

**Hector Gonzalez Montarelo**

**Inverter Programming of a competition electric  
motorcycle**

**Treball Fi de Màster  
dirigit pel Dr. Luis Guasch**

**Màster en Enginyeria Industrial**



UNIVERSITAT ROVIRA I VIRGILI

**Tarragona**

**2021**



# Table of contents

1	REPORT .....	1
1.1	Object.....	1
1.2	Scope.....	1
1.3	Background .....	1
1.3.1	Motostudent Competition.....	1
1.3.2	Simulation tools .....	2
1.4	Standards and references .....	3
1.4.1	Legal provisions and applied standards.....	3
1.4.2	Calculation programs .....	3
1.4.3	Quality management plan applied during project writing .....	3
1.4.4	Bibliography .....	3
1.4.5	Other references.....	3
1.5	Definitions and abbreviations .....	4
1.6	Design requirements .....	4
1.6.1	Model requirements .....	4
1.6.2	Assumptions.....	7
1.6.3	Simulation target .....	8
1.7	Solution analysis .....	8
1.8	Final results .....	9
1.8.1	Input parameters obtention .....	9
1.8.2	Input parameters process.....	10
1.8.3	Simulink modules description .....	10
1.8.4	Simulink model restrictions .....	15
1.8.5	Results analysis .....	16
1.8.6	Recommended inverter set-up .....	19
1.9	Planning .....	20
1.10	Priority order between the documents.....	20
2	ANNEXES .....	21
2.1	Annex 1: Simulink model mathematical background .....	21
2.1.1	Driver block.....	21
2.1.2	Motor block.....	22
2.1.3	Brake system block .....	24
2.1.4	Battery block .....	24
2.1.5	Driveline block.....	26

2.1.6 Glider block.....	28
2.1.7 Model inputs.....	30
2.2 Annex 2: Iterations analysis .....	31
2.3 Annex 3: Motor, battery and inverter specifications .....	33

## 1 REPORT

### 1.1 Object

The object of this project is to set the inverter of an electric motorbike for the different dynamic evaluations of the Motostudent Competition in order to fulfil the objectives of each evaluation in the most fast, reliable and efficient manner. These dynamic evaluations are the following:

- Braking test
- Gymkhana
- Acceleration test
- Qualifying
- Race

### 1.2 Scope

The scope of this project was to develop a 1-D simulation model of the motorbike powertrain in Matlab Simulink. Determine the parameters of the electric motorbike for the developed model. Set a configuration of the motorbike inverter for the race event of the MotoStudent Competition.

### 1.3 Background

#### 1.3.1 Motostudent Competition

The Motostudent Competition is a challenge between university students of all around the world promoted by the Moto Engineering Foundation and the TechnoPark Motorland. The aim of this competitions is to evaluate though different events the motorcycles designed and build by the university teams.



Figure 1. MotoStudent teams and bikes. Source: aragoncorporacion.com

The teams can enrol in the petrol or electric categories. In each category they are given a regulations booklet that sets the boundaries and requirements of the design of the motorbike in every aspect (mechanical, electrical, electronical...)

The Rovira i Virgili University participates on the competition in the electric category since the 2018 edition. On the last edition the university team finished on 14<sup>th</sup> place on the dynamic evaluations.



Figure 2. 2018 URV MotoStudent team. Source: diaridigital.urv.cat

### 1.3.2 Simulation tools

Since the early years of motorsport, having some advantage over your rival has been the key to success. In the fifties, the Mercedes Formula 1 team realised that the behaviour of the vehicle could be predicted with the obtention of some parameters of the car and the track, it was then when the first lap time simulation was developed.

Since then, all the teams through all the motorsport categories acquire data every race weekend. This data can be used to improve their simulation tools back at the office and their performance on the different venues by preparing the appropriate setup beforehand and just giving it the final touch when in the circuit.

The simulation tools can range from a simple spreadsheet that simulates a straight line acceleration to a driver-in-the-loop high end simulator like the ones used by Formula one teams.



Figure 3. Red Bull F1 simulator. Source: motorsport.com

Any simulation tool can be as complex as the designer wants it to be, it just needs to include as many parameters and variables as wanted or needed. There is no limits to simulation although the user needs to have caution because the results should never be taken as 100% real.

Nowadays there are many simulation tools that can be used in the motorsport world. Most of them are focussed on the automobile competitions and are very user friendly. But there is as well tools developed in-house by the racing teams and by users, like the one presented in this work.

## **1.4 Standards and references**

### **1.4.1 Legal provisions and applied standards**

This project will follow the standards listed below:

- UNE 157001:2014 for the report structure
- MotoStudent Competition Regulations for the model of the motorbike.

### **1.4.2 Calculation programs**

The programs used in the development of this project are the following:

- Matlab Simulink: the simulation model has been developed using this software.
- AIM RaceStudio 3: it is used to obtain the desired data from the real lap.
- Matlab: some of the results analysis has been carried out using this tool.
- Microsoft Excel: some of the results analysis has been carried out using this tool.

### **1.4.3 Quality management plan applied during project writing**

This section is not applicable for this kind of work.

### **1.4.4 Bibliography**

B. Siegler, "Lap time simulation for racing car design", University of Leeds (School of Mechanical Engineering), 2002

M. Nuruzzaman, "Modeling and Simulation in Simulink for Engineers and Scientists", AuthorHouse, 2005

P. Wright, J.Campbell-Brennan, A. Cotton, R. Divila, G. Hatton, "Anatomy of a Racecar", Chelsea Magazine, 2019

### **1.4.5 Other references**

C. Rouelle, "Data driven seminar", Optimum G, 2018

E. Marquez, C Hahn, "Vehicle modelling using Simulink", *Improving your race car development series*, MathWorks, 2018

## 1.5 Definitions and abbreviations

Blipper: when reducing gears, the action of increasing the engine speed to match it with the gear to be engaged to obtain a smooth deceleration and save the gearbox.

CEV – Campeonato Español de Velocidad

FIM – Fédération Internationale de Motocyclisme

SOC – State of Charge

## 1.6 Design requirements

### 1.6.1 Model requirements

The model had to replicate the real motorbike. The real motorbike was also constrained by the MotoStudent Competition regulations. The race event of the MotoStudent Competition was the length constrain.

The constrains that affected the model were the following:

- Motorland Circuit: the location and length of the race event determined the length of the simulation objective and the demand on the motor. Below are the main characteristics of the motor:
  - 5026 m longitude
  - 50 m altitude change
  - Located in Alcañiz, Spain
  - Average day temperature of 37,2 °C in July



Figure 4. Motorland Aragon aerial view. Source: [www.motorlandaragon.com](http://www.motorlandaragon.com)

- ENGIRO-MS1920 electric motor: this is the motor of mandatory use by all the teams in the competition. The specifications of the motor can be found on the Annex 3. Below are the main characteristics of the motor:
  - 95 Nm of maximum torque.
  - 42 kW of maximum power.
  - 200 V of maximum input voltage.
  - 781 A of maximum input current.
  - 8000 rpm of maximum motor speed.



Figure 5. Engiro MS1920 CAD model. Source: upcommons.upc.edu

- Battery: the battery designed by the team will constrain the energy available and the voltage output. The specifications of the battery can be found on the Annex 4. The battery is modular. It was designed to have three different modules but during the manufacturing one of the modules was left unusable. Therefore, the battery now has two modules. Below are the main characteristics of the battery:
  - 5.184 kWh of available energy.
  - 100.8 V maximum peak output voltage.
  - 88.8 V nominal output voltage.
  - 720 A maximum output current
  - Configuration of the battery modules: 24 in series by 12 in parallel



Figure 6. Module of the actual battery

- Inverter: the motorbike uses the SEVCON GEN4 Size 6 inverter to manage the electric motor input. The specifications of the inverter can be found on Annex 5. Below are the main characteristics of the inverter:
  - 72 – 80 V DC of nominal battery voltage
  - 116 V DC maximum operating voltage
  - 39,1 V DC minimum operating voltage
  - 550 A peak phase current
  - 660 A boost phase current
  - 220 A continuous phase current



Figure 7. SEVCON GEN4 Size 6 inverter. Source: sevcon.com

- Driveline: the driveline has been designed by the mechanical team. The chain ratio has been fixed as follows:
  - 14 teeth for the motor output gear
  - 43 teeth for the wheel crown gear



Figure 8. Driveline of a motorcycle. Source: motorbiscuit.com

- Brakes: the braking system of the motorbike has also been set and designed by the mechanical team as follows:
  - Front:
    - 320 mm disk radius
    - 2 piston brake calliper
  - Rear:
    - 220 mm disk radius
    - 1 piston brake calliper



Figure 9. Front brake disk of the motorcycle.

- Tyres and rims: the dimension of the tyres and the rims are stated in the MotoStudent regulations. These dimensions are as follows:
  - Front tyre: 90/580 R17
  - Rear tyre: 120/600 R17

### 1.6.2 Assumptions

To obtain appropriate results from the model, it was needed to include a list of parameters which values were not possible to obtain. The author made assumptions over these parameters to introduce them to the model in the most real way possible.

The following parameters were assumptions made by the author:

- Motorcycle mass: based on the previous motorcycle designed by the team and the weight of an average adult, the mass of the motorcycle has been set on 200 kg.
- Frontal area of the motorcycle: after some research the value of the frontal area has been set to be similar of the frontal area of any 125 cm<sup>3</sup> sports bike. The frontal area used on the model is 0,4 m<sup>2</sup>.
- Drag coefficient: as in the frontal area, the drag coefficient has been set taking as reference any 125 cm<sup>3</sup> sports bike. This time the drag coefficient used is 1.25.
- Rolling resistance coefficient: the rolling resistance coefficient of the tyres of a motorbike are around the 0,02. As a racing motorbike is being modelled, the racing tyres have higher rolling resistance. For this reason, the rolling resistance coefficient used in the simulation is 0,03.
- Accessory load: the power that the displays and electronic components are drawing from the battery has been estimated on 25 W.
- Losses of the motor: many of the losses coefficients of the motor were unknown. For this reason the losses coefficients have been set to zero. The only losses considered are constant losses of efficiency. The value of this losses has been set constant to account for the losses that have not been considered. It has been considered the worst case of efficiency at maximum power and the losses considered are 1,68 kW.
- Maximum traction force: it has been considered that there is no traction force limit, the limit will be set by the motor and the battery. For this reason it has been used a really high value of traction force to not interfere in the simulation results. The traction force values has been set on 10 kN.

- Maximum braking force: the maximum braking force has been estimated from the maximum braking capabilities of a Moto 3 motorbike. These motorcycles are able to brake on decelerations of up to 1,3 g.
- . In our model the maximum braking force has been set on 2550 N, which is the force experimented from a 1,3 g deceleration with a motorbike similar to the one modelled.

### 1.6.3 Simulation target

The main target of the simulation is to achieve a configuration of the inverter that allows the motorcycle to finish the race event of the MotoStudent competition. As the model has uncertainties compared to the original model, the requirements to validate the result are the following:

- Complete the length of the race: the main target, it is needed to develop a configuration that allows the motorcycle to finish the event.
- 10% SOC remaining at the end of the event: to protect the inverter from running on low voltages.
- Minimum time possible: to complete the event in the minimum time possible in order to get a good result in the standings.
- Maximum speed possible in the straights: in the Motorland circuit is very difficult to pass in the turns sections. The best overtaking points are in the end of the straights, having high speed through the straights helps attacking and defending.

## 1.7 Solution analysis

To achieve the final result, many iterations were undertaken. The different iterations differed in the battery maximum current allowed. This was the chosen parameter to modify as it is one of the parameters that can be altered through the inverter configuration.

The following table summarizes the different iterations taken until the final result was obtained:

Table 1. Simulation iterations

Parameter	Voc	I_max	Final SOC	Time	Vmax	Distance	% Race distance
<i>Description</i>	<i>Output voltage bat/inverter [V]</i>	<i>Maximum Current [A]</i>	<i>Final SOC [%]</i>	<i>Time to complete [s]</i>	<i>Maximum speed [km/h]</i>	<i>Distance travelled [km]</i>	<i>% of the race completed</i>
Baseline	88,8	660	5	675	179	23,8	95
Iteration 1	88,8	600	5	684	179	24,3	97
Iteration 2	88,8	550	7,3	706	179	25,1	100
Iteration 3	88,8	525	10	706	179	25,1	100
Iteration 4	88,8	500	13	706	179	25,1	100
Iteration 5	88,8	475	15,99	706	179	25,1	100
Iteration 6	88,8	450	18,7	710	176	25,1	100

The iteration used for the final results analysis is iteration nº 5 as is the iteration that achieves all the targets with the higher SOC remaining and the lower value of maximum current. Iteration nº 6 was discarded as the performance of the motorbike decreased.

The similarity in the first iterations is due to the power limit of the motor. The higher value of current meant that the battery was able to supply more power than the maximum

power of the motor. For this reason the simulations showed such similar results. In Figure 10 it can be easily observed how the battery supplied more power than the maximum capability of the motor (grey lines).

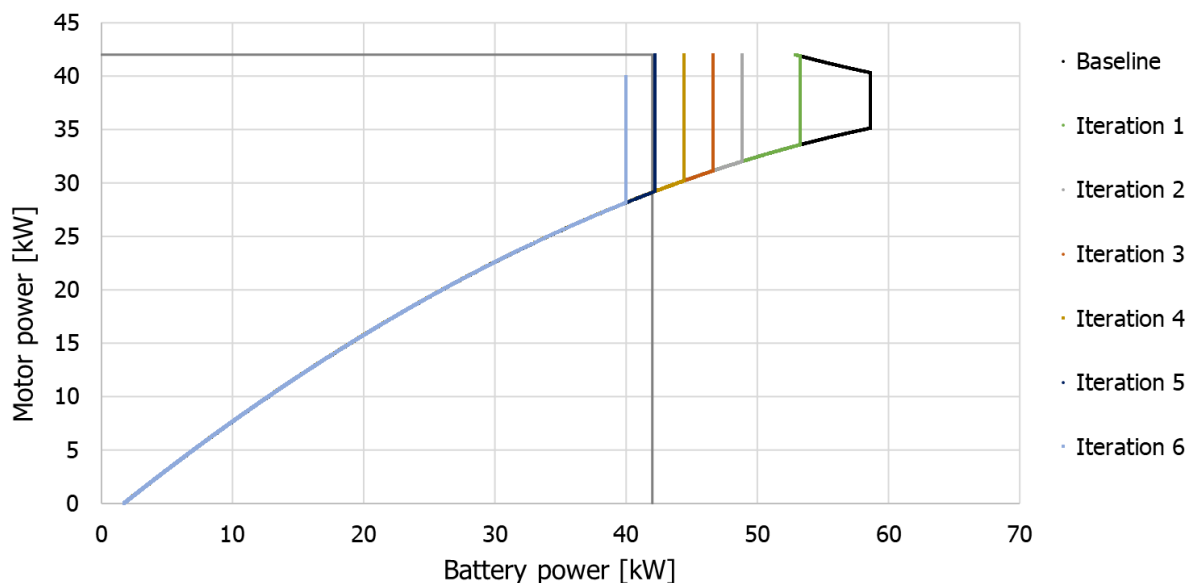


Figure 10. Motor power vs. Battery power for all the iterations

The reasons for selecting this iteration instead of other iterations are the uncertainty and the protection of the devices. As the model has uncertainties and parameters are not modelled, completing the race with higher SOC in the same time and achieving the same maximum speed gives more security to the team. Also, having lower levels of current flowing on the system reduces the probability of possible issues in the inverter and motor.

Further analysis of the iterations can be found on Annex 2.

## 1.8 Final results

### 1.8.1 Input parameters obtention

In order to obtain proper results from the model, the input parameters had to be reliable and appropriate for the type of modelling that has been used.

After some research and contacting different engineers of the CEV, the author was provided with a full set of data of a qualifying session for a racing motorcycle in the Motorland FIM circuit (the same layout as the Motostudent Competition).

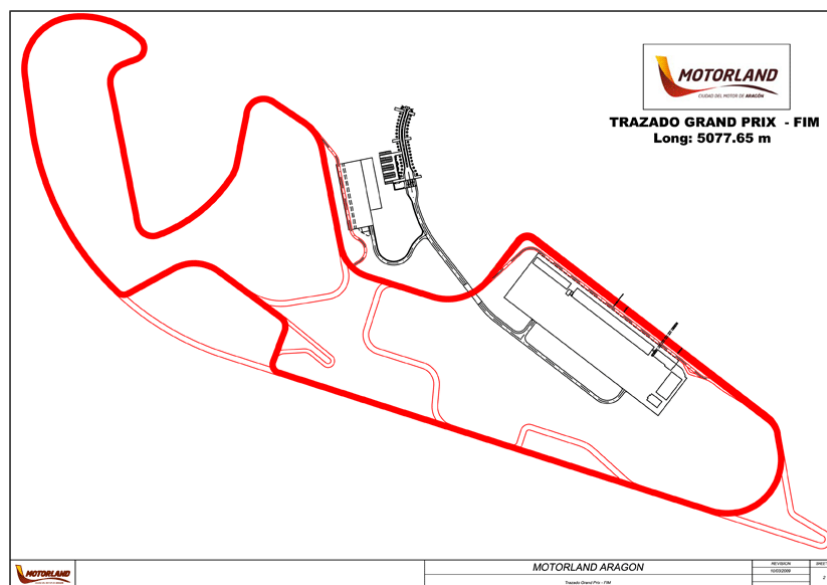


Figure 11. Motorland Aragon FIM layout. Source: motorlandaragon.com

For confidentiality reasons the motorcycle specifications, the pilot and the team cannot be shared in this project. For this reason the specifications are shared within a range to give the lector an idea of the type of motorcycle:

- 85 – 100 kW maximum engine power.
- 55 – 65 Nm maximum engine torque.
- 180 – 210 kg weight.

### 1.8.2 Input parameters process

The data provided from the CEV engineer underwent a treatment using the AIM RaceStudio 3 software.

The throttle twist position signal was smoothed to eliminate the manual “blipper”. The smoothed signal has an output that ranges from 0 to 100.

The brake pressure signals were added to obtain the total braking demand. The added signal was scaled to obtain the braking demand in a scale from 0 to 100.

After the scaling of the signals, the data was reprocessed using a distance treatment from the GPS speed channel of the logged data. Using the data in distance-based allows the model to eliminate the time dependence created by the logged data and obtain new lap-times and run more accurate simulations.

### 1.8.3 Simulink modules description

To define the parameters of the calculation in an orderly way, the Simulink model was split in different blocks. Each of these blocks model a different part of the motorcycle that affects the simulation results. Furthermore, a driver block has been created to act as a controller.

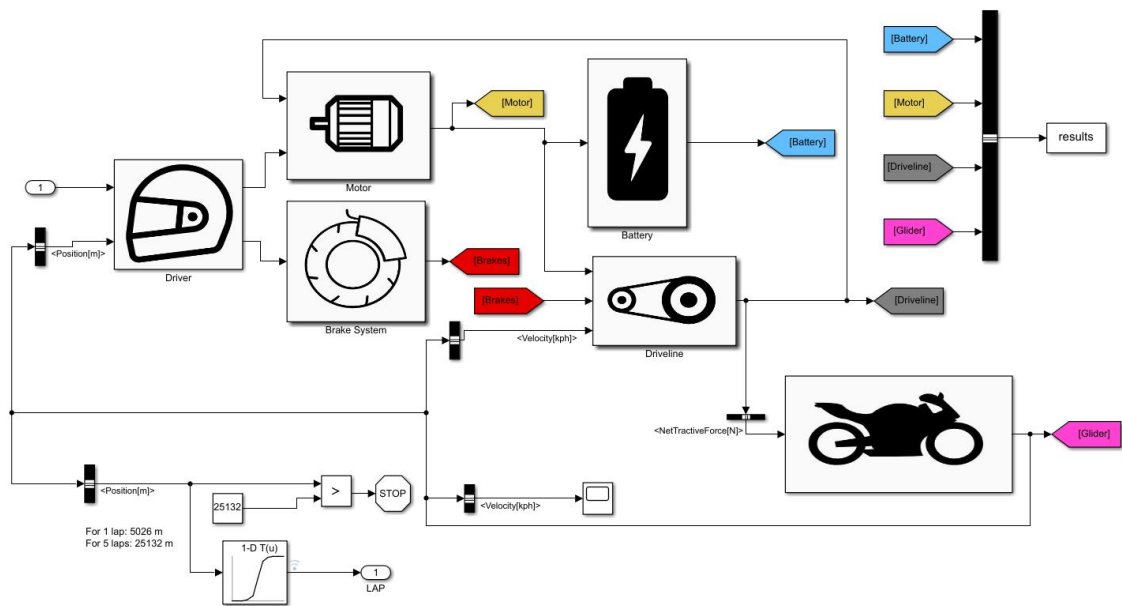


Figure 12. Simulink model

A part from the blocks, there is a results section where all the data is gathered and a lap counter that stops the simulation when the five laps have been completed.

### 1.8.3.1 Driver block

The driver block is the main control module for the motorcycle system. As in the real world, the driver is fully on charge of how the motorcycle model behaves.

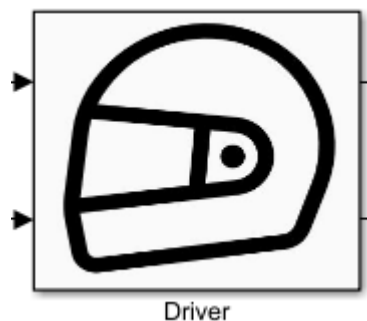


Figure 13. Driver block

This block has only one input:

- the position of the motorbike on the circuit [m].

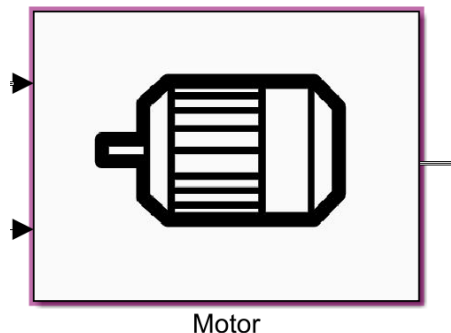
The driver block has two outputs:

- the throttle demand [%],
- the braking demand [%].

It is based on two look up tables that relate the input (position of the motorbike on the circuit) with the throttle and brake demand.

### 1.8.3.2 Motor block

The electric motor block models the behaviour of the electric motor. The modelled motor does not have regenerative braking capabilities.



Motor

Figure 14. Motor block

The inputs for this block are the following:

- Throttle demand [%],
- Motor speed [rad/s]

The motor block has the following outputs (some of them are only for results purposes):

- Positive torque [Nm]
- Motor power output [W]
- Motor energy output [J]
- Motor power input [W]
- Motor energy input [J]
- Motor power losses [W]
- Motor energy losses [J]

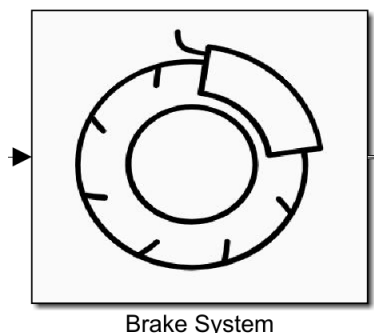
The first step of this block is comparing the maximum torque that the motor can provide and the torque obtained from the maximum power and the motor speed. The minimum of these two torque values is used. This is a simple way used to model the torque capabilities of the motor.

After the comparison the chosen value is multiplied by the throttle twist input. The maximum torque available from the designated throttle twist position is obtained, it is named positive torque.

Using the positive torque obtained in the step above, the losses of the electric motor are also modelled. The author only modelled the electric efficiency of the motor, other losses such as the thermal or friction losses were not modelled.

### 1.8.3.3 Brake system block

The brake system block models the braking capabilities of the motorbike.



Brake System

Figure 15. Brake system block

This block has only one input:

- Braking demand [%]

The braking system block has only one output:

- Friction brake force [N]

This block is based on a straightforward calculation. The braking demand is multiplied by the maximum braking force of the motorbike obtaining the total friction brake force applied by the driver.

#### 1.8.3.4 Battery block

The battery block models the behaviour of the battery under the demand of the motor.

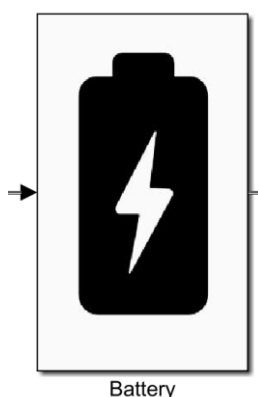


Figure 16. Battery block

This block has only one input:

- Motor power input [W]

The battery block has the following outputs (some of them are only for results purposes):

- SOC [%]
- Battery power losses [W]
- Battery energy losses [J]
- Voltage at terminals [V]
- Battery power at terminals [W]
- Battery energy at terminals [J]
- Battery current [A]

The battery block calculates the battery current from the motor power input and the open circuit voltage of the battery. The modelled battery is based on a theoretical approach and does not lose voltage while being discharged.

To calculate the SOC remaining on the battery the model integrates the power being drawn from the battery and compares it to the energy capacity of it.

This block has the ability to stop the simulation if the SOC of the battery reaches 5%.

#### 1.8.3.5 Driveline block

The driveline block models the behaviour of transmission and tyres of the motorcycle.

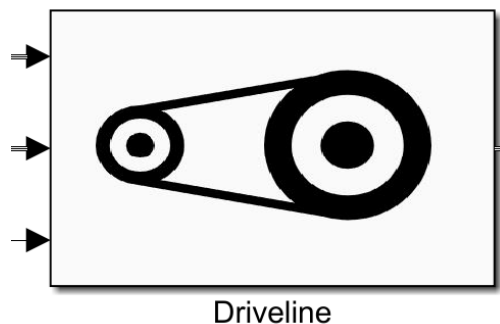


Figure 17. Driveline block

The inputs for this block are the following:

- Positive torque [Nm]
- Vehicle speed [km/h]
- Friction brake force [N]

The driveline block has the following outputs (some of them are only for results purposes):

- Driveline power losses [W]
- Driveline losses [kWh]
- Driveline energy losses [J]
- Driveline torque output [Nm]
- Net tractive force [N]
- Motor speed [rad/s]

The modelled driveline calculates the traction force using the gear ratio of the chain and the wheel's dynamic radius from the torque output of the motor. Adding the traction force to the friction brake force the net traction force of the vehicle is obtained.

The block also models the losses in the driveline such as spin losses. These have been estimated.

#### 1.8.3.6 Glider block

The glider block models the motorbike physical properties such as the weight, the aerodynamic resistance, or the rolling resistance.

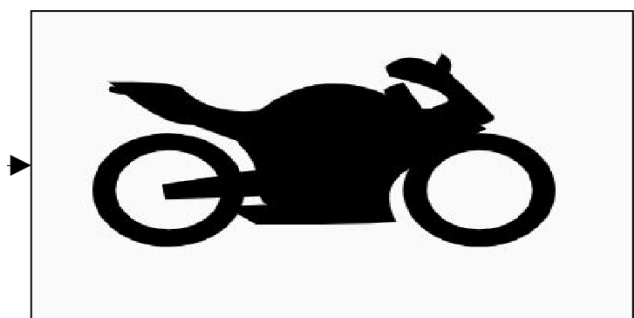


Figure 18. Glider block

This block has only one input:

- Net tractive force [N]

The glider block has the following outputs (some of them are only for results purposes):

- Tractive power [kW]
- Total tractive energy [kWh]
- Total tractive energy [J]
- Propelling energy [J]
- Braking energy [J]
- Velocity [km/h]
- Position [m]

The glider block uses the net tractive force to calculate the velocity after deducting the losses from the aerodynamic drag and the rolling resistance. The glider block represents the first step in any simulation block as the glider itself represents a simulation quite accurate for a simple simulations of a vehicle.

#### **1.8.4 Simulink model restrictions**

The Simulink model designed did not consider nor simulate the following aspects:

- Thermal performance of the motorcycle elements
- Dynamic behaviour of the motorcycle (pitch, roll, yaw)
- Turning performance
- Motorcycle balance
- Centre of gravity position variation
- Centre of pressure position variation
- Grip limit of the tyres
- Electric motor torque map efficiency
- Battery output voltage drop
- Driver aggressivity
- Driver judgement
- Influence of other motorbikes on the circuit (slipstream, overtaking)

## 1.8.5 Results analysis

### 1.8.5.1 Full race analysis

As stated previously, the iteration used for the results analysis is iteration nº 5 for the reasons already explained.

The main results for the simulation are the following:

Table 2. Race results

Total time [s]	Energy used [MJ]	Final SOC [%]	Maximum speed [km/h]
705,7	3,36	15,99	179

As it can be observed in the following histogram, the motorcycle is mainly running in the 106 to 135 km/h range and switching from low torque to high torque during the race.

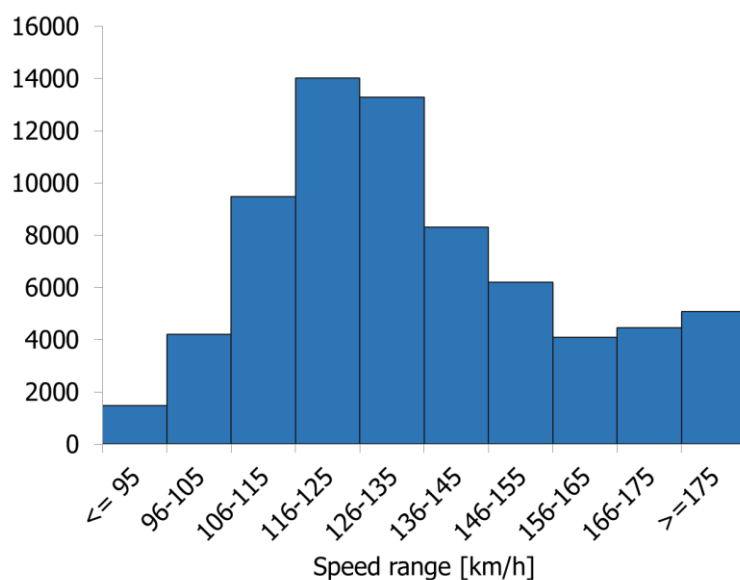


Figure 19. Speed histogram of the full race

The histogram shows the characteristics of the Motorland circuit. A high speed circuit that allow the drivers to carry speed through the corners.

Although an idea of how the motorbike will behave during the race can be drawn from the previously showed histograms, the following maps show the working areas of the electric motor during the race.

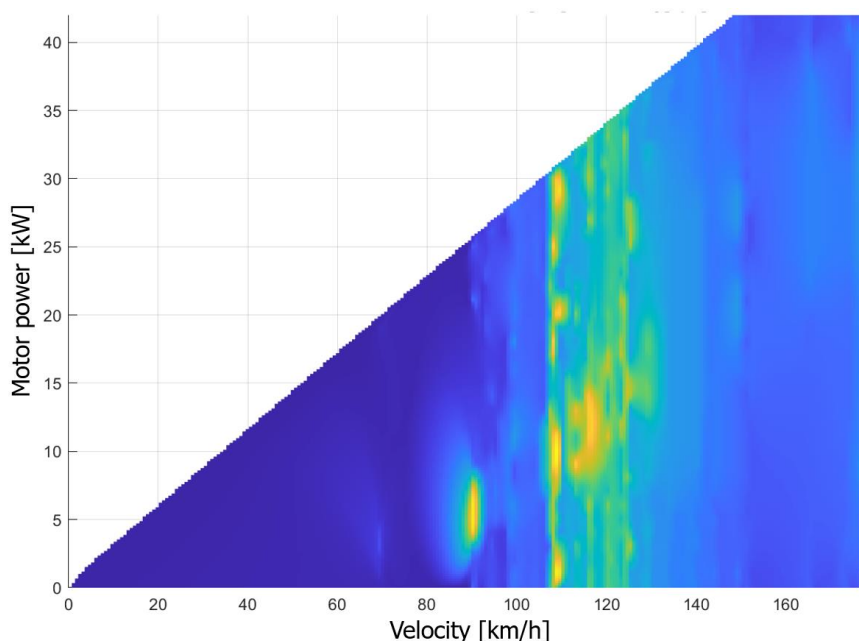


Figure 20. Power map of the full race

As it can be seen from the above map, the motorbike uses all the power on the 110 to 130 km/h range. The motorbike is not able to use all the torque range and power because of the driving chain ratio fitted.

Also, there is a noticeable area on the 90 km/h speed range. This area corresponds to the slow section of the circuit. As it can be observed, the torque and power seem very constant in the section as it is an isolated area. This shows that it is a constant speed section.

### 1.8.5.2 Lap analysis

As the simulation does not model the voltage drop, all the laps except from the first one (differs because of the standing start) have the same output. The lap results are the following:

Table 3. Lap results

Lap	Lap time [s]	Energy deployed [MJ]	SOC used [%]	Maximum speed [km/h]
1	151,41	2,35	16,17	179
2	138,58	2,26	15,71	179
3	138,58	2,26	15,71	179
4	138,57	2,26	15,71	179
5	138,58	2,26	15,71	179

From the laps above, it has been selected lap 3 as a model lap to illustrate the results obtained from the simulation and what to expect in powertrain terms.

The following graph shows the speed and SOC profile of lap 3:

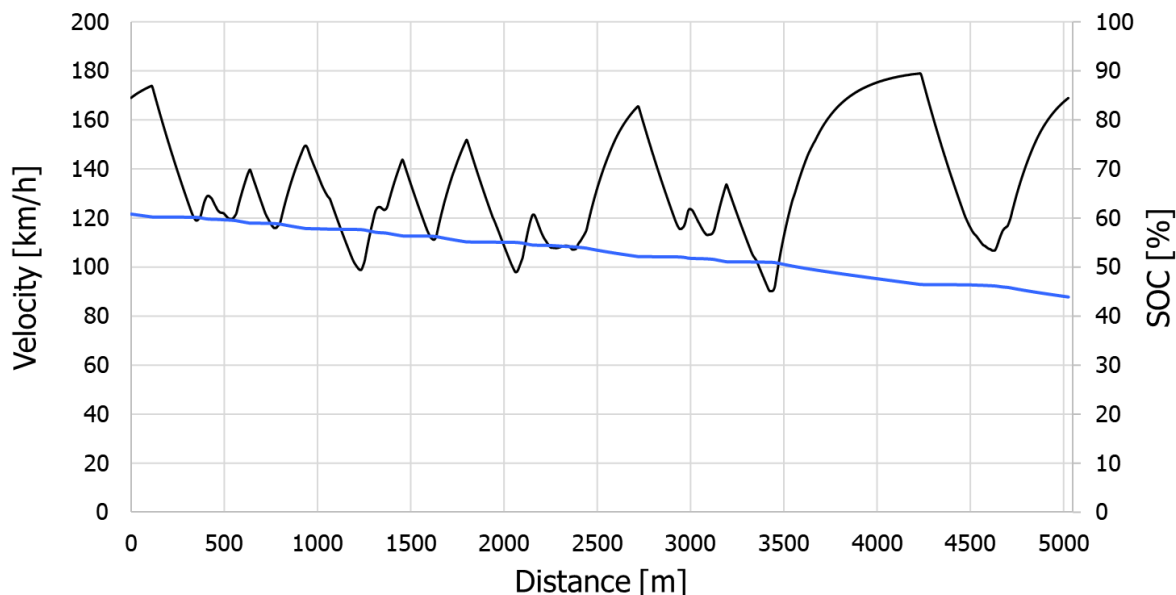


Figure 21. Speed and SOC profile of lap 3

On Figure 21 it can be checked that the range where the motorbike spends most of the time in in the previously mentioned 110 to 130 km/h range.

It can also be observed that the SOC level decreases uniformly during the lap and there is not a noticeable section that uses more energy than another. This uniform use of the energy allows to set the motorbike for an overall target without having to focus on an area that can draw trouble.

The following graph shows the motor speed and the motor output power during the course of the lap:

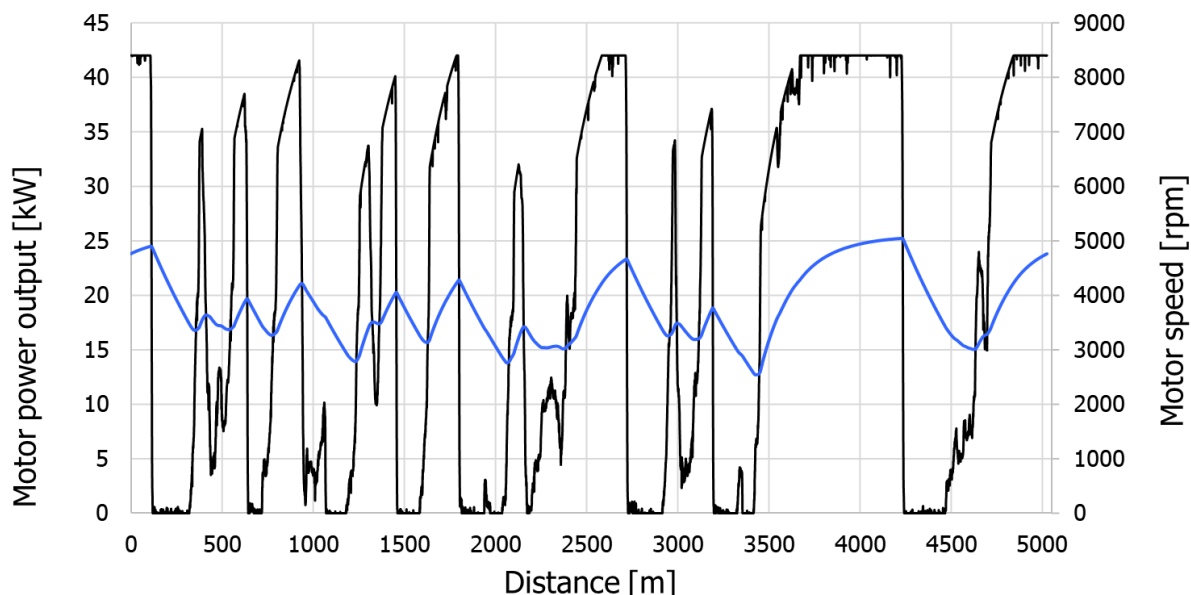


Figure 22. Motor speed and motor output power of lap 3

As the motorbike has a unique gear the motor speed and velocity profile have a very similar shape. It can also be observed that the motor reaches the maximum possible output when the motor speed is around 4300 rpm. When reaching the maximum output power the acceleration slope starts to noticeably decrease.

One of the key parts of the circuit is the long back straight (from 3500 to 4200 m in the X axis of the graph), with the current setup the maximum power is reached at around 3700 m allowing the motorbike to achieve the maximum speed of 179,95 km/h at the end of the straight.

As in the full race analysis, the power and torque maps have been obtained for the lap analysis:

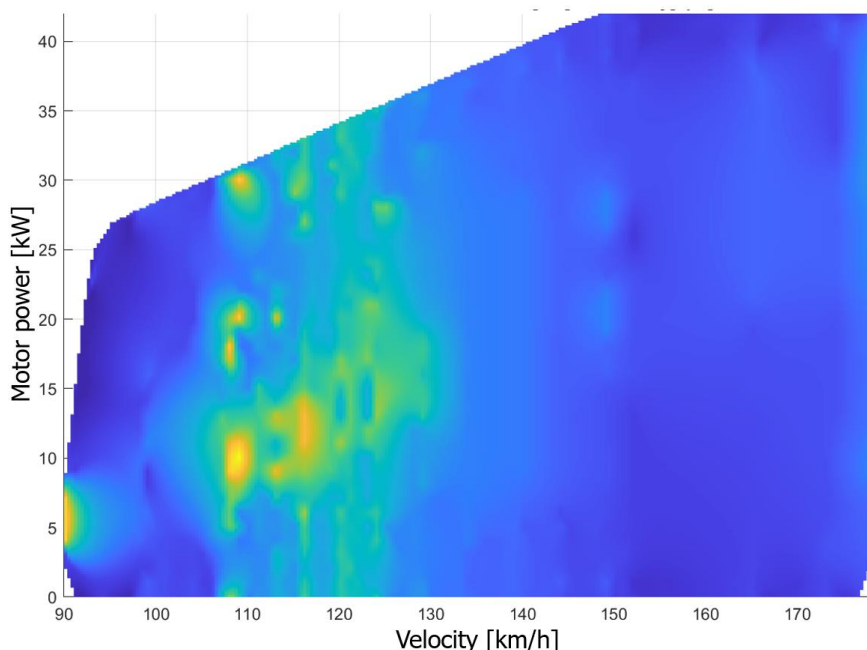


Figure 23. Power map

As in the full race analysis, the motorbike uses all the torque and power on the 110 to 130 km/h range. Regarding the low speed section, in a flying lap the motorbike does not run at less than 90 km/h in this circuit.

### 1.8.6 Recommended inverter set-up

Considering the previously shown results, in order to achieve the objectives of finishing the race event with the conditions mentioned on section 3.6.3, the following output parameters need to be set at the maximums showed in Table 4:

Table 4. Inverter set-up

Parameter	Maximum value
Voltage	88,8 V
Current	475 A

Therefore, following the result of the simulation, this result can be used as a guide to achieve the desired outcome of the race event on the 2021 MotoStudent Competition.

## **1.9 Planning**

The competition will be held on July 2021. It is recommended to test the inverter configuration proposed in this work prior to the competition in a test session.

### **1.10 Priority order between the documents**

The priority of the documents are as follows:

1. Report
2. Annex 2: Iterations analysis
3. Annex 1: Simulink model mathematical background

## 2 ANNEXES

### 2.1 Annex 1: Simulink model mathematical background

The motorcycle simulation was done using a Matlab Simulink model. The model was based on a formula approach and was divided into different blocks to model the different parts of the motorcycle. The simulation was run at a 10 Hz calculation frequency.

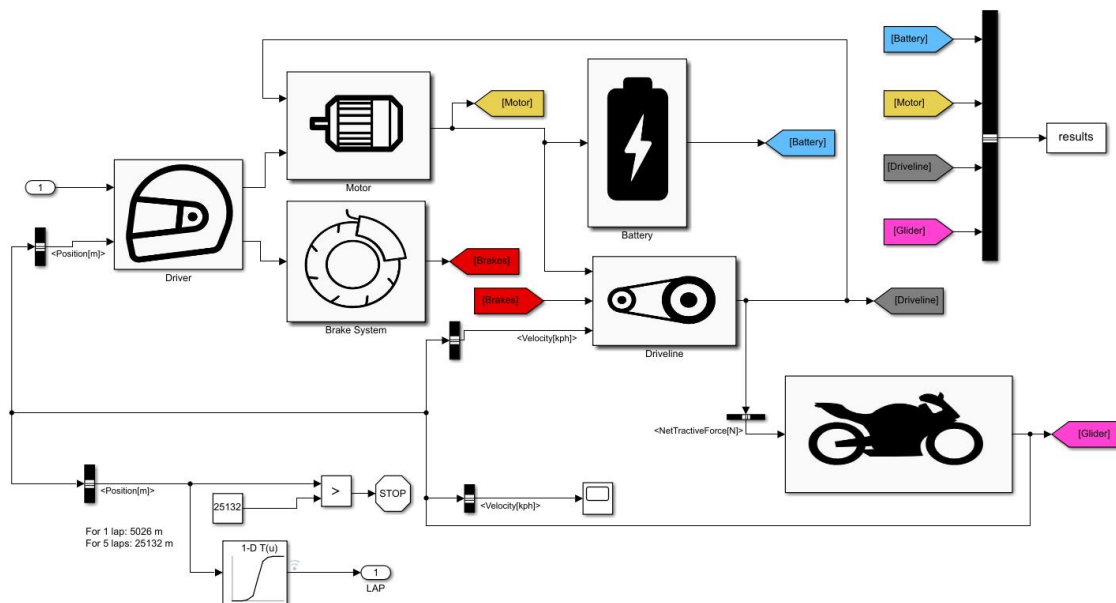


Figure 24. Simulink model

#### 2.1.1 Driver block

The driver block is based on two look-up tables that relate the position in the circuit with the throttle and brake actuation. The output of both look-up tables are values that range from 0 to 100.

Prior to the look-up tables, an offset of 10 cm is added to the position signal to avoid errors at the beginning of the simulation due to the number of signals that are 0. Without the offset the simulation will be executed but the motorcycle will not move.

Both look-up tables follow a linear with point-to-point slope interpolation methodology.

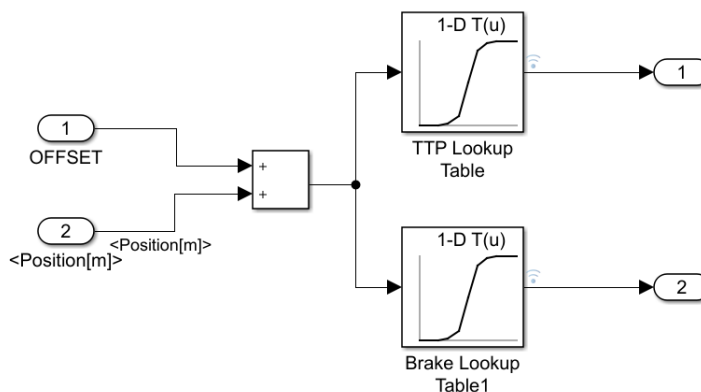


Figure 25. Driver block Simulink model

### 2.1.2 Motor block

The motor block converts the demand of the driver in terms of throttle application into usable torque. The block is based into two sub-blocks and an analysis section.

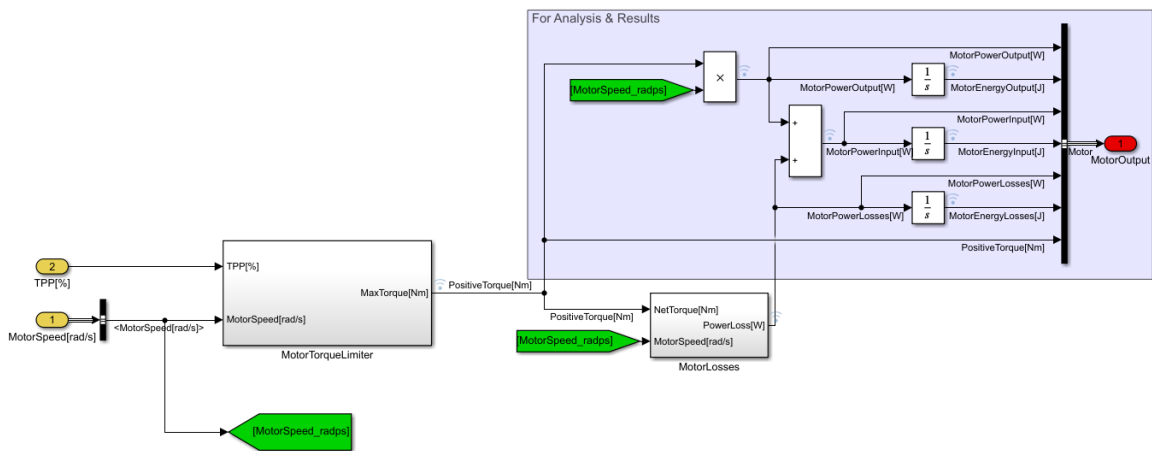


Figure 26. Motor block

The first sub-block is the torque limiter block. This block uses a maximum torque and maximum power available approach. From the following formula, the maximum power of the motor is divided by the current speed of the motor, this operation has as a result a value of torque.

$$P_{mot} = \tau_{mot} \omega_{mot} \quad (1)$$

The torque obtained is compared to the maximum torque of the motor. The minimum value of torque is multiplied by the demand of the driver to obtain the positive torque demanded.

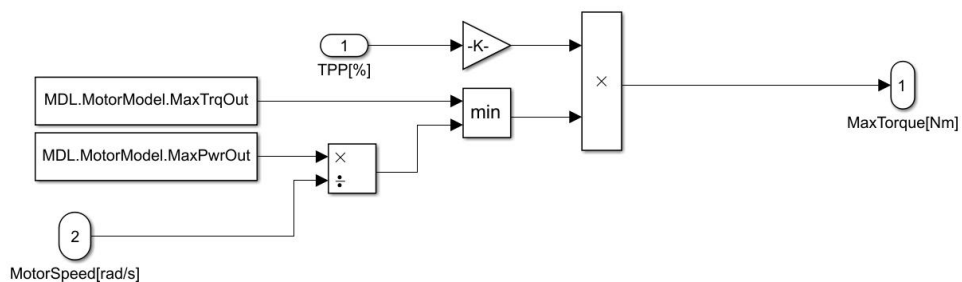


Figure 27. Torque limiter sub-block

This approach allows reducing the input data needed to run the model as it simulates the torque map in a reliable manner without considering efficiencies.

The output of the torque limiter sub-block is introduced into the motor losses sub-block. In this block the losses are calculated. The model is prepared to consider different efficiency coefficients. The losses are calculated using the following formula:

$$P_{Loss} = k_c \tau^2 + k_i + \omega + k_\omega \omega^3 + C \quad (2)$$

Where:

- $P_{Loss}$  = Power losses in W
- $\tau$  = torque of the motor in Nm
- $\omega$  = motor speed in rad/s
- $K_c$  = torque losses coefficient
- $K_i$  = friction losses coefficient
- $K_w$  = inertial losses coefficient
- $C$  = constant losses in W

For the simulation of the model, it has only been considered the constant motor losses with a value of 1640 W. The motor losses sub-block uses a trigger to activate or de-activate the losses depending on if the motor is running or not.

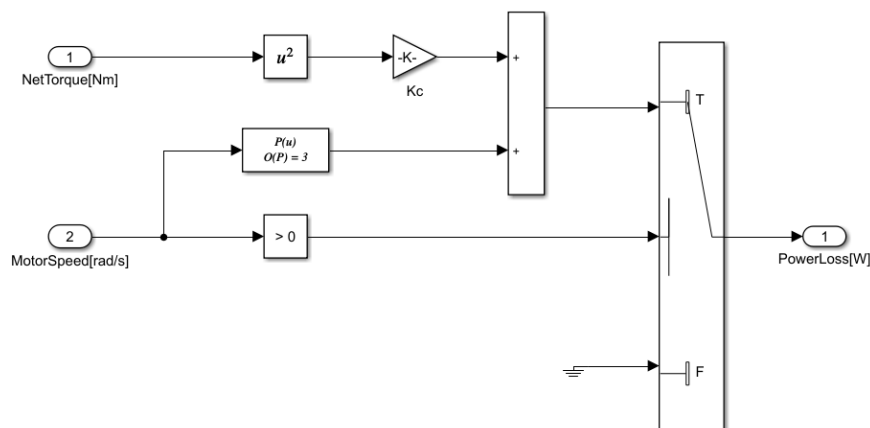


Figure 28. Motor losses Sub-block

In the analysis and results section different outputs are calculated using basic engineering formulae and knowledge. The motor power input is calculated using the equation below:

$$P_{in} = \tau\omega + P_{Loss} \quad (3)$$

Where:

- $P_{in}$  = power input to the battery in W
- $\tau$  = torque of the motor in Nm
- $\omega$  = motor speed in rad/s
- $P_{Loss}$  = motor power losses in W

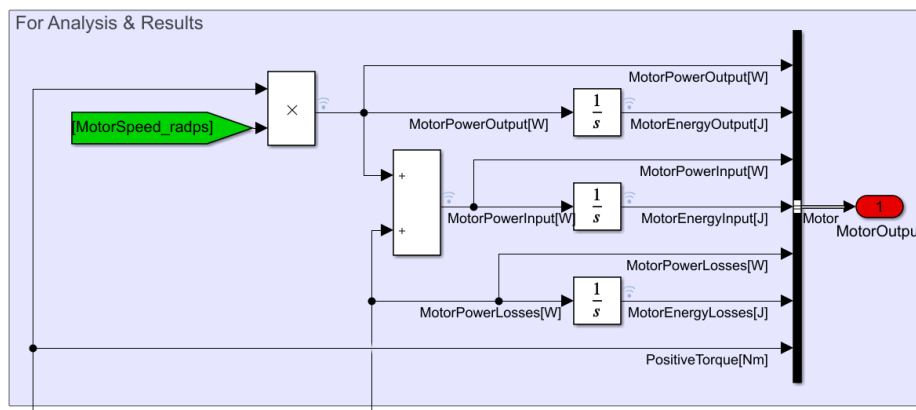


Figure 29. Motor analysis and results section

### 2.1.3 Brake system block

The brake system block uses a straight forward approach. The braking demand from the driver block is introduced as an input. The % is multiplied by the predefined maximum braking force of the vehicle and a braking force value is obtained.

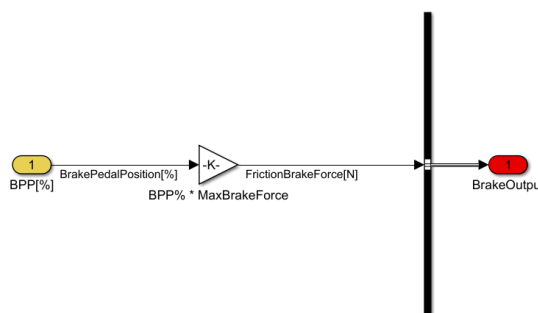


Figure 30. Brake system block

### 2.1.4 Battery block

The battery block is divided in two parts. The current calculation sub-block and the analysis and results section. Prior to the current calculation sub-block, an accessory load is added to the motor power input to simulate the load of the displays and other electronic components that draw energy from the battery.

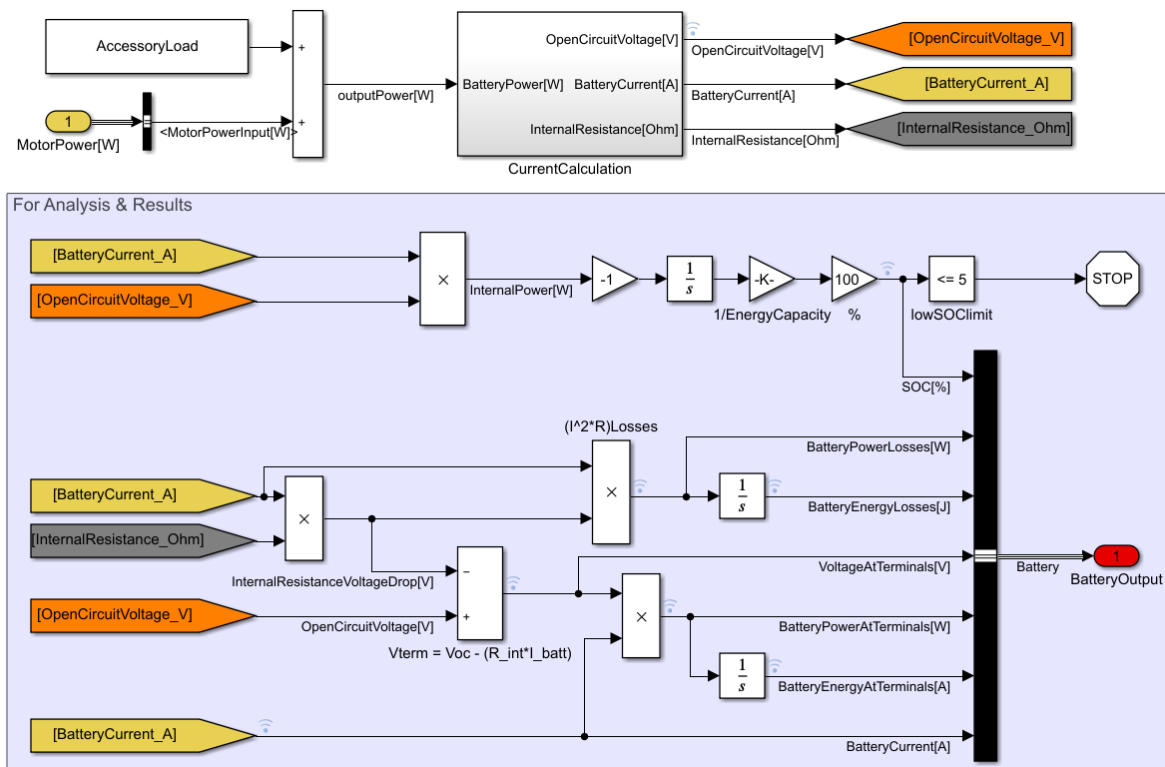


Figure 31. Battery block

In the current calculation sub-block the current is calculated using the equation below:

$$I = \frac{V_{OC} - \sqrt{V_{OC}^2 - 4RP}}{2R} \tag{4}$$

Where:

- I = battery current in A
- $V_{OC}$  = open circuit voltage of the battery in V
- R = internal resistance of the battery in  $\Omega$
- P = power input in W

To avoid undefined solutions in the simulation, the square root terms have been forced to be always positive by adding an absolute value block. To not surpass the current limit of the battery, the output of the calculation is compared to the maximum value of current by design and the minimum of the two values is used in the simulation guaranteeing that the design limit will not be surpassed.

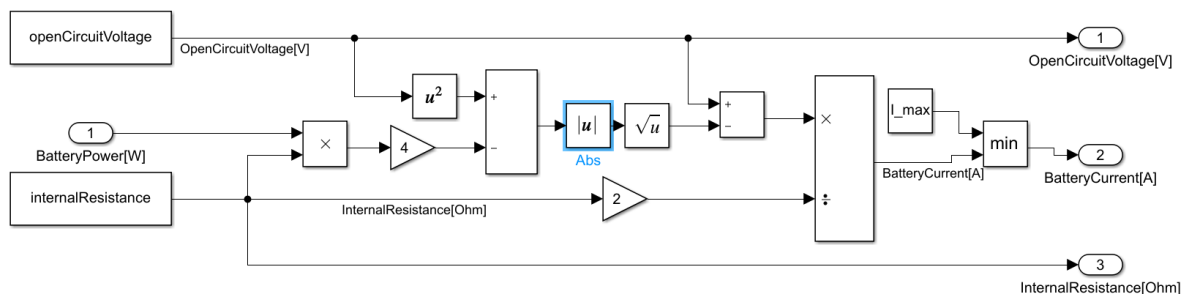


Figure 32. Battery current calculation

In the analysis and results section, the SOC is calculated by integrating the internal power of the battery to obtain energy and comparing it to the energy capacity of the designed battery. The block is set to stop the simulation if the SOC gets below 5%.

In this section are also calculated the battery power losses, the voltage at the terminals within others using the following equations:

$$P_{Loss} = I^2 R_{int} \tag{5}$$

Where:

- $P_{Loss}$  = battery power losses in W
- $I$  = battery current in A
- $R_{int}$  = internal resistance in  $\Omega$

$$V_{term} = V_{OC} - (R_{int}I) \tag{6}$$

Where:

- $V_{term}$  = voltage at the terminals in V
- $V_{OC}$  = open circuit voltage of the battery in V
- $I$  = battery current in A
- $R_{int}$  = internal resistance in  $\Omega$

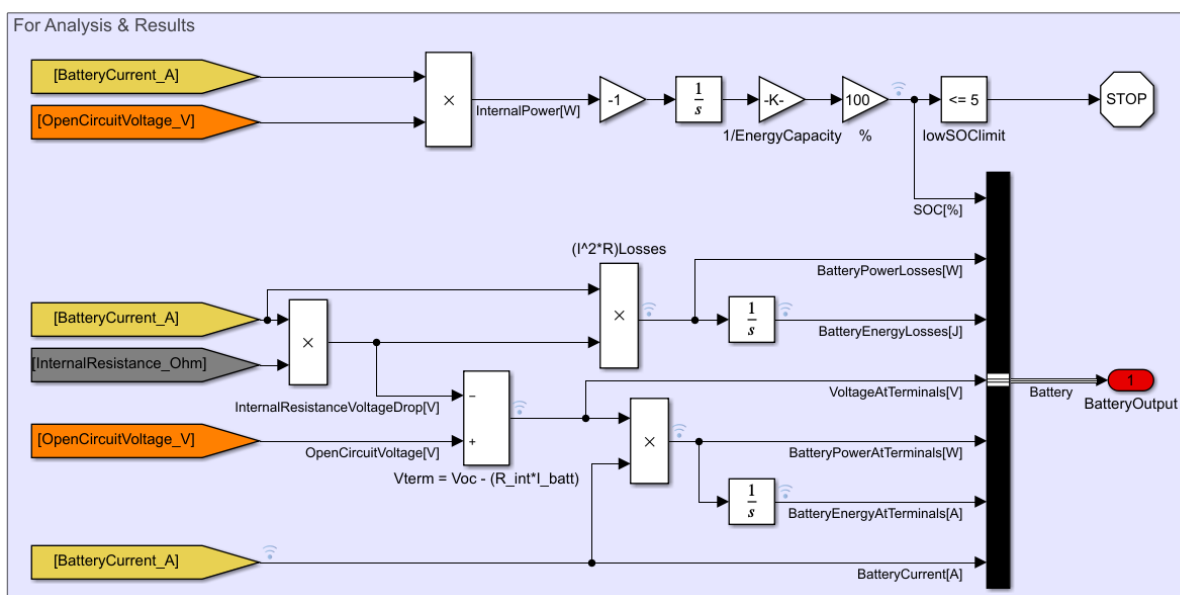


Figure 33. Battery analysis and results

To calculate power it has been used Ohm’s law and to calculate energy, the power obtained has been integrated.

### 2.1.5 Driveline block

The driveline block calculates to main outputs for the system, the tractive force of the motorcycle and the motor speed to be used in the next iteration.

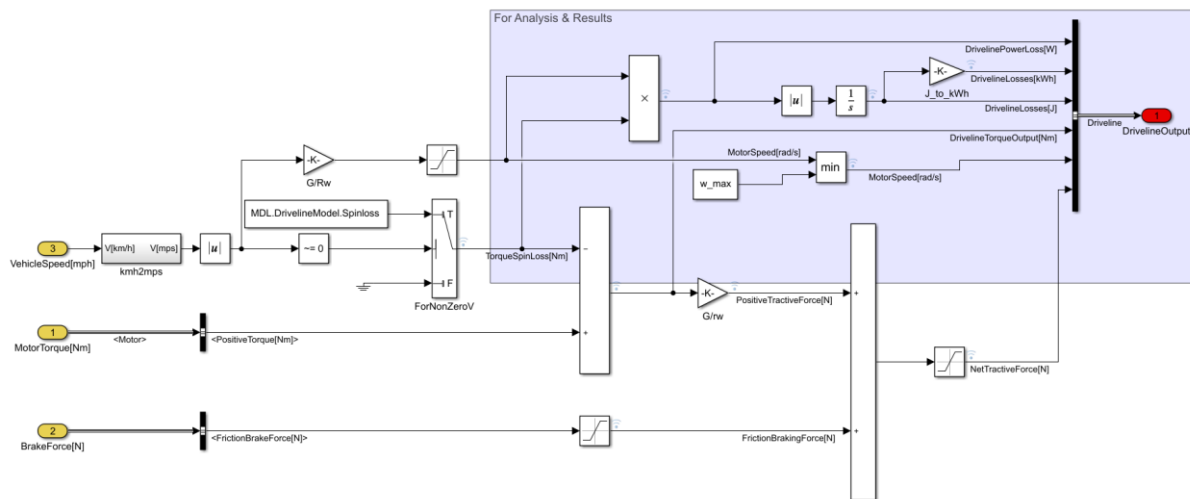


Figure 34. Driveline block

To calculate the motor speed it used the wheel radius, the chain ratio and the vehicle speed as it can be seen in the formula below:

$$\omega_{motor} = \frac{v G}{r_w} \tag{7}$$

Where

- $\omega_{motor}$  = motor speed in rad/s
- $v$  = vehicle speed in m/s
- $G$  = chain ratio
- $r_w$  = wheel radius in m

The motor speed obtained is compared to the design maximum speed of the motor and the minimum value is used.

As in other blocks, a switch is used to activate the losses when the motor is running, in this case the losses of the chain are modelled using a constant value of spin loss.

To the positive torque output of the motor it is subtracted the driveline torque losses. The result is multiplied by the chain ratio and divided by the wheel radius and a positive tractive force is obtained. The braking force is subtracted to the positive tractive force to obtain the tractive force of the motorcycle. The equation below describes the obtaining of the tractive force:

$$F_{tr} = (T_{motor} - T_{Loss}) \frac{G}{r_w} - F_{Br} \tag{8}$$

Where:

- $F_{tr}$  = traction force in N
- $T_{motor}$  = torque of the motor in Nm
- $T_{Loss}$  = torque losses of the driveline in Nm
- $G$  = chain ratio
- $r_w$  = wheel radius in m
- $F_{br}$  = braking force in N

In the analysis and results section different outputs are calculated using basic engineering formulae and knowledge.

### 2.1.6 Glider block

In the glider block the tractive force is used to calculate the speed and tractive values of the model. To the previously obtained tractive force the following losses are applied:

- Aerodynamic drag: the aerodynamic resistance of the vehicle is modelled using the following equation:

$$F_{aero} = \frac{1}{2} \rho C_d A_f V^2 \quad (9)$$

Where:

- $F_{aero}$  = aerodynamic force in N
- $\rho$  = air density in  $\text{kg/m}^3$
- $C_d$  = drag coefficient
- $A_f$  = frontal area in  $\text{m}^2$
- $V$  = vehicle speed
- Rolling resistance: models the resistance of the tyre with the tarmac. The following equation has been used:

$$F_{rr} = m g C_{rr} \quad (10)$$

Where:

- $F_{rr}$  = rolling resistance force in N
- $m$  = mass of the motorcycle in kg
- $g$  = gravity in  $\text{m/s}^2$
- $C_{rr}$  = rolling resistance coefficient
- Grade force: the grade force that a slope creates on the vehicle. In our simulation the grade will be 0 but if it wants to be implemented the following equation is used:

$$F_{grade} = m g \sin(\theta) \quad (11)$$

Where:

- $F_{grade}$  = grade force in N
- $m$  = mass of the motorcycle in kg
- $g$  = gravity in  $\text{m/s}^2$
- $\theta$  = angle of the slope in  $^\circ$

Therefore, using all the previous equations the tractive force results in the following:

$$F_{tr} = F_{aero} + F_i + F_{grade} + F_{rr} \quad (12)$$

Where:

- $F_{tr}$  = tractive force in N
- $F_{aero}$  = aerodynamical force in N
- $F_i$  = inertial force in N
- $F_{grade}$  = grade force in N
- $F_{rr}$  = rolling resistance force in N

From the previous equation the Inertial force is obtained , and the acceleration can be calculated:

$$a = \frac{F_{tr} - F_{aero} - F_{grade} - F_{rr}}{m_i} \tag{13}$$

Where:

- a = acceleration in m/s<sup>2</sup>
- F<sub>tr</sub> = tractive force in N
- F<sub>aero</sub> = aerodynamical force in N
- F<sub>grade</sub> = grade force in N
- F<sub>rr</sub> = rolling resistance force in N
- m<sub>i</sub> = inertial mass in kg

From the obtained acceleration, integrating once the velocity of the vehicle is obtained and, integrating the velocity the distance travelled (position) can also be calculated.

In the analysis and results section different outputs are calculated using basic engineering formulae and knowledge.

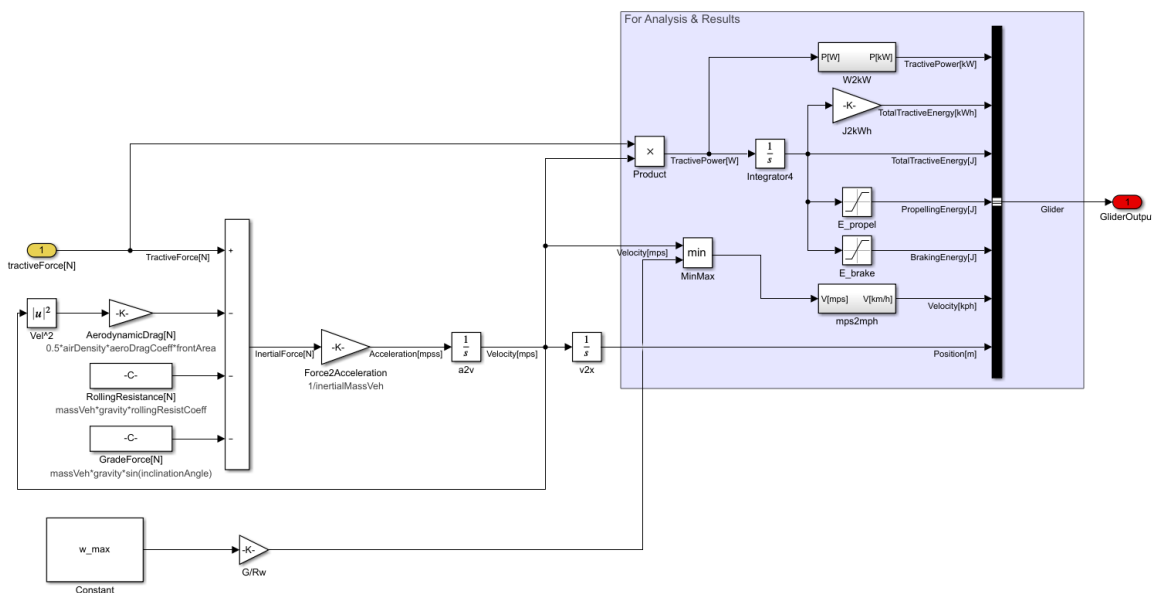


Figure 35. Glider block

### 2.1.7 Model inputs

The table below shows all the necessary inputs to run the model:

Table 5. Model inputs

<b>Input</b>	<b>Unit</b>	<b>Data type</b>
Accesory load	W	Real number
Aero drag coefficient	--	Real number
Air density	kg/m <sup>3</sup>	Real number
Brake application	%	1D array
Distance reference	M	1D array
Energy capacity	kWh	Real number
Frontal area	m <sup>2</sup>	Real number
Gravity	m/s <sup>2</sup>	Real number
Maximum current	A	Real number
Inclination angle	°	Real number
Inertial mass	kg	Real number
Initial SOC	%	Real number
Internal resistance	Ω	Real number
Lap trigger	m	1D array
Mass of the vehicle	kg	Real number
Open circuit voltage	V	Real number
Rolling resistance coefficient	---	Real number
Maximum torque	Nm	Real number
Throttle demand	%	1D array
Maximum motor speed	rad/s	Real number
Wheel radius	m	Real number
Motor torque losses coefficient	---	Real number
Motor friction losses coefficient	---	Real number
Motor inertial losses coefficient	---	Real number
Motor constant losses	W	Real number
Motor maximum power	W	Real number
Motor maximum torque	Nm	Real number
Chain ratio	---	Real number
Spin loss torque	Nm	Real number
Maximum traction force	N	Real number
Maximum braking force	N	Real number

## 2.2 Annex 2: Iterations analysis

The analysis undertaken had as objective to obtain the best possible race time and highest maximum speed. Also, it was needed to end the race length with at least 10% SOC remaining on the battery.

In Table 6 the results of the iterations performed are showed. In the table it has been highlighted in yellow the SOC level that not fulfil the 10% SOC requirement. Also it is highlighted in red if the race distance has not been covered. As stated in the work, the simulation is automatically stopped at 5% SOC, for this reason the baseline and iteration 1 simulations do not complete the length of the race.

Table 6. Iterations results

Parameter	Voc	I_max	Final SOC	Time	Vmax	Distance	% Race distance
Description	Output voltage bat/inverter [V]	Maximum Current [A]	Final SOC [%]	Time to complete [s]	Maximum speed [km/h]	Distance travelled [km]	% of the race completed
Baseline	88,8	660	5	675	179	23,8	95
Iteration 1	88,8	600	5	684	179	24,3	97
Iteration 2	88,8	550	7,3	706	179	25,1	100
Iteration 3	88,8	525	10	706	179	25,1	100
Iteration 4	88,8	500	13	706	179	25,1	100
Iteration 5	88,8	475	15,99	706	179	25,1	100
Iteration 6	88,8	450	18,7	710	176	25,1	100

As it can be observed in Table 6 the from iteration 2 to iteration 5 very similar results are obtained, only differing in the final SOC. The reason for these results is the maximum power of the motor. The battery is able to deploy more power than the maximum power of the motor. On Figure 36 can be observed the power deployed by the battery vs the power delivered by the motor. The vertical and horizontal darker grey lines represent the 42 kW mark, maximum power output of the motor.

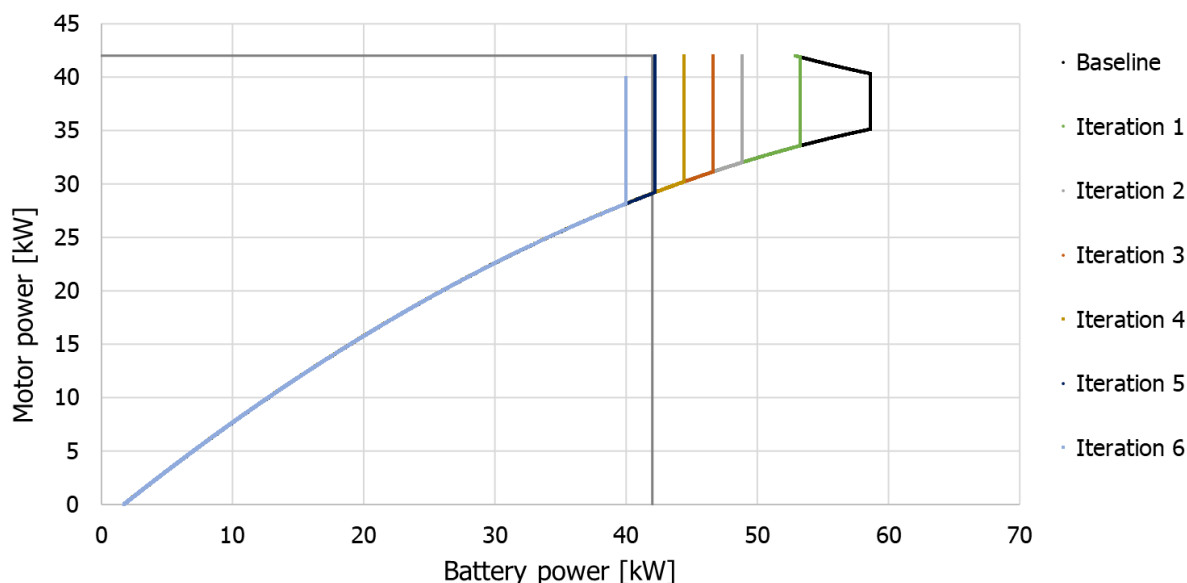


Figure 36. Motor power vs. Battery power for all the iterations

As it can be observed on Figure 36, the baseline simulation and iterations 1 to 4 deploy power from the battery surpassing the limit of the motor, losing all the extra power and affecting the final SOC.

Therefore, iterations 5 and 6 do not surpass the maximum output power of the motor and do not lose power inefficiently.

The difference in time between iteration 5 and 6 is due to the fact that in iteration 6 all the available power from the motor is not used, the battery has a power limit lower than the limit of the motor, this affects to the total time and the maximum speed achievable. Below, in Figure 37 it is compared the speed profile of the third lap in both iteration 5 (black) and 6 (blue).

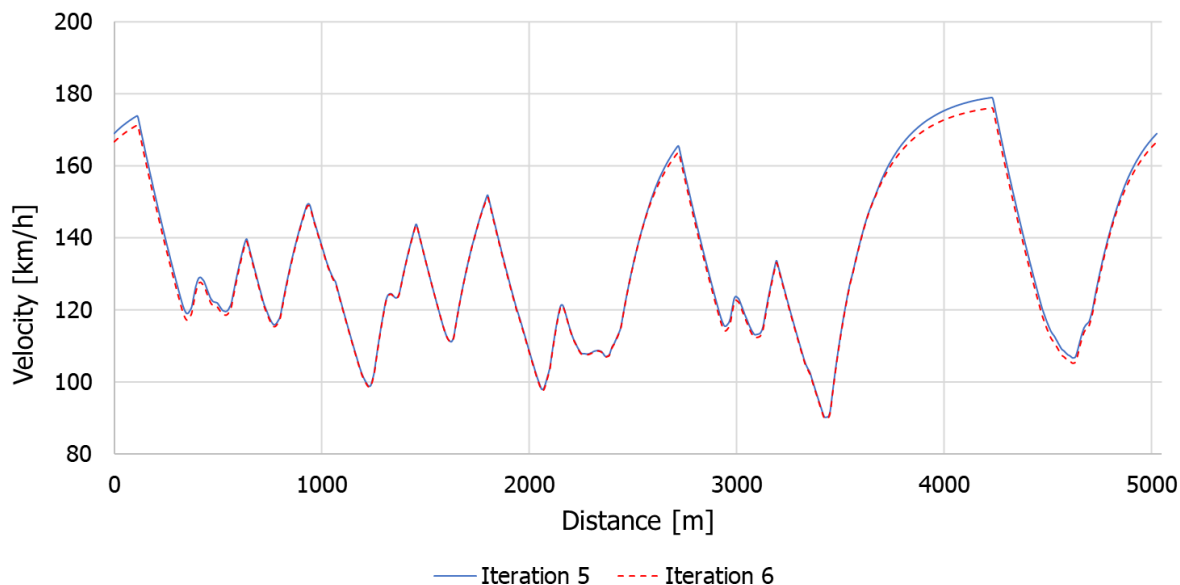


Figure 37. Speed profile of lap 3 of iteration 5 and iteration 6

In Figure 37 it is noticeable the previously mentioned lack of speed of iteration 6, achieving lower speeds at the end of the straights, costing around 8 tenths of a second per lap.

## **2.3 Annex 3: Motor, battery and inverter specifications**



# VI INTERNATIONAL COMPETITION 2019 - 2020

**ENGIRO**  
Advanced · Drive · Solutions

OFFICIAL MOTOR SUPPLIER

## TECHNICAL SPECS

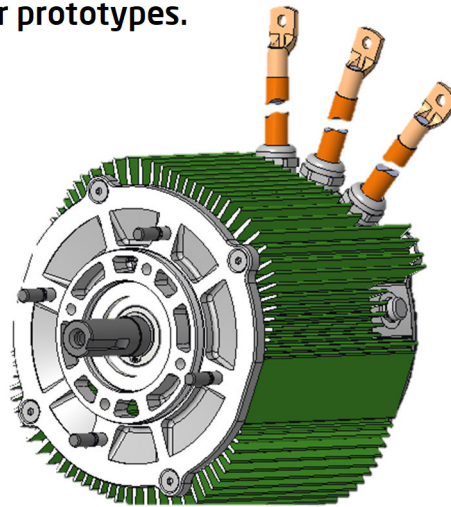


# VI MOTOSTUDENT INTERNATIONAL COMPETITION

## 2019-2020

### ENGIRO-MS1920 OFFICIAL ELECTRIC MOTOR

ENGIRO has developed the ENGIRO-MS1920, the Official Electric Motor for the VI MotoStudent International Competition 2019-2020. All teams registered in the MotoStudent Electric Category will receive a unit of this motor within their MotoStudent Kit, compulsory to install in their prototypes.



#### GENERAL CONSIDERATIONS

The ENGIRO-MS1920 Official Electric Motor supplied will be sealed by the MotoStudent Organization to avoid internal manipulations, as established in Art. D.2.1 of the Technical Regulations.

These seals will avoid the opening of the crankcases and covers, and must be intact at the moment of participation at the Final Event in Autumn 2020. These seals will be strictly checked at the Static Scrutineering.

#### **ANY BROKEN OR DAMAGED SEAL WILL BE REASON FOR TECHNICAL NON-CONFORMITY**

In case of breakdown or malfunction of any internal part, please contact the Organization to take the appropriate solution.

# ENGIRO-MS1920 - TECHNICAL SPECS

## TECHNICAL SPECS

Nominal Operation			
Torque	$T_{nom}$	22	Nm
Power	$P_{nom}$	13	kW
Speed	$n_{nom}$	5720	rpm
Phase rms-current	$I_{nom}$	156	A
Battery voltage (DC)	$U_{nom}$	96	V
Electric frequency	$f_{el,nom}$	381	Hz
Power factor	$\cos(\phi)$	0.75	

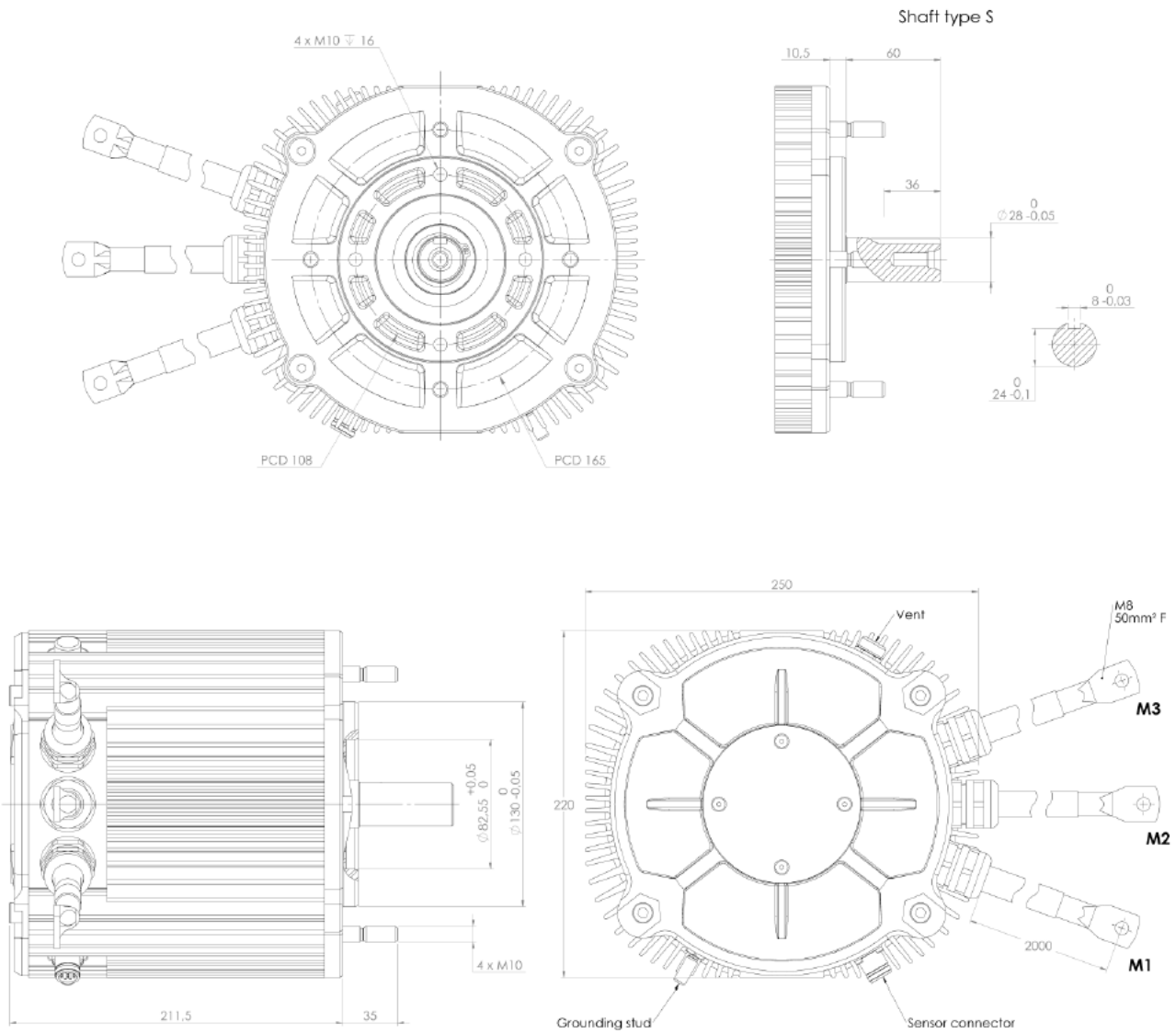
Maximal Values			
Torque	$T_{max}$	95	Nm
Power	$P_{max}$	42	kW
Speed	$n_{max}$	8000	rpm
Phase rms-current	$I_{max}$	781	A
Battery voltage (DC)	$U_{max}$	200	V
Electric frequency	$f_{el,max}$	533	Hz

Electrical Data			
Number of phases		3	
Number of poles		8	
Maximal efficiency		> 96	%
$T/I$ constant ( $I < I_{nom}$ )		0.14	Nm/ $A_{rms}$
$U/n$ constant (AC)	rms: 9.1	peak: 12.9	V/(1000rpm)
$K_e$ constant (AC)	rms: 0.022	peak: 0.031	V/(rad*s <sup>-1</sup> )

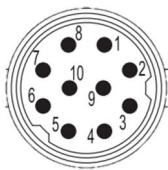
Additional Data			
Type	Permanent Magnet Synchronous Machine		
Weight (w/o cables)		20	kg
Rotor moment of inertia		0.009	kg*m <sup>2</sup>
Protection category		IP65	
Maximal motor temperature		120	°C
Allowed ambient temperature		-20 ... 45	°C
Cooling (medium, flow rate, inlet temperature, pressure)		air, 18 m/s, ≤ 45°C	
Temperature monitoring		1 x KTY84-130	

Connectors			
Power terminals	3 x 50 mm <sup>2</sup> cables with M8 cable lugs		
Power cables weight		3.3	kg
Signal connectors	M16, 10 Pin		

## TECHNICAL DRAWINGS



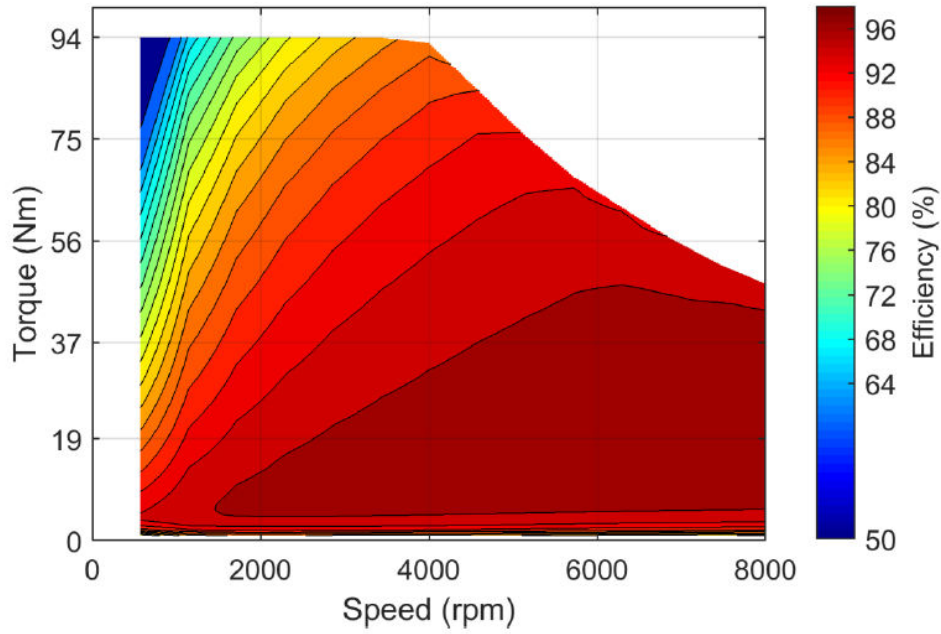
## SENSOR CONNECTOR PIN REFERENCE



	Cable	Signal	Hummel 10P Connector
Twisted Pair	Brown	KTY	1
	White	KTY	5
Twisted Pair	Blue	Sensor GND	7
	Red	+5V	8
Twisted Pair	Yellow	Sin	9
	Green	Cos	10

## SIMULATED CHARACTERISTICS GRAPHS

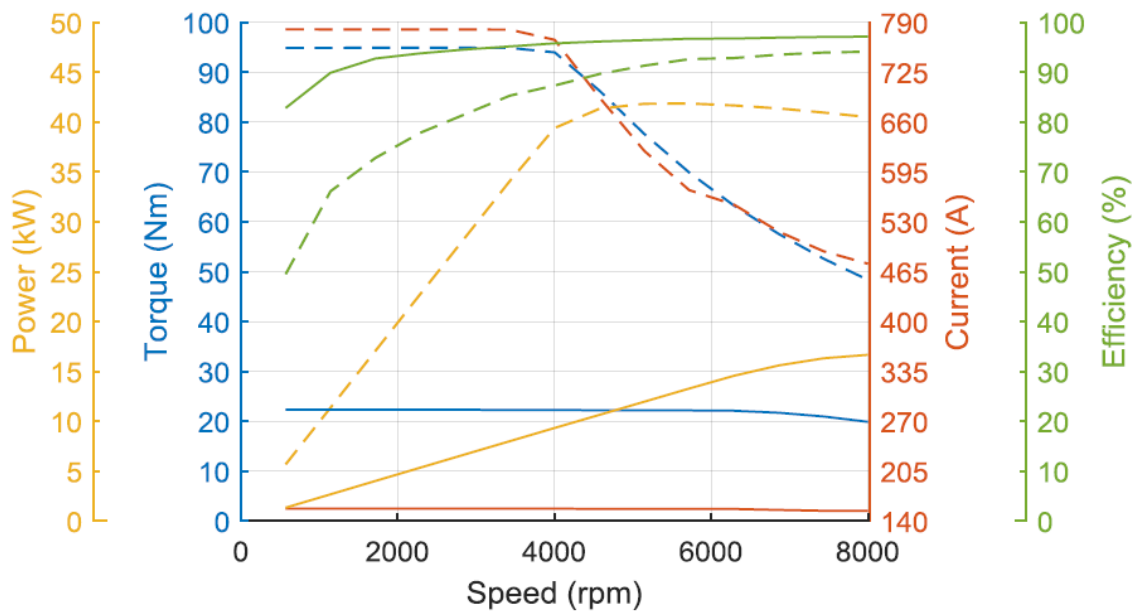
Simulated Efficiency of Motor Application  
(electric machine only;  $U_{nom} = 96\text{ V}$ ; machine at  $100\text{ }^{\circ}\text{C}$ ;) )



Simulated Characteristic Motor Parameters

$$U_{nom} = 96\text{ V}$$

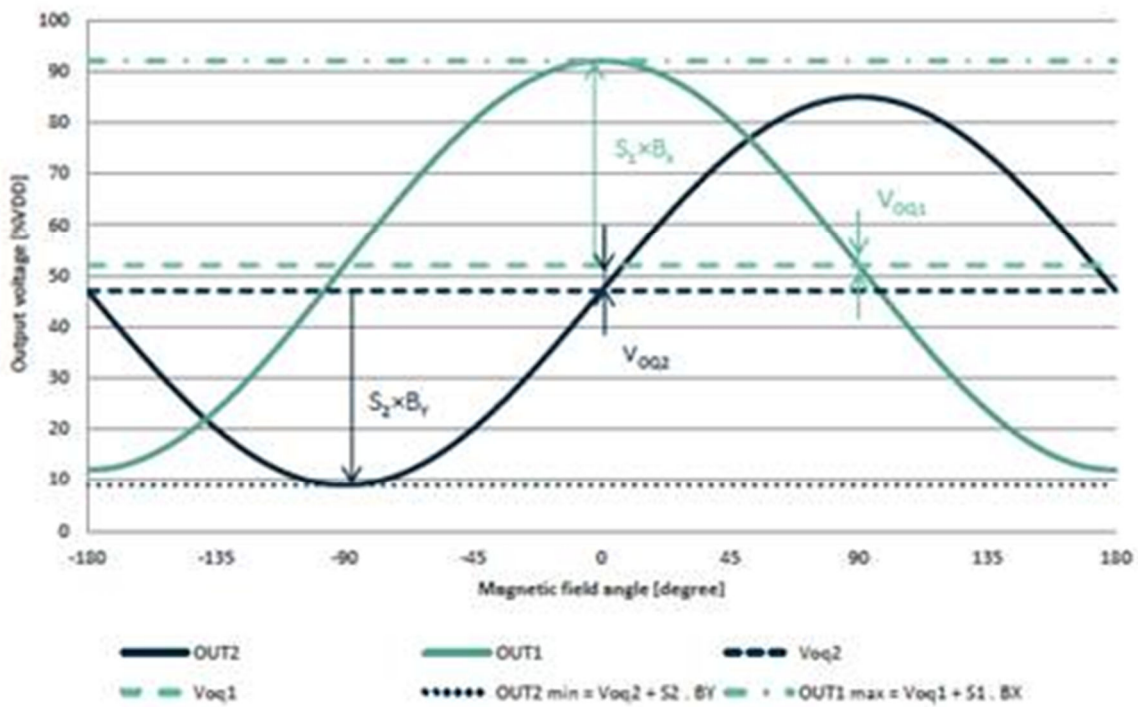
solid lines: continuous; dashed lines: maximum;  
(jitter is caused by numerical inaccuracies in the simulation software)



## ENCODER SPECS

Encoder position sensor (analogue sinusoidal)		
Power supply (VDD)	$5 \pm 10\%$	V
Power consumption	8	mA
Output signal amplitude	$1.5 \pm 0.5$	V
Resolution	1	sine/cosine wave per revolution
Accuracy	$\pm 1$	$^\circ$

## ENCODER FUNCTIONAL DESCRIPTION



# C.PROTOTYPING AND TESTING

URVoltageRacing

Marzo 2021

MotoStudent 2020



## B. PROTOTYPING AND TESTING

C.1 Deviation Description Report.....	1
C.1.1 Baterías .....	1
C.1.2 Contenedor de Baterías.....	2
C.1.3 Distribución Final de la Motocicleta.....	3
C.1.4 Convertidor DC/DC.....	4
C.1.5 Esquema del Circuito Eléctrico .....	5
C.2 Validation Report.....	6
C.2.1 Test de Validación en Componentes y Sistemas .....	6
C.2.1.1 Conjunto del Tren Motriz .....	6
C.2.1.2 Battery Management System .....	7
C.2.1.3 Sistema de Comunicación.....	9
C.2.2 Test de Validación de la Motocicleta en Banco de Pruebas.....	10
C.2.3 Test de Validación de la Motocicleta en Circuito .....	10
C.2.4 Test de Verificación de Acuerdo con la Normativa.....	10
C.2.4.1 Prueba del Dispositivo de vigilancia de aislamiento.....	10
C.2.4.2 Prueba de Medición de Aislamiento .....	11
C.4.3 Prueba del Circuito de Desconexión.....	11
C.3 Manufacturing Budget .....	13
C.4 Annexes .....	15
C.4.1 Plano del Contenedor de Baterías .....	15
C.4.2 Plano del Subchasis .....	16

## C.1 Deviation Description Report

### C.1.1 Baterías

En un primer momento, se contemplo el uso de una batería cuya tensión máxima se ajustaría a la máxima tensión permitida por el reglamento (126 V), esta batería estaría formada por 30 celdas en serie de Ion-Litio modelo SAMSUNG 18650 25R cuya tensión máxima es de 4,2 V. Esta batería tendría una tensión nominal de 111 V y una capacidad total de 70 A/h (paralelos de 28 celdas) con una potencia total de 7,78 kWh.

Un tiempo después, tal y como se detalla en la segunda entrega del MSE (Battery Pack Specs) cambiamos de idea y optamos por el uso de tres baterías modulares construidas por el mismo tipo de celda, pero con una estructura de 24S x 12P las cuales entregan en conjunto una tensión máxima de 100,8 V, una tensión nominal de 88,8 V una capacidad de 90 A/h y 7,992 kWh de energía.

Este cambio se realizó para ajustarse al rango de funcionamiento del inversor utilizado para el control del motor. Este es el modelo Sevcon Gen 4 size 6 el cual tiene una tensión máxima de funcionamiento de 116 V y un rango de operación nominal entre 72 y 80 V. Optamos utilizar una tensión nominal de batería algo superior para asegurarnos de que el inversor pueda funcionar en todo el rango de tensión de la batería el cual es de 100,8 a 60 V. También decidimos hacerlas modulares para facilitar la refrigeración de los bloques, su montaje y su reparación.

Finalmente, estos packs han sido fabricados por Ukai los cuales nos han proporcionado las baterías con los cables necesarios para conectar el BMS y el resto de los componentes que irán dentro de cada uno de los contenedores. A continuación, se adjunta tanto el diseño como el resultado final:

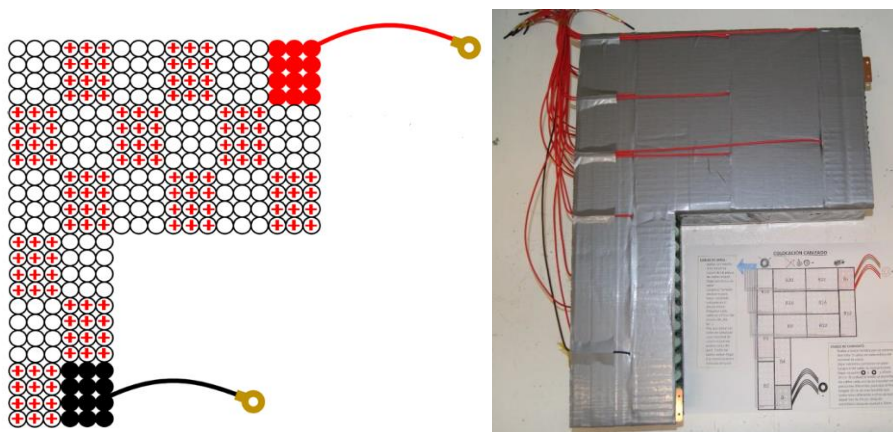


Imagen 1: Diseño y resultado final de uno de los packs de baterías

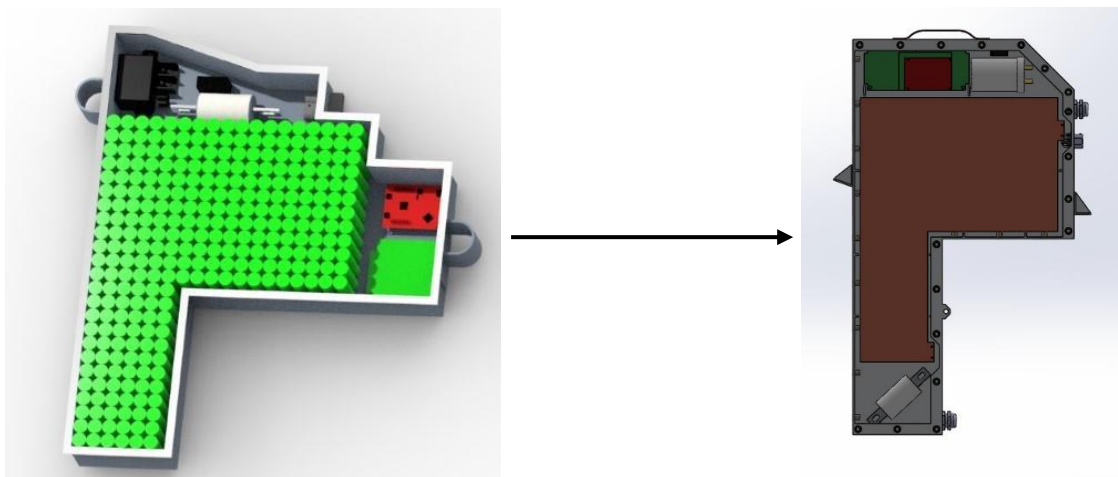
## C.1

Finalmente, debido en parte a los daños producidos en una de las baterías durante el proceso de prototipado y ensamblaje, hemos optado por la utilización de únicamente dos de estos packs detallados anteriormente. Esto puede parecer una reducción de las prestaciones, pero tras mucho pensarlo, hemos llegado a la conclusión de que puede aportar más ventajas que desventajas. El primer motivo es la refrigeración, el mismo contenedor de las baterías, al ser de aluminio es el que se va a encargar de disipar toda la energía térmica generada por las baterías, por lo tanto, cuanto más separación entre los módulos, más eficiente va a ser el sistema. Es segundo aspecto es el de autonomía, es cierto de que la autonomía de la motocicleta se va a ver reducida, pero hay que remarcar que al usar un pack menos, el peso de esta también va a disminuir, finalmente los cálculos nos demuestran que con dos baterías es suficiente para acabar satisfactoriamente todas las carreras. El último aspecto es el de montaje, al utilizar dos packs, estos van a estar más separados entre ellos lo cual nos va a facilitar su manipulación y este aspecto nos va a facilitar notablemente el conexionado de estas al inversor.

En resumen, la motocicleta va a contar con dos baterías independiente de 24S x 12P cada una de ellas, lo que nos va a proporcionar una tensión nominal de 88,8 V, una capacidad de 60 A/h y por lo tanto 5,184 kWh de energía. Estas podrán entregar una corriente en descarga continua de hasta 480 A y una corriente máxima de 720 A en picos de 6 s.

### **C.1.2 Contenedor de Baterías**

El contenedor de baterías ha sido uno de los componentes que más modificaciones ha sufrido a lo largo del diseño del prototipo. Estas modificaciones se han realizado básicamente por dos tres motivos, el primero de todos para ajustar el tamaño de este y asegurar que entre a la perfección dentro del chasis, el segundo para optimizar la distribución de componentes internos y por último para facilitar la colocación de las baterías dentro de este. A lo largo de este proceso también se ha ido definiendo y mejorando el sistema de anclado de los contenedores al cuerpo de la motocicleta. Esta evolución se puede contemplar a lo largo de las distintas entregas que conforman el MSE hasta llegar al diseño final que se adjunta como plano en los anexos de esta entrega (C.4.1). A continuación, se muestran los distintos diseños, juntamente con el prototipo final. Tal y como se puede apreciar en las imágenes, una vez construida, se han hecho algunos ajustes a esta misma, para facilitar el proceso de anclado de cada uno de sus componentes.



*A la izquierda primer diseño de las baterías y a su izquierda la segunda iteración*



*Imagen del contenedor de baterías final, con tapa y sin esta (en su interior se haya una réplica exacta de la batería, pero en madera).*

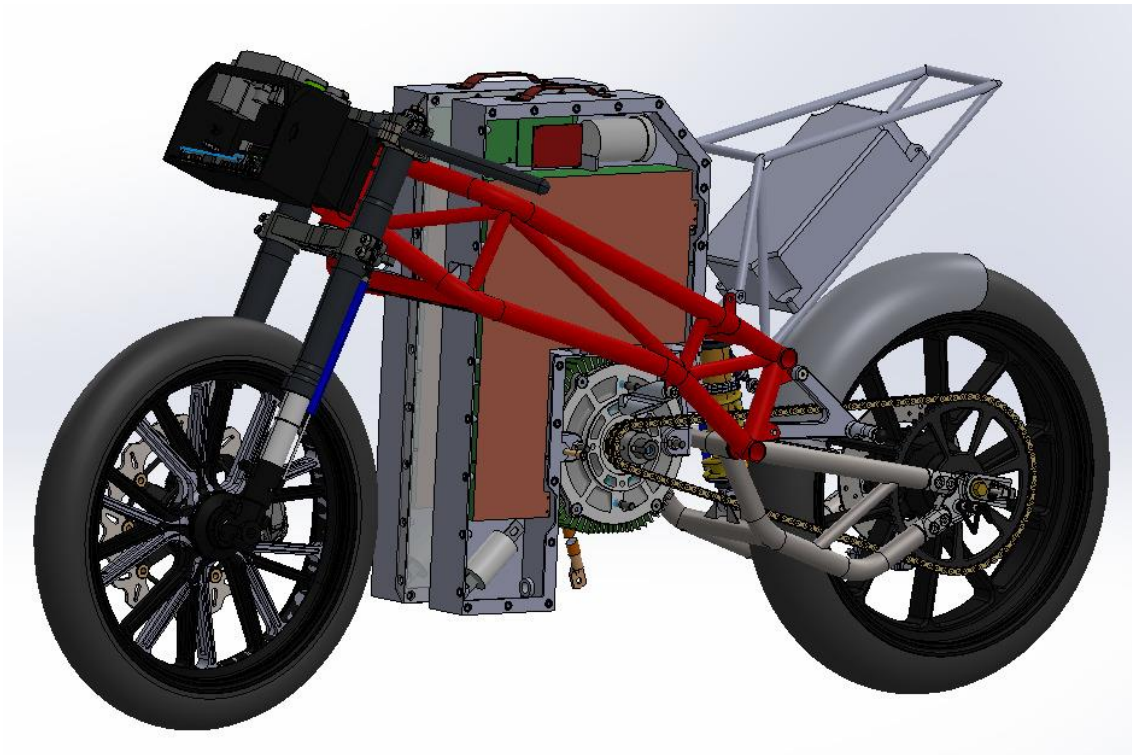
### **C.1.3 Distribución Final de la Motocicleta**

Tal y como se puede ver en la forma de los contenedores de las baterías, estas van a ocupar la mayor parte del cuerpo de la motocicleta, situándose en la parte delantera y superior del motor. En un principio no se estimó que las baterías fueran a ocupar tanto espacio y por lo tanto se pensaba reservar el espacio superior del motor (lo que en una motocicleta de gasolina sería el depósito) para albergar tanto el inversor como el resto de los componentes electrónicos del prototipo. Finalmente se ha tenido que

## C.1

redistribuir los espacios y se ha decidido situar el inversor en el subchasis y el resto de los componentes electrónicos en la parte delantera de la motocicleta.

Esto ha hecho que tengamos que diseñar un subchasis tubular el cual pueda sostener el inversor, se añaden los planos en el anexo. (C.4.2)



*Modelo 3D final de la motocicleta*

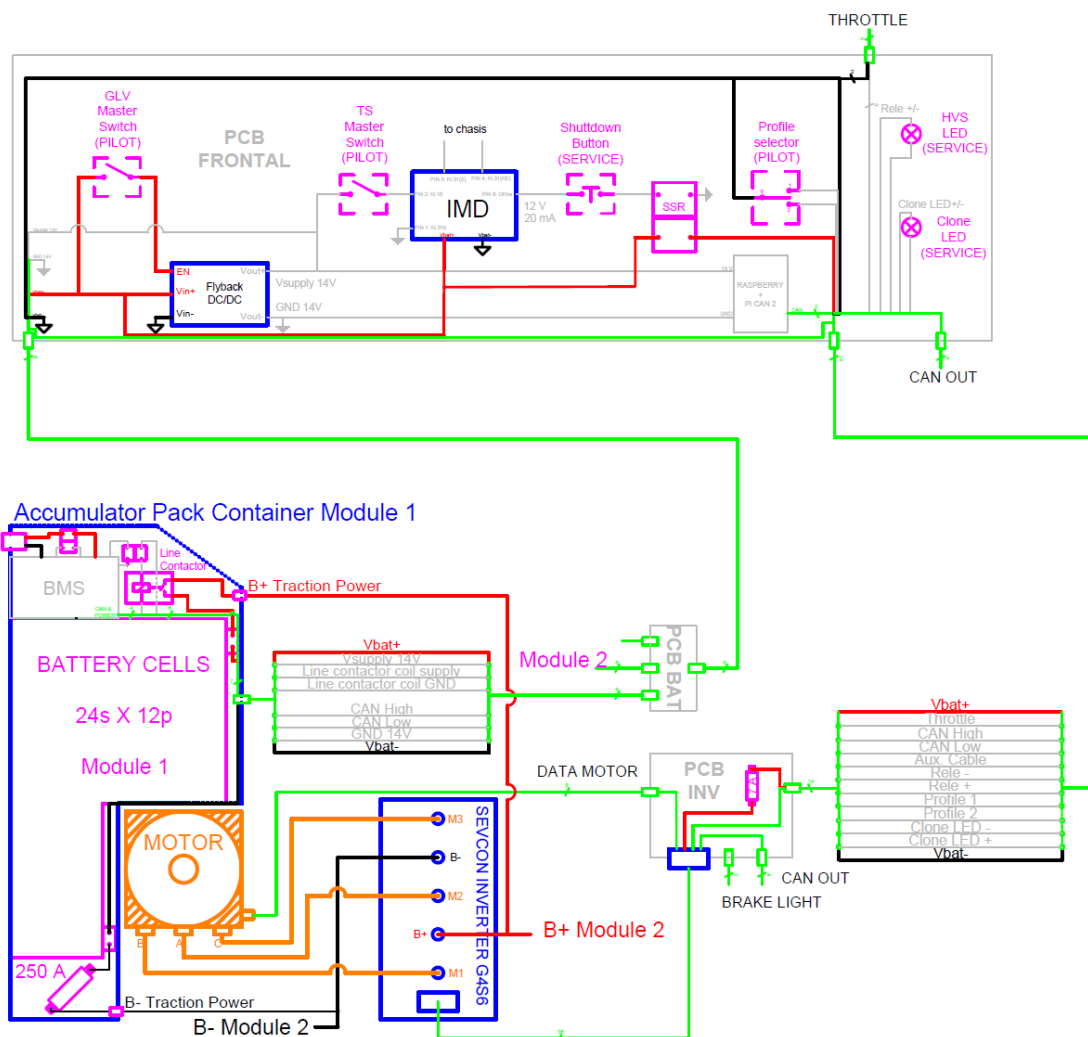
### **C.1.4 Convertidor DC/DC**

En un principio se optó por la utilización de un convertidor flyback de diseño y construcción propios para la alimentación del circuito de baja tensión, pero lamentablemente, pese a tener el diseño hecho, no se ha podido fabricar este componente debido a las restricciones de movilidad aplicadas en este año 2020. Para remediarlo finalmente se ha decidido utilizar un convertidor flyback comercial de una única salida a 14 V, pero con certificado de protección IP67 y con una entrada para controlar su encendido/apagado. Al ser un componente probado y fiable, también se ha decidido prescindir del sistema de alimentación auxiliar que en un principio se planteó para dar soporte al convertidor.

C.1

**C.1.5 Esquema del Circuito Eléctrico**

El cambio de convertidor, pasando de uno multisalida (24 – 12 V) a uno de salida única, ha hecho que tengamos que modificar ligeramente el esquema eléctrico del prototipo. A continuación, se adjunta el circuito definitivo:



*Esquema del circuito eléctrico final y completo*

También cabe remarcar la incorporación de tres placas de circuito impreso diseñadas en específico para esta motocicleta. Estas son: PCB inversor, PCB baterías y PCB frontal o de control, las cuales se utilizan respectivamente para interconectar el inversor, las baterías y los distintos componentes que permiten el control y la gestión de la motocicleta.

## C.2 Validation Report

### C.2.1 Test de Validación en Componentes y Sistemas

#### C.2.1.1 Conjunto del Tren Motriz

Se han realizado un seguido de ensayos en el conjunto del tren motriz con el objetivo de verificar el correcto funcionamiento del circuito de alta tensión, el correcto funcionamiento del motor y que la configuración del inversor es adecuada.

Para ello se ha reproducido el mismo circuito que se montará en la motocicleta, pero en un espacio controlado en nuestro taller. Esto nos permite tener un control total del circuito ya que la accesibilidad es mucho mayor, también nos permite detectar a simple vista fallos en el circuito ya que todos los componentes están distribuidos sobre un mismo plano.

Una vez montado el circuito, se comprueba la correcta conexión de este con la ayuda de un multímetro antes de alimentarlo por primera vez. Su primera alimentación se hace utilizando una fuente de tensión la cual nos permite tener un límite de corriente que nos asegure la integridad del circuito en caso de fallo y a la vez nos permite probar distintos rangos de tensión de entrada simulando así el comportamiento de nuestra batería. Con la fuente de tensión únicamente se alimenta el circuito de baja tensión el cual nos permite acceder a la configuración del inversor, pero no accionar el motor.

Una vez validado el circuito de baja tensión y comprobado que el inversor está bien configurado y que es capaz de leer correctamente todas las entradas que se han configurado (selector de modo, acelerador, etc), se pasa a alimentarlo con uno de los módulos de baterías. Para facilitar la gestión del circuito, el fusible de estas se mantiene dentro de su caja contenedora mientras que el relé de potencia se fija a la mesa. Una vez alimentado el circuito de baja tensión se vuelve a analizar su funcionamiento y se pasa a alimentar el circuito de potencia.

Una vez alimentado el circuito de potencia se acciona el acelerador de distintas formas para poder probar la respuesta del motor. Cabe destacar que en todo momento las tensiones y corrientes de entrada (DC) y salida (trifásica) están monitorizadas gracias a la comunicación CAN establecida entre PC e inversor. A su vez estas tramas son guardadas por el sistema de dataloggin para ser analizadas de forma posterior al ensayo tal y como se explica en el apartado del sistema de comunicación (C.2.1.3).

## C.2

Finalmente, los resultados extraídos tanto del análisis en vivo como el posterior análisis de los datos guardados por el datalogger son positivos, demostrando que el circuito es estable y que la configuración del inversor es la adecuada para el motor utilizado en este caso.

Obviamente la validación del conjunto del tren motriz no salió bien a la primera y durante su realización se encontraron errores tanto en el conexionado como en la configuración del inversor. No obstante, todos estos errores fueron fácilmente solucionados sin tener que hacer cambios en el diseño del circuito.



*Fotografía del motor reposando en su bancada de ensayo*

Este ensayo se ha reproducido de una forma más explicativa y breve para ser entregado en la MSE Special Milestone Electric Powertrain Test, también será subido con intención divulgativa a nuestro canal de youtube.

### **C.2.1.2 Battery Management System**

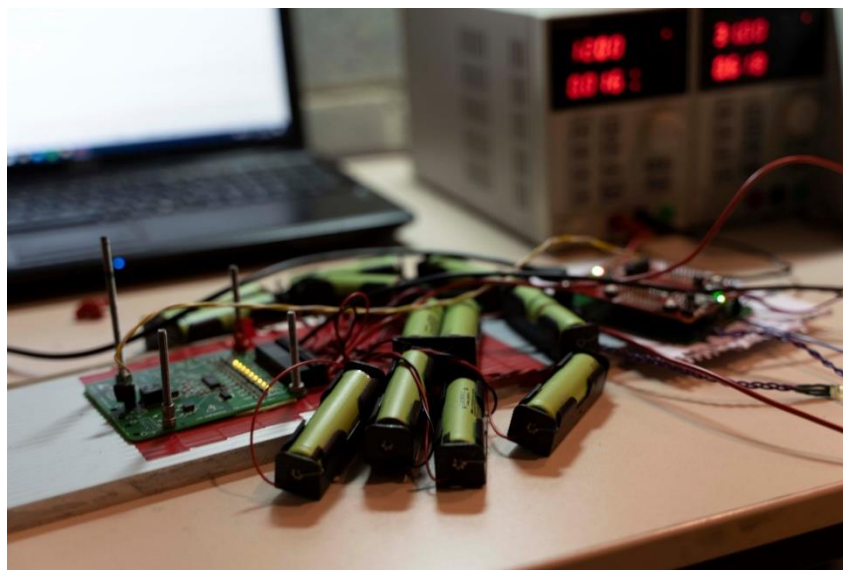
La validación del BMS (Battery Management System) se ha desarrollado en distintas etapas. La primera etapa fue de forma visual, donde se validó que todos los componentes fuesen soldados correctamente, evitando así un problema en las siguientes pruebas por causa de la construcción del BMS. Una vez validado su construcción se le sometió en un test donde se validó todas sus funciones, asegurando que cumpliesen con las especificaciones iniciales.

En el test de validación se siguió las siguientes pautas:

## C.2

1. Se simularon las celdas de las baterías con resistencias del mismo valor y se alimentó con una fuente de tensión. Mediante el depurador del microcontrolador, se determinó que las tensiones leídas eran las correctas.
2. Con la misma lógica que el punto anterior, se simuló las celdas de la misma manera, pero esta vez, en una de las resistencias se le colocó una fuente de tensión regulable. Con esta fuente pudimos simular la tensión de una celda. Haciendo que cuando la tensión era superior a la tensión máxima de la celda, se activaba el modo de balanceo y se le colocaba una resistencia en paralelo a la fuente de tensión. De la misma forma, se validó que cuando la tensión era inferior a la mínima de la celda, se desconectaba el relé de la batería.
3. Otro punto que se validó fue los sensores de temperatura, los cuales se conectaron y, depurando el microcontrolador, se observó que se medían correctamente. Para esto también se usó un sensor de temperatura de referencia, para validar que la temperatura medida fuese la correcta.
4. Usando un generador de calor, se calentaron los sensores de temperatura hasta llegar a la temperatura máxima de las celdas, donde el BMS ordenó desconectar el relé de la batería.
5. En el proceso de todos los puntos anteriores, también se observó que en el busCAN se enviasen los mensajes correctos y adecuados en cada situación.

Una vez validadas todas sus funciones de forma independiente, se realizó una carga completa con unas celdas de pruebas, como se puede ver en la siguiente fotografía.



*Fotografía del BMS durante el proceso de validación*

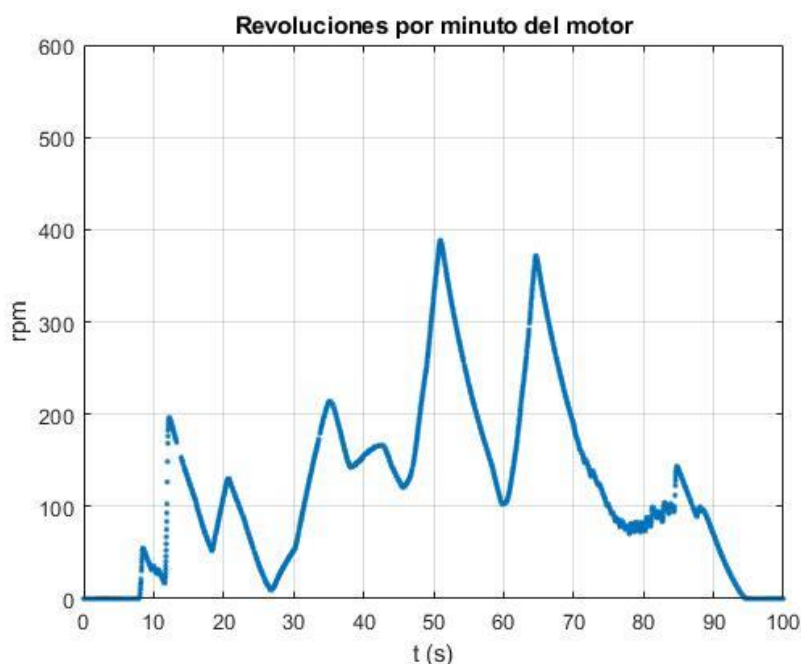
## C.2

Los resultados de la prueba fueron satisfactorios, se realizó el balanceo correctamente. De este modo se aseguró que todo su funcionamiento fuese el correcto en todas las situaciones posibles.

El último paso fue conectar el BMS en la batería definitiva, dejando el sistema tal y como estará en la motocicleta, haciendo ciclos de carga y descarga.

### **C.2.1.3 Sistema de Comunicación**

Utilizando el datalogger se han monitorizado todas las tramas de CAN enviadas por los distintos componentes que integran la motocicleta. Estas pruebas se han llevado a cabo juntamente a la validación del conjunto del tren motriz el cual se ha detallado anteriormente. De este modo hemos podido registrar todos los datos mandados durante el encendido del motor, verificando así que todos estos son correctos y se hayan dentro del rango de valores esperado y comprobando que no aparezca ninguna trama de error inesperada. Se adjunta un ejemplo de los datos extraídos y analizados a lo largo de este ensayo:



*Captura del análisis de rpm del motor*

En la captura superior se puede ver el comportamiento en revoluciones por minuto del motor durante uno de los ensayos del tren motriz. Los datos han sido guardados por el datalogger para ser procesados posteriormente con un PC utilizando Matlab.

## C.2

### **C.2.2 Test de Validación de la Motocicleta en Banco de Pruebas**

No se han podido realizar este tipo de prueba puesto que a día 27 de marzo el prototipo no está construido en su totalidad. No obstante, se plantea realizar una validación completa y controlada de la motocicleta en un banco de pruebas a principios de junio, para verificar su correcto funcionamiento antes de empezar con las pruebas con el piloto oficial en el circuito.

### **C.2.3 Test de Validación de la Motocicleta en Circuito**

No se han podido realizar este tipo de prueba puesto que a día 27 de marzo el prototipo no está construido en su totalidad. No obstante, se plantea realizar una serie de pruebas en pista para mediados de junio donde se comprobará el correcto funcionamiento del prototipo y se simularán todas las pruebas dinámicas que se van a llevar a cabo el día de la competición. En estas jornadas también se espera que el piloto de su feedback para poder realizar un ajuste final de la motocicleta que se adapte a su forma de conducción.

### **C.2.4 Test de Verificación de Acuerdo con la Normativa**

#### ***C.2.4.1 Prueba del Dispositivo de vigilancia de aislamiento***

Se ha realizado un ensayo con el objetivo de comprobar el correcto funcionamiento del dispositivo de vigilancia de aislamiento (IMD). Los pasos seguidos han sido los siguientes:

Primero se ha verificado por separado el comportamiento del IMD, utilizando fuentes de tensión para reproducir la tensión de baterías y de la salida del convertidor flyback.

A continuación, se ha montado de forma provisional el circuito de baja tensión en un espacio controlado dentro de nuestro taller, no obstante, tanto los componentes como el conexionado se han reproducido de forma exacta a la del circuito que se montará en la motocicleta.

Una vez montado, se alimenta el circuito utilizando una fuente de tensión y se procede a reproducir distintos escenarios:

- 1- Se cortocircuitan los pines 2 y 3 del IMD (Chassis Ground) y se alimenta el circuito: Se observa que la señal de OK (Status Output high side Pin 8) se acciona al poco tiempo y se mantiene constantemente accionada. Si se desconectan esos dos pines, la señal deja de estar accionada al cabo de unos

## C.2

20 s a partir de esta. Partiendo de la situación inicial (señal OK accionada) si se conecta una resistencia de conectando una resistencia de 50 k $\Omega$  entre los pines 2 y 3 del IMD y el GND del circuito la señal se deja de accionar en unos 10s aproximadamente

- 2- Se alimenta el circuito con los pines 2 y 3 del IMD al aire: la señal de OK se acciona momentáneamente durante un minuto aproximadamente para posteriormente apagarse.
- 3- Se alimenta el circuito conectando una resistencia de 50 k $\Omega$  entre los pines 2 y 3 del IMD y el GND del circuito: la señal de OK nunca llega a ser accionada.

### **C.2.4.2 Prueba de Medición de Aislamiento**

Esta prueba se lleva a cabo utilizando el mismo circuito utilizado durante la validación del conjunto del tren motriz una vez este se ha conectado a uno de los módulos de baterías.

Como está indicado en el reglamento, se llevará a la práctica un test para comprobar el correcto aislamiento entre HVS y el GLV. Teniendo en cuenta que para que nuestro prototipo se considere apto para la participación en la Competición, la medición entre ambos sistemas deberá ser superior o igual a 100 k $\Omega$ .

La metodología aplicada para esta parte consiste en realizar medidas sobre en el convertidor DC / DC que alimenta la parte de control, concretamente hablamos de medir la impedancia que hay entre los terminales de tierra en bornes del convertidor flyback que tenemos integrado en el circuito de la motocicleta.

Como también especifica el reglamento este nos proporciona aislamiento galvánico de tal modo que mediante dos inductores de alta frecuencia acoplados podemos convertir de un nivel de tensión continua a otro teniendo diferentes masas o puntos de referencia en su circuito primario y secundario, es por eso que se ha considerado este como el punto crítico de análisis.

Finalmente, los resultados obtenidos han sido satisfactorios obteniendo impedancias superiores a la demandada por normativa. De hecho, del orden de hasta 3 veces superiores (300 k $\Omega$ ).

### **C.4.3 Prueba del Circuito de Desconexión**

Esta prueba se lleva a cabo utilizando el mismo circuito utilizado durante la validación del conjunto del tren motriz, pero siendo alimentado por una fuente de tensión.

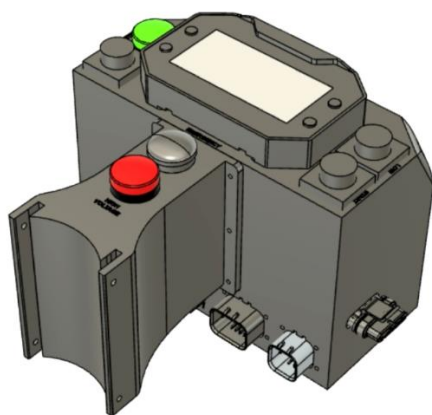
## C.2

En este circuito juegan un papel importante los siguientes elementos:

- **GLV Master Switch:** Este interruptor giratorio activa directamente el convertidor flyback dándole alimentación al circuito de Baja tensión.
- **TS Master Switch:** Este interruptor giratorio permite controlar el accionamiento del circuito de alta tensión. Alimenta el circuito de control del inversor, lo que permite que este cierre el relé de alta tensión.
- **Shutdown Button:** seta de emergencia que permite desalimentar el circuito de forma inmediata al ser pulsada.
- **HVS LED:** indica que el relé de alta tensión se ha cerrado.
- **Display:** muestra en tiempo real el valor de tensión de las baterías.

Todos estos elementos y su conexionado se puede ver en detalle en el apartado C.1.5 Esquema del Circuito Eléctrico. Partiendo de la misma base, con todos los circuitos alimentados y por lo tanto el HSV LED activado se comprueban las siguientes secuencias:

- Se acciona el Shutdown Button: el circuito de alta tensión queda desalimentado, el HSV LED se apaga y el display muestra 0 V.
- Se apaga el TS Master Switch: funcionamiento idéntico al del Shutdown Button.
- Se apaga el GLV Master Switch: los circuitos tanto de alta como de baja tensión quedan desalimentados, por lo tanto, el HSV LED se apaga juntamente al display.



*Modelo 3D (izquierda) e imagen real (derecha) del cuadro de instrumentos*

Una parte de esta validación se ha mostrado en la MSE Special Milestone Electric Powertrain Test, también será subido con intención divulgativa a nuestro canal de youtube.

## C.3 Manufacturing Budget

En este punto se va a desarrollar el presupuesto de fabricación de prototipo de la motocicleta eléctrica. Como únicamente se ha desarrollado una unidad, este presupuesto únicamente se calculará por una unidad.

<b>Presupuesto de fabricación</b>		
<b>Costes de fabricación</b>		
	Costes materiales	23.617,63 €
	Costes mano de obra	7.060,00 €
	Costes indirectos	2.957,95 €
Total Costos de fabricación		33.635,58 €
<b>Costos de administración</b>		
	Impuestos	7.063,47 €
	Documentación asociación	215,98 €
	Comisiones	2.500,00 €
Total costos de administración		9.779,45 €
<b>Total costos</b>		<b>43.415,03 €</b>

Como se puede observar, el coste total de producción de la motocicleta ha sido de 43.615,03 €. Este presupuesto se ha dividido en 2 grandes grupos: los costes de fabricación y los costes de administración. Los primeros costes se desglosan en costes de material que engloba todo el material que se adquirido, tanto productos definitivos (como por ejemplo la pantalla) como materiales que posteriormente se han manipulado (por ejemplo las barras de acero para la fabricación del chasis); también

### C.3

hay los costes de mano de obra, los cuales son la mano de obra de empresas externas que hemos contratado para la construcción de distintas partes de la moto (como por ejemplo la fabricación del basculante, donde en una empresa le entregamos los pláns y esta realizó la construcción); finalmente, en el apartado de costes de material, se ha avaluado los costes indirectos, estos son los relacionados con las herramientas que hemos comprado para la construcción propia de ciertas partes, además de todos los costes de envío de los materiales comprados.

En los costes de administración se ha separado en 3 partes: los costes por impuestos, los costes por la documentación de la asociación y los costes por las comisiones. Los costes por impuestos son principalmente el IVA del coste de materiales. Los costes por la documentación de la asociación son los costes que hemos tenido que pagar para hacer legal la asociación ya que el equipo es una asociación con lo cual, cada vez que se cambia de presidente, secretario y tesorero, hay que actualizar los papeles, lo cual implica un coste. Finalmente, los costes por comisiones. El equipo tiene 2 cuentas bancarias a las cuáles, periódicamente, tenemos que pagar unas comisiones para mantener las cuentas.



Hybrid



Electric

# Explore our Technologies

## AC Motor Controller

### Gen4 Size 2/4/6

# AC Motor Controller Gen4 (Size 2/4/6)

The Gen4 range represents a well established design in compact AC controllers. These reliable controllers are intended for on-road and off-road electric vehicles and feature the smallest size in the industry for their power capacity.

Thanks to the high efficiency it is possible to integrate these controllers into very tight spaces without sacrificing performance. The design has been optimised for the lowest possible installed cost while maintaining superior reliability in the most demanding applications.

## Integrated I/O

Gen4 includes a fully-integrated set of inputs and outputs (I/O) designed to handle a wide range of vehicle requirements. This eliminates the need for additional external I/O modules or vehicle controllers and connectors.

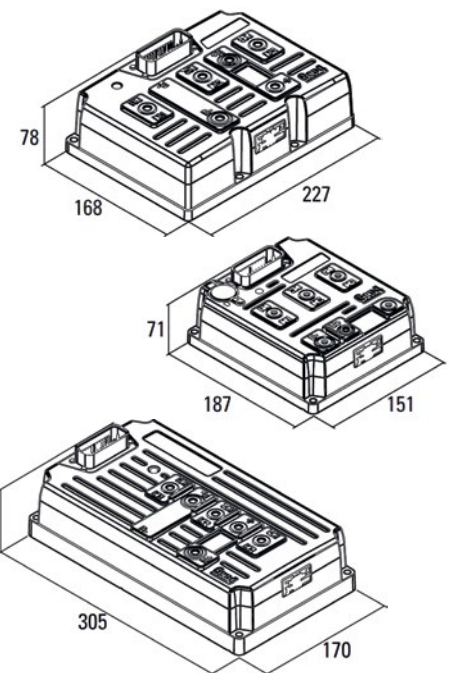
- 8 digital inputs
- 2 analogue inputs (can be configured as digital)
- 3 contactor/solenoid outputs
- 1 encoder supply output – programmable 5 V or 10 V
- Motor temperature sensor input
- Motor encoders supported include UVW hall effect sensors, Sin/Cos sensors and incremental AB encoders

## Features

- Advanced Field Oriented Control
- AC Permanent Magnet Synchronous motor control, including salient, non-salient and BLDC motors
- AC induction motor control
- CAN communications bus allows for easy interconnection of controllers and devices such as Battery Management Systems, displays and VCUs
- CANopen protocols
- Configurable as a vehicle control master or as a motor control slave
- Autocheck system diagnostic
- Hardware & software failsafe watchdog operation
- Integrated fuse holder
- IP66 protection
- Highly configurable

## Key Parameters

Model	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 4
Nominal Battery Voltage	24 VDC	24 – 36 VDC		36 – 48 VDC			72 – 80 VDC			96 – 120 VDC
Maximum Operating Voltage	34.8 VDC	52.2 VDC		69.6 VDC			116 VDC			150 VDC
Minimum Operating Voltage	12.7 VDC			19.3 VDC			39.1 VDC			48 VDC
Peak Phase Current (2 min)	300 A	450 A	650 A	275 A	450 A	650 A	180 A	350 A	550 A	300 A
Boost Phase Current (10 sec)	360 A	540 A	780 A	330 A	540 A	780 A	215 A	420 A	660 A	360 A
Continuous Phase Current (60 min)	120 A	180 A	260 A	110 A	180 A	260 A	75 A	140 A	220 A	120 A



For Additional BorgWarner Information  
 North America: [US.drives.sales@borgwarner.com](mailto:US.drives.sales@borgwarner.com)  
 Rest of World: [drives.sales@borgwarner.com](mailto:drives.sales@borgwarner.com)  
[borgwarner.com](http://borgwarner.com)

