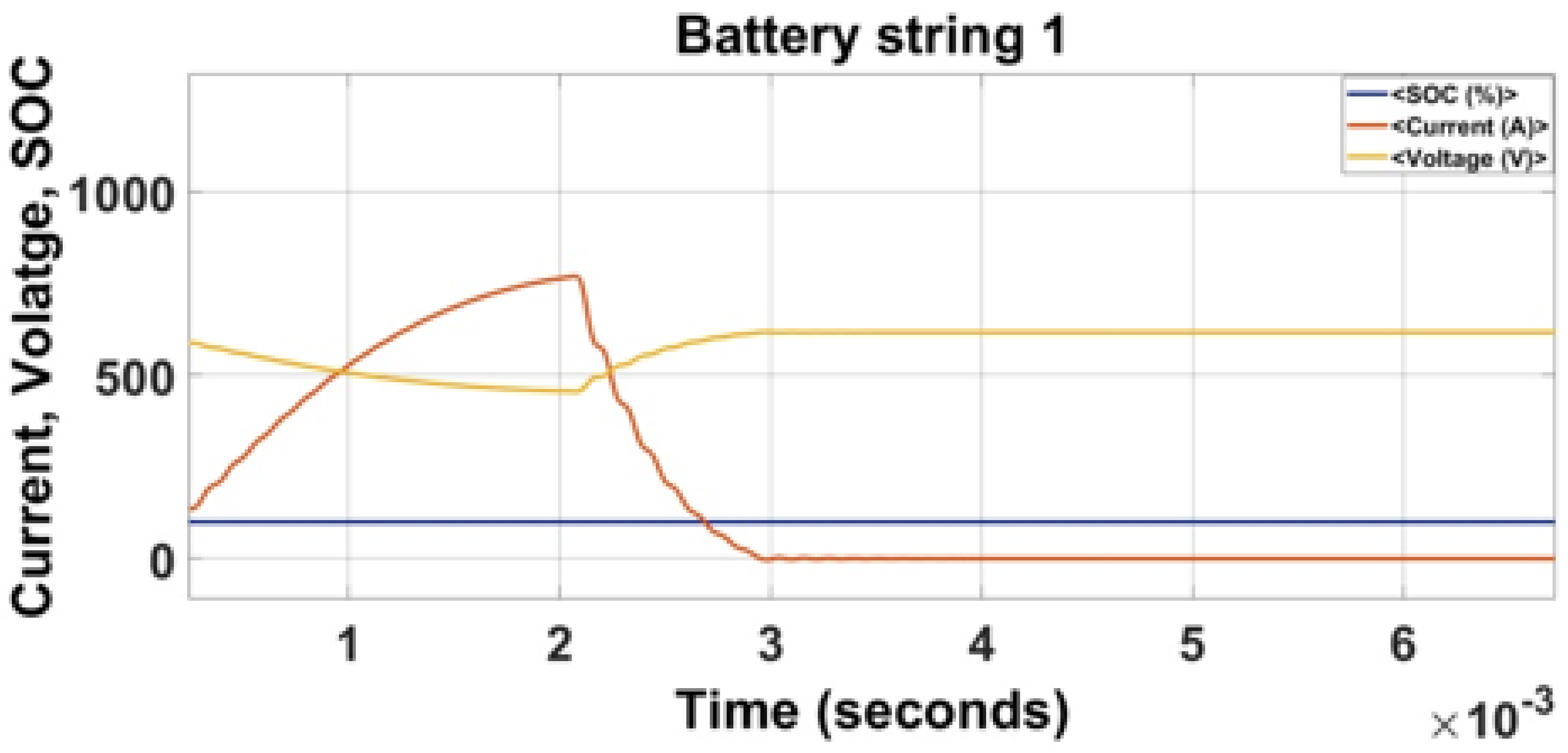


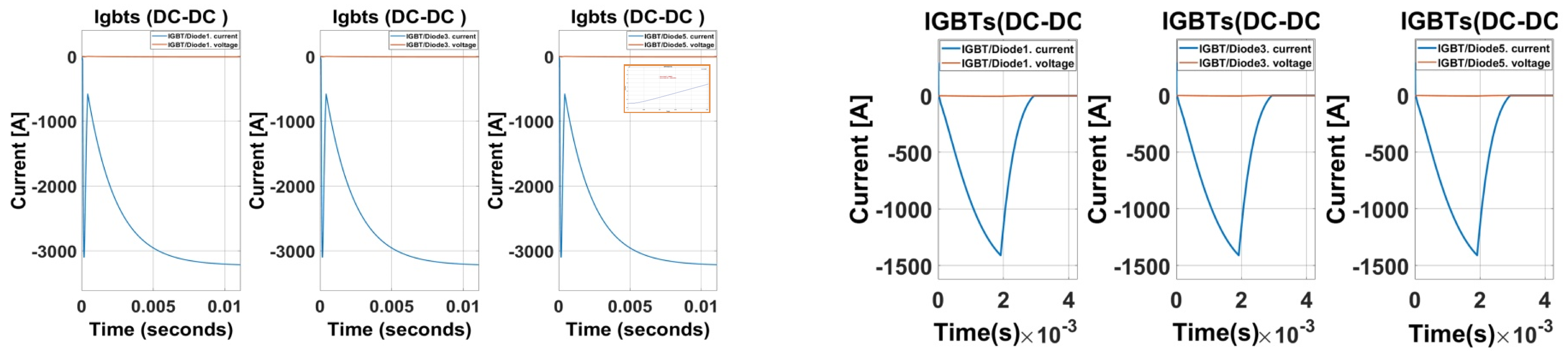




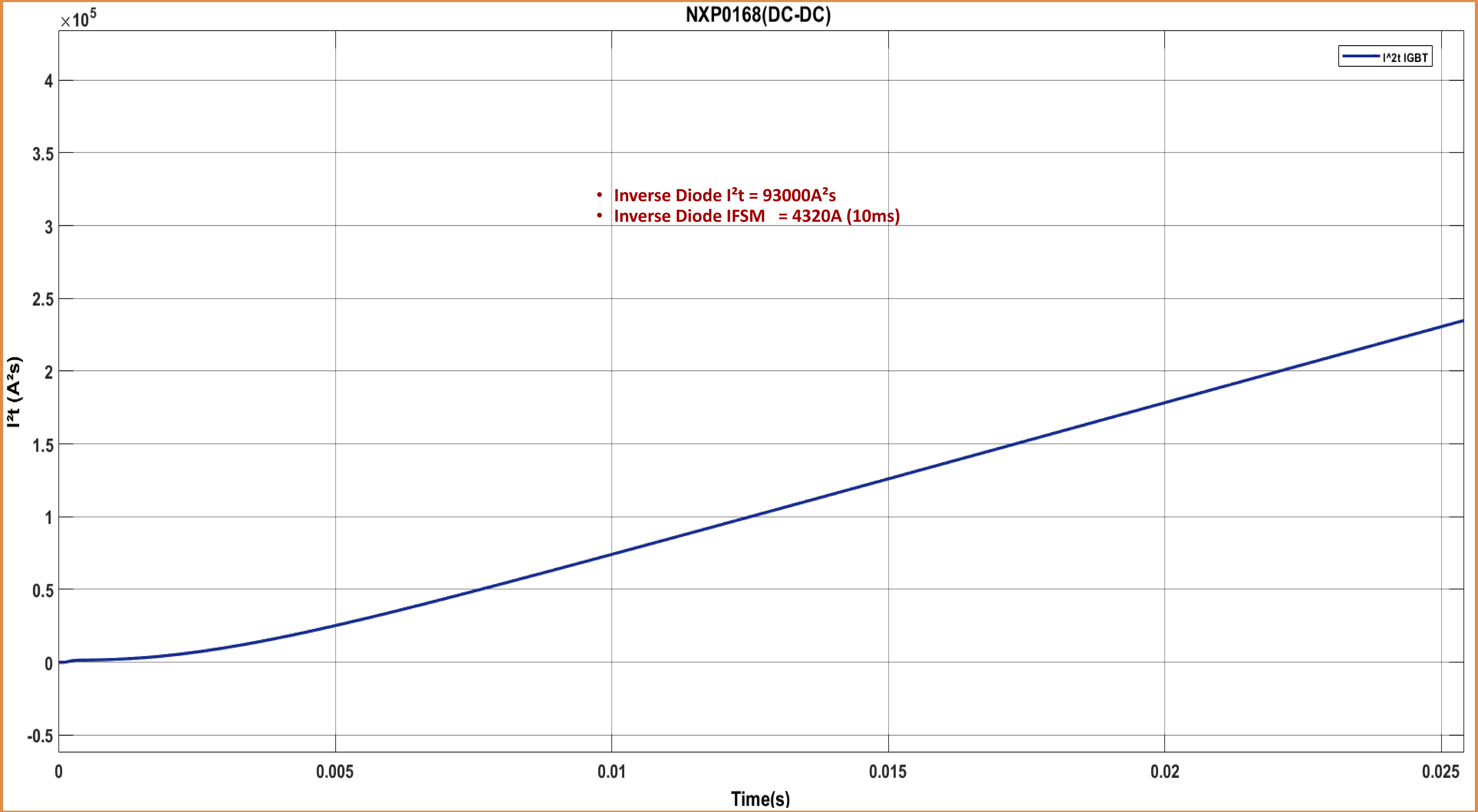
Capacitor Current
×10^4
10
8
6
4
2
0
Current [A]
IC_AFE
IC_INU
IC_DC-DC
IC_filter
0
1
2
3
Time (seconds)
×10^-4

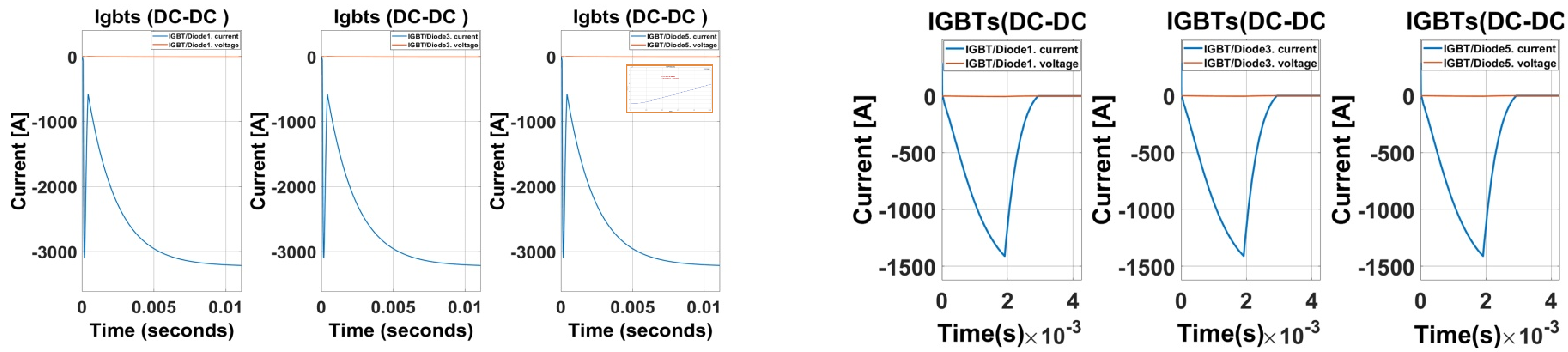

Battery String 1
Current[A], Voltage[V], SOC[%]
Time (seconds)
0
500
1000
1500
2000
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01


Battery string 1
<SOC (%)>
<Current (A)>
<Voltage (V)>
Current, Volatge, SOC
Time (seconds)
0
500
1000
1
2
3
4
5
6
×10^-3



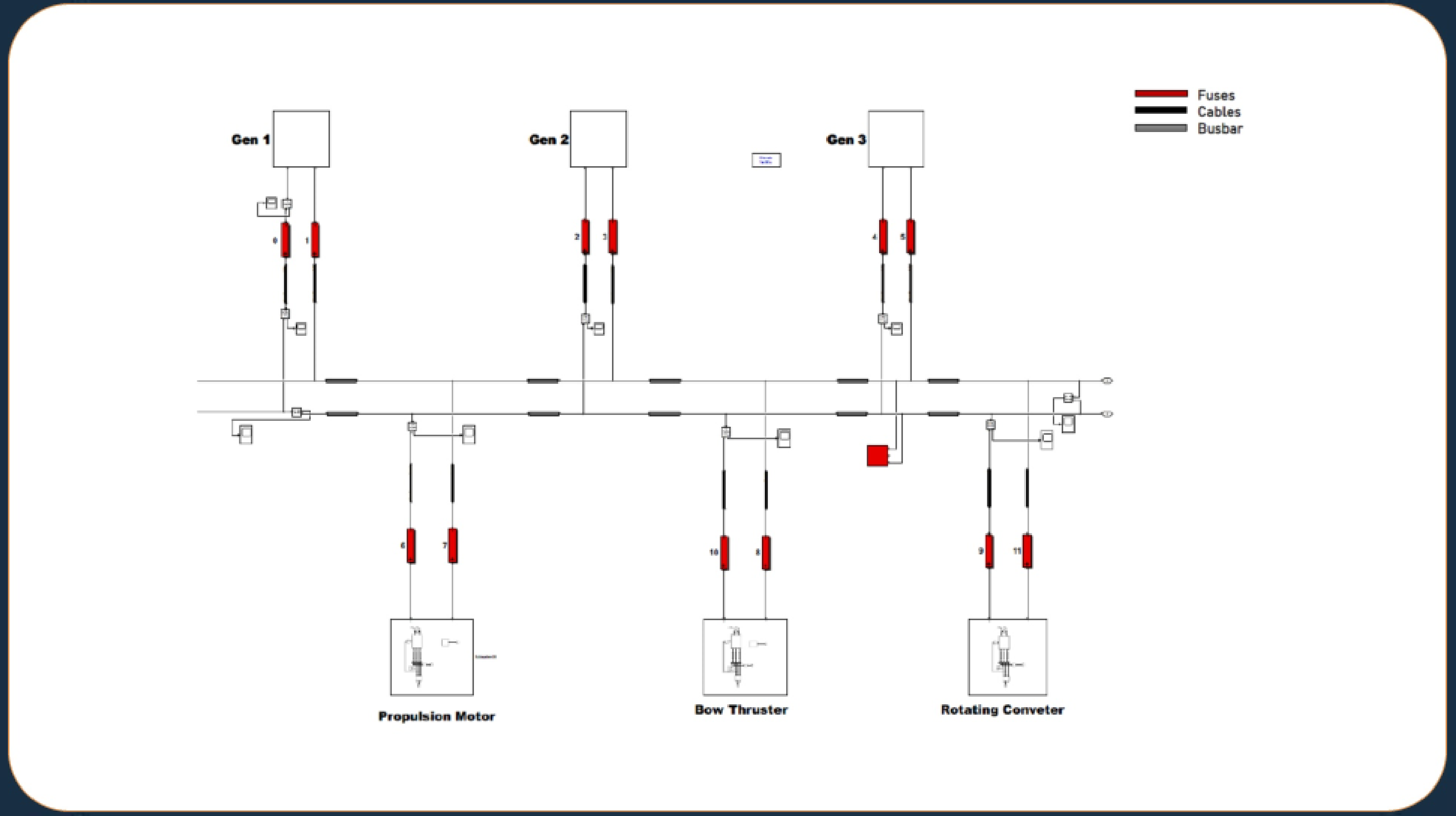
Igbts (DC-DC)
IGBT/Diode1. current
IGBT/Diode1. voltage
Current [A]
Time (seconds)
Igbts (DC-DC)
IGBT/Diode3. current
IGBT/Diode3. voltage
Current [A]
Time (seconds)
Igbts (DC-DC)
IGBT/Diode5. current
IGBT/Diode5. voltage
Current [A]
Time (seconds)
IGBTs(DC-DC
IGBT/Diode1. current
IGBT/Diode1. voltage
Current [A]
Time(s) $\times 10^{-3}$
IGBTs(DC-DC
IGBT/Diode3. current
IGBT/Diode3. voltage
Current [A]
Time(s) $\times 10^{-3}$
IGBTs(DC-DC
IGBT/Diode5. current
IGBT/Diode5. voltage
Current [A]
Time(s) $\times 10^{-3}$

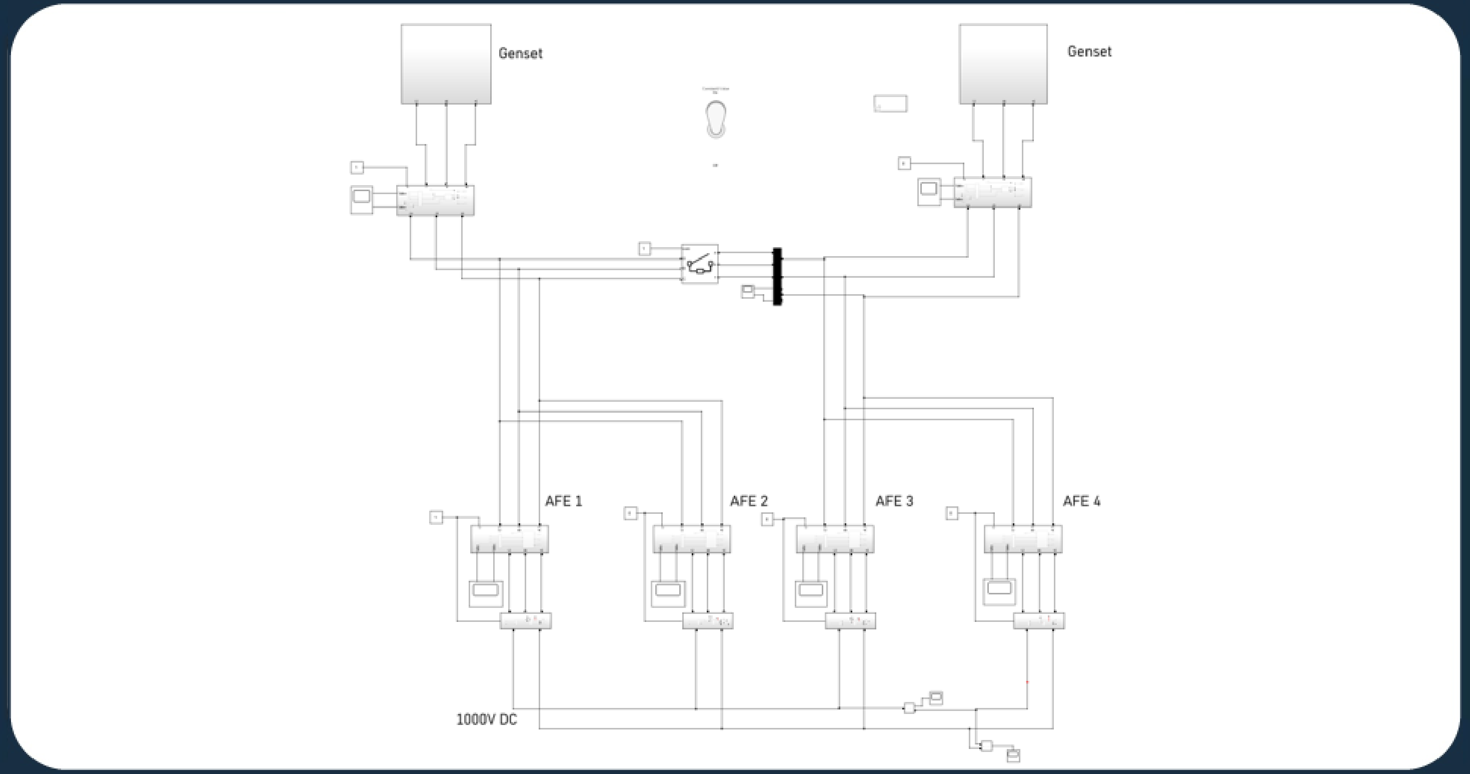

NXP0168(DC-DC)
×10^5
I^2t IGBT
Inverse Diode I²t = 93000A²s
Inverse Diode IFSM = 4320A (10ms)
I²t (A²s)
Time(s)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.005
0.01
0.015
0.02
0.025

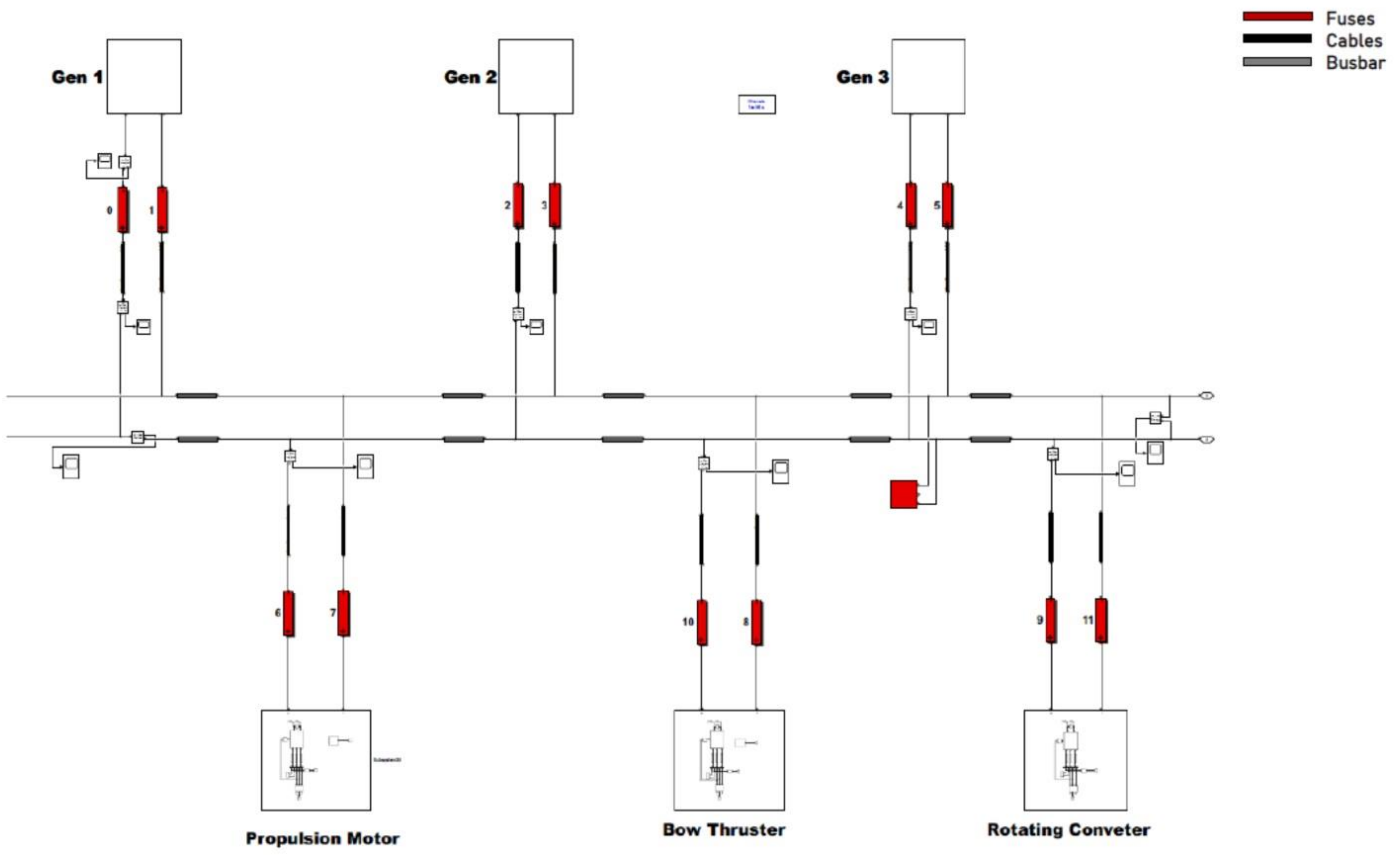


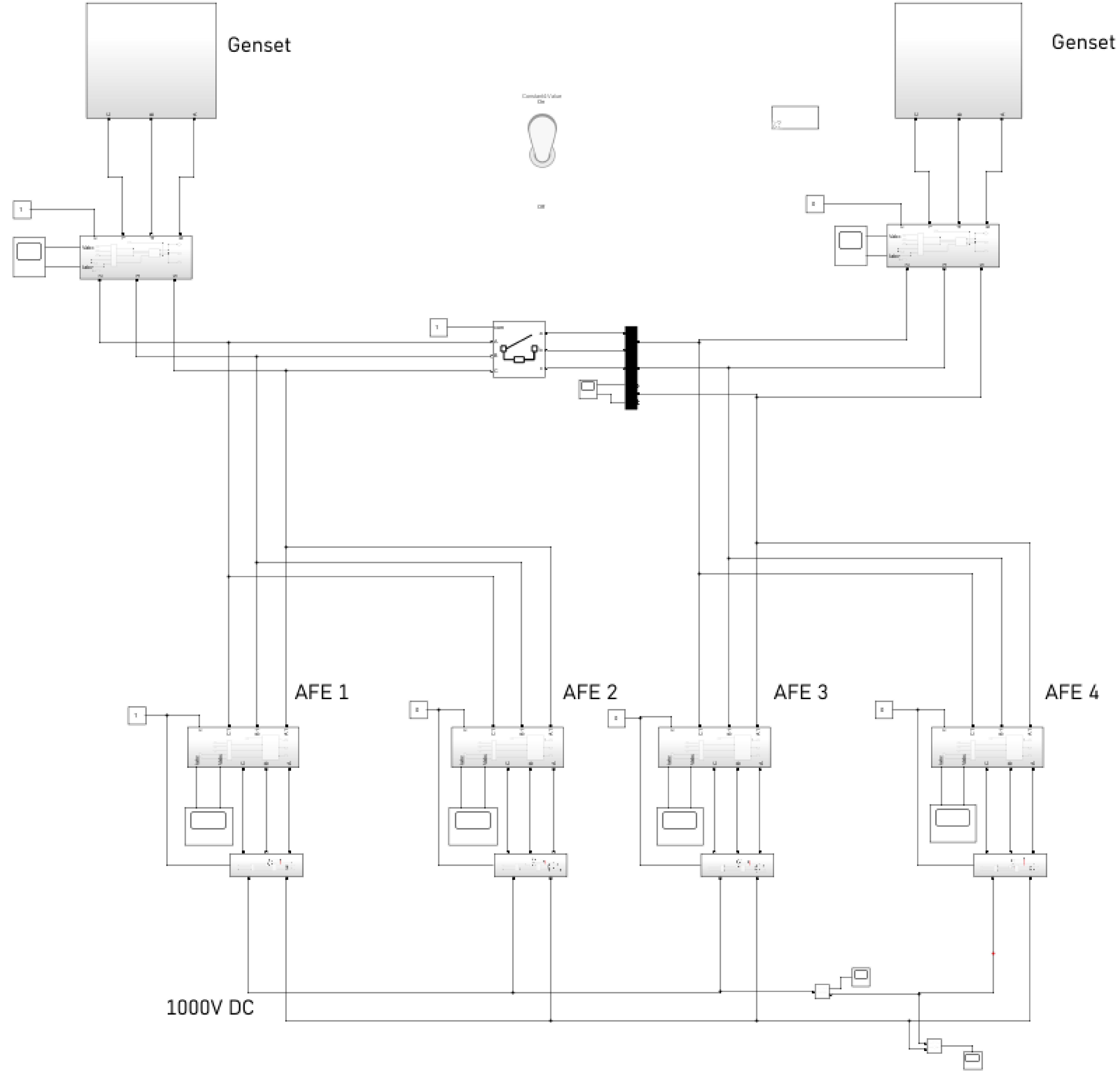
Igbts (DC-DC)
IGBT/Diode1. current
IGBT/Diode1. voltage
Current [A]
Time (seconds)
Igbts (DC-DC)
IGBT/Diode3. current
IGBT/Diode3. voltage
Current [A]
Time (seconds)
Igbts (DC-DC)
IGBT/Diode5. current
IGBT/Diode5. voltage
Current [A]
Time (seconds)
IGBTs(DC-DC
IGBT/Diode1. current
IGBT/Diode1. voltage
Current [A]
Time(s) ×10^-3
IGBTs(DC-DC
IGBT/Diode3. current
IGBT/Diode3. voltage
Current [A]
Time(s) ×10^-3
IGBTs(DC-DC
IGBT/Diode5. current
IGBT/Diode5. voltage
Current [A]
Time(s) ×10^-3

Example Projects



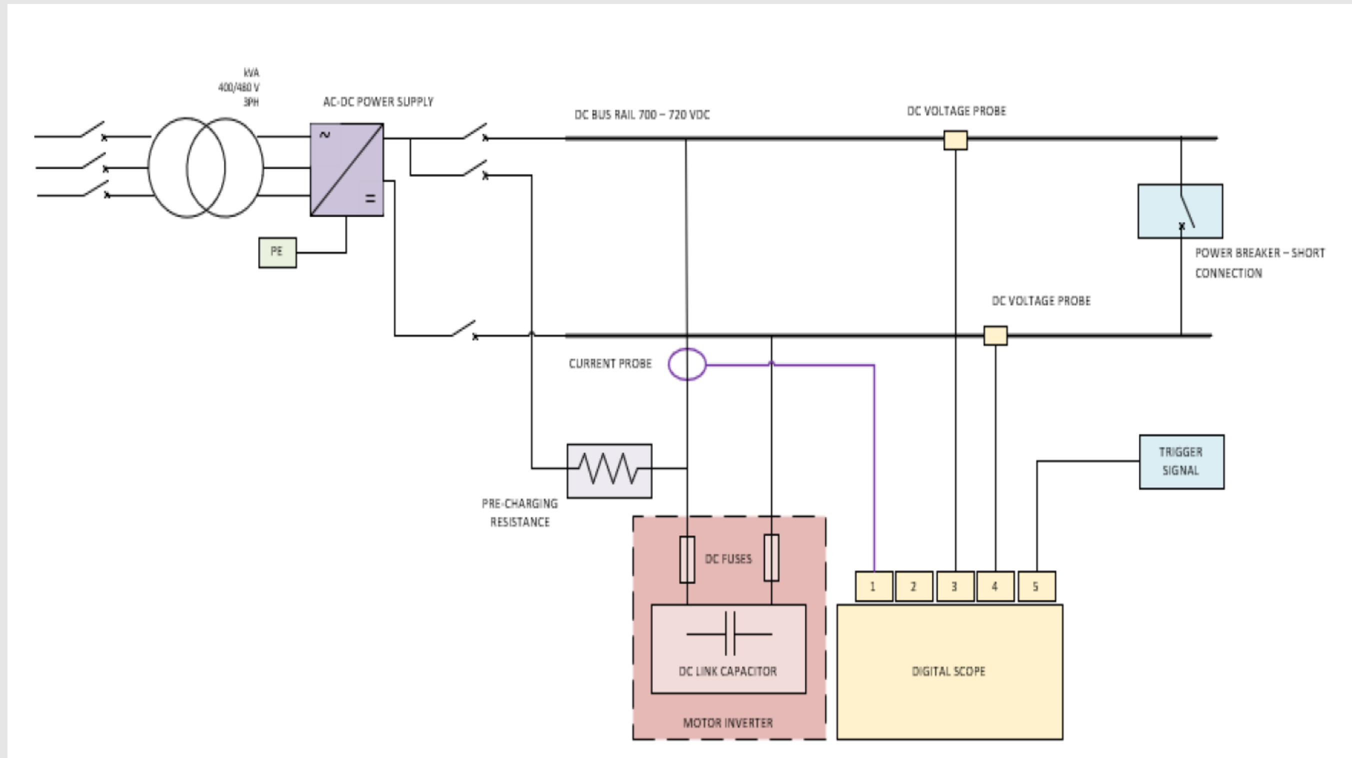



Fuses
Cables
Busbar
Gen 1
Gen 2
Gen 3
0
1
2
3
4
5
6
7
10
8
9
11
Propulsion Motor
Bow Thruster
Rotating Conveter


Genset
Genset
AFE 1
AFE 2
AFE 3
AFE 4
1000V DC

Future Developments

- Verification and Validation
- Test Setup and Class Approval



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