Engineering Design Presentation (EDP)

Table of Contents

Why Electric?

- No Gas Required
- Reduced Air/Noise Pollution
- More Convenient
- Battery life and Cost
- No Emission
- Easy Driving
- Low maintenance cost
- Safe To Drive

General approach

Gathering Information → **Design** → **Optimization**

Gathering Information

- Collecting information.
- Manipulating information as per need.

Design

- Preparing model in software environment.
- Structuring it to system level.
- Finalizing control strategy and dynamic system model.

Optimization

- Performing many trial runs.
- Checking whether the design characteristics meet the required characteristics.

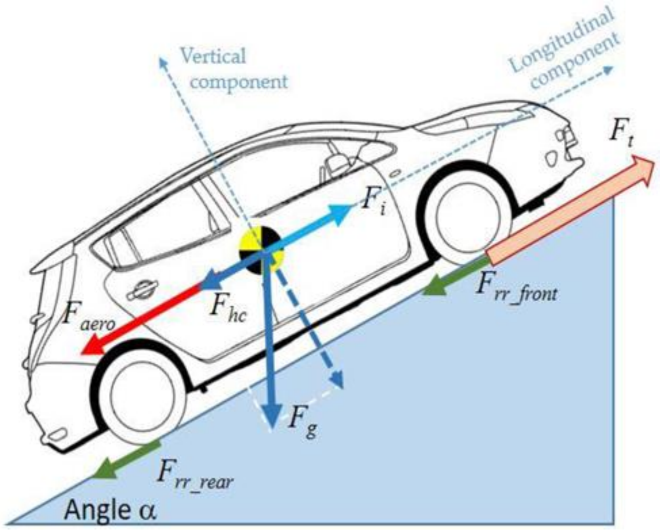
Preliminary Analysis

Design Objectives

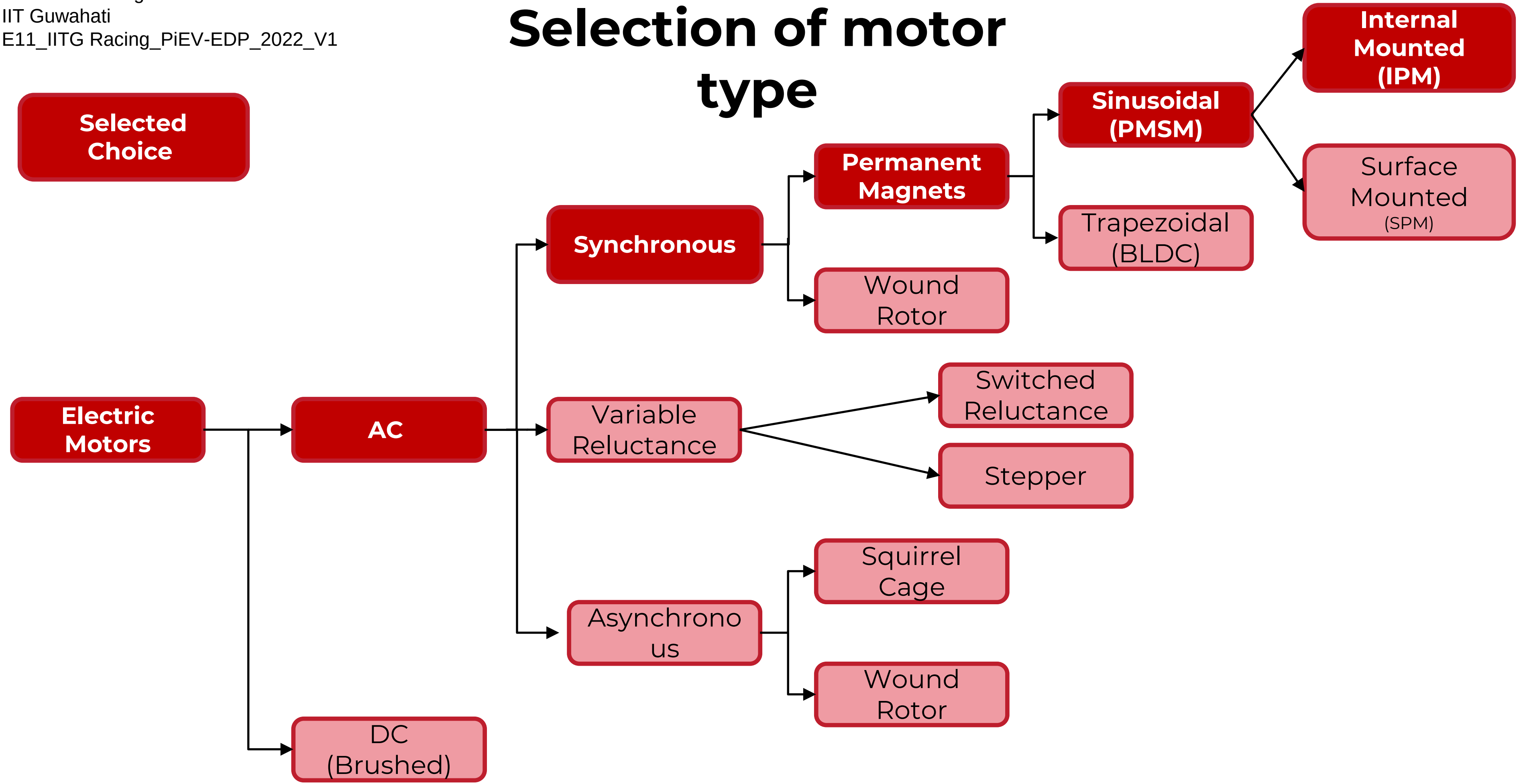
- Vehicle speed: 0 to 100 kmph in 3-5s
- Maximum speed: 110-125 kmph

$$\text{Force on car} = ma + \frac{1}{2}C_d\rho A v^2 + C_r W\cos\theta + W\sin\theta$$

Parameters	Values
Mass of the vehicle (m)	280 kg
Drag Coefficient (C_d)	0.725
Density of air (ρ)	1.125
Frontal Area (A)	0.86 m^2
Road frictional resistance coefficient (C_r)	0.015
Slope Angle (θ)	0
Diameter of Wheel	45.72 cm (18")



Selection of motor type



Transmission Concept Selection

First year in EV

+

No standard of comparison for Torque Vectoring Models (dual/4 motors) due to lack of complete model of single motor

+

Experience in CV Transmission

=

Single (Rear) Motor with Chain-Sprocket drive and Differential

Methodology-I

1. Make a list of considerable motors as permitted by Formula Bharat rules.
2. Tabulate maximum speed (rpm) without flux weakening.
3. Tabulate Final Gear Ratio for achieving design objectives of maximum vehicle speed.
4. Using the gear ratios and torque-speed characteristics, compare 0-100 kmph timings of each motor from vehicle dynamics calculation simulations.
5. Power density and cost considerations are taken into account along with timings to select appropriate motors.

Motor selection

Motor	EMRAX 188	EMRAX 208	REX90
Maximum Power	52 kW	68 kW	70 kW
Weight	7kg	9kg	17.3 kg
Cost	3260 €	3580 €	9000 €
Maximum RPM	6500	6000	4000
Final Ratio for 150 kmph	3.73	3.45	2.30
Maximum Torque	90 Nm	140 Nm	200 Nm
0-100kmph Time	5.839 s	3.93 s	4.14 s

Methodology-II

- Use Torque-Speed Characteristics to simulate Lap time Vehicle Dynamics of Car.
- Compute Drive Cycle characteristics for total energy requirements.
- Using appropriate assumptions and efficiency considerations, estimate net energy requirements for pack design.
- Preliminary Analysis is complete. Proceed to cell selection and detailed analysis.

Accumulator and AMS

Pack sizing

Tractive Energy required for 1 laps (5 km) = 699 Wh
Tractive Energy required for 5 laps (25 km) = 3.5 kWh

Motor efficiency = 94%
Controller efficiency = 97%
Transmission efficiency = 96%

Pack energy required = 3.99 kWh

Considering a factor of safety of 15%,
Final Pack energy = 4.59 kWh

Current Requirements

Max tractive power during the drive cycle = 40.1 kW
Again, considering the efficiencies,
Max continuous power delivered by pack = 45.81 kW
Max peak power delivered by pack = 77.69 kW

Max continuous current required = 130.9 A
Max peak current required = 221.9 A

Cell Comparison

	LG INR18650HE2	LPHDA885155	NMC (HHPOWER)
Type	Cylinder	Pouch	Pouch
Voltage	3.6 V	3.7 V	3.7 V
Capacity	2.5 Ah	16.8 Ah	32 Ah
Max discharge	8C	10C	8C
Configuration	7P98S	1P95S	1P95S
Pack Energy	6.17 kWh	5.9 kWh	11.25 kWh

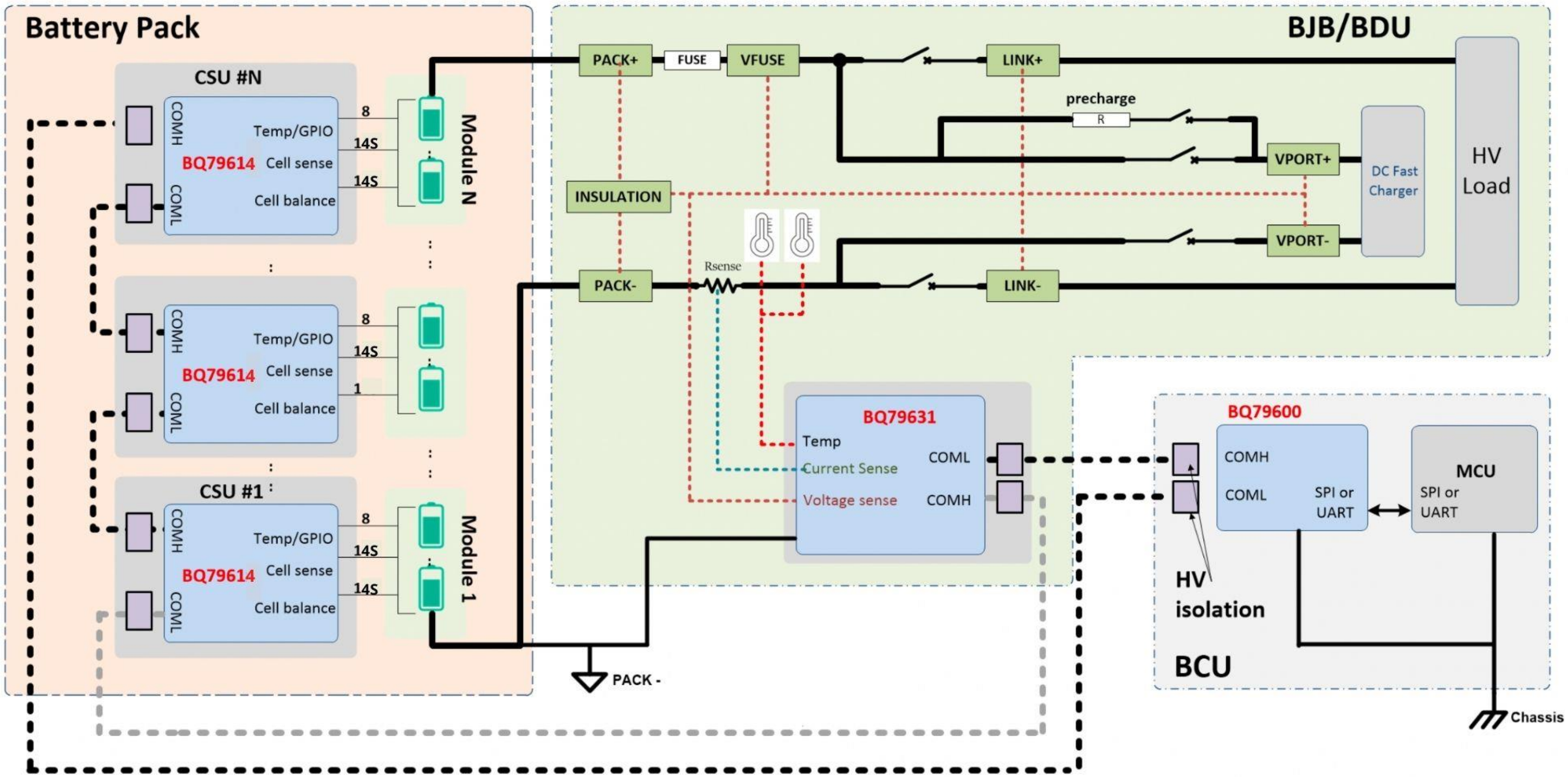
Cell and Pack Size

LG INR18650HE2 2500mAh (8c) LI-ION BATTERY

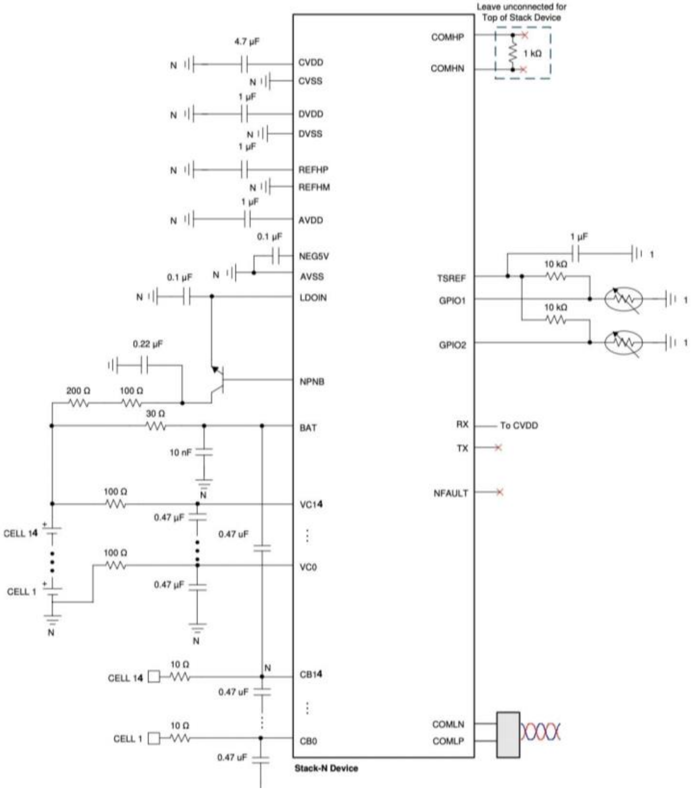
- Chemistry : ICR
- Capacity (mAh) : 2500
- Output Voltage : 3.6V
- Charge Rate : 0.5C
- Continuous Discharge Rate : 8C
- Peak discharge Rate : 35C for 1s
- Weight of single cell : 48gm

Pack :
Series : 350/3.6 ≈ 98
Parallel : 130.9/20 ≈ 7
7P98S (Voltage = 352.8V ; Current= 140A)
Can sustain 221.9A for few secs
Pack Total Energy= **6.17 kWh** (>4.59kWh)

AMS Architecture

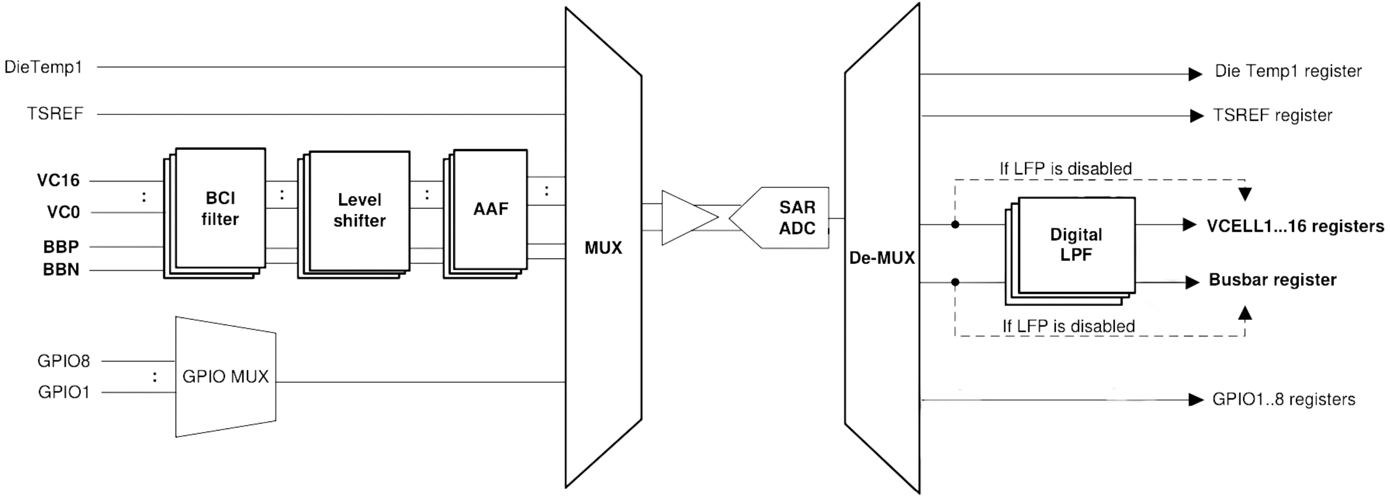


BQ79614 functions



- Voltage monitoring (2.4mV accuracy)
- Temperature sensing
- Autonomous passive cell balancing
- Configurable digital low-pass filters
- Overvoltage and undervoltage protection
- Over temperature and Under temperature protection

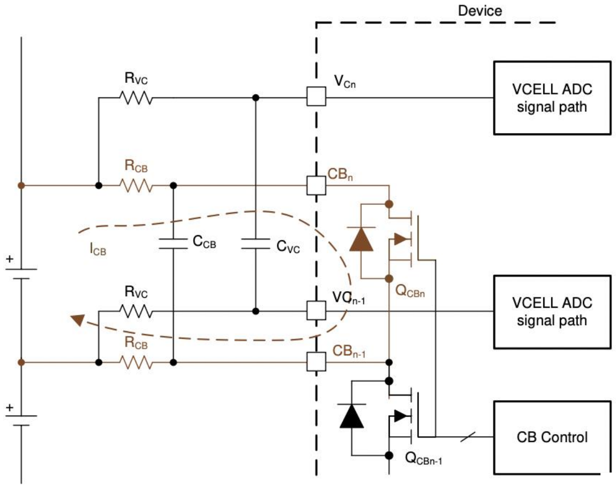
Measurement (ADC and Timing)



Main ADC Measurement Path

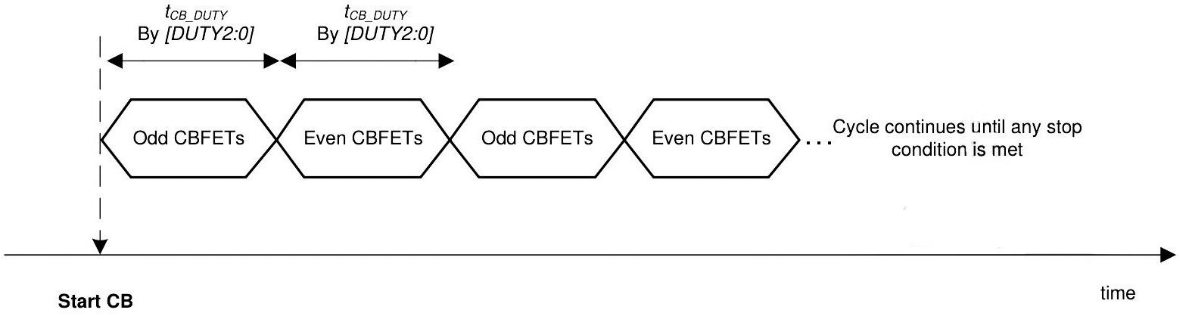
2 filters on Analog side
1 filter on Digital side
192µs for one cycle

Passive Cell balancing

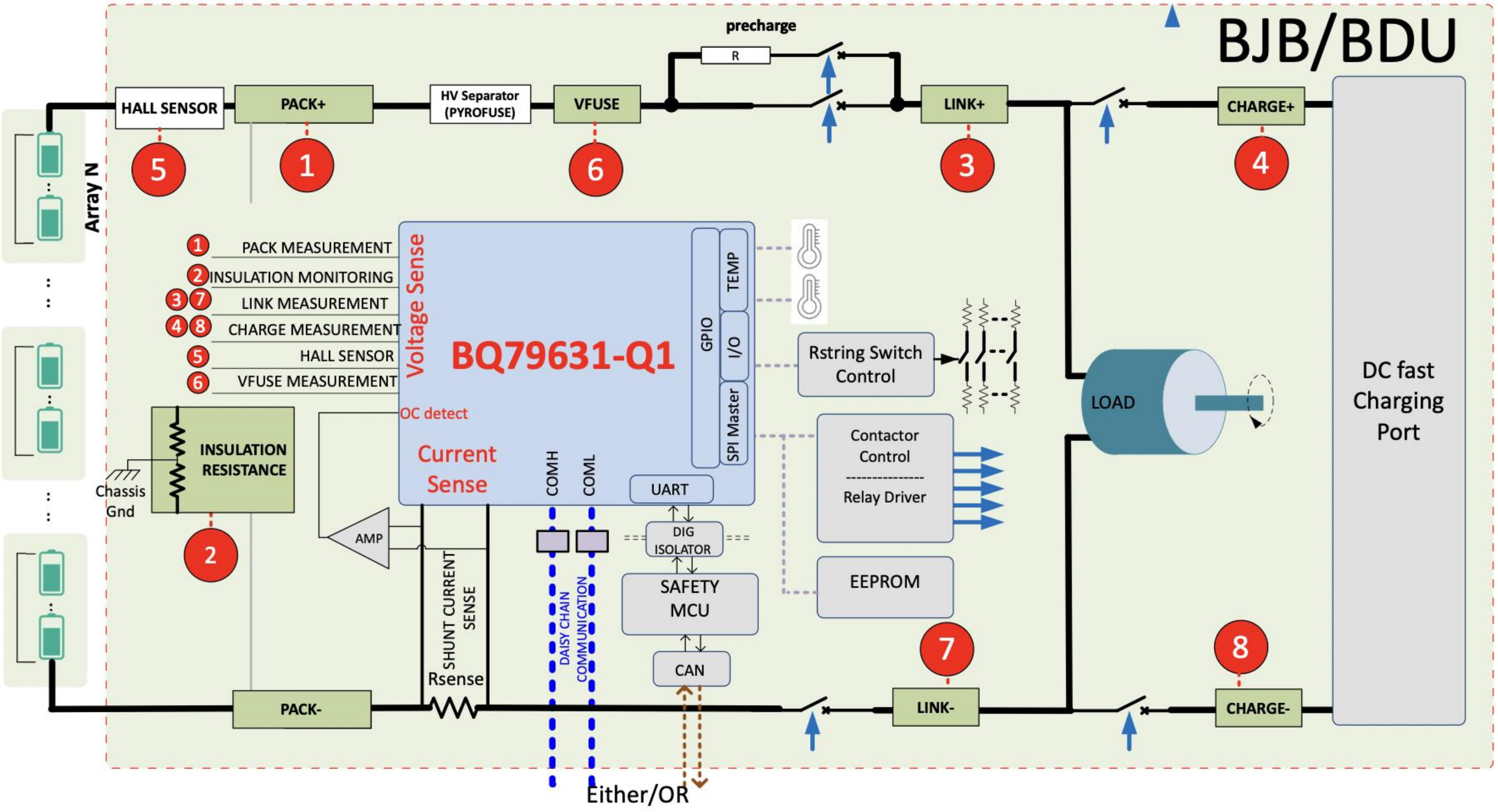


- **The device automatically sets balance timers registers**
- **Each channel is controlled by a Mosfet.**

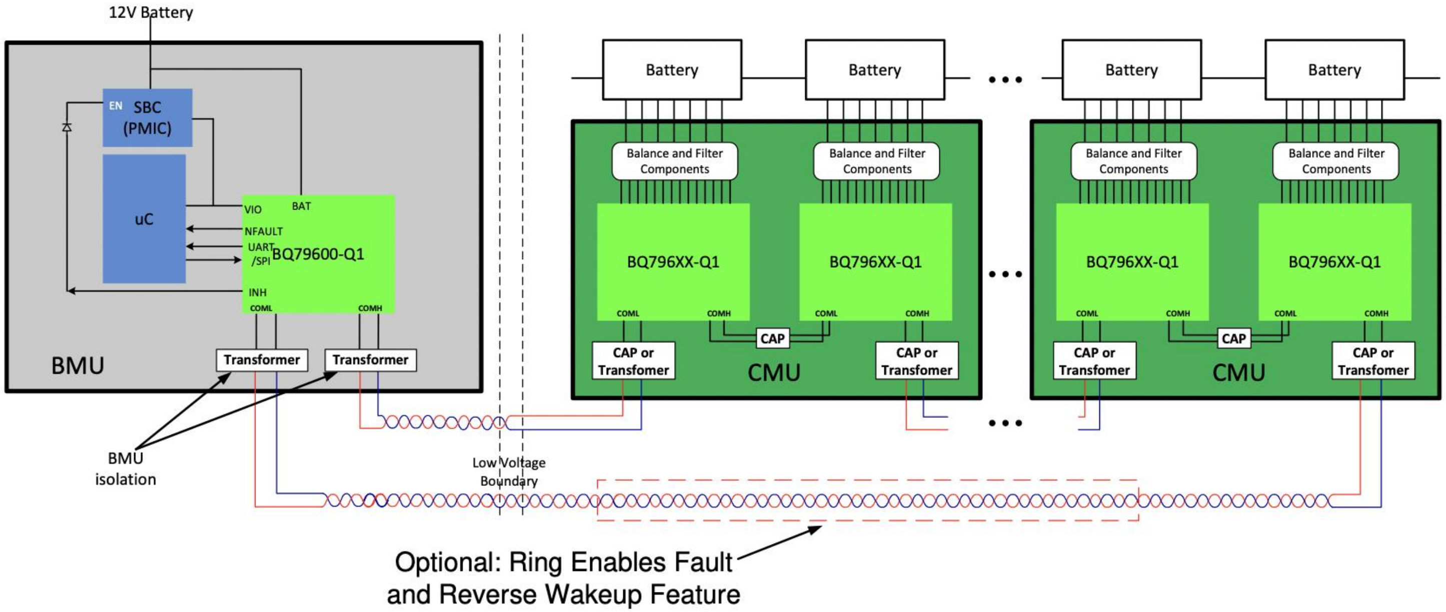
- **Odd-even cycles**
- **Stops if balancing timer is 0 or voltage reaches threshold.**



BQ79631 functions



BQ79600 functions



Additional Code considerations

Charging

Communication error

Short circuit across any cell

Fault in any cell

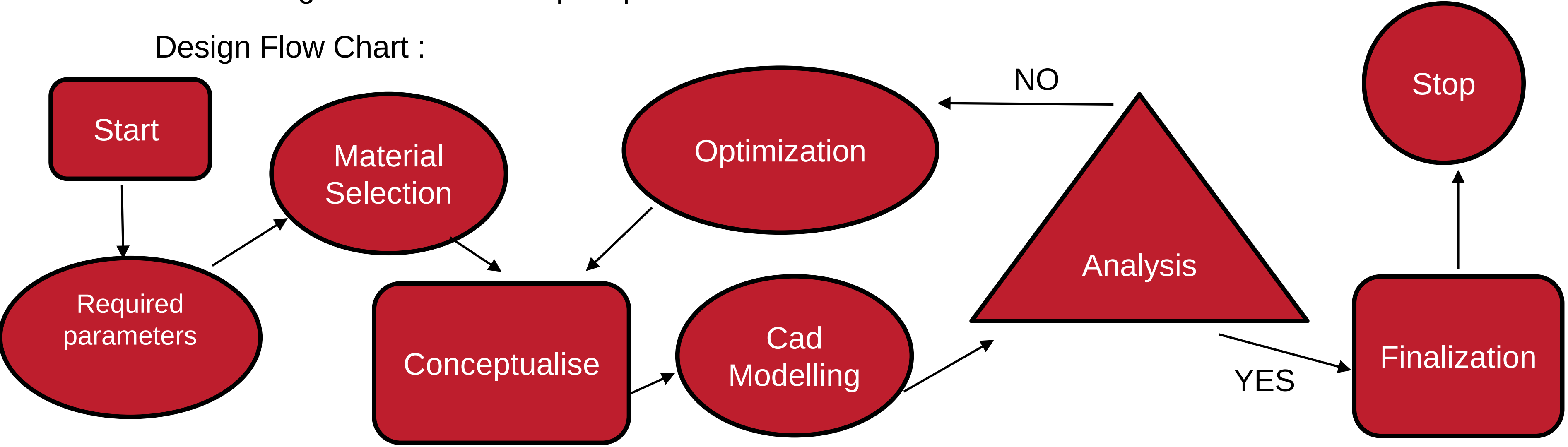
Direct MCU control of AIR

Accumulator Mechanical Configuration

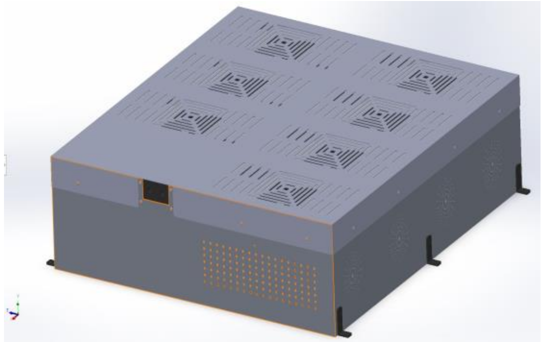
Design Target :

- Abides by the rules
- Safe and easy to assemble
- Easy to maintain
- Light weight with robust design
- Packing in vehicle with impact protection

Design Flow Chart :

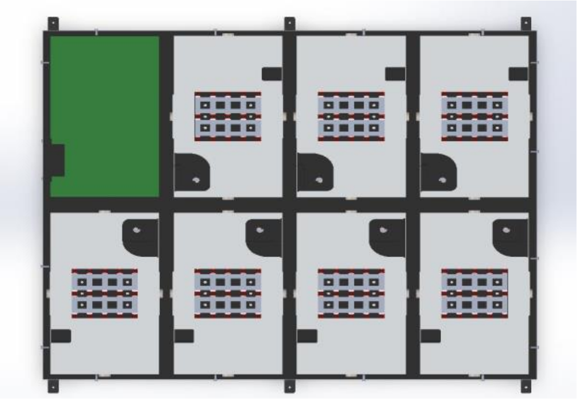


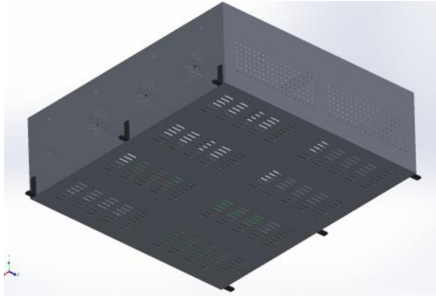
Battery Pack Cad Model



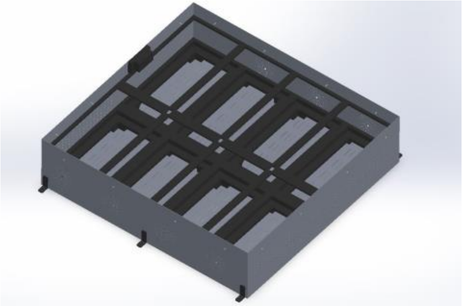
Isometric View of Battery Pack

Top view showing arrangement inside accumulator container

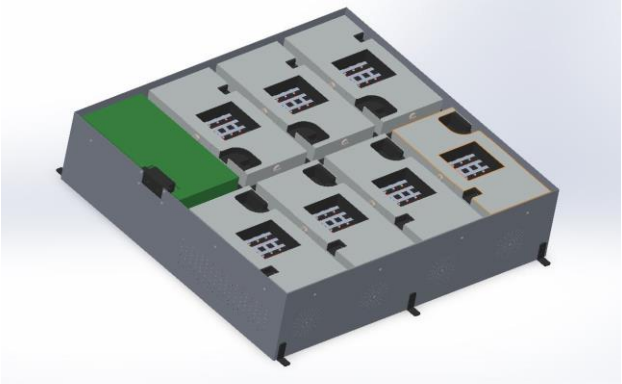




Lower view of accumulator container

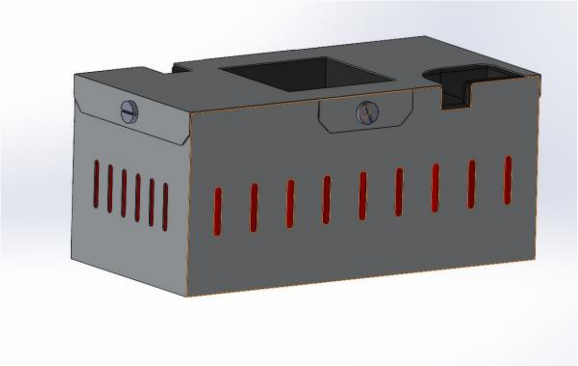


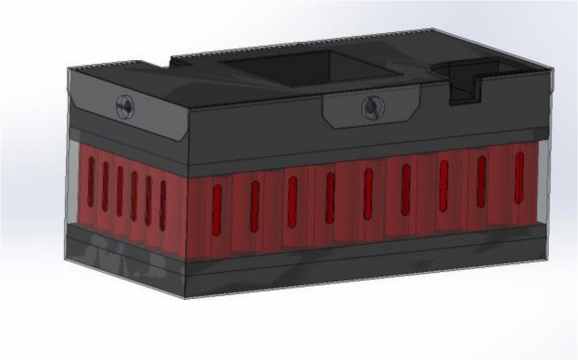
Compartments for battery modules



Module Configuration

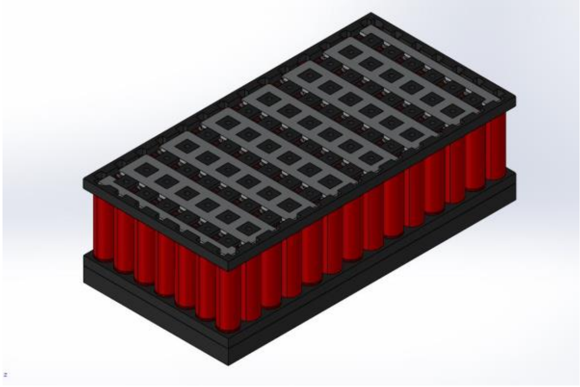
- Total 7 modules
- Each module contain 98 cells
- 7P14S Configuration
- Each cell holds properly
- Light weight
- Rule compliant





Mass distribution for module

- Mass of each cell   :   0.048 kg
- Mass of module   :   2kg
- Total mass of module   -
  = 2 + (0.048*98)
  = 6.7kg
- 6.7 kg < 12kg



E11 IITG Racing
IIT Guwahati
E11_IITG Racing_PiEV-EDP_2022_V1

Module Simulation and Structural Analysis

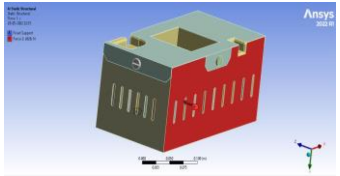
All constraints : FIXED MOUNTS

Analysis at 40 g load in horizontal direction

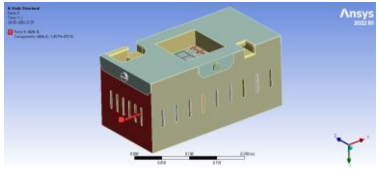
Analysis at 40 g load in lateral direction

Analysis at 20 g load in vertical direction

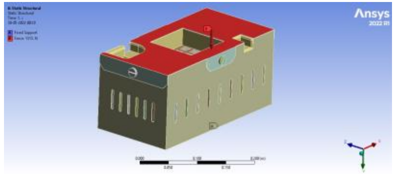
Force fig.



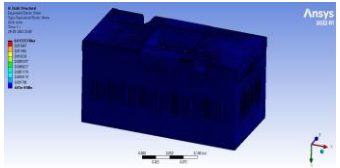
Force fig.



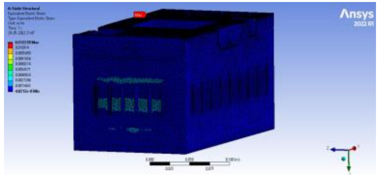
Force fig.



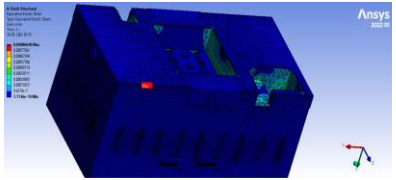
Equivalent Elastic Max. Strain 0.015353 m/m



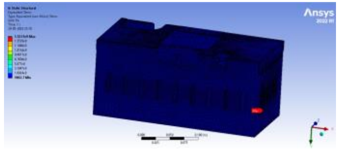
Equivalent Elastic Max. Strain 0.012278 m/m



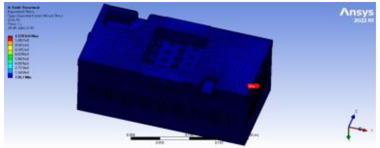
Equivalent Elastic Max. Strain 0.00089949 m/m



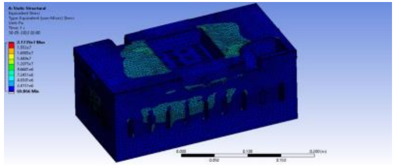
Equivalent (von -Mises) Stress Max. 1.5231e9 Pa



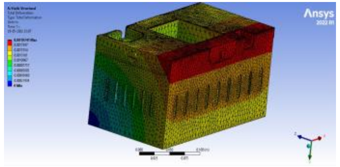
Equivalent (von -Mises) Stress Max. 1.2293e9 Pa



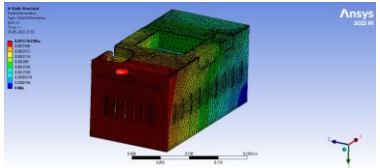
Equivalent (von -Mises) Stress Max. 2.1735e7 Pa



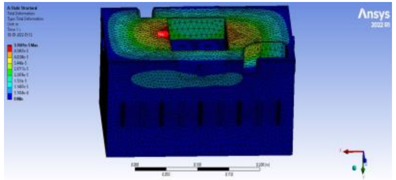
Total Deformation 1.9741 mm



Total Deformation 3.7764 mm



Total Deformation 5.1691e-5 m



Cooling of Accumulator

Reasons for heat generation

- Internal Resistance due to flow of current
- Heat generation due to chemical reaction within the cell

Why is Cooling for Accumulator necessary?

- Overheating during operation will happen without proper cooling which will affect performance and overall life
- Efficiency gets reduced above given operating temperatures of the cell
- Heated cells pose a threat to the driver's life

Goals for pack cooling

- To keep the cell temperature below **50 deg Celsius**
- To keep the cell temperature within the limits of operating temp

Thermal Specification of cell

Weight	48 gm
Internal Resistance	12 mΩ
Voltage	3.6 V
Rated Working Temperature	0-50 deg Celsius
Chemistry	ICR
Chemical	Lithium cobalt oxides
Molar Heat Capacity (Cp)	0.735 KJ/K-kg
Battery Pack Configuration	1 Module = 14S7P and 7 module in series

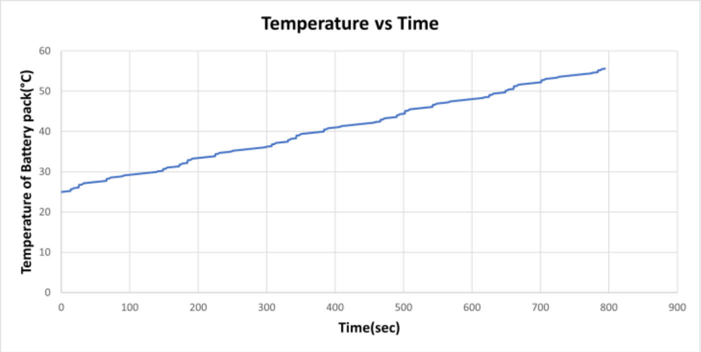
Thermal Analysis of Battery pack

Using the drive cycle from Buddh international circuit the thermal analysis of the battery pack was conducted

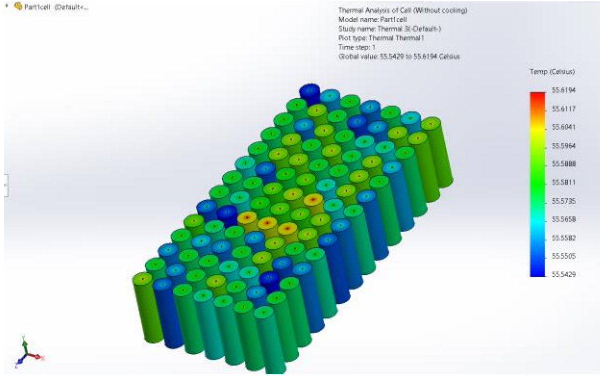
Average power dissipated = 933.7 W
Total energy released by the battery pack as heat = 1080.9 kJ

Using $Q_{battery} = m_{battery} Cp \Delta T$
$T_{5\ drive\ cycle} = 55.6°C$

Thus, Cooling is required as the battery packs crosses the rated operation temperature



Rise in Temperature after 5 drive cycle



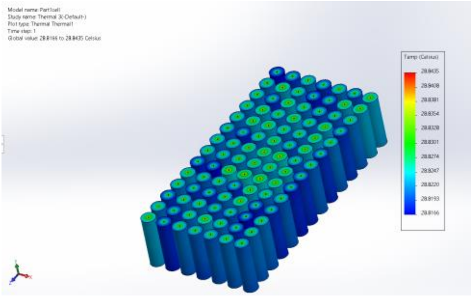
Battery pack without cooling

Cooling process and Fan selection

Passive Air Cooling	Active Air Cooling	Liquid Cooling
No additional Cost	Low Cost	High Cost
Low Cooling	Moderate Cooling	Cooling Efficient
Cannot be used as a cooling option for high performance or for long durations	Can be used when lower amount of cooling is required	Is used when there is a large amount of generation of heat

Fan Specification:-

Specification	Value
Dimensions	92mm x 92mm x 25mm
Speed	3000 RPM
Max volume flow rate	50 CFM



Battery pack with cooling

Temperature of 28.8°C was maintained after installation of the cooling system

Battery Charger

Charger selection criterion:
- Charging voltage = 350V
- Standard charge current = 1.25 A*7= 8.75A

Charger / Specification	Current Ways	Dilong Technology	Magenta Power	Elcom
Output voltage	225-450 V	250-420V	230 @ 50 Hz AC	321-417
Max Charging Current(A)	13.5	12	16	7
IP protection	IP67	IP67	IP54	IP46
Output power (kW)	3	3.3	3.3	3

Specifications of Dilong (DA3K3M17/ M17E OBC)

- Input voltage: 85 – 264 Vac
- Input Current: 16@220 Vac
- Input Frequency: 47 – 63 Hz
- Active Power Factor correction: >= 0.99
- Efficiency: 95%
- Accumulator full charge time: 2 Hrs 5 mins
- Cooling type: Air
- Constant power and constant voltage state automatic conversion.

Charging Time Calculation:
- Battery Total energy : 9*686Wh = 6.17kWh
- Assuming 10% losses in heat.
- Effective output power: 3300*0.9 = 2.97kW
- Charging Time: Maximum Battery power / effective Output power = 2 hrs 5 mins

Charging and Discharging Contact

AMP+HVP800 from TE Connectivity

- Operating voltage range — 850 Vdc
- Contact Current Rating — 200A
- UL Flammability Rating — UL 94V-0
- IP Rating — IP6K9K
- Operating Temp — -40°C to 125°C

Charger Cables

TE Connectivity, HVA280 EV Charging Cable

- Current Rating — 40A
- IP Rating — IP69K
- Temperature — -40°C to 140°C
- Color — Orange

Fuse

Eaton BUSSMANN XEV30-250-SP

- Current Rating — 250 A
- Voltage Rating — 500 VDC
- Diameter — 30 mm
- Fuse Type — Fast blow

Insulation Material

Nomex Paper

- Dielectric Strength — 32kV/mm
- Thermal Insulation — 0.15 W/mK
- Temperature Resistance — 300°C
- Tensile Strength — 2.85 Mpa
- Durability — High
- Thickness — 0.25 mm
- Flame Retardant

Maintenance plug

Amphenol Radlok

- Current Rating 70 A – 500 A
- Voltage Rating 1000 V
- Tool-free mechanical locking
- One way locking mechanism

High Voltage Disconnect

TE Connectivity AMP +
Manual Service Disconnect

- Current Rating 350 A
- Voltage Rating 700 VDC
- Temperature Rating -40°C – 65°C
- Number of contacts 2

High Voltage Wiring

Polycab

- Core Material Copper
- Current Rating 600 A
- Voltage Rating 1.1 kV
- Nominal Area 75 sq mm

Low Voltage Pack Cell Configuration

- Nominal Cell Voltage : 3.3 V
- Cell Capacity : 2.5 Ah
- Nominal discharge : 10 A

- Total Voltage Required : 12 V
- Power required = 120 W (100W for pump and 20W for fans)
- Cell current required : 120/12 = 10A

- No of cells in series = 12/3.3 = 3.63 ≈ 4 cells
- No of cells in parallel = 10/9 = 1 cell

Fig.- A123 ANR26650M1-B

The required configuration is **4S1P**

Motor and Motor Controller

Selected Motor: EMRAX 208

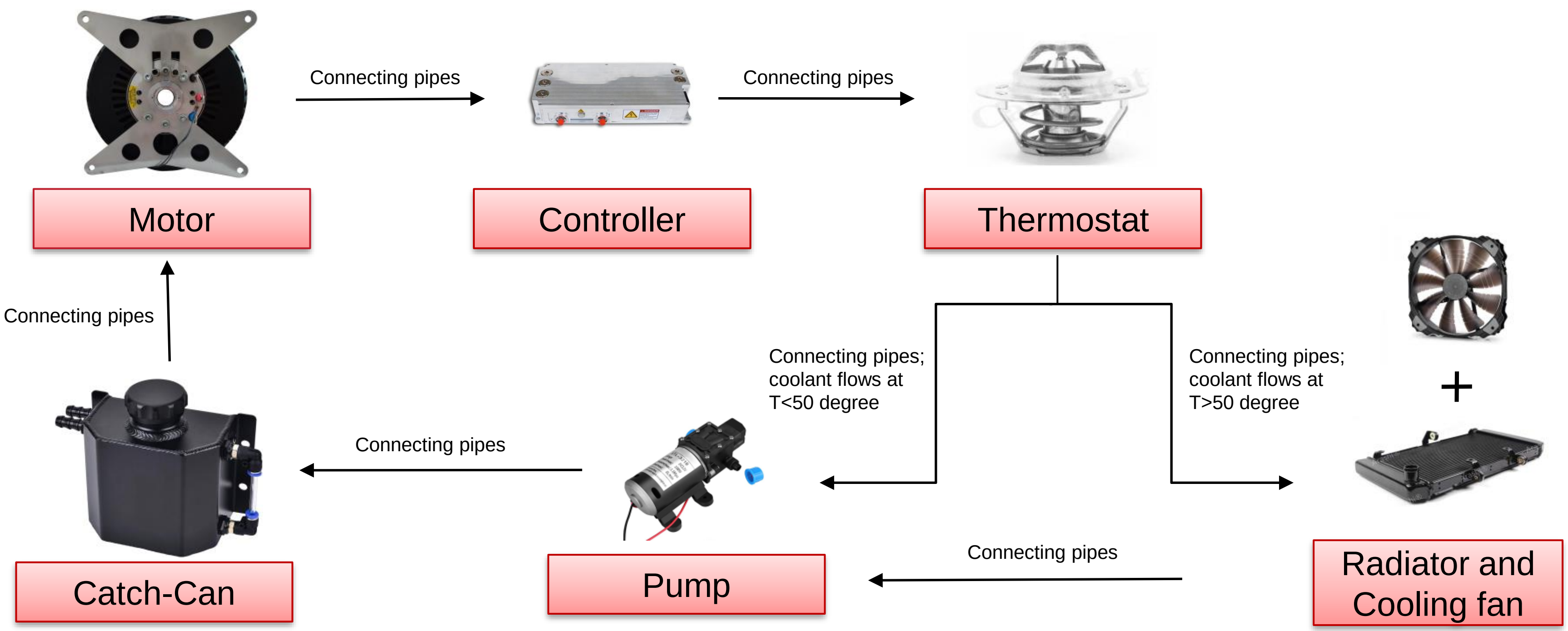
Technical data / Type	EMRAX 208 High Voltage			EMRAX 208 Medium Voltage			EMRAX 208 Low Voltage		
Air cooled = AC Liquid cooled = LC Combined cooled = Air + Liquid cooled = CC	AC	LC	CC	AC	LC	CC	AC	LC	CC
Ingress protection	IP21	IP65	IP21	IP21	IP65	IP21	IP21	IP65	IP21
Cooling medium specification (Air Flow = AF; Inlet Water/glycol Flow = WF; Ambient Air = AA) If inlet WF temperature and/or AA temperature are lower, then continuous power is higher.	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C	AF=20m/s; AA=25°C	WF=8l/min at 50°C; AA=25°C	WF=8l/min at 50°C; AA=25°C
Weight [kg]	9,1	9,4	9,3	9,1	9,4	9,3	9,1	9,4	9,3
Diameter ø / width [mm]	208 / 85								
Maximal battery voltage [Vdc] and max load RPM	550 Vdc (6000 RPM)			350 Vdc (6000 RPM)			120 Vdc (6000 RPM)		
Peak motor power at max load RPM (few min at cold start / few seconds at hot start) [kW]	68								
Continuous motor power (at 6500 RPM)	33	35	41	33	35	41	33	35	41
Maximal rotation speed [RPM]	6000 (7000 for a few seconds with magnetic field weakening)								
Maximal motor current (for 2 min if cooled as described in Manual) [Arms]	200			320			800		
Continuous motor current [Arms]	100			160			400		
Maximal peak motor torque [Nm]	140								
Continuous motor torque [Nm]	64	68	80	64	68	80	64	68	80

Best Torque Rating

Controller Selection

CONTROLLER	PEAK CURRENT [Arms]	CONT. CURRENT [Arms]	PEAK VOLTAGE [Vdc]	PEAK POWER [kW]	SWITCHING FREQUENCY [kHz]	WEIGHT [kg]	BEST SENSOR	MFW OPTION	SENSORLESS OPTION	OTHER SENSOR OPTIONS	NEEDED SENSOR IN CASE OF 2XUVW CONNECTORS OR TWIN MOTOR
Drivetrain innovation DTI HV-500	350	250	720	250	8--14	6.7	Encoder RM44SI		N	Hall sensors, encoder, resolver	
Emsiso emDrive 500	800	500	120	95	16	5.2	Encoder RM44SC (SSI)	Y	Y	resolvers, hall sensors	tandem resolver
Unitek Bamocar D3 400 125/250	180	125	400	70	8--24	5.8	1-pole pair resolver	Y	N	sin/cos encoders, hall sensors	tandem resolver
Unitek Bamocar D3 400 200/400	280	200	400	110	8--24	6.8					
Unitek Bamocar D3 700 125/250	180	125	700	125	8--16	5.8					
Unitek Bamocar D3 700 200/400	280	200	700	200	8--16	6.8					
Sevcon Gen4-S8	300	200	400	100	8	10	Encoder RM44AC (sin/cos)	Y	N	Resolver	tandem resolver
Sevcon Gen4-S10	400	200	800	300	8	10.9					
Sevcon Gen5-S9	400	200	450	180	8--12	6.8					
RMS PM100DX	350	300	400	100	12	7.5	5-pole pair resolver	Y	N	/	tandem 5-pole pair resolver
RMS PM100DZ	200	150	800	100	12	7.5					
RMS PM150DX	450	250	400	150	12	10.7					
RMS PM150DZ	300	225	800	150	12	10.7					
RMS PM250DX	750	450	400	300	12	20					
RMS PM250DZ	600	450	800	460	12	20					
Scott Drive SD100	330	260	400	130	10--15	12.5	5-pole pair resolver	Y	N	Hall sensors, analog/sin/cos encoders	tandem resolver
Scott Drive SD200	450	360	400	180	10--15	12.5					
Scott Drive SD250	600	480	400	240	11--16	14					
Scott Drive SD300	500	400	800	400	11--16	14					

Cooling Process of Motor and Controller



Calculation Process for Required Cooling

$\dot{Q}_{DT} = \dot{m}_{AIR} Cp_{AIR}(T_{AIRO} - T_{AIRI}) = \dot{m}_{W} Cp_{W}(T_{WO} - T_{WI})$

Where $\dot{Q}_{DT}$ = Power dissipated by the Motor and Controller = $(1 - \eta_{Motor} \text{x} \eta_{Controller}) P_{max}$

P_{max}= 68kW ; η_{motor}= 94%; $\eta_{Controller}$= 97%

$\dot{m}_{W}$= 8 lpm

We get T_{WO} =50˚C ; T_{WI} =40.47˚C

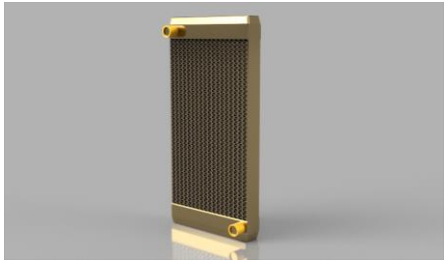
Using LMTD method

$\dot{Q}_{DT} = U_O A_O F\ LMTD_{CF}$

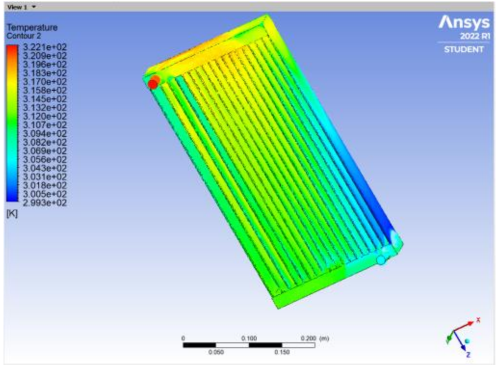
Where U_O = 162.67 W/(m²°C) ; A_O = 6.257 m²

We get T_{AIRO} =28.835 ˚C ; T_{AIRI} =25 ˚C

With the help of Cooling fan air must pass through the radiator at speeds of about 67.2 kmph



CAD model of Radiator



Simulation of Radiator cooling

Specification table for Cooling System

Component	Specification	Value
Radiator	Dimensions	418mm×216mm×38mm
	Tube Diameter	1.75mm
	Tube thickness	0.3mm
	Fin Spacing	2mm
	Fin Height	9.25mm
	Fin Density	95 fins/dm
Cooling Fan	Dimension	200mm×200mm×32mm
	RPM	700
	Air Flow	86.57 CFM

Component	Specification	Value
Water Pump	Power	100 Watt
	Max Discharge Capacity	8LPM
Thermostat	Range	45 deg- 50 deg Celsius
Catch-can	Dimension	203mm×162mm×100mm

Gearing

Experience in CV + Reliable + Efficient + Cheap +Light ------> Chain Drive

Possible combinations of Sprocket Teeth	Actual Ratio
31-9	3.44
38-11	3.45
45-13	3.46
55-16	3.44
76-22	3.45

Close to desired value
Favourable sizing

Gearing

Selected Chain No. 525 with pitch 0.625""

MATLAB Code for necessary design calculations

Results

Front Sprocket	
Parameter	Results
No of Teeth	11
Teeth in Contact	4.5
Diameter in mm	56.3478

Rear Sprocket	
Parameter	Results
No of Teeth	38
Teeth in Contact	22.46
Diameter in mm	192.24

Parameter	Result
Number of chain links	56
Centre to Centre Distance(mm)	240.35 (favourable as per proposed chassis design)
Other values such as contact angles, critical back-tension on each tooth (at maximum motor torque) etc. required for sprocket design are calculated and tabulated using the same code.	

Torque Control: Differential

Limited Slip Differential over Open for better Torque Vectoring

Torsen	Clutch Type (Salisbury)
Cheap	Expensive
Reliable without Oil	Oil sealed
~3.3 kg	~2.6 kg
When one wheel loses grip, all the torque goes to that wheel.	Very wide adaptations in torque bias. Different characteristic for accelerating and braking

Drexler like Clutch Type LSD

Designing differential mounts, CV Joints and Driveshafts

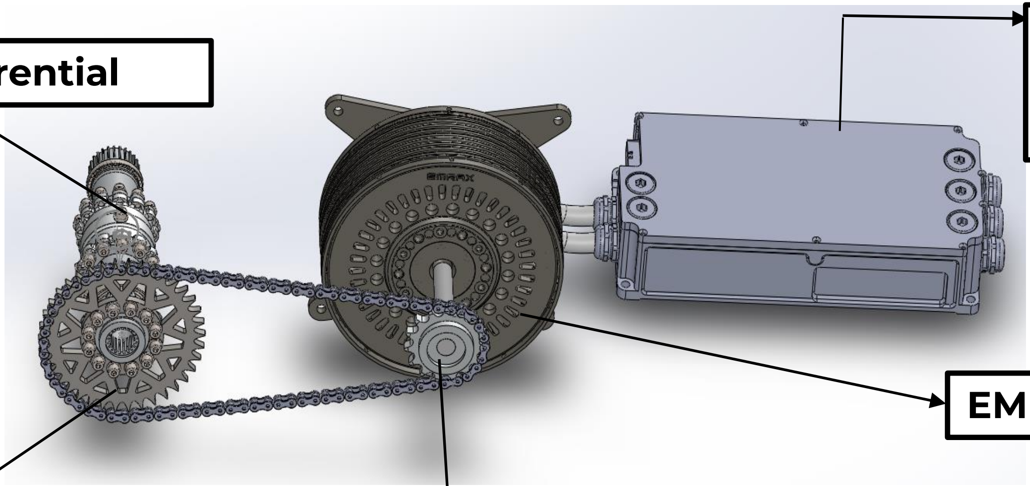
Selection of Bearings

FEA Analysis

Assembly

Packaging: CAD Model

Compact Packaging to be mounted on chassis



Limited Slip Differential

Rinehart PM100DX Motor Controller

EMRAX 208

Sprocket (38 teeth)

Sprocket (11 teeth)

SUP

Regenerative Braking

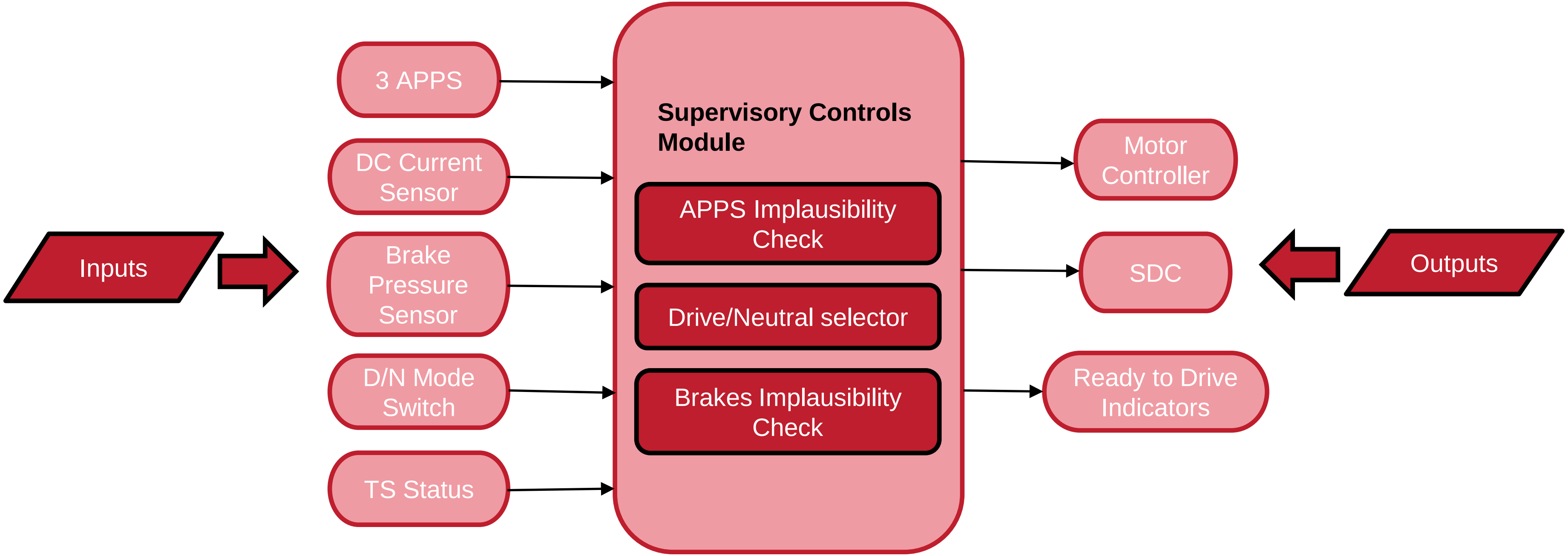
Method
- Controller assisted regenerative braking
- Use of REGEN function for negative torque command

Targets
- 35% conversion efficiency

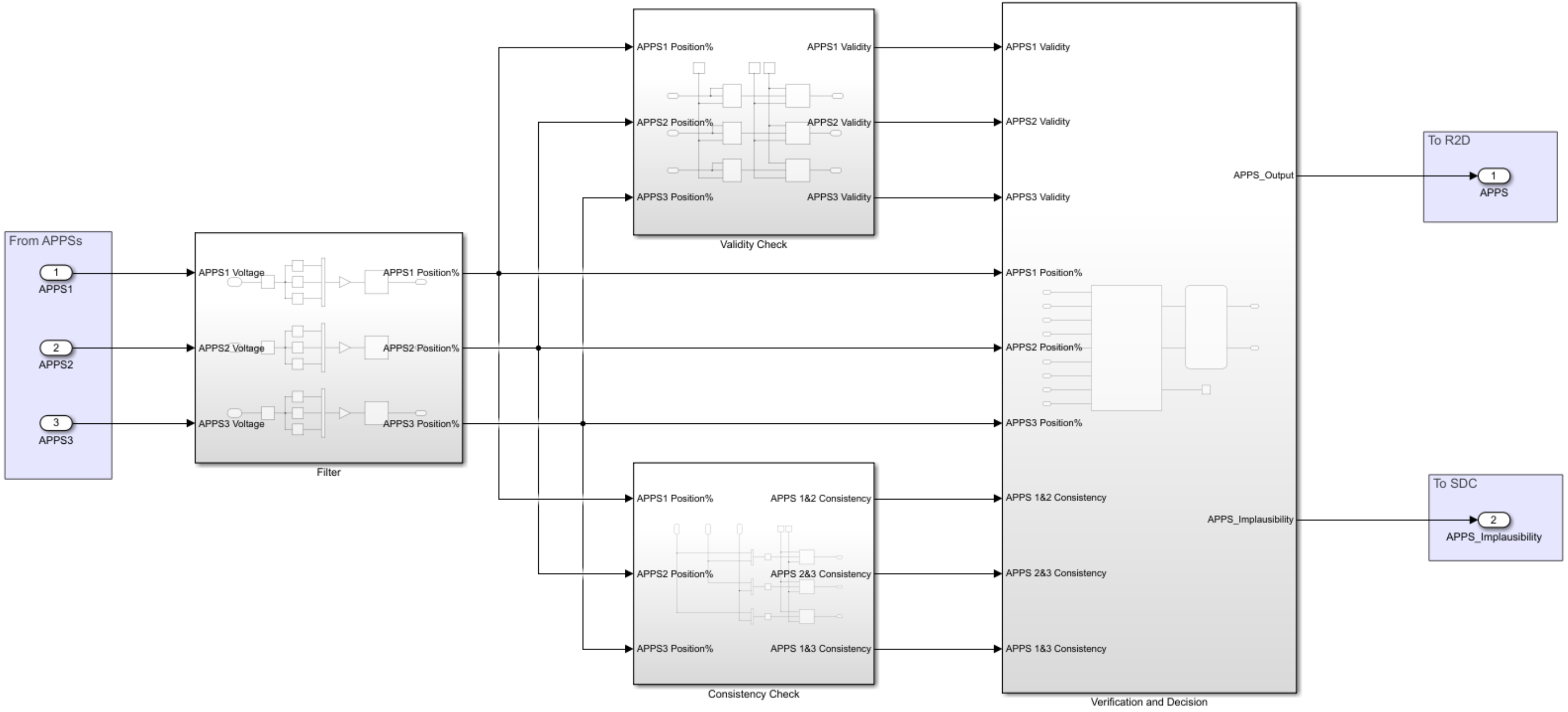
Impact on sizing
- Decrease in accumulator size as a result of recovery
- 3.37% Weight reduction (9.5 kg of 280 kg)

Supervisory Control System (SCS)

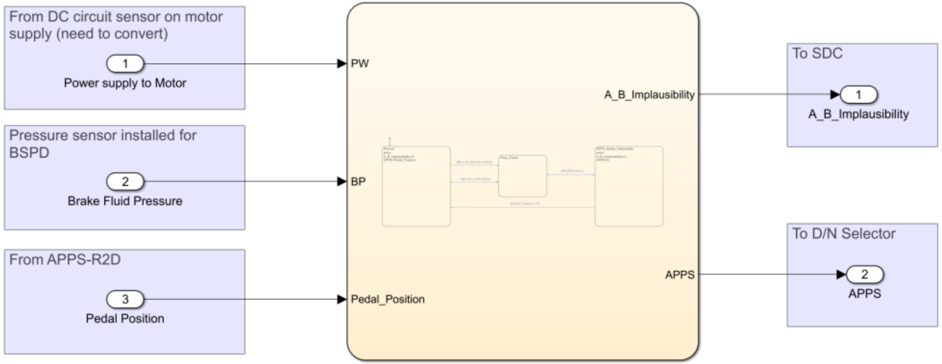
Basic flow of information in SCS

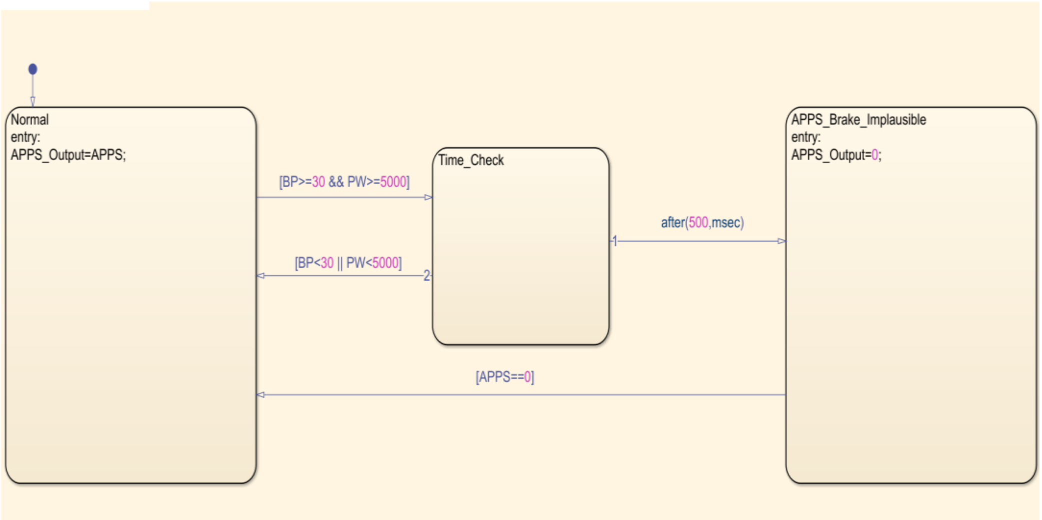


APPS Signal Processing model

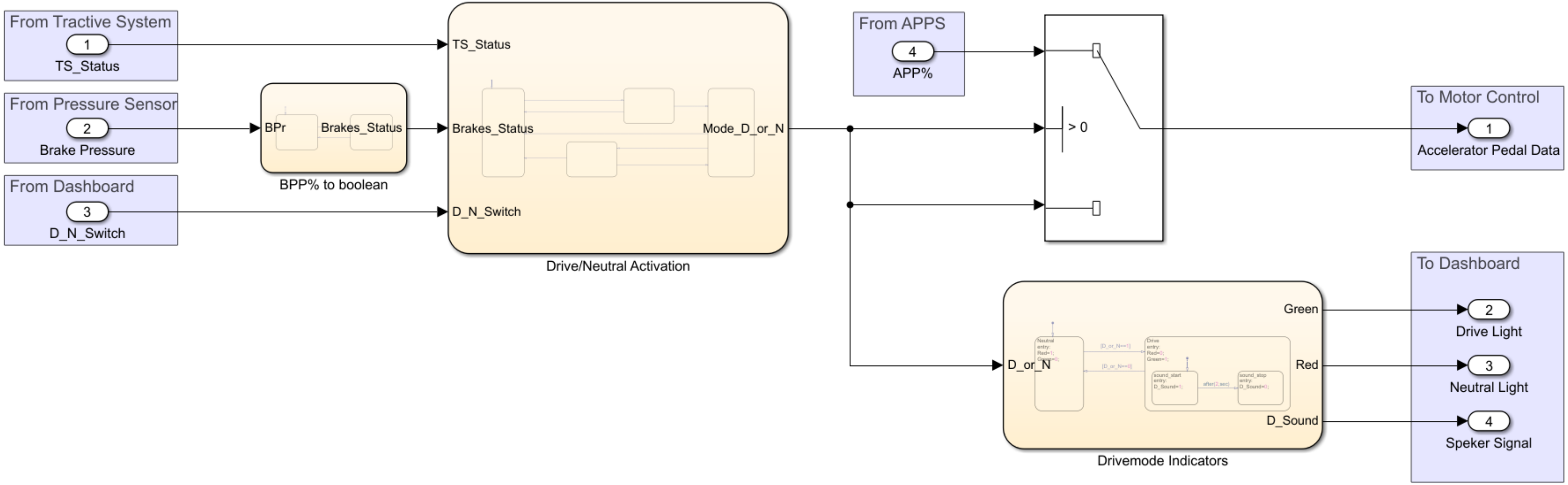


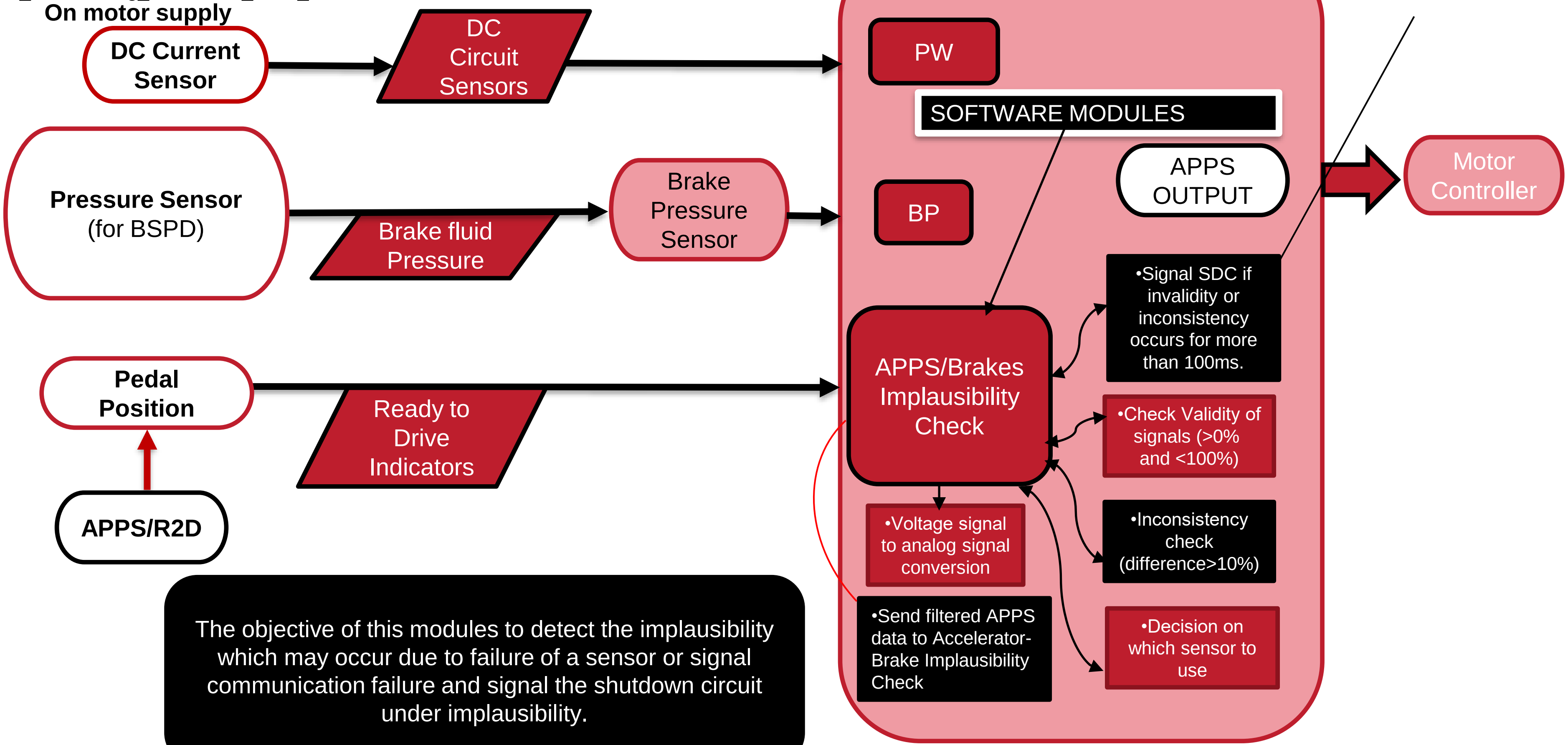
Brake Plausibility Model



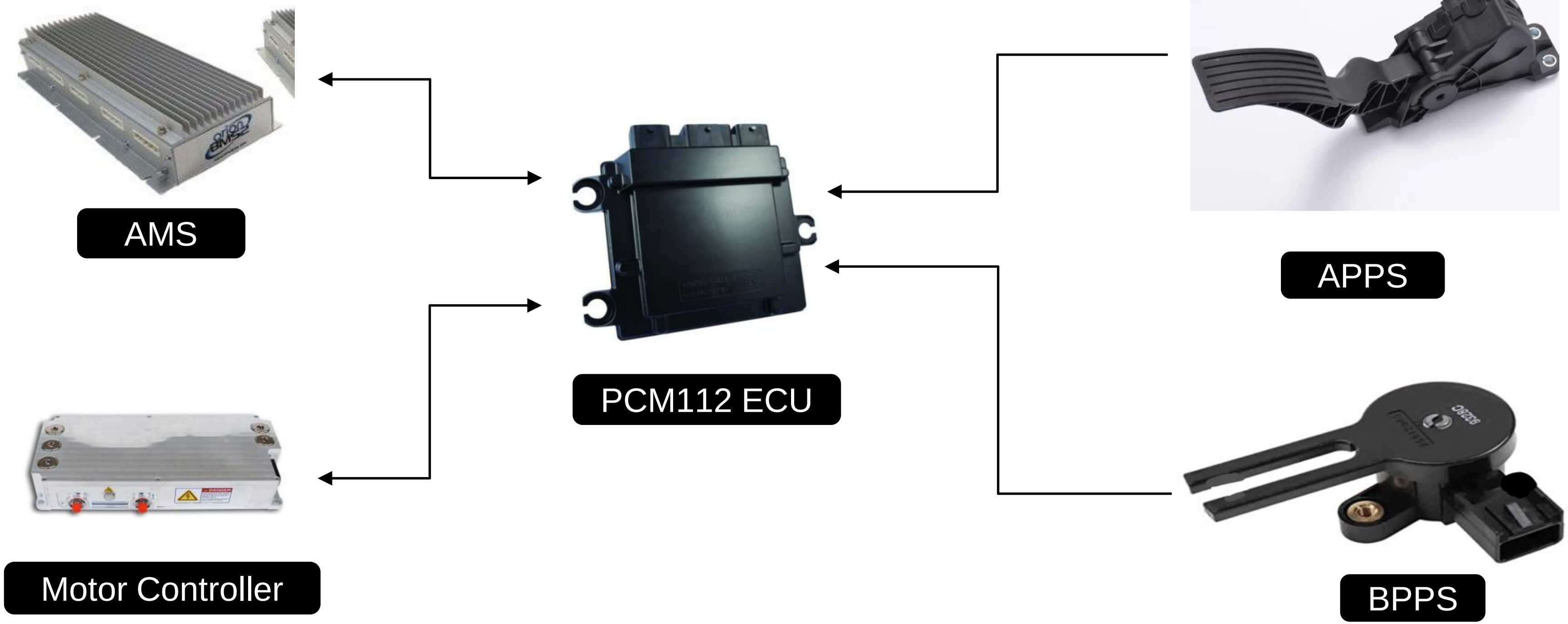


Ready To Drive Mode Model





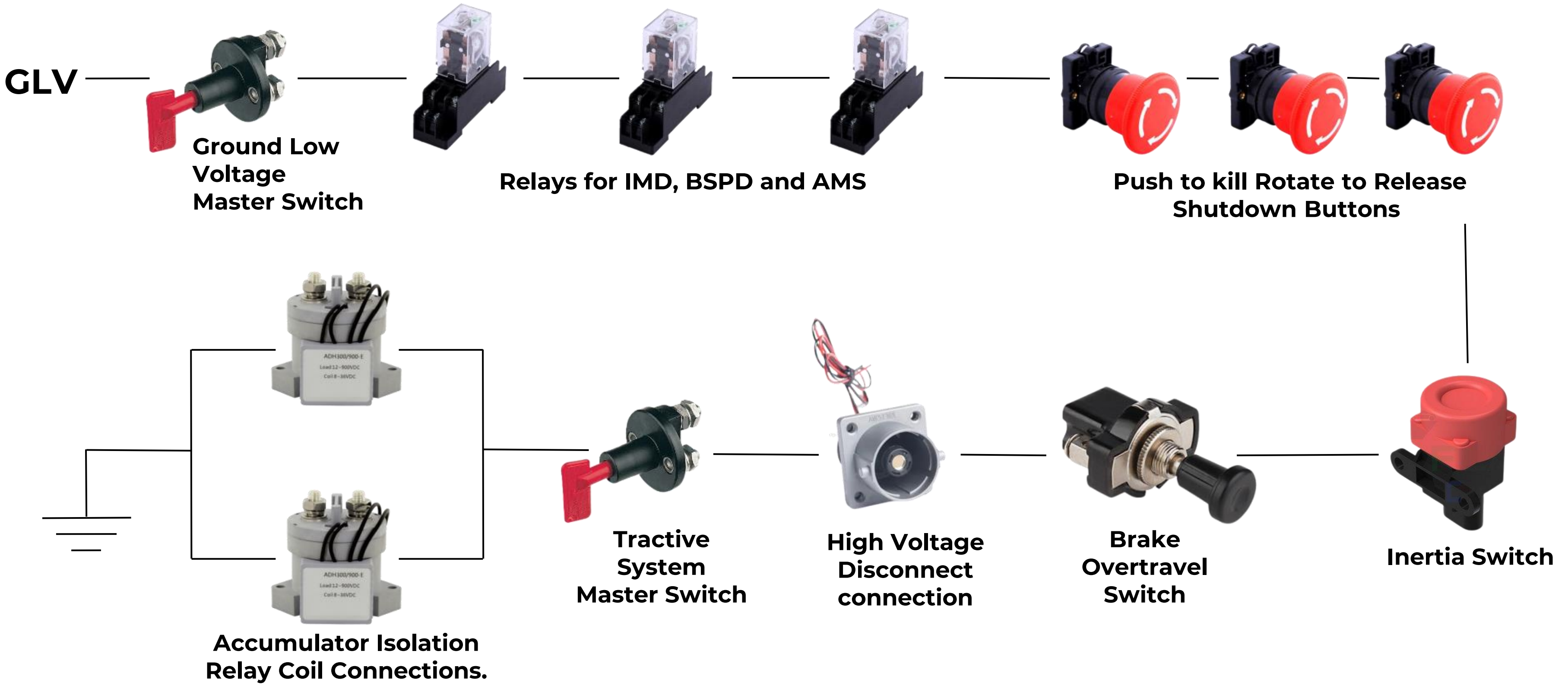
The objective of this modules to detect the implausibility which may occur due to failure of a sensor or signal communication failure and signal the shutdown circuit under implausibility.

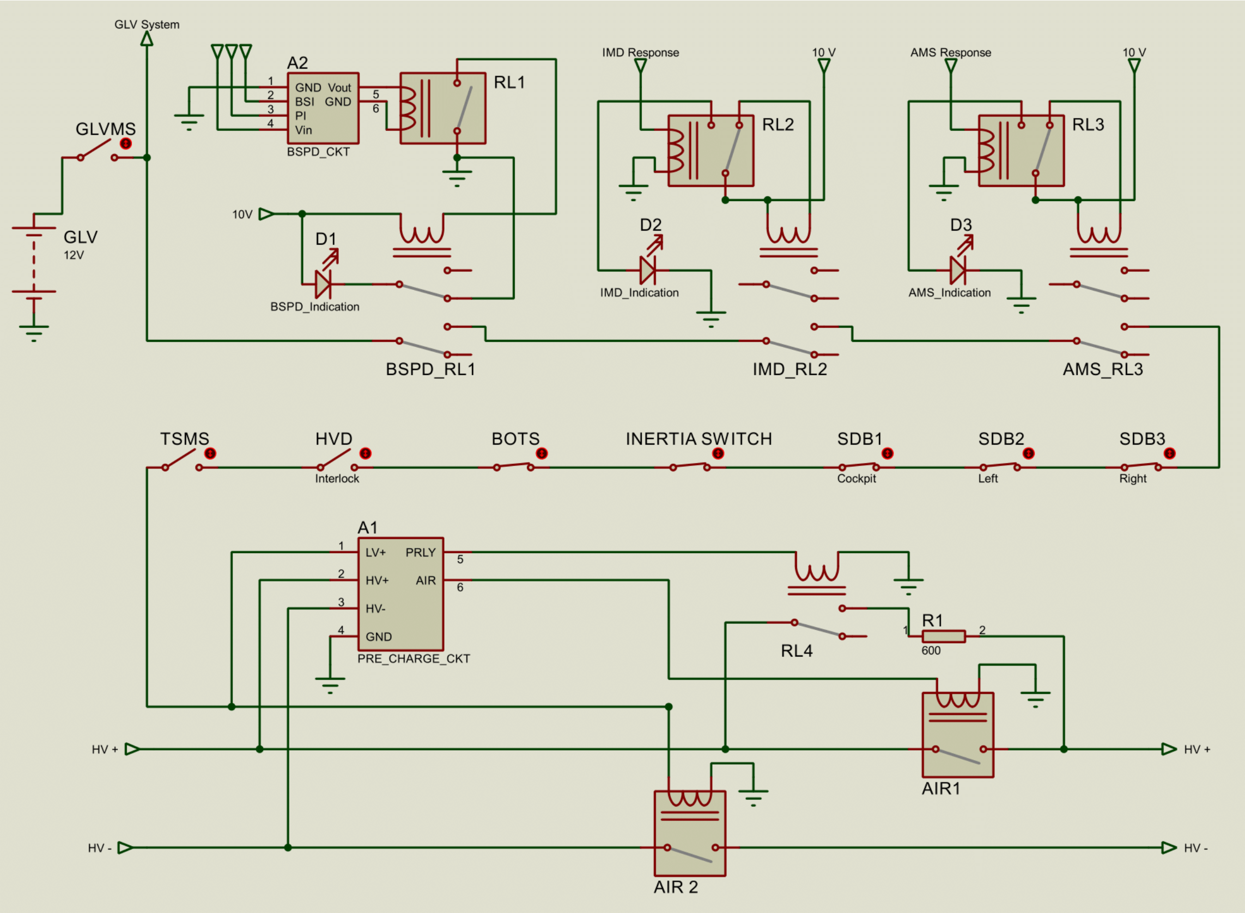


1. Initially , the ECU takes the raw data from APPS and gives the filtered value to the motor controller.
2. Then the ECU takes the raw data from BPPS and the plausibility of the system is checked, if it does not satisfy the required conditions, the motor is turned off immediately.

Safety System

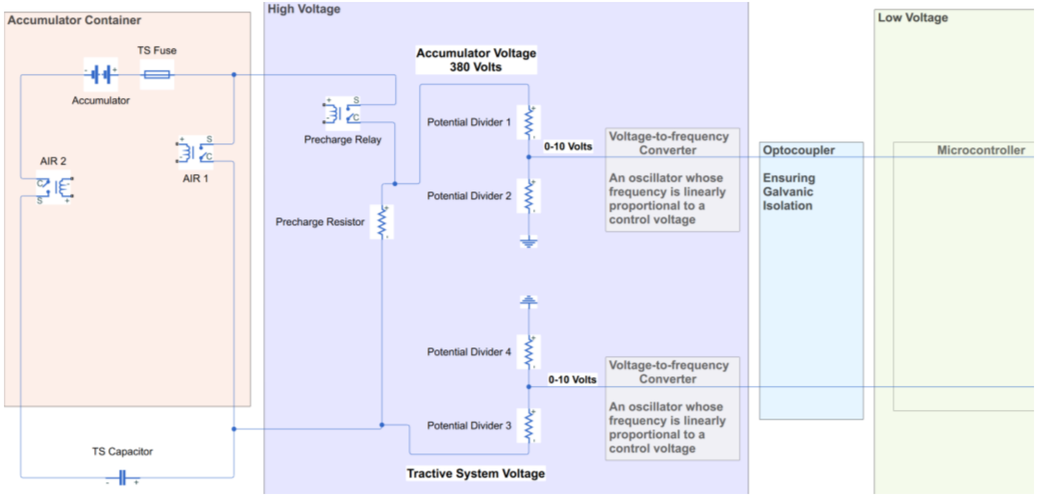
Shutdown Circuit Overview

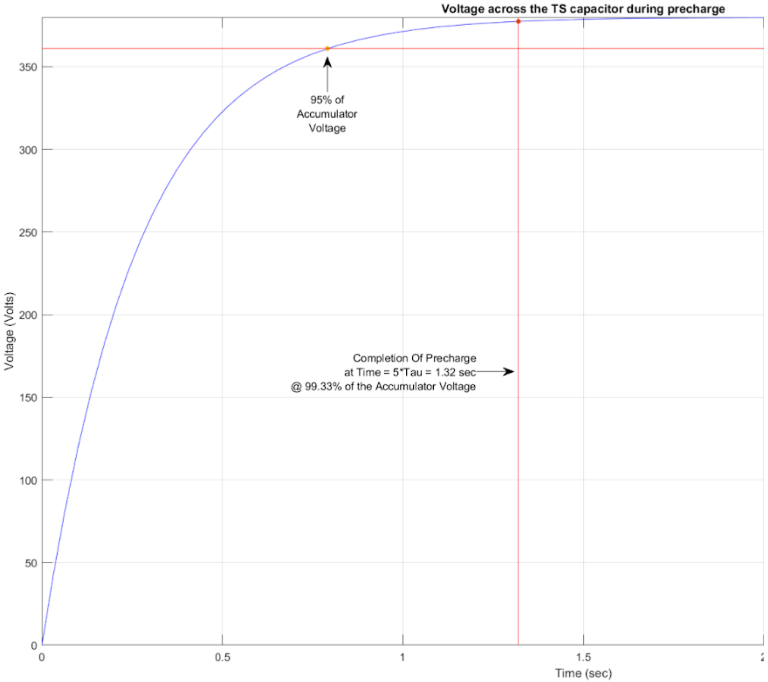




Shutdown Circuit Schematic

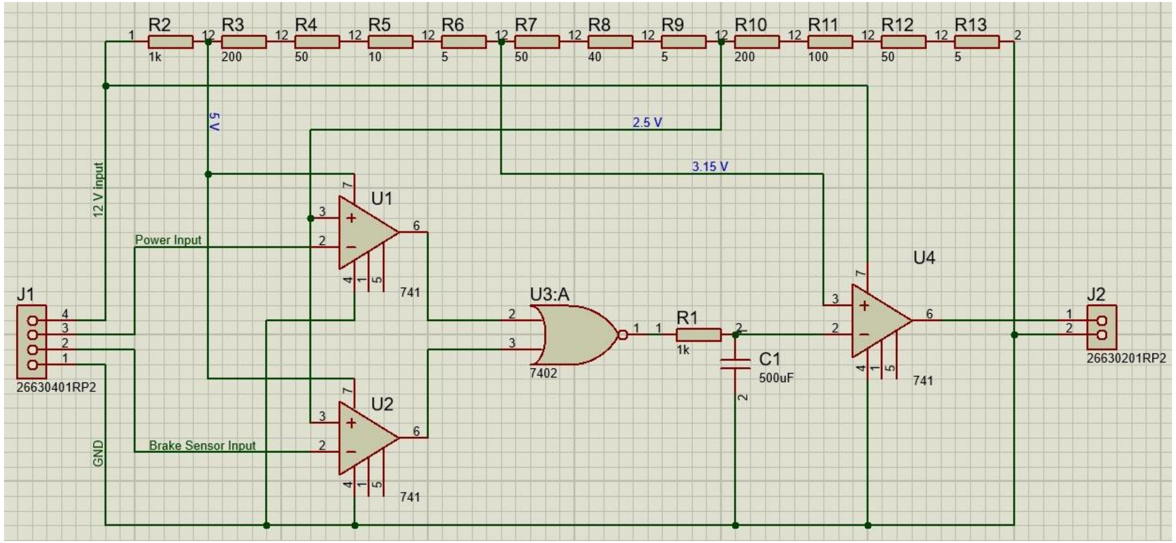
Pre-charge Circuitry

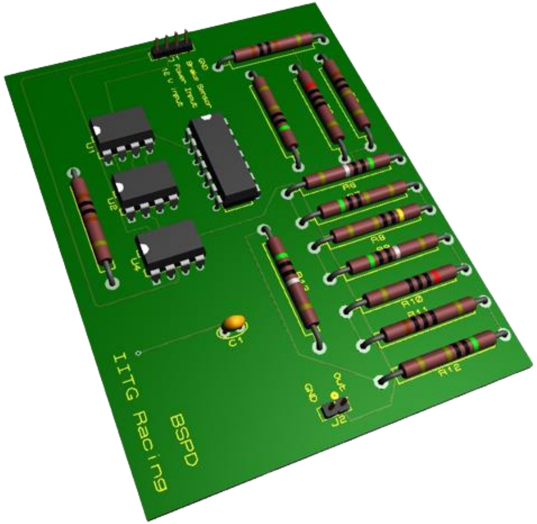




Tractive System Voltage	380 V
Capacitance	440 μF
Precharge Resistance	600 Ω
τ = R*C	0.264 sec
Precharge Time (5τ)	1.32 sec

Brake System Plausibility Device





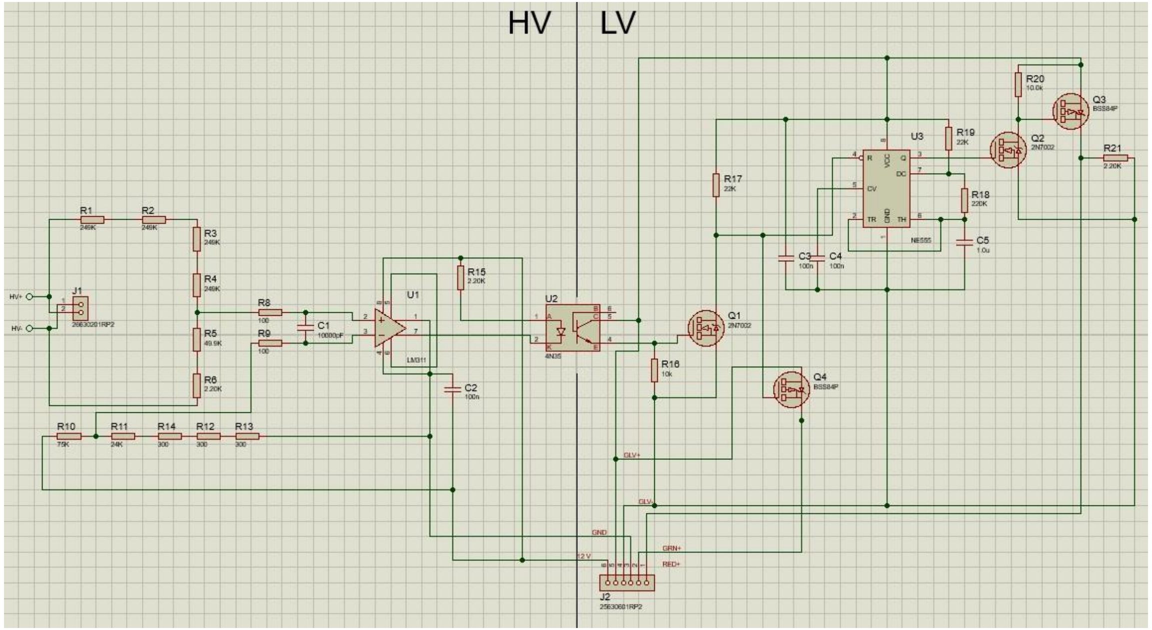
The BSPD ensures the 500ms delay by the RC circuit (R = 1kΩ and C = 500μF). In one time constant (τ = 500ms), the potential across the resistor crosses 3.15 V which is greater than the non-inverting input and cut-offs the continuous supply at the outer pin.

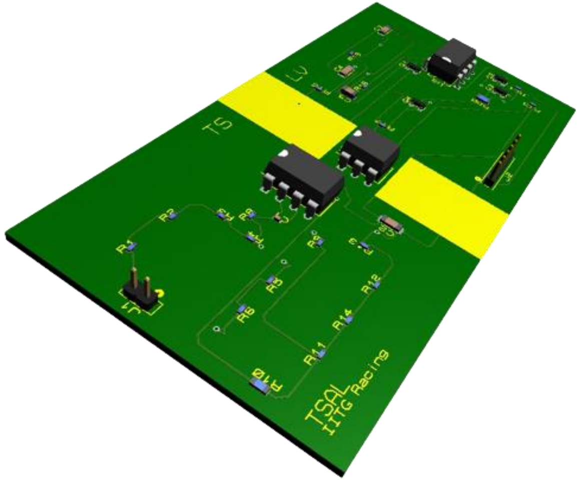
Insulation Monitoring device

Specification	Value
Model	**Bender ISOMETER® iso165C-1**
Application in	Automotive
Nominal supply voltage	12 V
Max. operational current	300 mA (typ. 185 mA)
Max. current	5 A
Rated voltage range	DC 0 to 600 V
Temperature range	-40 to +85 °C
Response value Alarm 1 (Error)	30 kΩ to 1 MΩ (default: 300 kΩ)
Response value Alarm 2 (Warning)	40 kΩ to 2 MΩ (default: 55 kΩ)

- **Bender ISOMETER® iso165C-1 IMD is used in electric vehicles and is chosen as an alternative to ISOMETER® IR155-4203 / IR155-4204**.
- The response value of Alarm (Error) is set to **190kΩ (500Ω/V*380V)**.

Tractive System Active Light





The HV passes through a potential divider and then to a comparator with LV supply. It passes through Optocoupler to reach the LV. The HV and LV are separated by 12.7 mm in the PCB. The output RED+ is high when HV > 60V. Lower than that the output GRN+ is high.

Thank you