Inspired Karters —Electric

Electrical Package Design and Thermal Management

Link to the Video Presentation

Indigenous Lap Time Simulation

Need for a Laptime Simulation

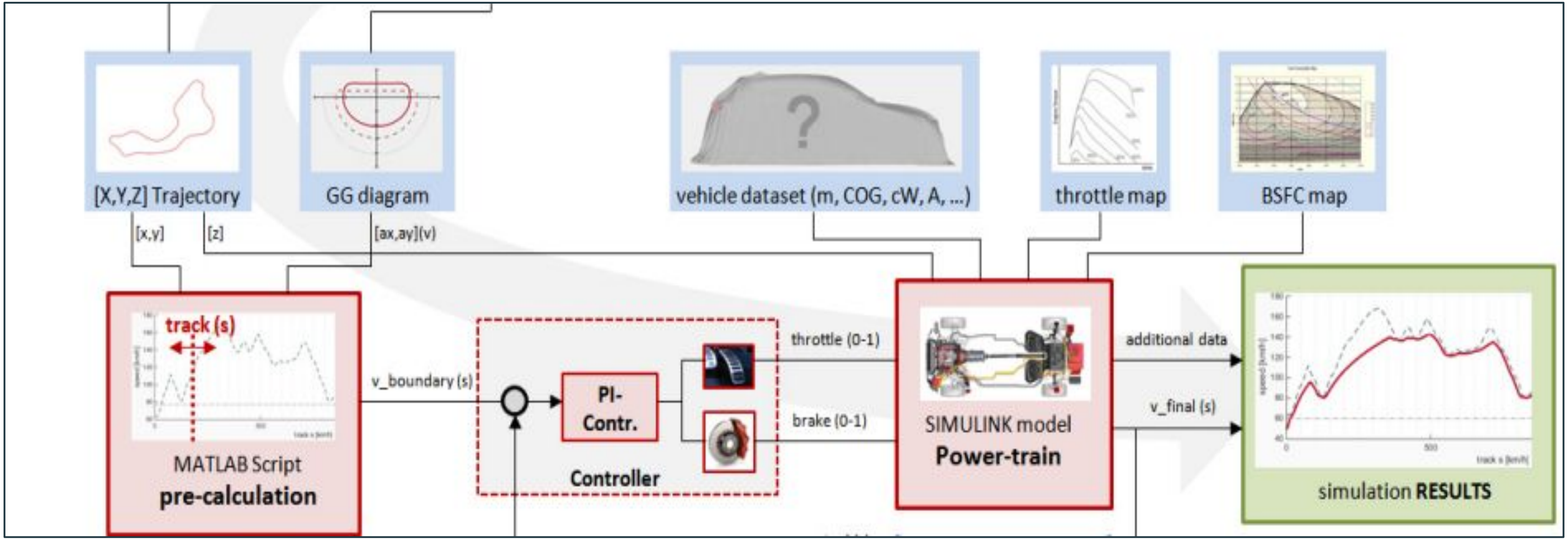
- Calculation of Points Scored
- Calculation of Relevant Perfomance Metrics
- Full Body Vehicle Simulation
- Competition Strategy
- Overall Team Goals

Limitations of OptimumLap

1. OptimumLap is not open-source
2. Only Point Mass Model — Inability to increase complexity
3. Complete Vehicle simulation — not possible

Implementation of the Simulation

1. Developed on MATLAB/Simulink
2. Currently Developed upto Bicycle Model
3. Takes Vehicle inputs and outputs performance parameters



[X,Y,Z] Trajectory
GG diagram
vehicle dataset (m, COG, cW, A, ...)
throttle map
BSFC map
[x,y]
[z]
[ax,ay](v)
track (s)
MATLAB Script
pre-calculation
v_boundary (s)
PI-
Contr.
Controller
throttle (0-1)
brake (0-1)
SIMULINK model
Power-train
additional data
v_final (s)
simulation RESULTS

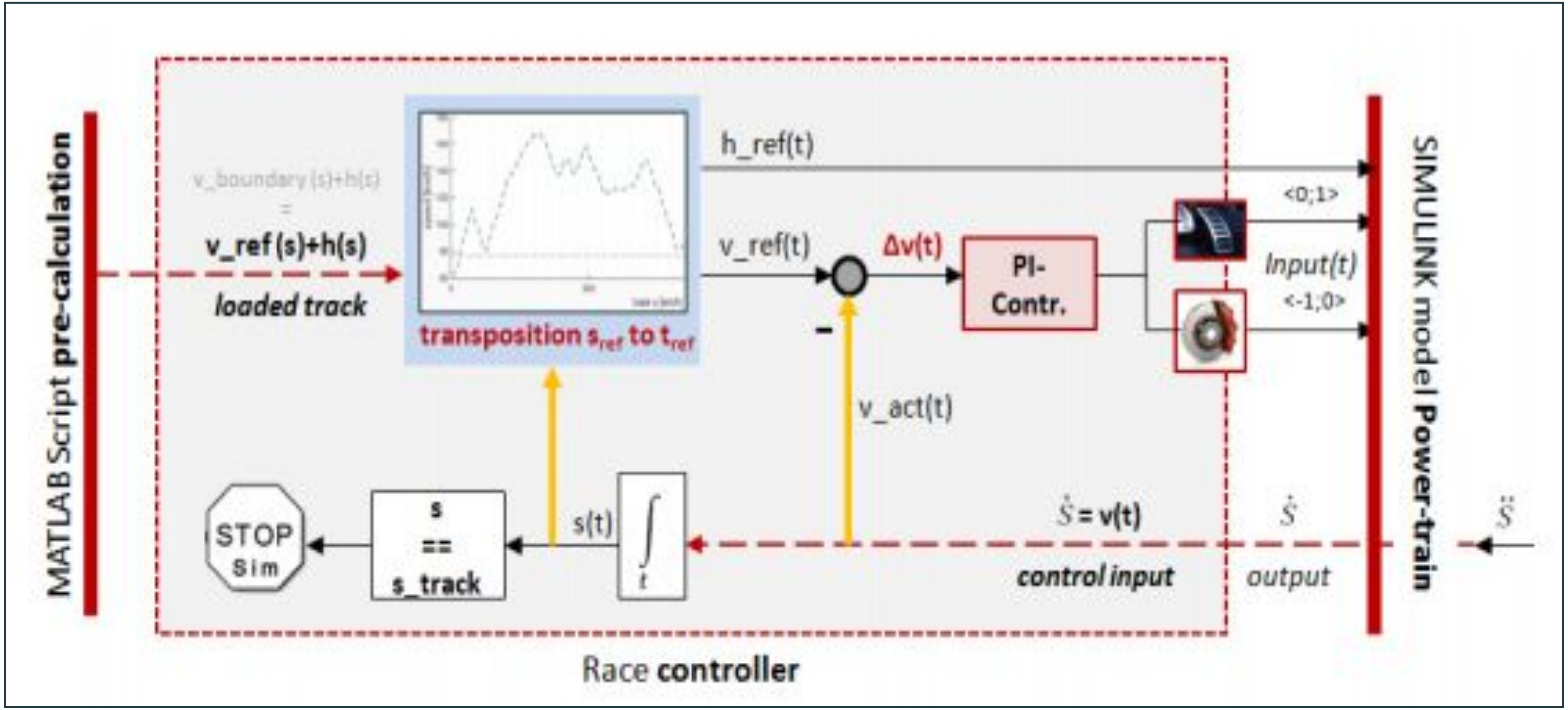


Fig: Schematic of Race Controller Strategy

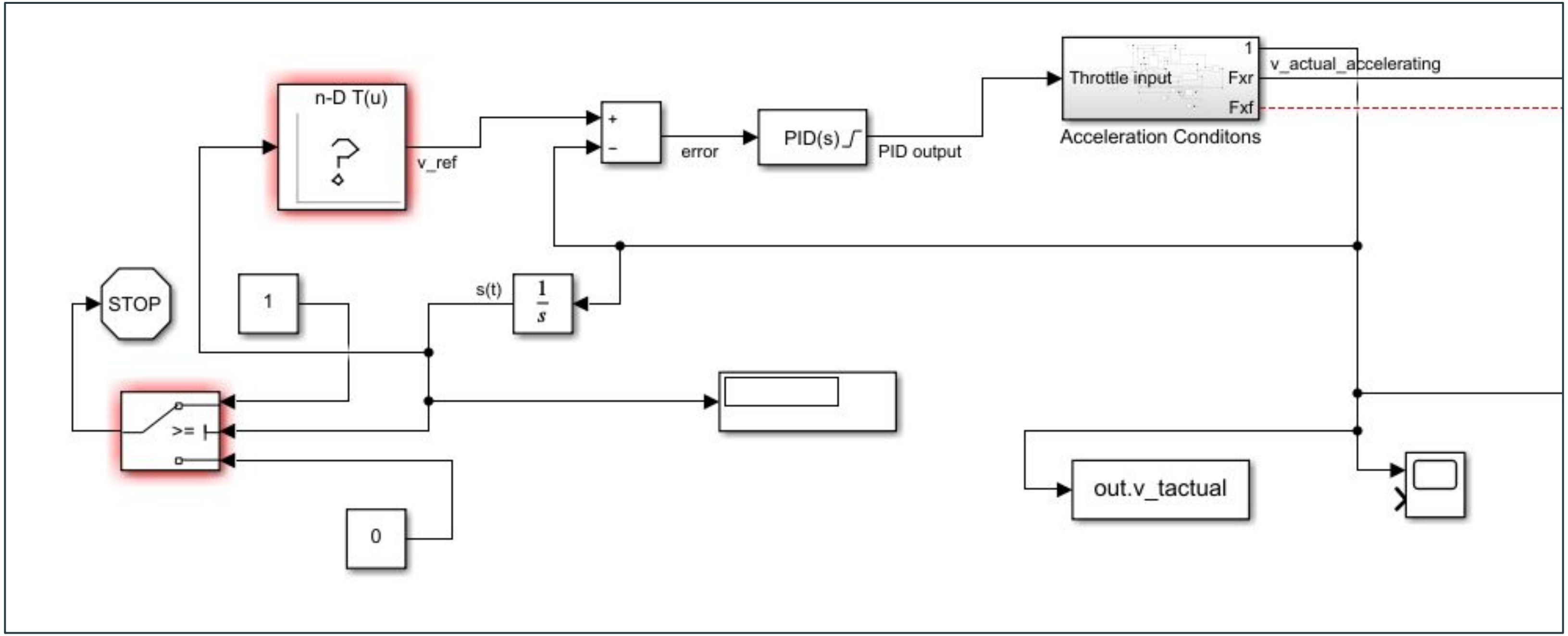
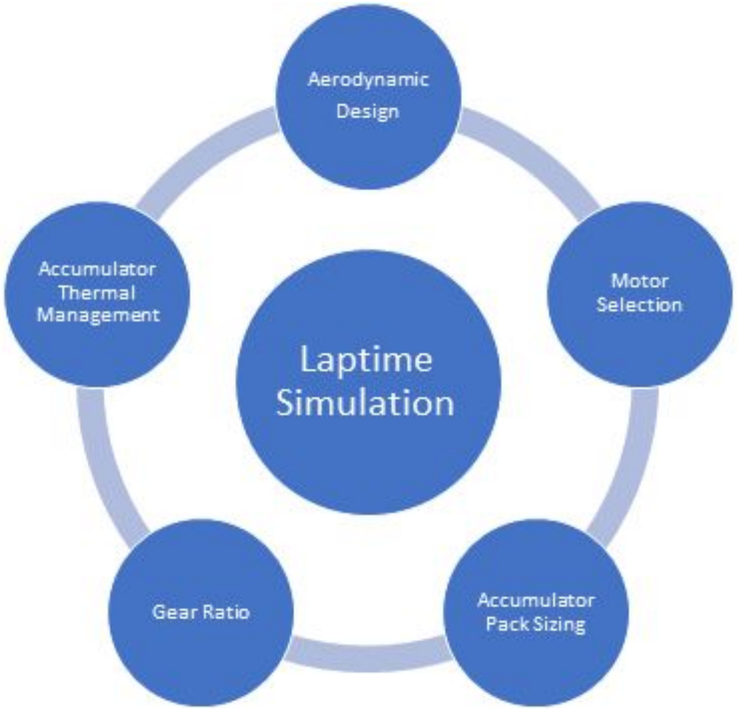


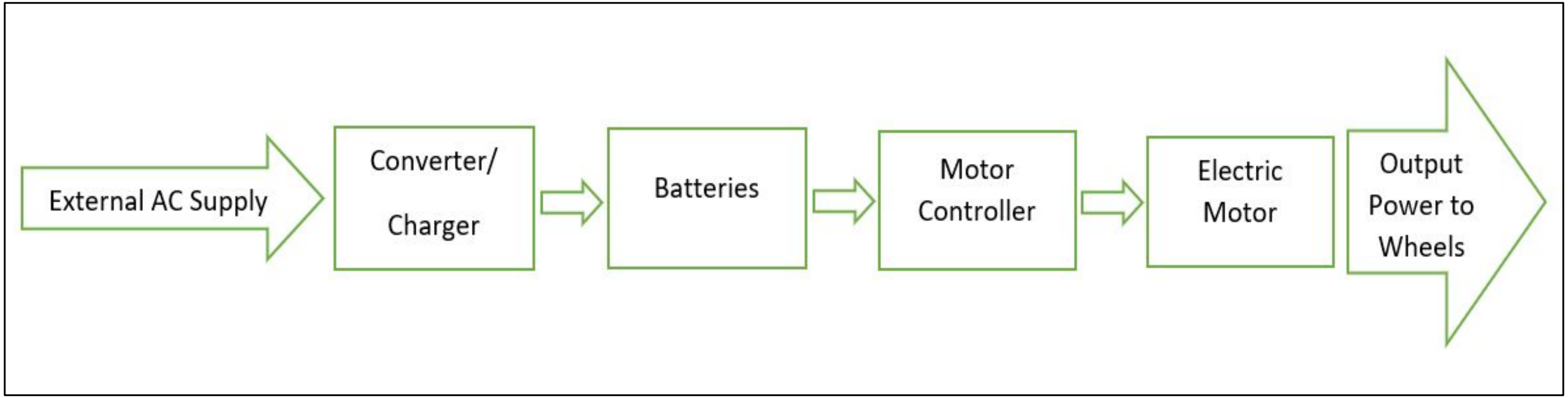
Fig: Snapshot of Simulink Model

Design Decisions

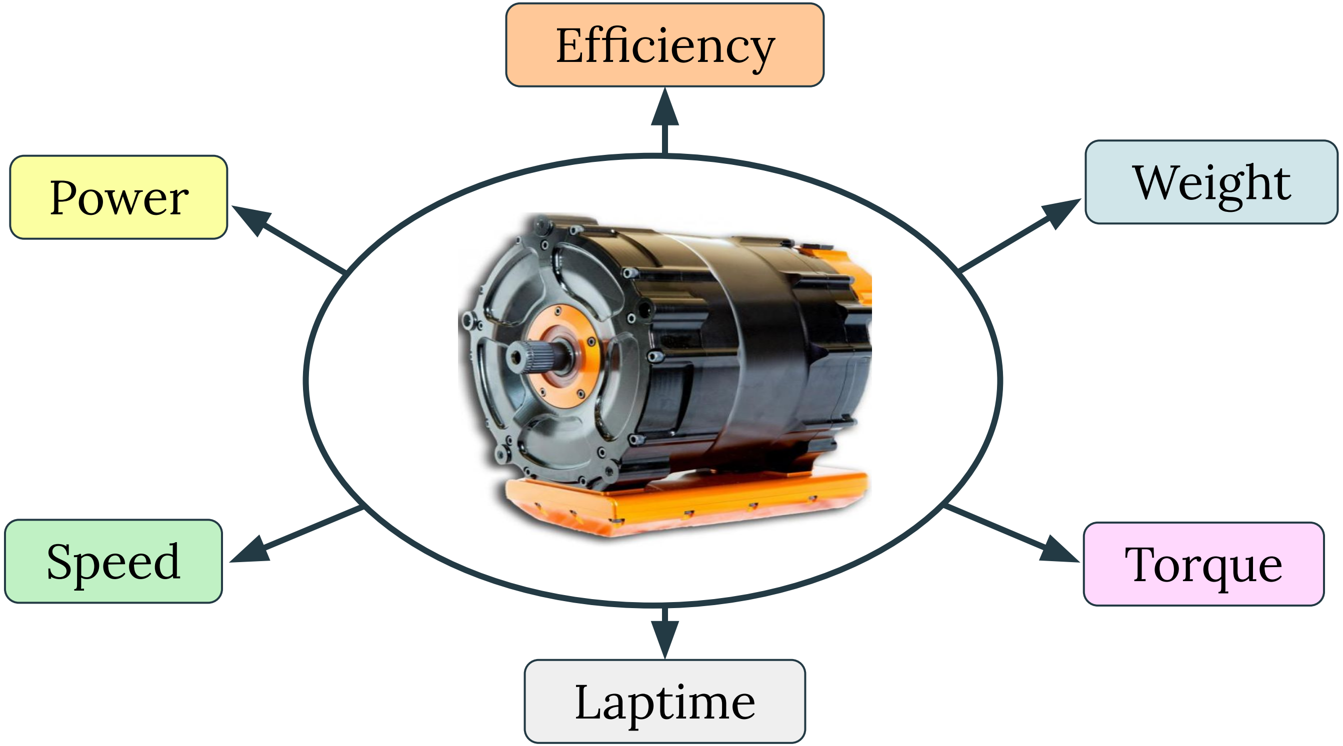


Motor Selection

Power Flow in an Electric Vehicle



Motor Selection Parameters

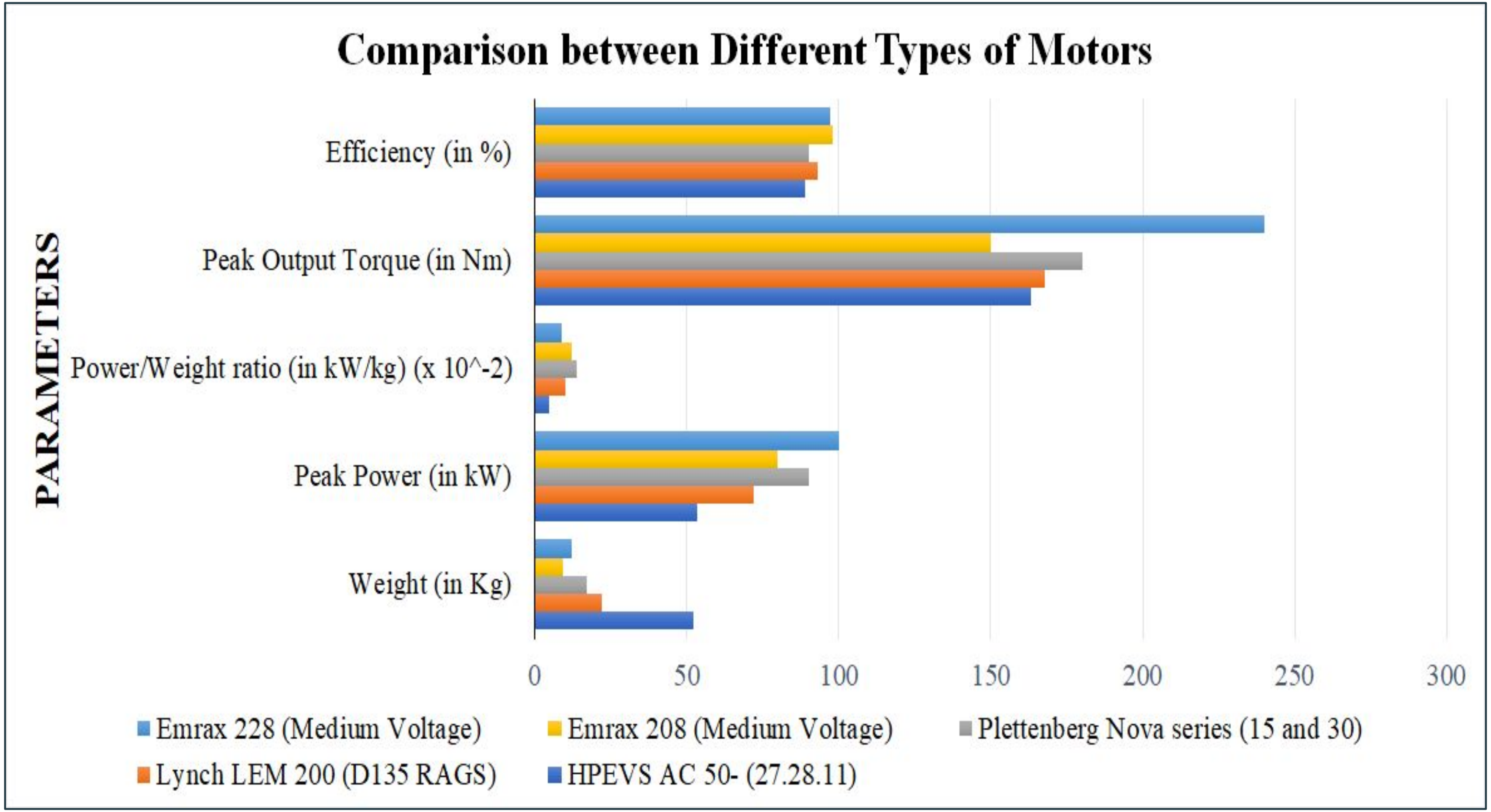


Selection Pool

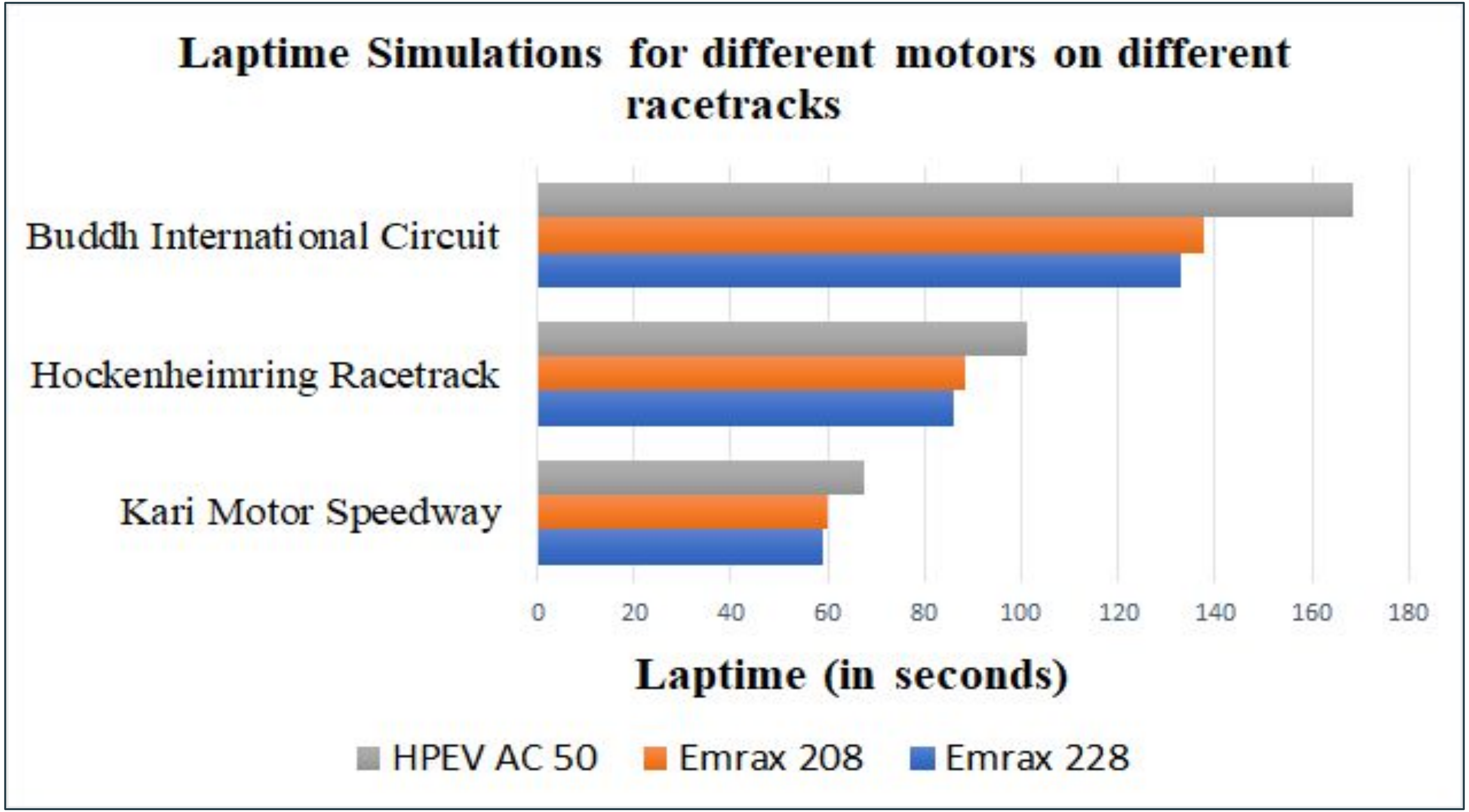
1. HPEV AC 50 – (27.28.11)
2. Lynch LEM 200 (D135 RAGS)
3. Plettenberg Nova series (15 and 30)
4. EMRAX 228 (Medium Voltage)
5. EMRAX 208 (Medium Voltage)

Motor Selection

1. HPEV AC 50 – (27.28.11) X
2. Lynch LEM 200 (D135 RAGS) X
3. Plettenberg Nova series (15 and 30) X
4. EMRAX 228 (Medium Voltage) X
5. EMRAX 208 (Medium Voltage) ✓



Comparison between Different Types of Motors
PARAMETERS
Efficiency (in %)
Peak Output Torque (in Nm)
Power/Weight ratio (in kW/kg) (x 10^-2)
Peak Power (in kW)
Weight (in Kg)
0
50
100
150
200
250
300
Emrax 228 (Medium Voltage)
Emrax 208 (Medium Voltage)
Plettenberg Nova series (15 and 30)
Lynch LEM 200 (D135 RAGS)
HPEVS AC 50- (27.28.11)


Laptime Simulations for different motors on different racetracks
Buddh International Circuit
Hockenheimring Racetrack
Kari Motor Speedway
0
20
40
60
80
100
120
140
160
180
Laptime (in seconds)
HPEV AC 50
Emrax 208
Emrax 228

EMRAX 208 (Medium Voltage)

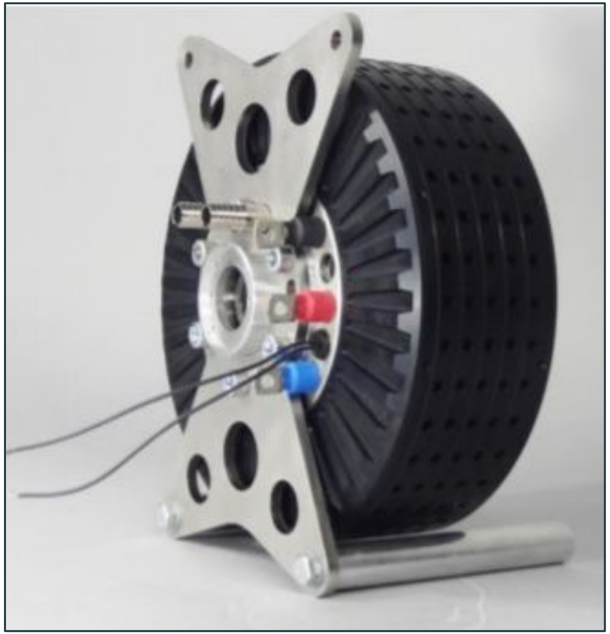


Fig: EMRAX 208

1. High Power (80kW)
2. Highest Efficiency (98%)
3. Light Weighted (9.4 Kg)
4. High Power/Weight ratio
5. Optimum Lap time
6. Sufficiently High Torque

Cell Chemistry and Model Selection

Cell Selection Criteria

1. High Energy Density (Wh/L)
2. High Specific Energy (Wh/kg)
3. High Specific Power (W/kg)
4. Charging and Discharging abilities
5. Ecologically sound
6. Sustainable

Energy Capacity Calculation

Minimum Range = 22km

Average power = 16.212 kW

Average Speed = 60 km/hr

Calculate time = Range/Average speed = 22/60 = 0.367 hours

Energy required = Average power * time = **5.94 kWh**

Value calculated from the lap time simulation software = **5.87 kWh**

Cell Comparison

Name	A123	Melasta	Samsung	Bestgo	TEAMGIANT	Melasta
Model Number	AMP20M1HD-A	SLPBB042126	INR18650-25R5	BCPNE20T	HR3780156240	HP49C260
Column2	Lithuim-ion	Lithium-ion	Lithium-ion	Lithium-ion	Lithium-ion	Ni-Zn
Type	Pouch	Pouch	Cylindrical	Pouch	Pouch	Cylindrical
Specific Energy (Wh/kg)	131	190	206	180	210	213
Specific Power(W/kg)	1333	2400	1627	361	628	286
Energy Density(Wh/L)	247	445	545	372	395	525
Weight(g)	495	126	45	410	565	45
Energy(KWh)	0.064845	0.02394	0.00927	0.0738	0.11865	0.009585
No. of cells required	90	245	633	79	49	613

Factors in Favour of Li-ion battery

1. **No memory effect** which allows users to charge and discharge them much more flexibly than other batteries.
2. **High coulombic efficiency** throughout the state of charge range.
3. **Low self-discharge rates** compared to other types of batteries.

Factors in Favour of Pouch Cells

1. 90-95% packing efficiency
2. Light and compact

Cell Finalisation

We selected **20Ah, 3.3V Li ion phosphate pouch cells** (Model No. – **AMP20M1HD-A**) produced by **A123 systems**.

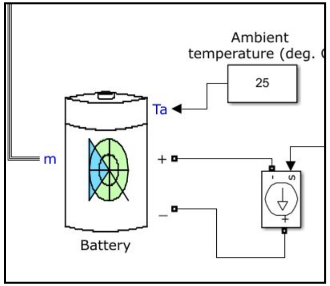
Specification	Value	Notes/Comments
Peak 10s Discharge power	820W	SOC = 100%, Tcell = 23 °C, Assumed DCR = 2 mOhm (nominal)
DCR Impedance ACR Impedance	1.5 – 3 mOhm 0.78 mOhm	10s, 240A, @ 50% SOC 1kHz, @ 50% SOC
Operating Temp Range	-30 °C to +60 °C	Ambient around cell
Storage temperature range	-40 °C to +65 °C	
Weight	495 gm	
Cycle Life To 80% Beginning of Life (BOL) capacity	3000 cycles	100% Full DOD cycles, 1C/-2C @ 23 °C, 8 – 14 psi face clamp pressure

Specification	Value	Notes/Comments
Nominal capacity	20 Ah	
Minimum Capacity	19.5 Ah	25 °C, 6A Discharge, 3.6V to 2.0V, at BOL
Nominal voltage	3.3 V	
Voltage Range	2.0 to 3.6V	Fully Discharged to Fully Charged
Absolute Maximum terminal voltage	4.0	Above which will cause immediate damage to the cell
Recommended maximum charge voltage	3.6V	
Recommended float charge voltage	3.5V	
Recommended end of discharge cutoff	2.0V	
Recommended standard charge current	20A	to 3.6V
Recommended maximum charge current	100A	to 3.6V , Cell temperature < +85 °C
Pulse 10s charge current	200A	23 °C ≤ Tcell < +85 °C, Vcell < 3.8V
Max continuous discharge current	200 A	
Pulse 10s discharge current	600A	23 °C ≤ Tcell < +85 °C, SOC = 50%

Battery Modelling

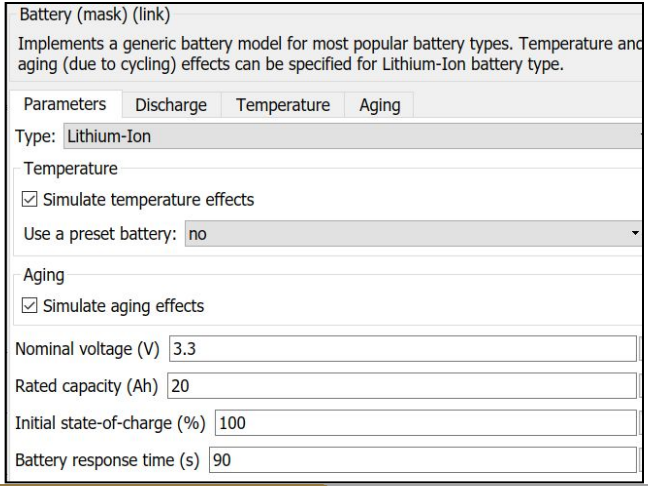
1. Understanding Li-ion Battery Functionality
2. Researching about Modelling Methods
3. Modelling on MATLAB-Simulink
4. Analysing Results, Documentation

Battery Block in Simulink



Battery Block in Simulink; has 6 ports which measure SoC, Voltage, Current, Temperature, Cell Age, and Max Capacity

Basic Cell Details from the Datasheet


Battery (mask) (link)

Implements a generic battery model for most popular battery types. Temperature and aging (due to cycling) effects can be specified for Lithium-Ion battery type.

Parameters | Discharge | Temperature | Aging

Type: Lithium-Ion

Temperature

☑ Simulate temperature effects

Use a preset battery: no

Aging

☑ Simulate aging effects

Nominal voltage (V) 3.3

Rated capacity (Ah) 20

Initial state-of-charge (%) 100

Battery response time (s) 90

Battery Block Parameters

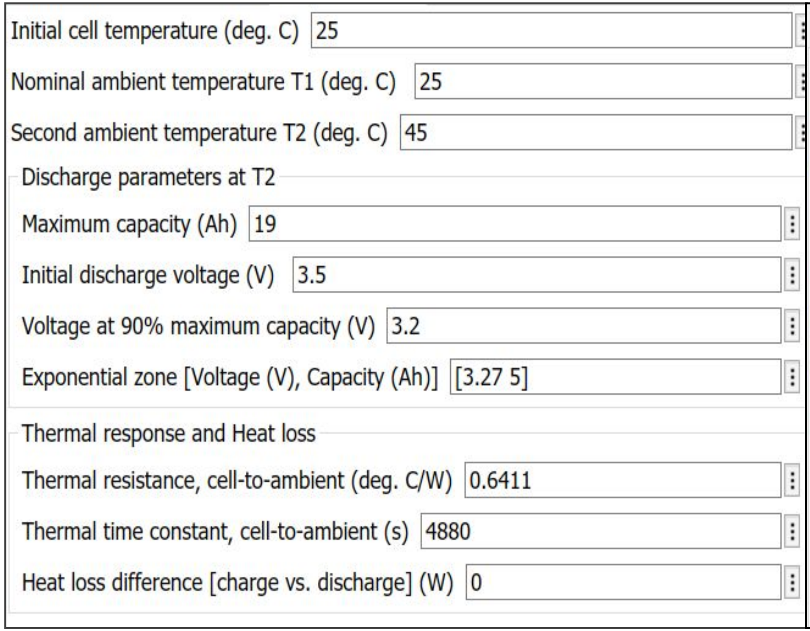


Fig: Thermal Properties

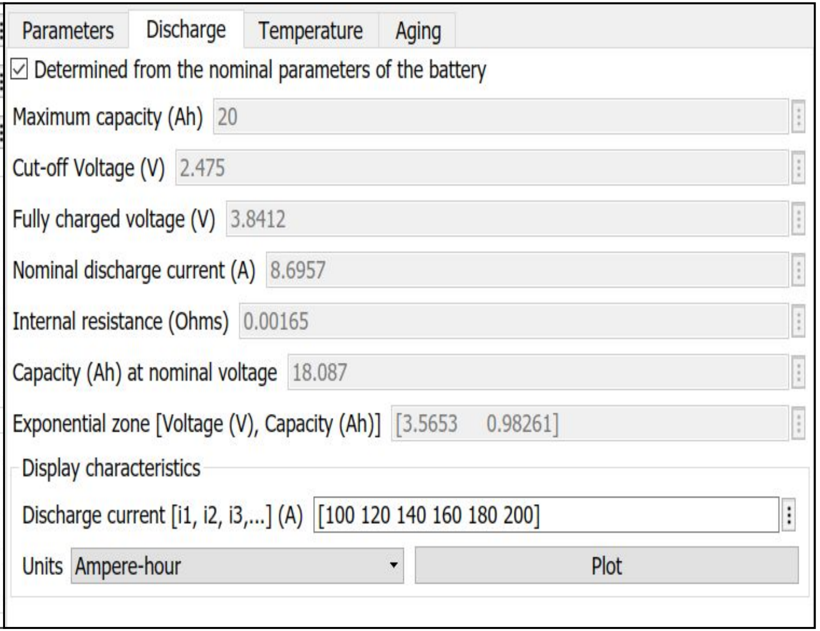


Fig: Discharge Characteristics

Pulse Discharge Model

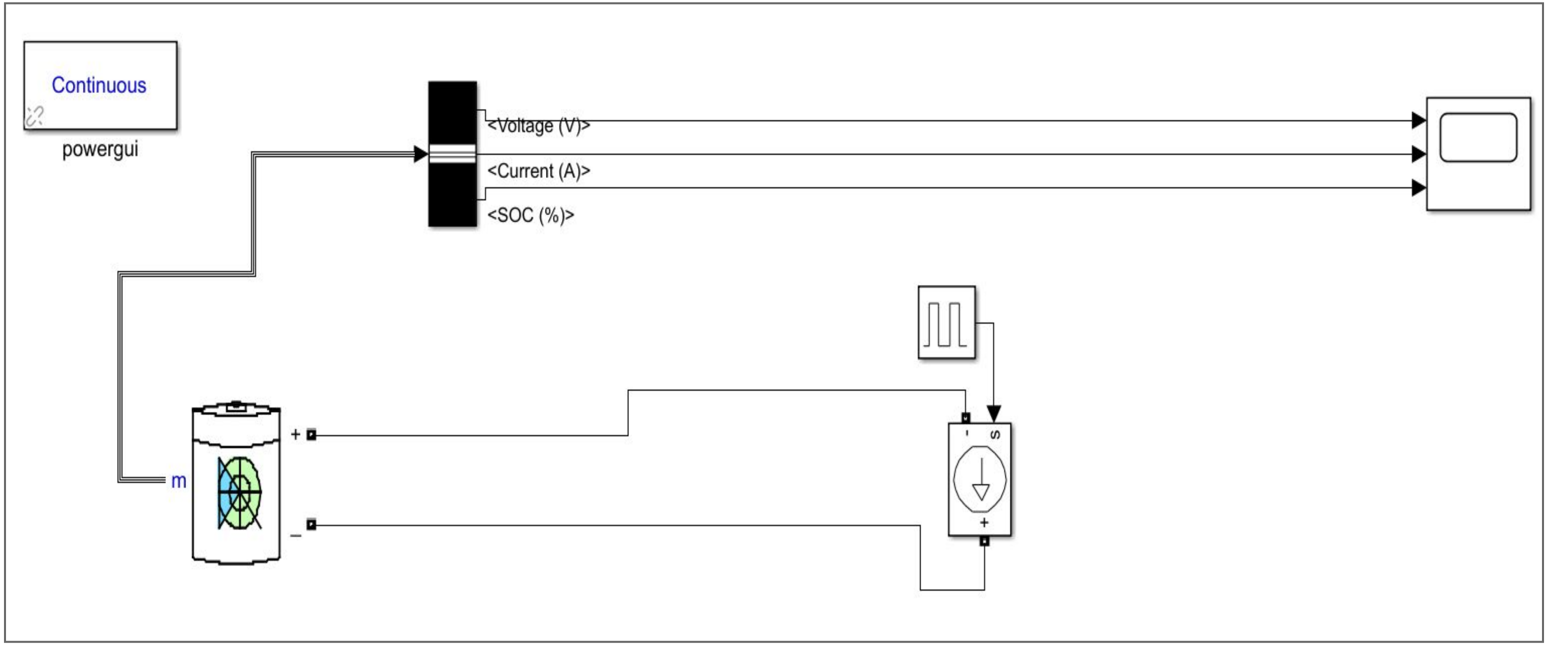


Fig: Pulse Discharge Model

Results

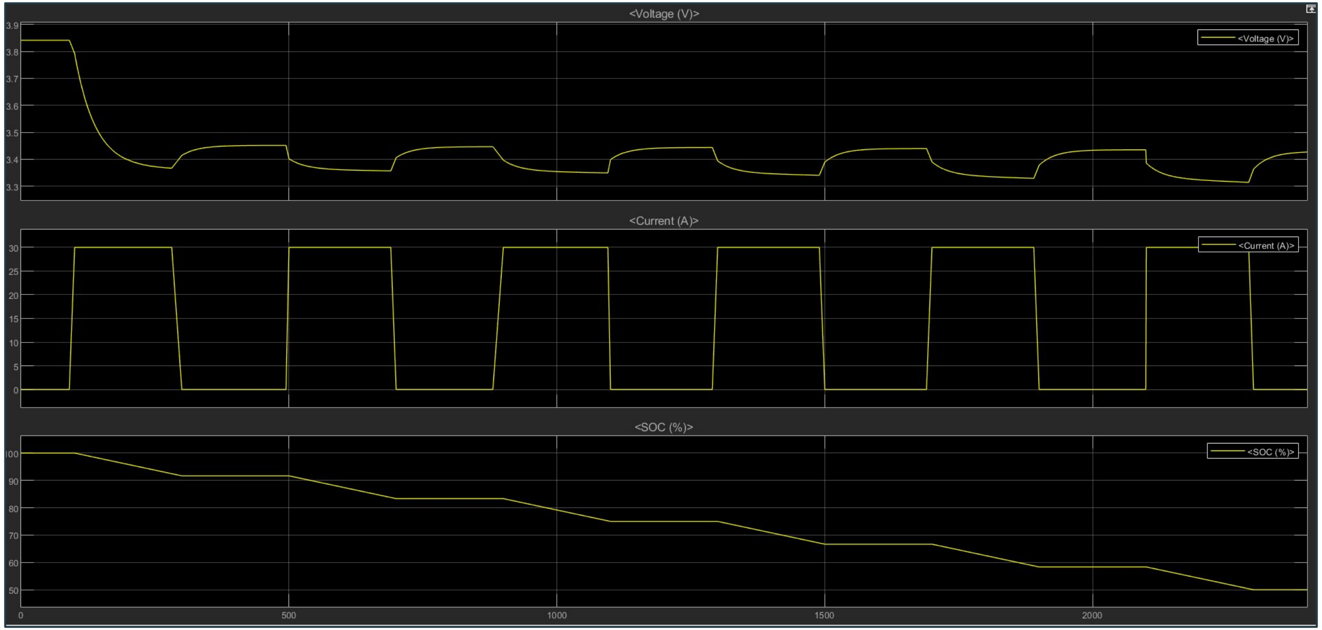


Fig: Results of the Pulse Discharge at 25°C of 30A for 200s

Results

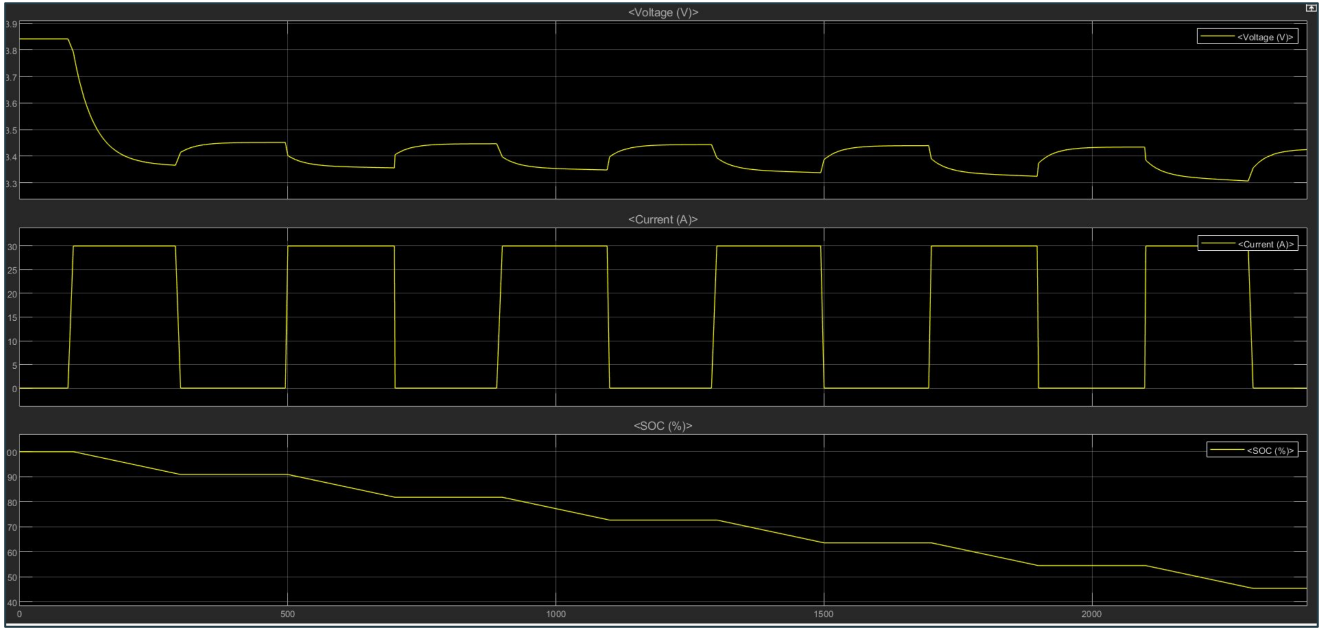


Fig: Model Results on Increasing Ambient Temperature from 25°C to 60°C

Remarks

1. On increasing the temperature of the cell, keeping the rest constant, a **higher decrease in SoC** (~5%) is observed
2. Due to a negative temperature coefficient of voltage for the cell at lower SoC, at higher temperatures, acute undervolting can occur

Design Decision Taken

1. Supports the decision to implement cooling system to extract maximum energy out of cells

Cell Discharge Characteristics

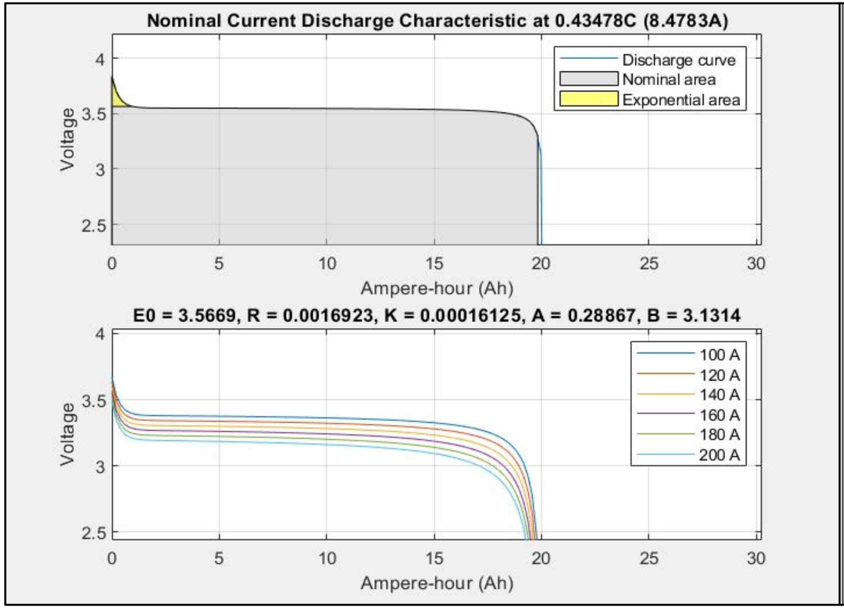


Fig: Discharge Characters from the Model

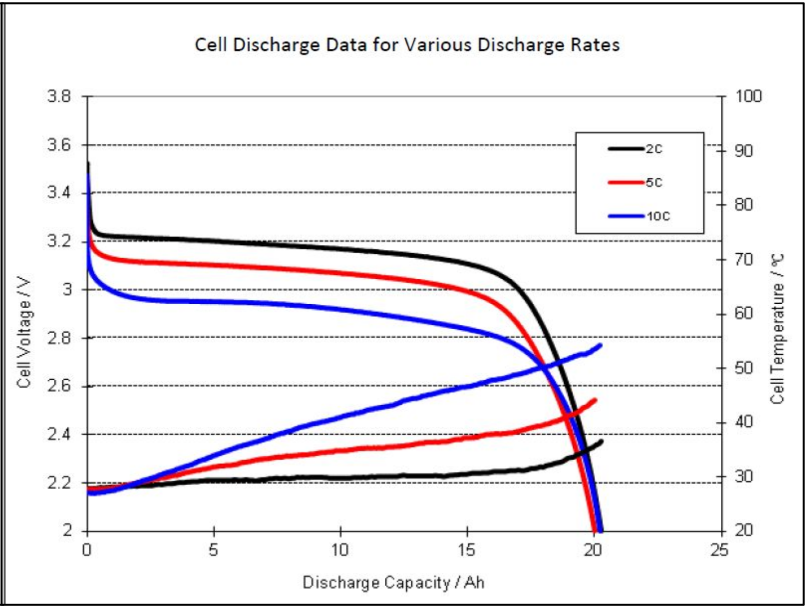


Fig: Discharge Characters from the Datasheet

Cell Ageing Simulation

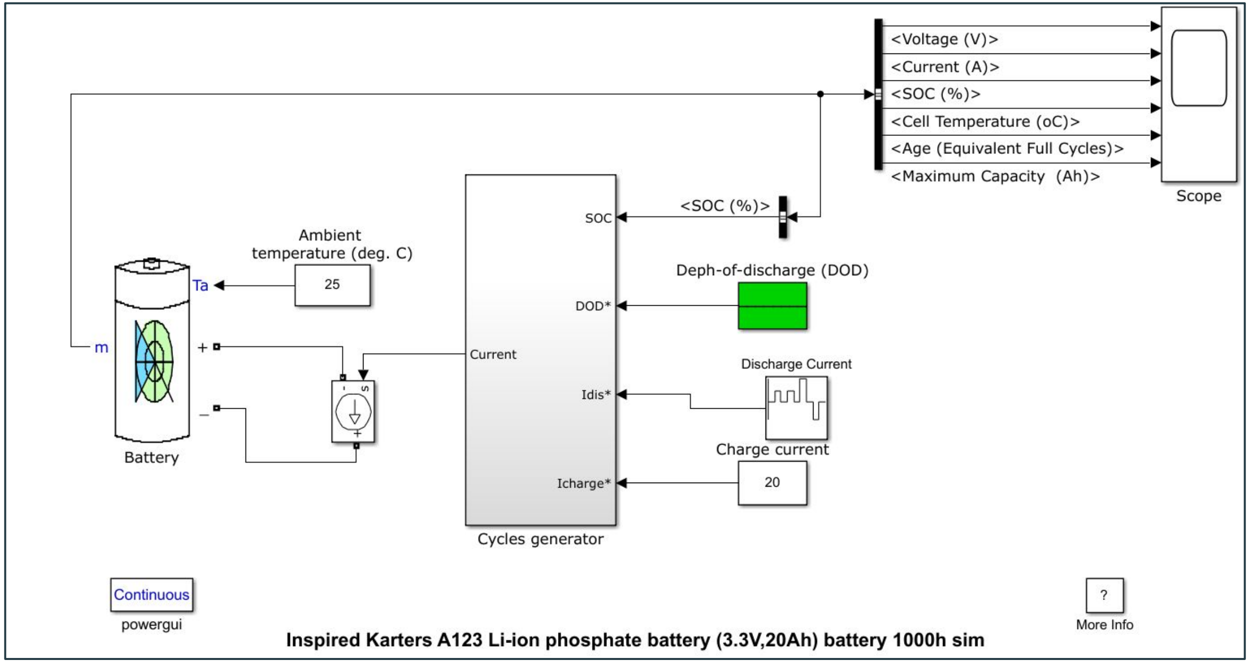


Fig: Model 1

Cell Ageing Simulation

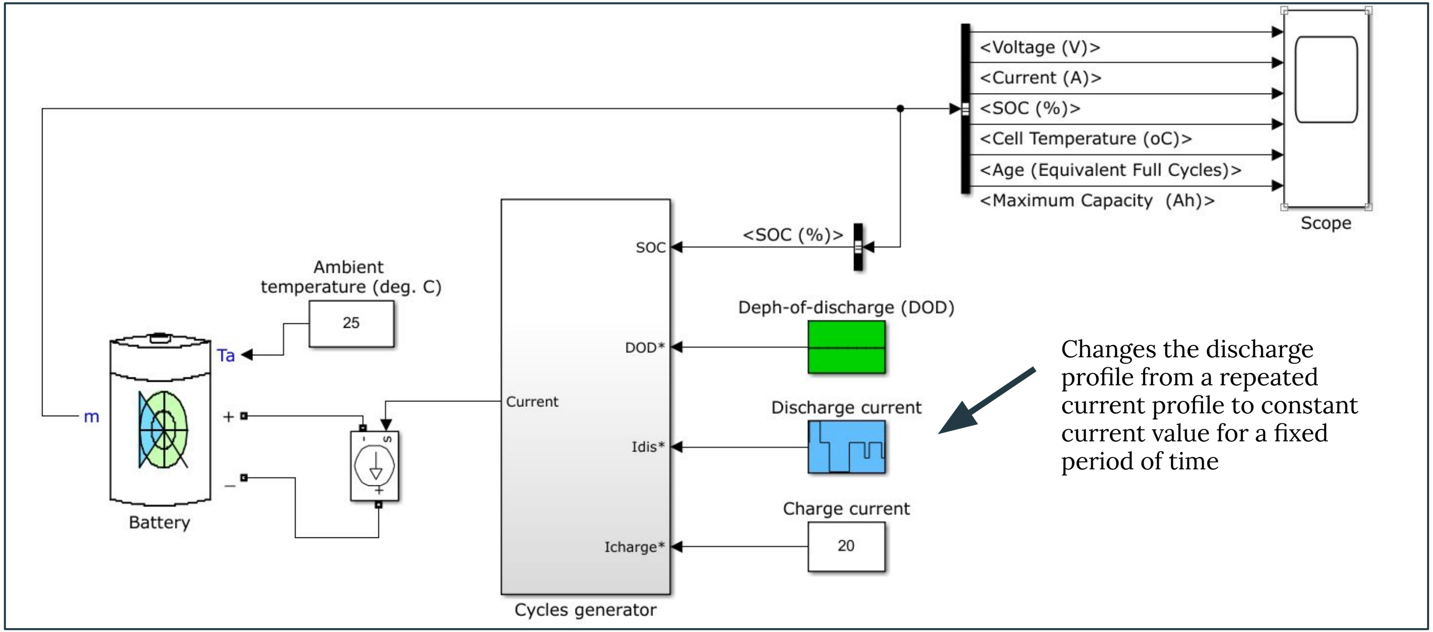


Fig: Model 2

Comparison of the Results

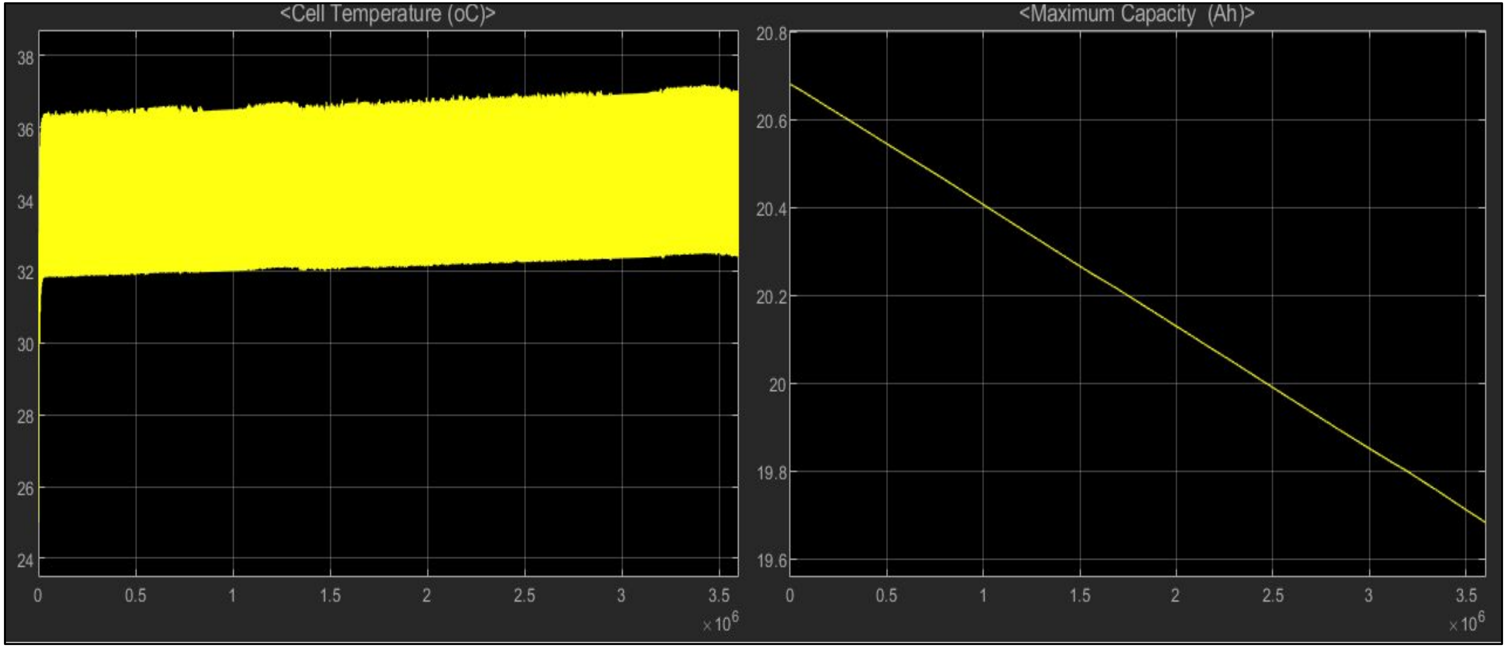


Fig: Model 1

Comparison of the Results

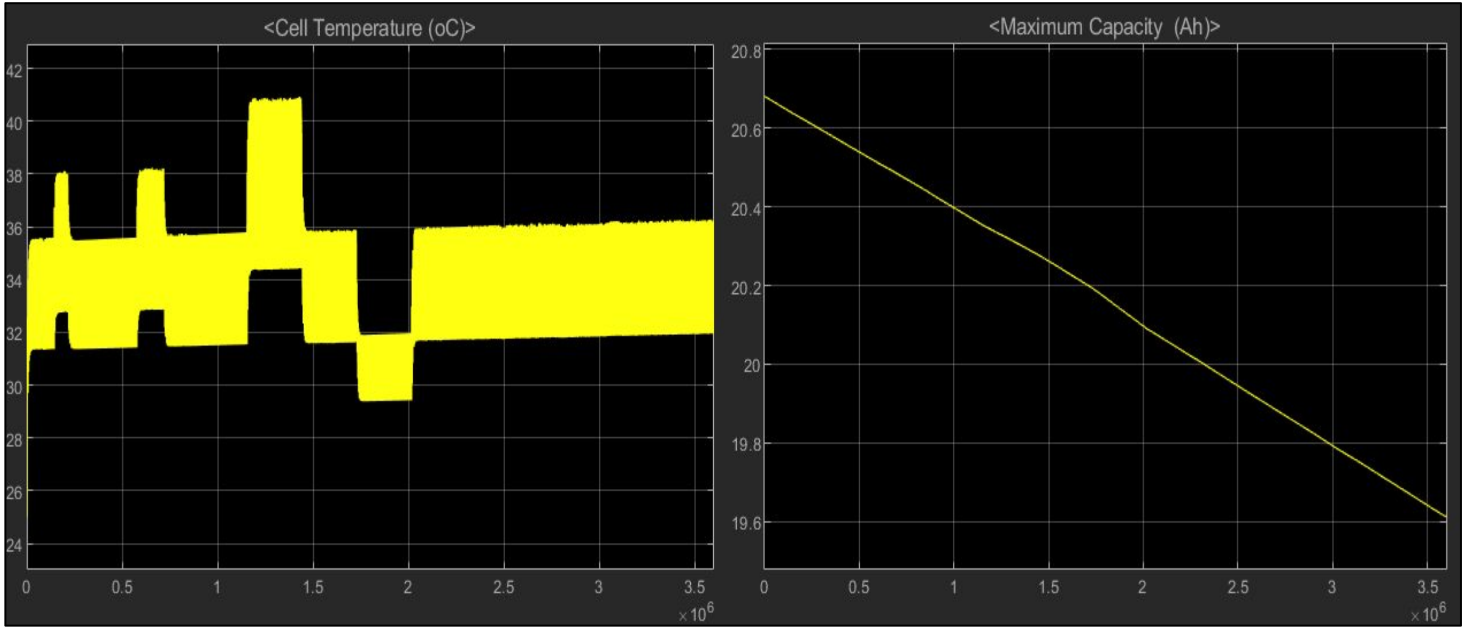


Fig: Model 2

Remarks

1. **Slightly higher capacity decrease (~0.1 Ah)** on having a constant high discharge for Model-2
2. **Higher temperature fluctuation** in Model-2
3. Instances of undervolting due to the excess temperature in the voltage plots(refer Design Report)

Accumulator Structure and Module Design

Overview of Accumulator Design

Electrical Configuration: 90s1p

Mechanical Configuration:

1. Battery Compartment: Cells and Modules
2. Electronics Compartment: BMS, AIRs, IMD, Precharge Circuit, and Tractive Fuse

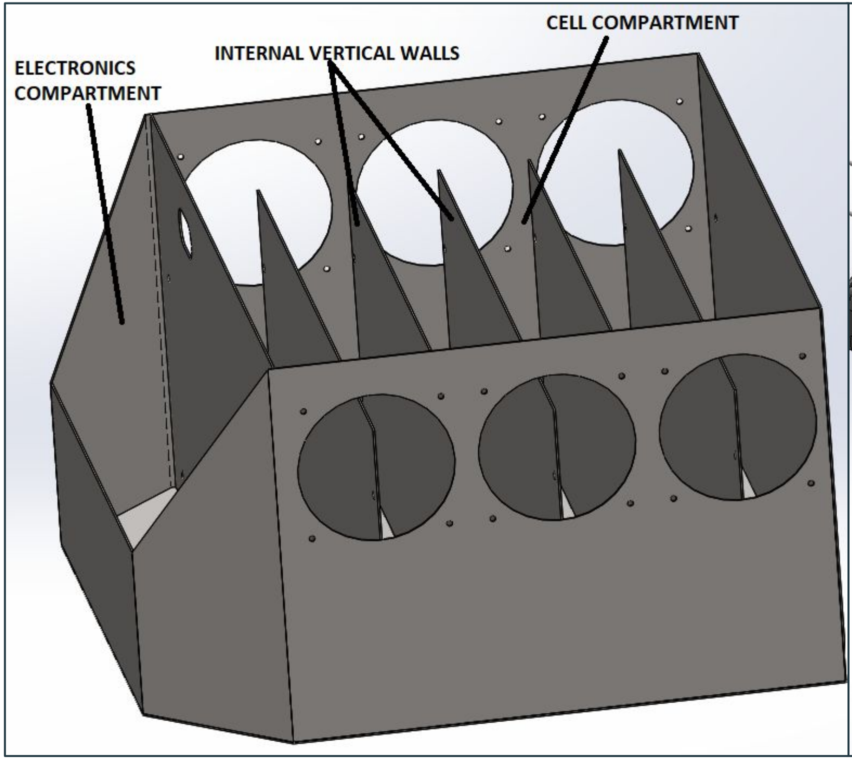


Fig: Container CAD Showing the 2 Compartments

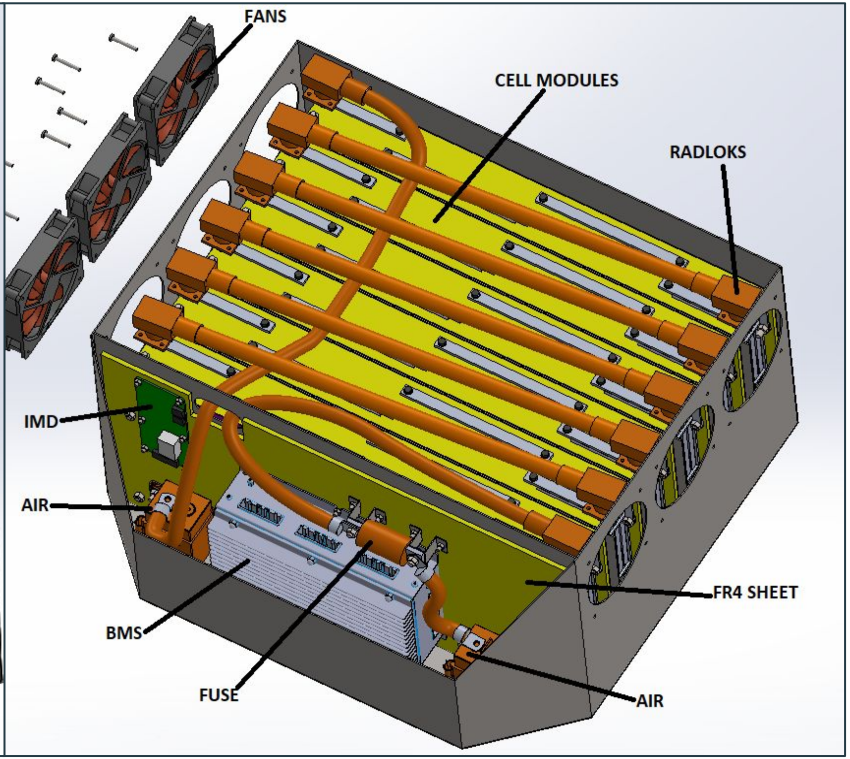


Fig: Complete Accumulator CAD Showing Most Components

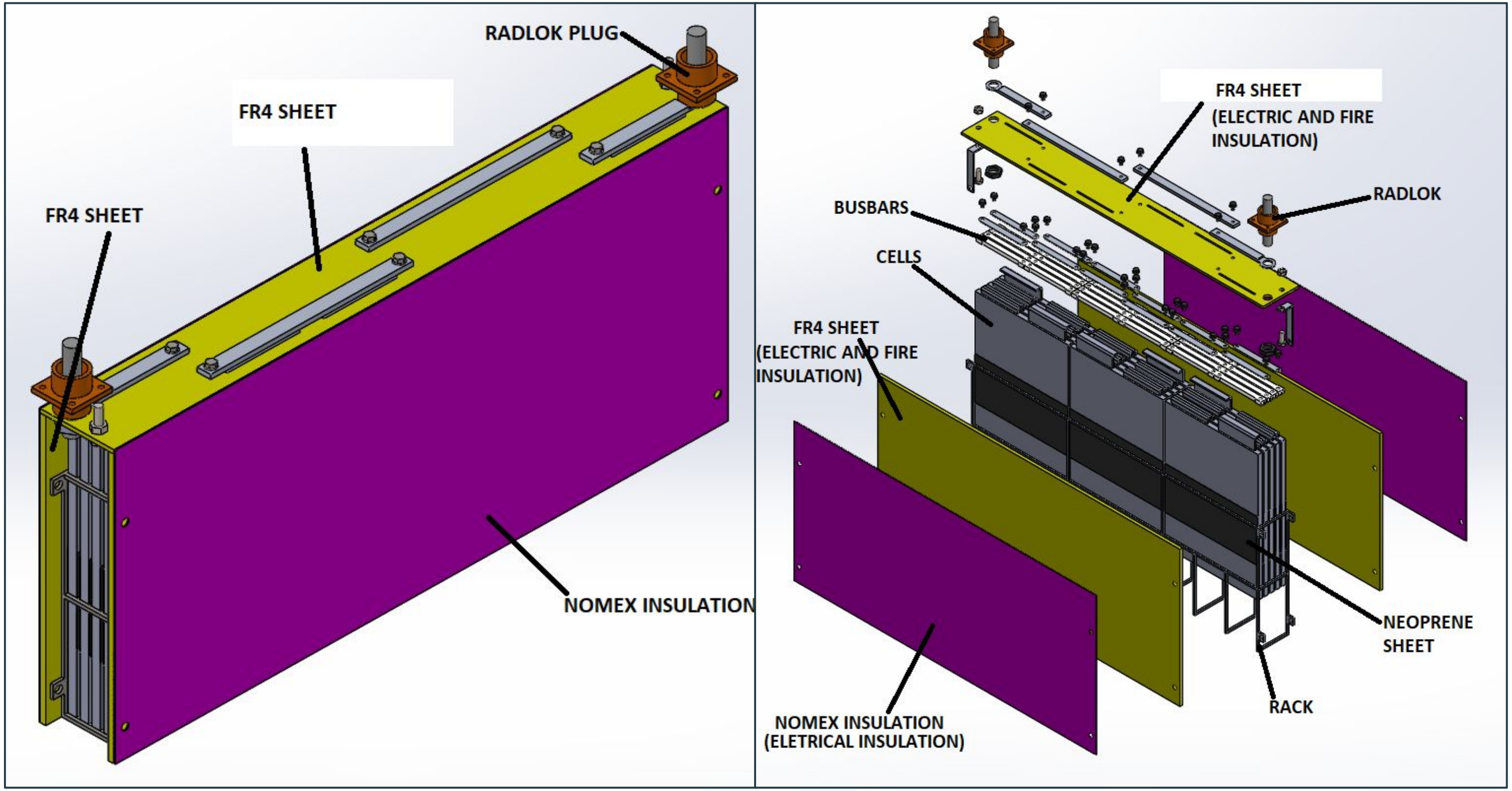


Fig: CAD Images Showing the Module Design and Structure

Stress Simulations

Stress simulations performed on container according to accelerations faced in case of crash, as mentioned in EV.5.5.9.

1. 20g in vertical direction.
2. 40g in lateral direction.
3. 40g in longitudinal direction.

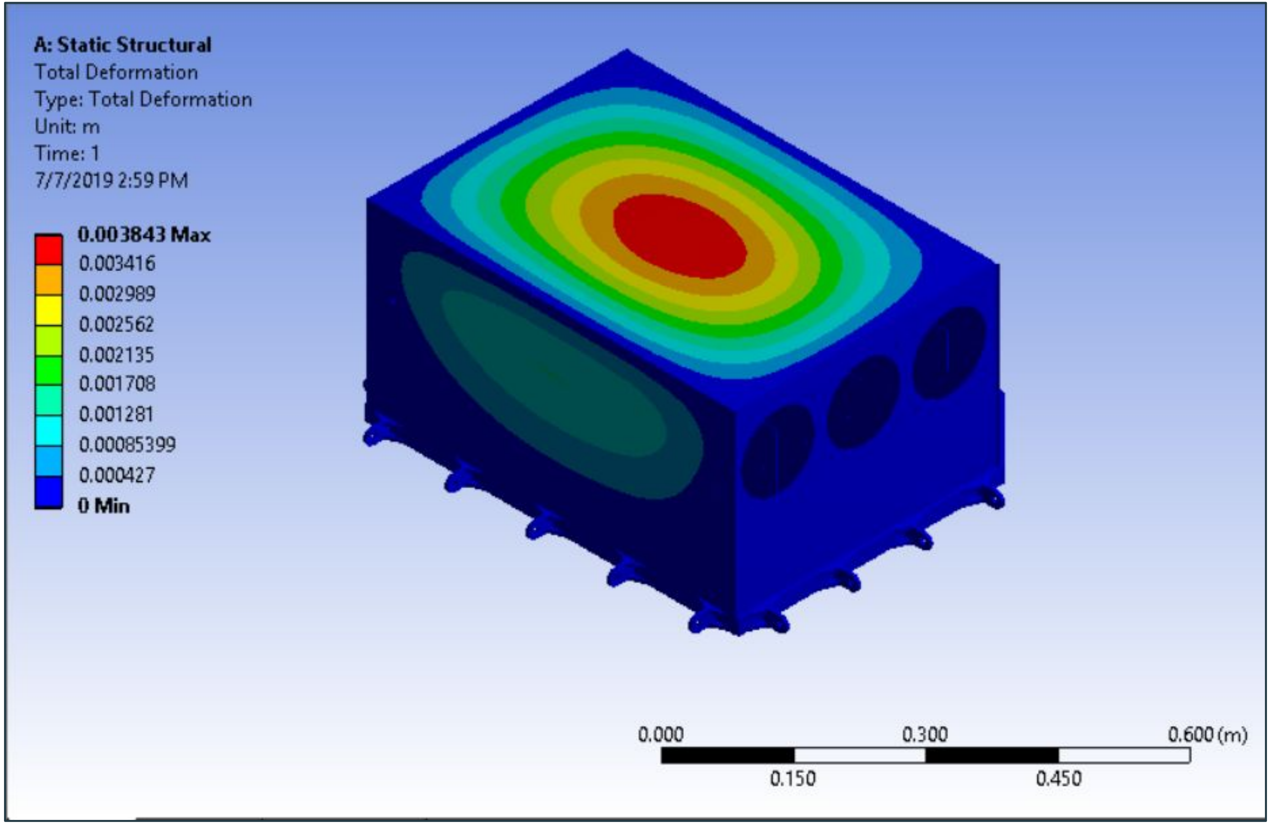


Fig: 20g Vertical Acceleration Shows Max. 3.8mm Deflection

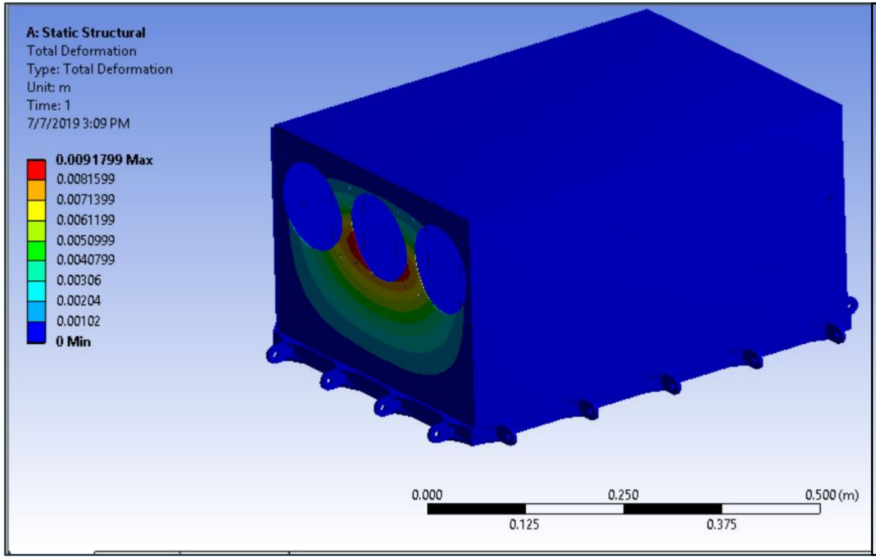


Fig: 40g Lateral Acceleration Shows Max. 9.2mm Deflection

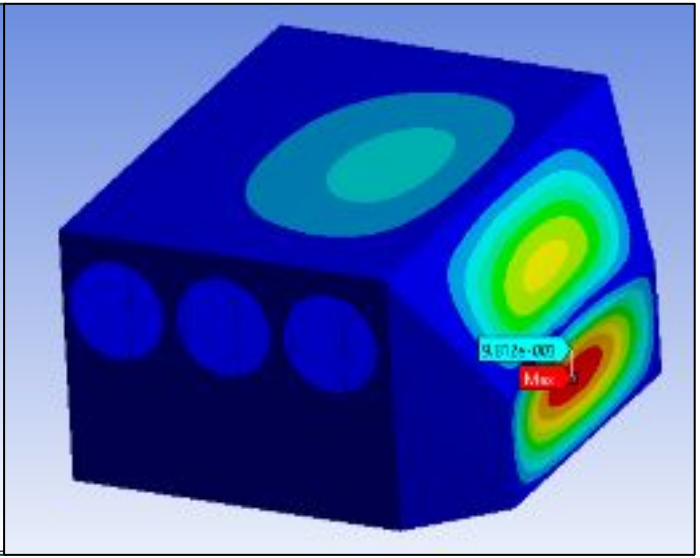


Fig: 40g Longitudinal Acceleration Shows Max. 9mm Deflection

Battery Management System

BMS Model

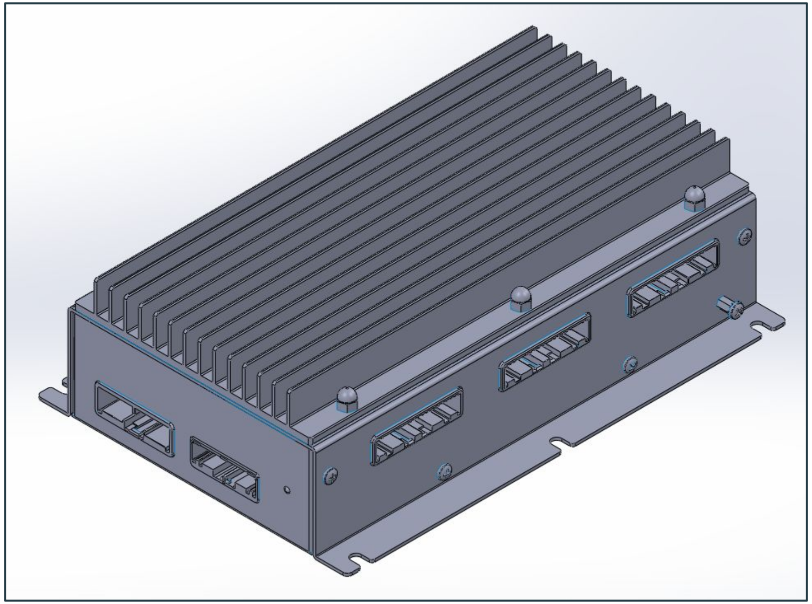
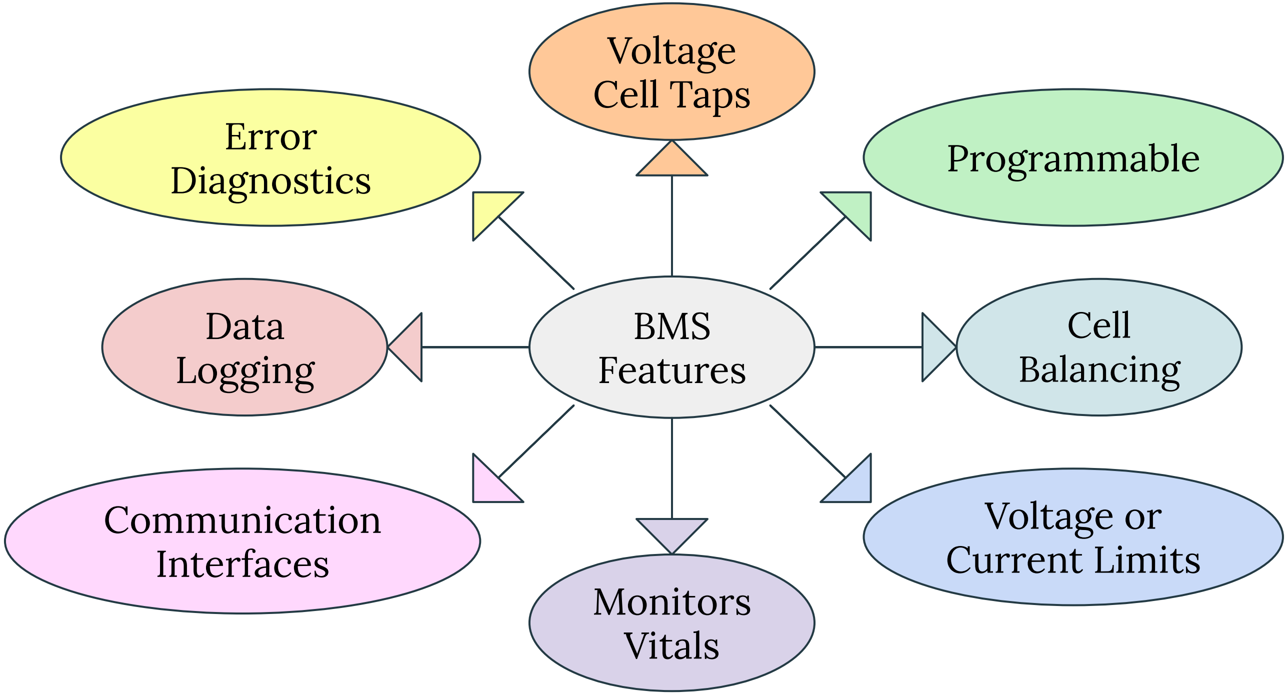


Fig: Orion BMS 2 (108 Cell Configuration)

BMS Features



Charger

Charger Model

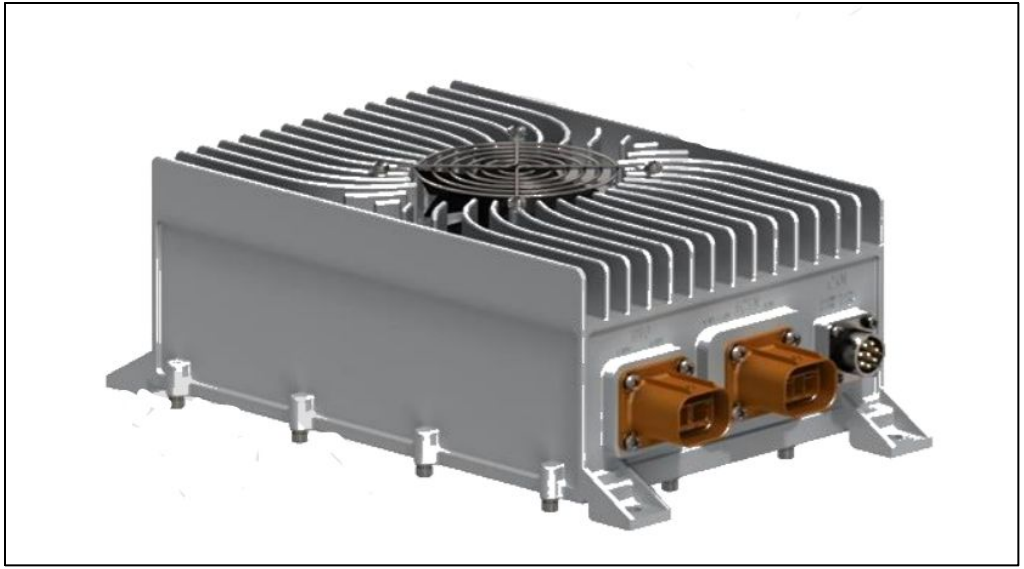


Fig: DA3KM17-360

Charger Specifications

Specification/ Unit \ Model			DA3K3M17-360
Mains Input	Rated voltage		220 Vac
	Voltage Range	Vac	85 ～ 264 (Input 85-176, automatically drop to 1200W）
	FREQ RANGE	HZ	47～63
	Efficiency(max)	%	≥95
	Power Factor		≥0.99@220Vac,rated power
	Current(MAX)	A	≤16@220Vac
Mains output	Rated voltage		360 Vdc
	Constant voltage output range	Vdc	250 ～ 420 (According to the customer battery final decision)
	Max current		12A
	Constant power output		3300 W
	Output voltage accuracy	V	≤±1%Vo input 176Vac-264Vac，output 10%-100% load
	Line regulation	%	≤±0.2%Vo input 176Vac-264Vac，output 100% load
	Load regulation	%	≤±0.5%Vo input 220Vac，output 10%-100% load
	Ripple and noise	mV	≤±3%Vo 20M oscilloscope Twisted-pair cable test.

Charger Schematic

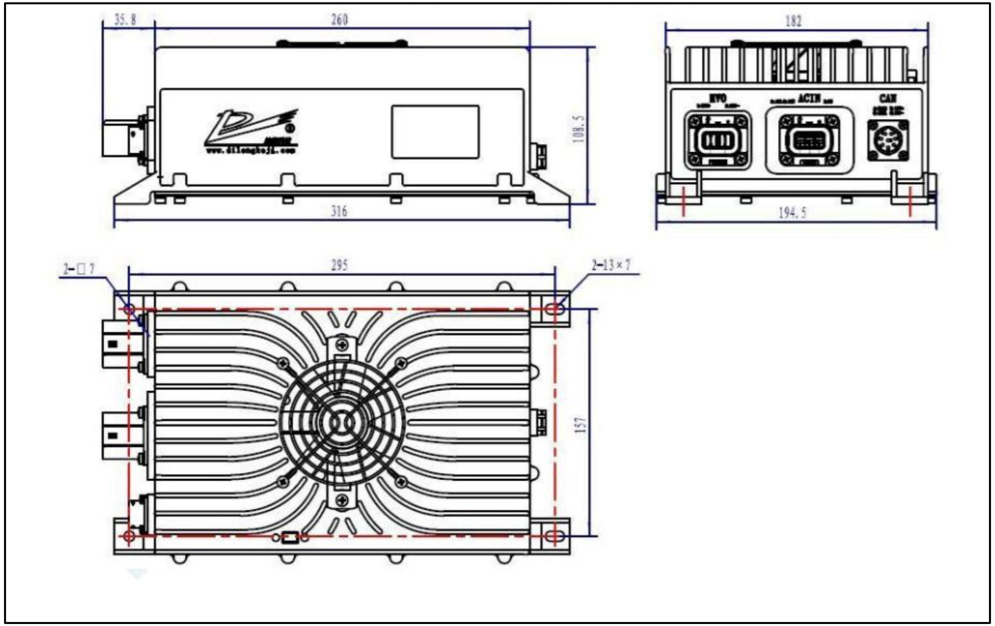


Fig: DA3KM17-360

Battery Thermal Management

Design Objectives

1. Cell Temp under safe limit (50°C)
2. Minimize spatial dimensions of accumulator-design parameter

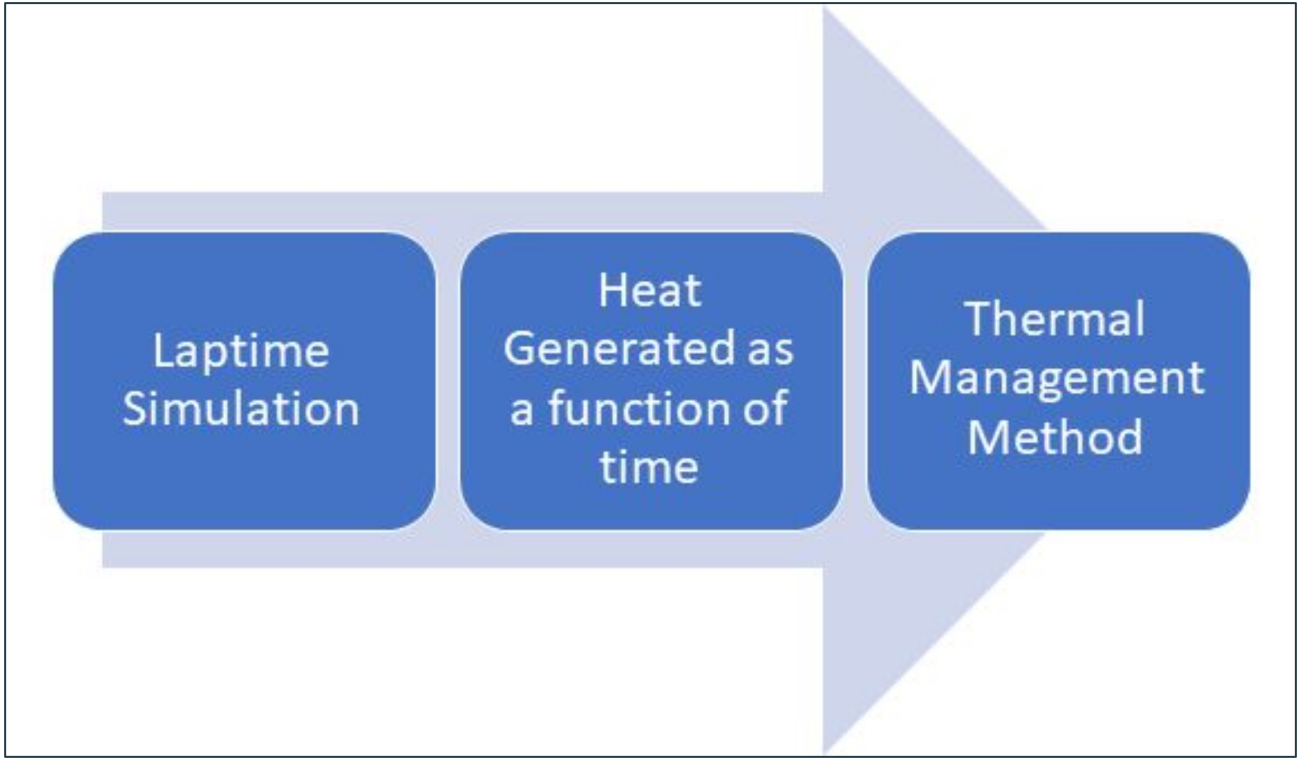


Fig: Design Process Flowchart

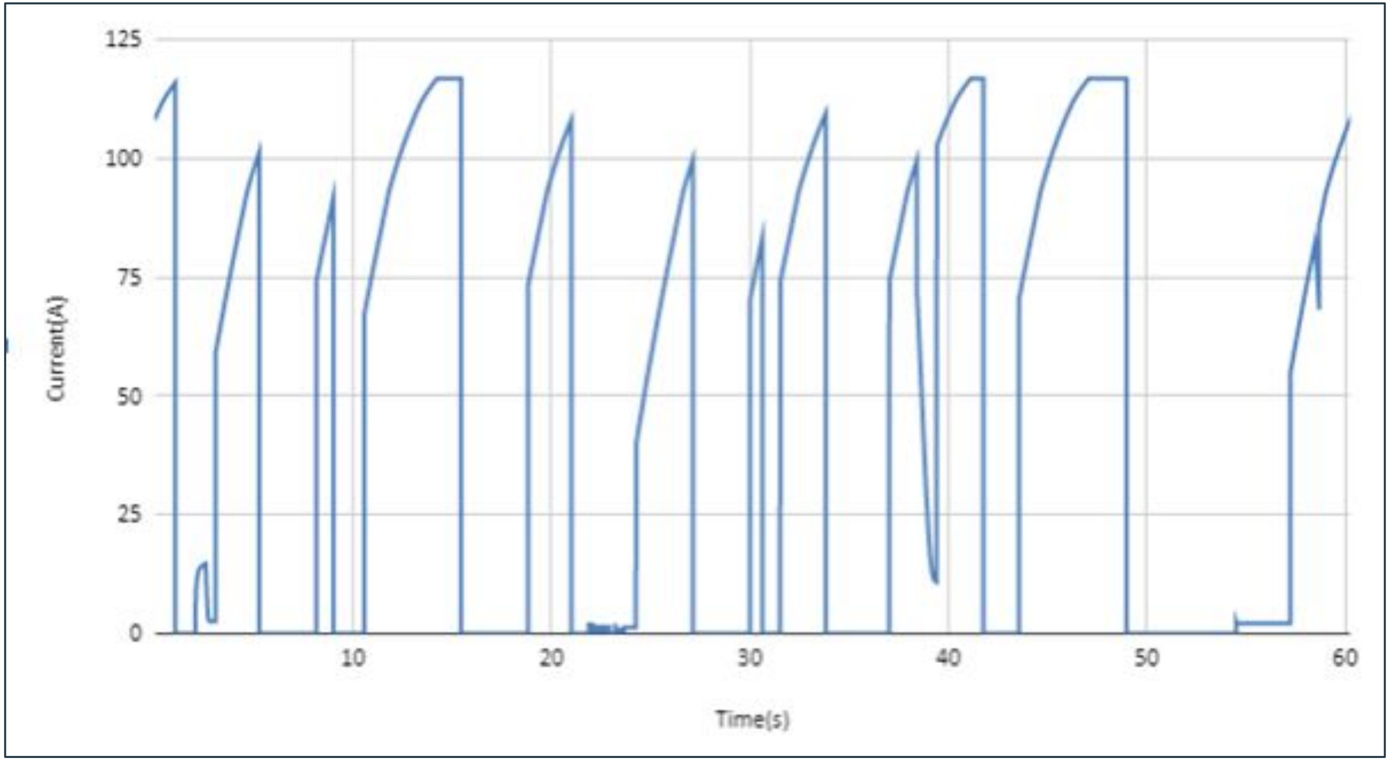


Fig: Current vs Time for a Single Lap of Endurance

Cooling Solution

Liquid Cooling

1. More powerful
2. Complex Design and Handling
3. Safety and Reliability issues

Forced Convection Air Cooling

1. Less Powerful
2. Reliable and Easier to design and implement
3. Sufficient for cooling requirements

Implementation

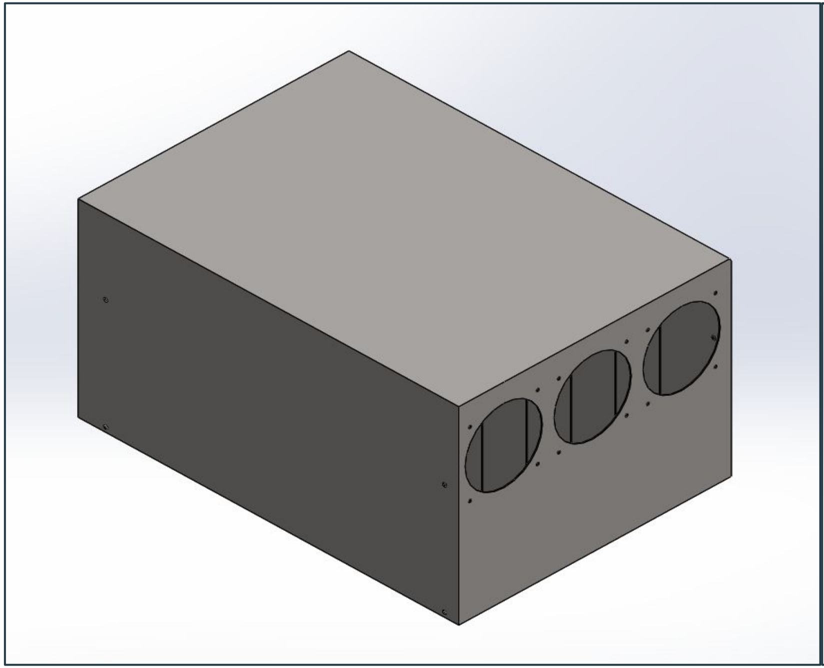


Fig: Accumulator container-Fan inlet

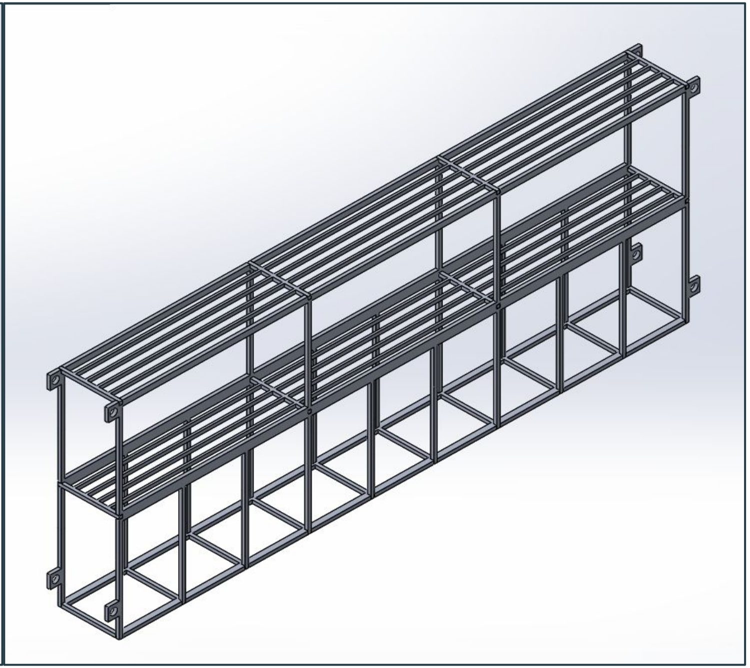


Fig: Cell racks-Airflow Channels

Fan Selection

1. Fan with min. 27 CFM considered.
2. Selection based on
   a. Fan Curve
   b. Ease of Procurement
   c. Iterative Process Based on Simulation

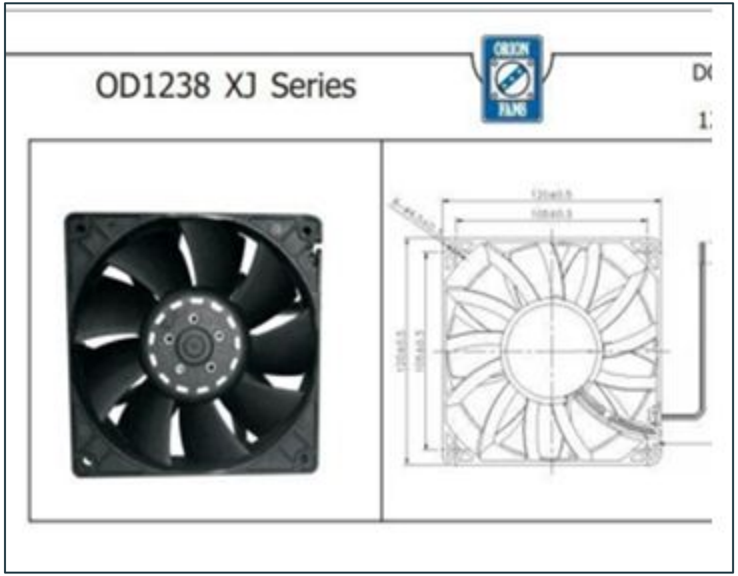


Fig: OD1238 XJ Fan

Analysis through CFD Simulation

1. Pre-Analysis and Calculation
2. Geometry and Meshing
3. Problem Setup and Solution Procedure
4. Validation
5. Post-processing and Results

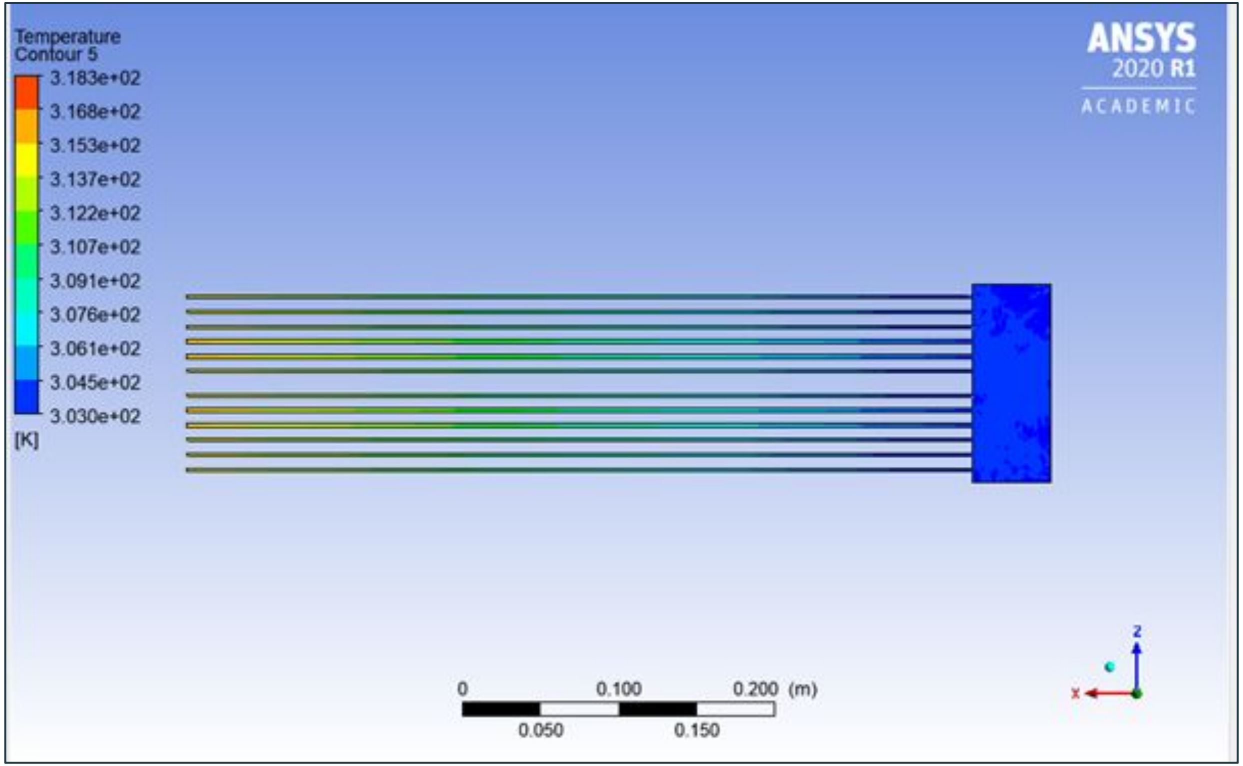


Fig: Top View of Temperature Distribution

Results

Maximum Local Temperature of Cell Wall	45.348°C
Maximum Temperature of Cell	43.2°C
Fan Operating Point	215Pa,0.0027m^3/s
Cell operating well under the safe limit	

Control Circuits

Essential Control Networks

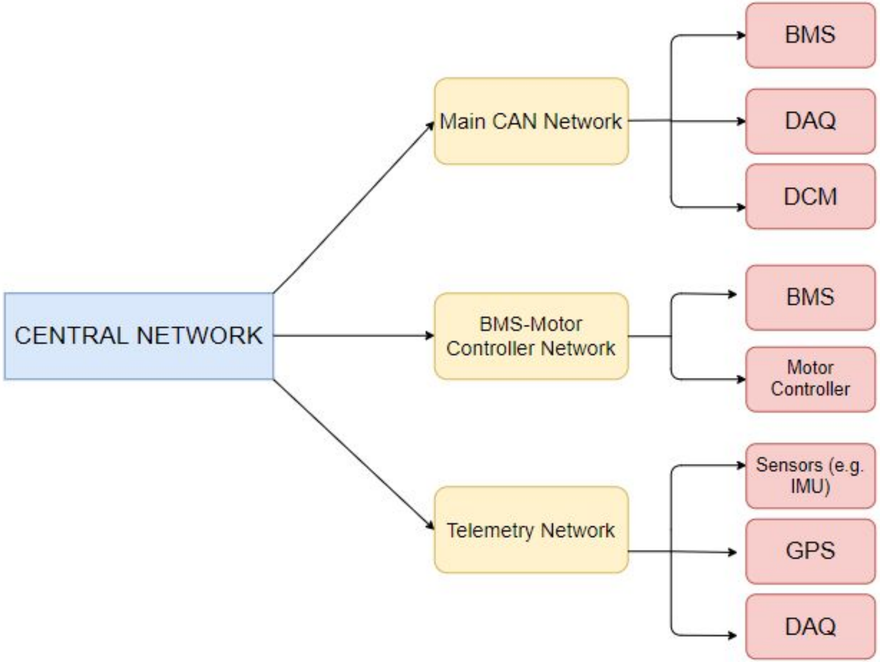
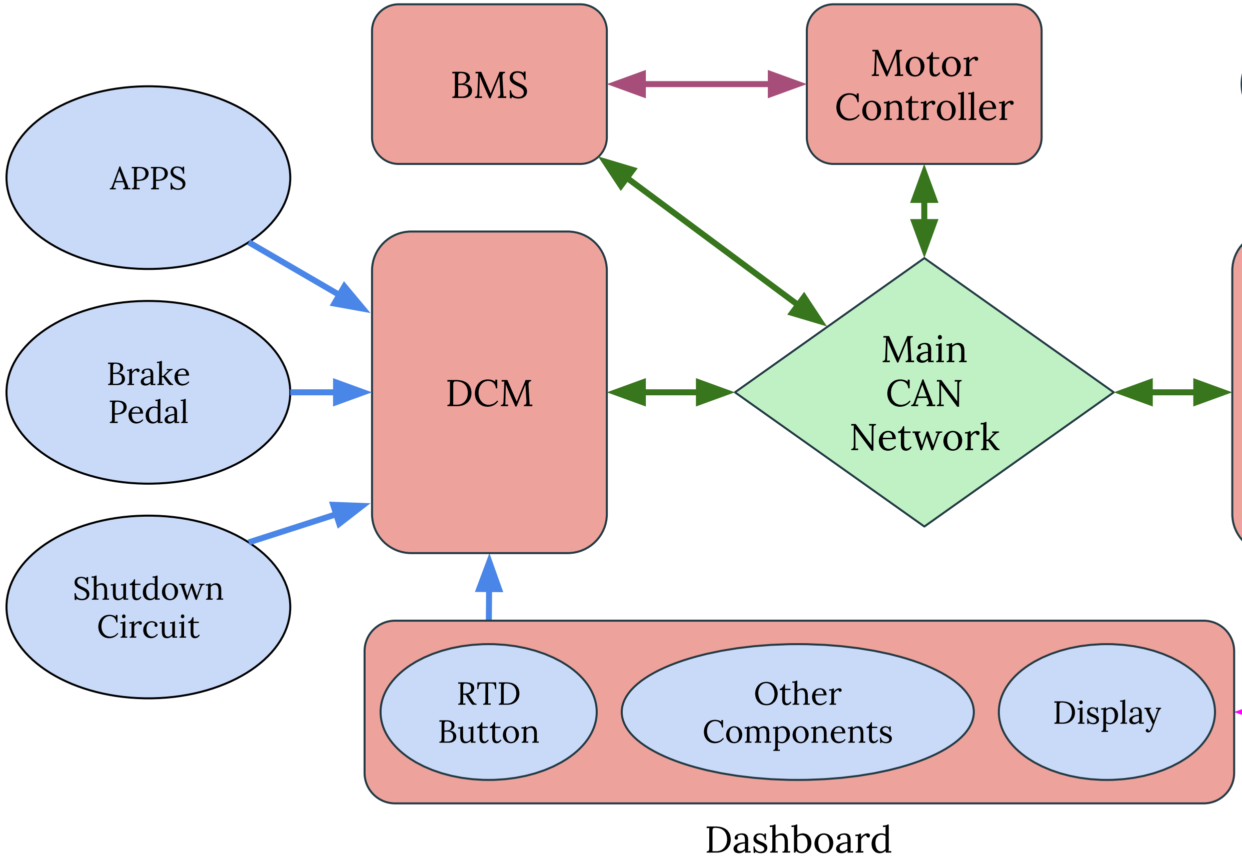


Fig: Control Network Layout


BMS
Motor Controller
IMU & GPS
APPS
DCM
Main CAN Network
DAQ
Brake Pedal
Shutdown Circuit
RTD Button
Other Components
Display
Dashboard

Drive Control Module (DCM)

STM32F412zg Nucleo MCU is used, the board having 2 inbuilt CAN 2.0 B controllers for connecting it to our CAN network.

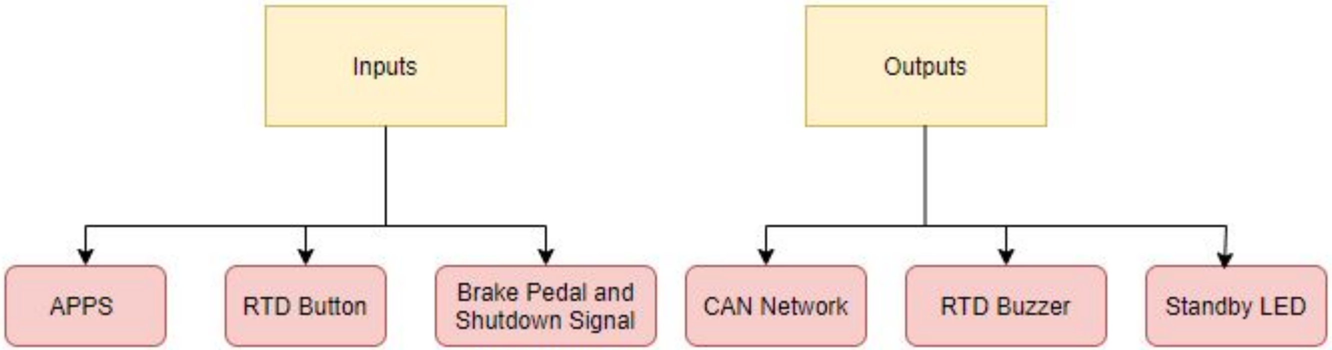


Fig: DCM Inputs and Outputs

Functions of the DCM

Torque Encoder

'RTD - Stand By' Mode Toggle

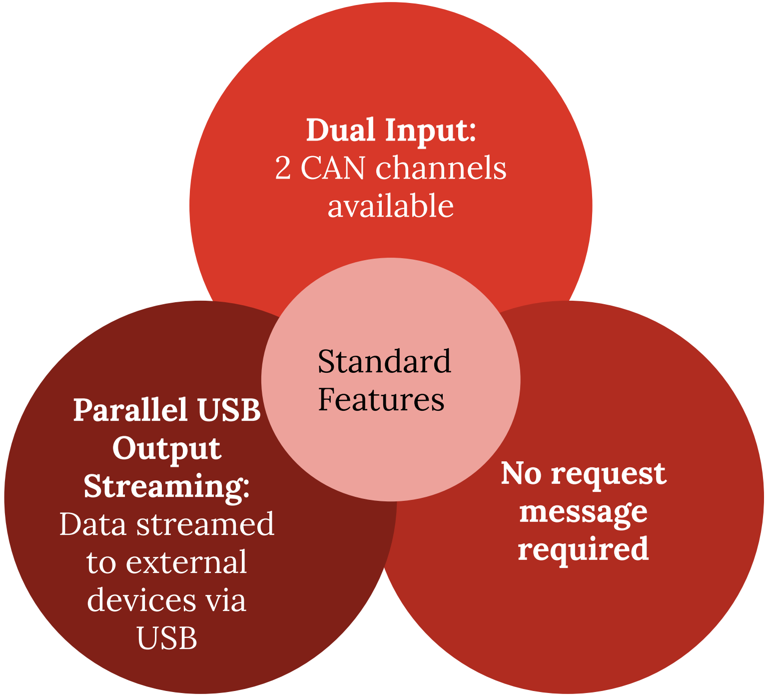
Brake Interrupt

Post -Shutdown Sequence

Data Acquisition System

We will be using a Kvaser Memorator Pro 2xHS V2 USB to CAN Data logger.

This logger will then, parallely publish the data to dashboard and to the wifi module.



Data Acquisition System

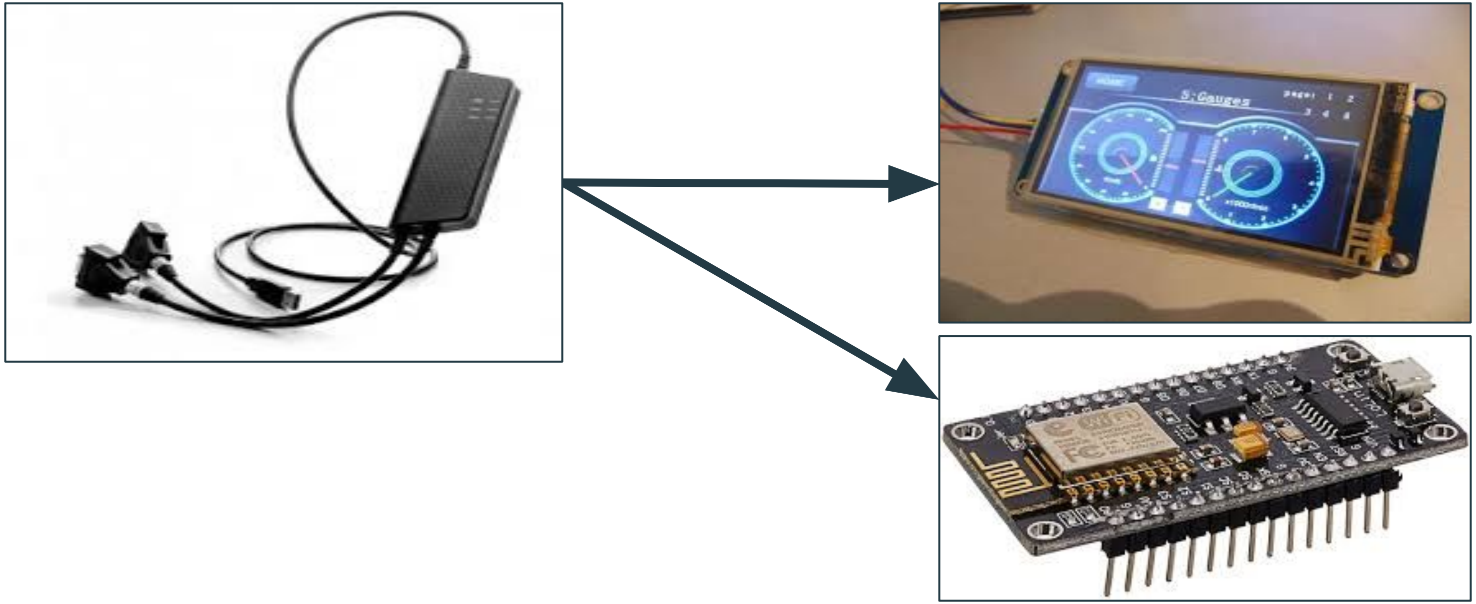


Fig: Kvaser Memorator Pro HS v2 Connected to the Display and the Wi-Fi Module

Additional Application Protocol

An additional layer of protocol is added to the CAN layer. This is to facilitate the following features:

1. **Priority Shift:** Dedicated algorithm to identify and move up the priority of the starved nodes.
2. **Transmitting Starved Messages:** A specialized function will encrypt all the starved messages in a way that they can be sent via a single CAN message.
3. **Smart Receiver:** The receiver is smart enough to retrieve the starved data from the new message.

Safety Circuits

Shutdown Circuit

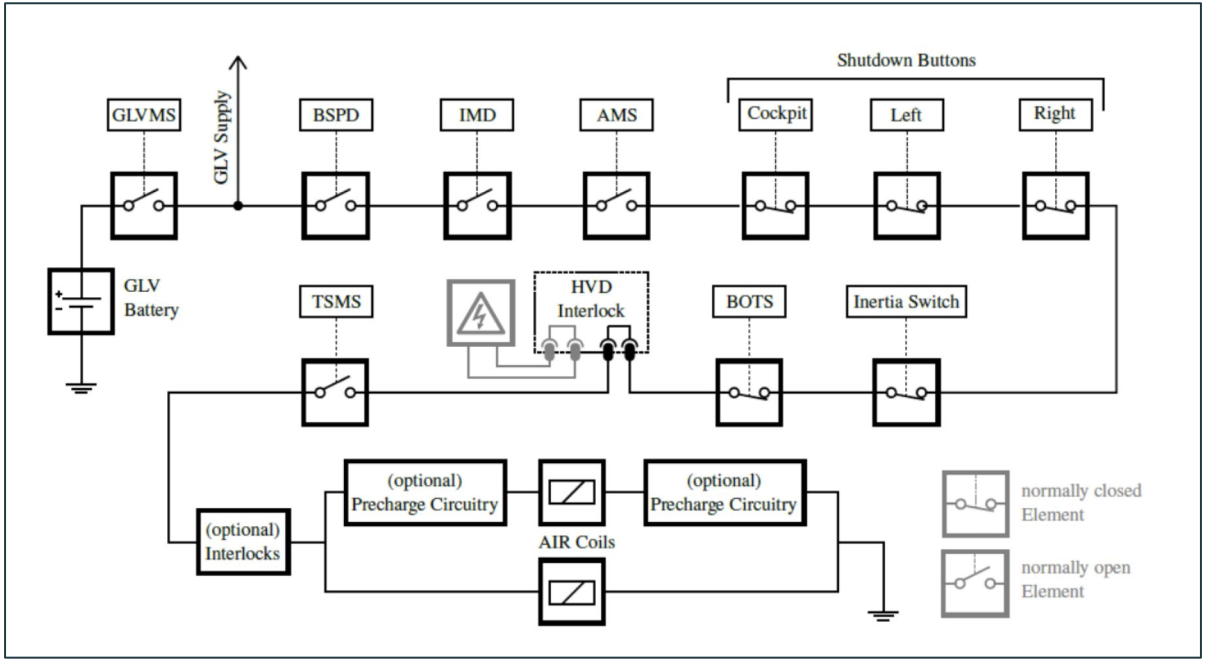


Fig: Shutdown Circuit Diagram

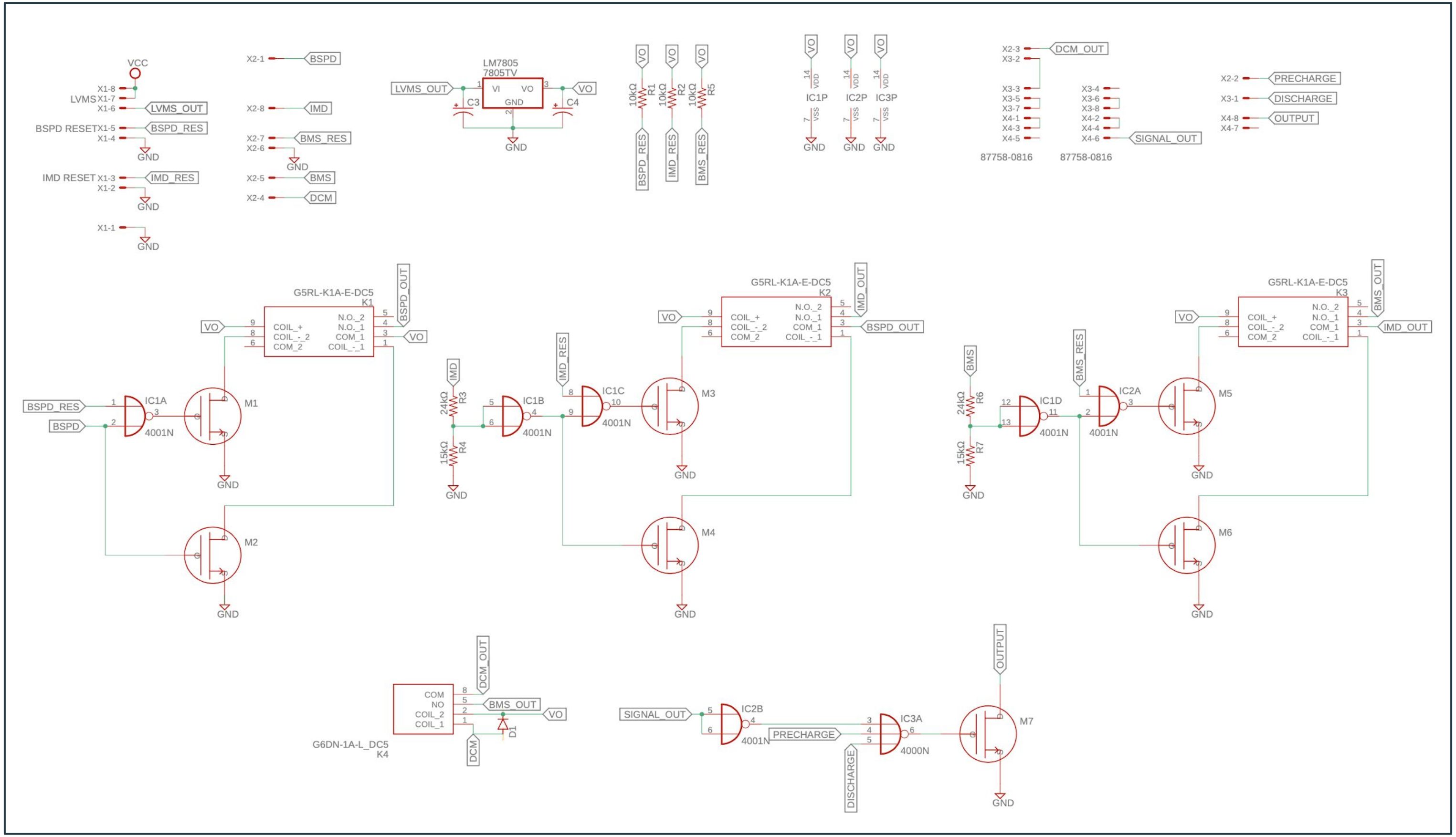


Fig: Shutdown Circuit Schematic

Brake System Plausibility Device

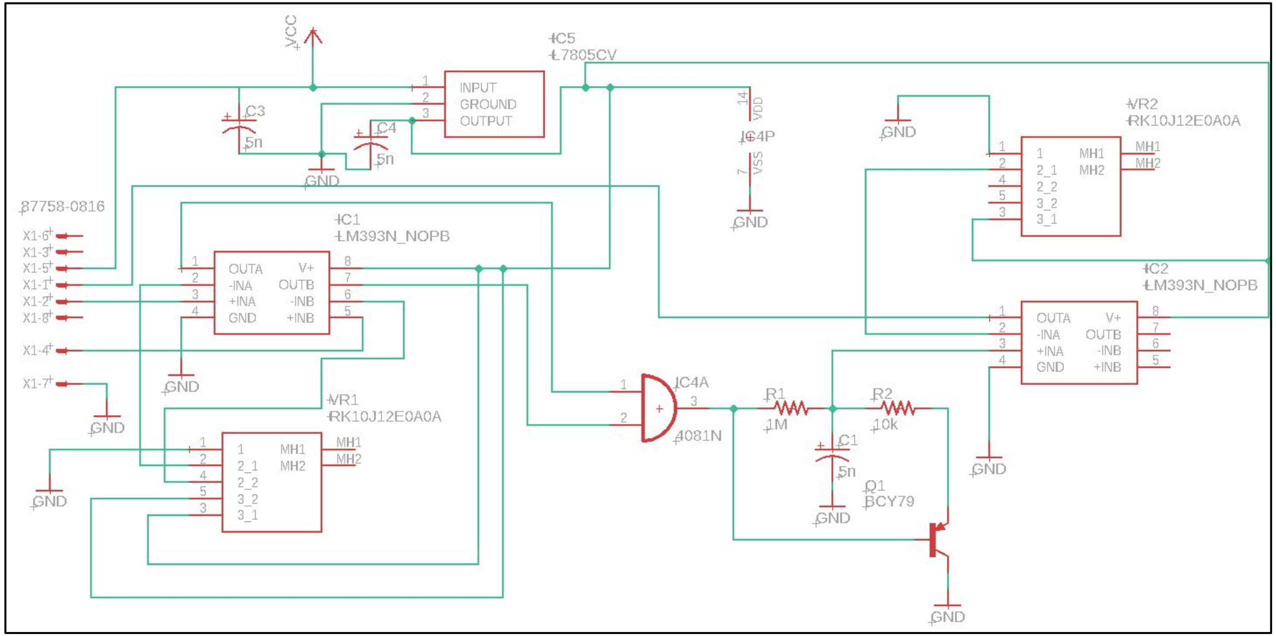


Fig: BSPD Schematic

Precharge Circuit

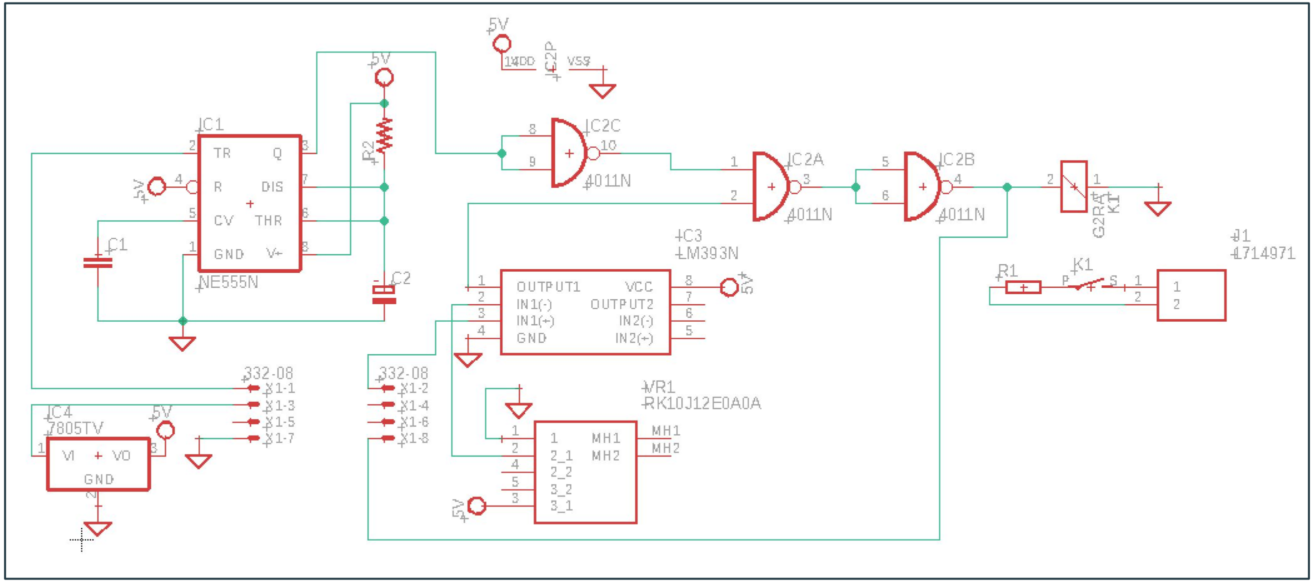


Fig: Precharge Circuit Schematic

Discharge Circuit

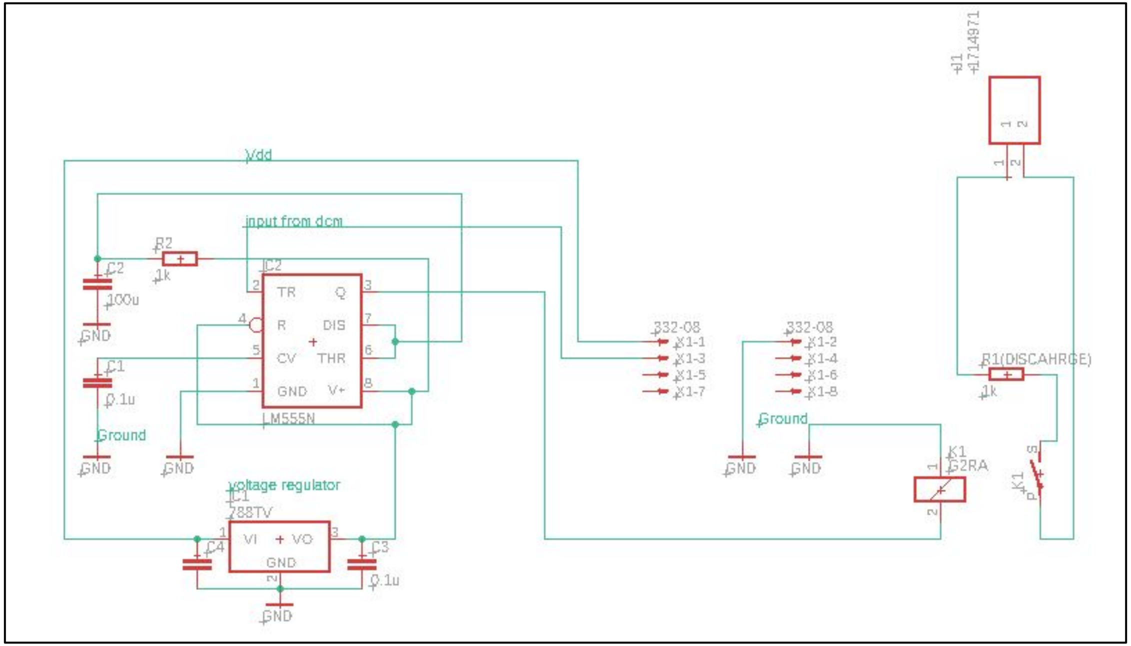


Fig: Discharge Circuit Schematic

To understand our design in greater detail, please do take a look at our Design Report, which can be found here.

Thank you!