Electric Motorcycle Powertrain Development

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ABSTRACT

The first electric vehicle dates from 1881, built by the French engineer Gustave Trouvé, in Paris. From this on, the development of electric vehicles grew in quantity and types, being considered the "Golden Era" between 1895-1910. As an example, in 1900, Ferdinand Porsche, founder of the automotive Company Dr. Ing. h.c. F. Porsche AG, created what can be called as the first functional hybrid vehicle in history, "Sempre Vivus", which used two internal combustion engines (ICE) and two electric motors installed directly in the wheels. In the following years, changes in the global economics scenario, left the electric vehicle aside, and the focus shifted to the products that used the internal combustion technology. Nowadays, the electric vehicles are being pointed as an important factor in the reduction of the greenhouse gas emission, caused by the transportation sector, and its acceptance by the public is growing, as the energy storage technologies and energetic efficiency evolve. This paper aims to develop the basic technical specifications of an electric motor and battery pack to be used in a medium size electric motorcycle. It is known that currently, the acceptance of low performance electric motorcycles is growing by the public, on the other hand equipment's with medium/high performance have the potential to be a market niche, in developed countries. There will be used as main theoretical basis for the powertrain system development, the classic vehicle dynamics methodologies, with emphasis in the papers developed by Barreto [1] and Murphy [2], nevertheless it is known that a deeper understanding of the rolling resistance is needed, for this specific application. A few parameters have been estimated based on existing electric motorcycles and shall be validated for specific use. During the development of this project, CAD (computer aided design) software have been used to define some of the parameters.

INTRODUCTION

Over the past few years, many countries have manifested a big concern with the impact in the increasing global average temperature, which current politics of generation and use of energy are driving.

The Paris agreement, signed in 2016 by 195 countries, proposes the commitment of the nations in limiting the increasing in the global average temperature in 1.5ºC, compared with the 14.5ºC from the pre-industrial period (1850-1900). With this agreement, each country signed the commitment of determining its own goals for the greenhouse gas (GHG) emission reduction, according to what it is feasible, based on the local social-economic scenario [3].

The transportation sector had the second larger GHG emission rate, in the year 2014, indicating the importance of governmental politics and tax regimes to those who replace the energetic matrix, from based on fossil fuels, to sustainable energy sources. Tax breaks play an important role, since they are the bridge between the costs of implementing new technologies and the ones already in place [4].

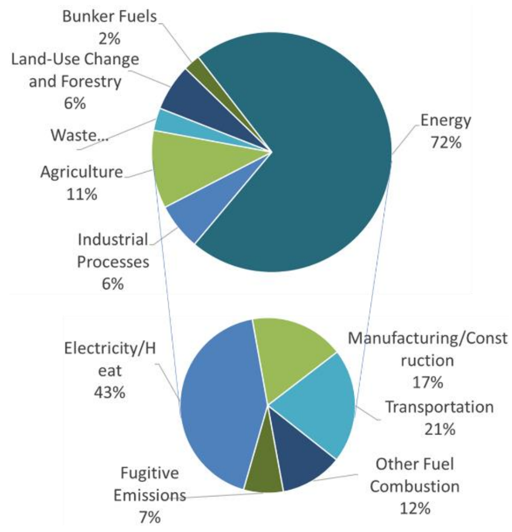

Figure 1. GHG Emissions by Sector – World 2014 [4]

According to data from World Resources Institute (WRI), the global levels of carbon dioxide (CO2) increased 43%, from 1990 to 2014, reaching levels close to 50 Gigaton of CO2 [4].

Data from U.S. Energy Information Administration (EIA), indicate that the levels of CO2 from energy related sources, emitted by countries outside the Organization for Economic Cooperation and Development (OECD), will increase in 1% by year, until 2050, while OECD member countries will experience a 0.2% drop per year [5].

On the other hand, in a *per capta* comparison, OECD members emit more CO2, in absolute numbers, 9.5 tons per person in 2018, versus 3.6 tons in countries outside the group. This difference is mainly due to the social-economic level of each country, being the ones outside OECD collectively denser in population, which demands a greater energy consumption and due to the bigger gross domestic product (GDP) [5].

The key alternative to reduce the levels of CO2 emissions by the transportation sector, has been the vehicles with some level of electrification in the propulsion system, being commonly classified as: micro-hybrid electric vehicles (µHEV), mild-hybrid electric vehicles (mHEV), full hybrid electric vehicles (FHEV), plug-in hybrid electric vehicles (PHEV) e battery electric vehicles (BEV).

The table 1 describes the main differences between the levels of electrification. In the specialized literature, differences in the definitions of the electric vehicles primary functions may be found.

Table 1. Definition of the Electric Vehicle Types [6]

Primary Functions	µHEV	mHEV	FHEV	PHEV	BEV
Start/Stop System	X	X	X	X	X
Regenerative braking		X	X	X	X
Electric additional traction for short period of time		X	X	X	X
Electric additional traction for medium distance			X	X	X
Electric traction for long distance and recharge in the grid				X	X
Fuel economy	3-6%	8-12%	50%	80%	-

The demand for electric vehicles is growing fast, in 2018 the world fleet of electric vehicles reached 5.1 million units, an additional of 2 million vehicles over 2017. The Chinese market leads the ranking, followed by Europe and USA, while the Norway has the bigger market share, with 46% of electric vehicles [7].

The two-wheeler electric vehicle fleet reached 260 million and buses are at 406 thousand units, at the end of 2018, showing a smaller sells volume compared with the potential of the market growth [7].

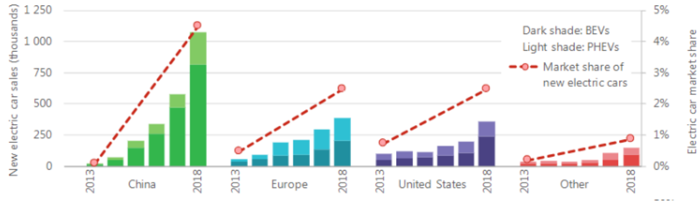

Figure 2. Total of Sells and Market Share of Electric Vehicles from 2013 to 2018 [7]

Predictions indicate that the electric vehicle sells will grow exponentially in the next few years. Two scenarios were estimated: "New Policies" describes the impacts of the main objectives already announced by the countries and "EV30@30", which considers 30% of the market share occupied by electric vehicles, in 2030 [7].

Both scenarios propose a substantial raise in the number of electric vehicles on the streets, and the increasing in annual sells, potentially reaching at a 250 million electric vehicle fleet and more than 40% of share, until 2030 [7].

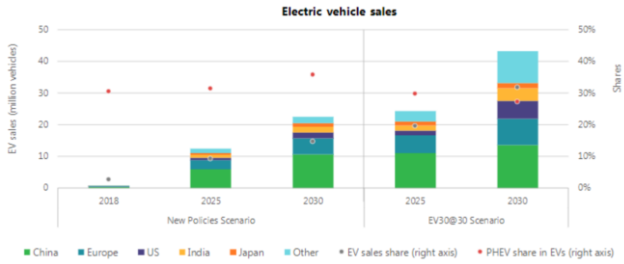

Figure 3. Market Projection of Electric Vehicles Sells and Fleet, from 2018 to 2030 [7]

Regarding two-wheelers, the chart below shows the number of scooters and electric motorcycles sold in Colombia, since 2011. It can be seen the same pattern found in the global market of electric vehicles, with an exponential growth in sells in the year 2018.

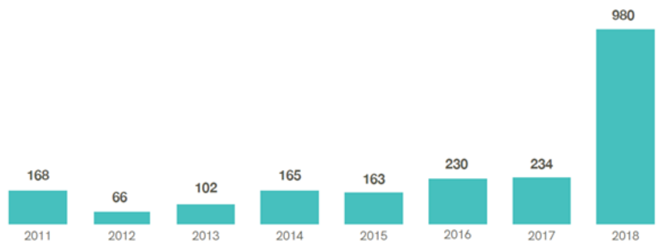

Figure 4. Sells of Scooter and Electric Motorcycles in Colombia from 2011 to 2018 [8]

Nowadays, in Brazil, there are 26.4 million two-wheeler vehicles, being 45% within the cities, this number exceeds the number of cars. It is also noted, an increase in the feminine public interest for scooters and electric motorcycles, representing more than half of the users [8].

The main pros in the use of electric motorcycles are low maintenance cost, according to Rui Almeida, director of the automotive company Riba Brasil, while the ICE motorcycles have around 100 movable pieces, being 50 to 60 only in the engine, the electric scooters have only 8 movable parts, they also have a more practical recharging procedure, does not emit CO2 nor make loud sounds, and it is easy to handle in big cities traffics [8].

Being easy to handle in heavy traffic, it is possible to draw a comparison between the motorcycle' size and torque, which show us that the electric motorcycles have bigger efficiency, reaching high torque with a smaller size. The charts below show comparisons between torque, wheelbase, and overall vehicle length.

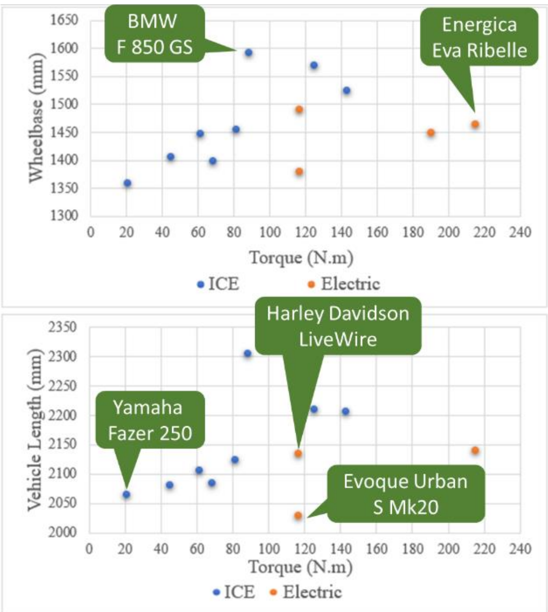

Figure 5. Chart with External Dimensions versus Torque. Source: author

Surprisingly, the big four major motorcycle original equipment manufacturers (OEM): Honda, Yamaha, Suzuki, and Kawasaki, don't have in their portfolio electric products of global relevance, although being public knowledge that they joined forces to develop battery cells technology, aiming cost reduction and consequently making the electric vehicles more viable financially [8]. It can be noted that one of the few OEMs with international renown to get into this market is Harley Davidson, with the launch of the electric motorcycle called LiveWire, while the greater portion of the market share is occupied by smaller OEMs.

The image below shows some electric motorcycles:

Figure 6. Examples of Electric Motorcycles. Source: author

The growth in the electric vehicle fleet will bring a big reduction in the level of GHG emissions. In a well-to-wheel analysis, which considers the emission from the well to the wheel, which means, from the manufacturer to the final customer, the avoided emissions (considering a fleet of ICE vehicles of the same size) could surpass 400 Gt of CO2, aligning with the initiatives proposed in the Paris agreement [7].

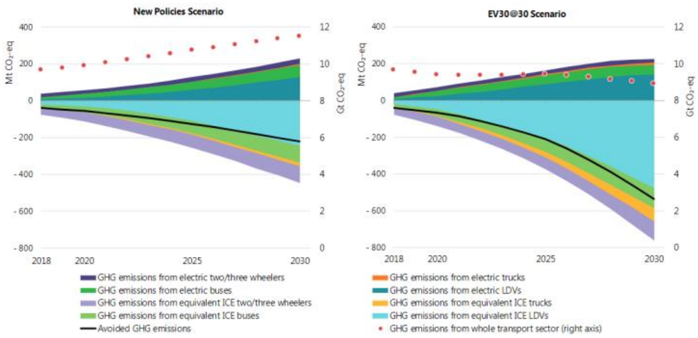

Figure 7. Projection of CO2 Emissions [7]

It is worth mentioning that the impact of implementing electric vehicles is different from country to country, due to the preponderant type of energetic source. Vehicles with 100% electric propulsion (BEV), bring greater advantages in countries with low carbon energy matrix, for example hydroelectric plants, whereas in countries that burn carbon as primary source of energy, it is more efficient to use hybrid vehicles.

Per Sheikh Ahmed-Zaki Yamani quote, the stone age did not end for lack of stone, and the oil age will end long before the world runs out of oil.

DEVELOPMENT

In the development of a vehicle, being it either powered by electricity or internal combustion, it is quite important to understand the amount of energy required to move it, being it in a highway with constant speed during longs periods of time, or in cities with smaller average speeds and countless stops, or even in a mixed course.

In the electric vehicles, it is crucial to balance power and range, since nowadays the charging grid and the time required to fully charge the battery, are still far from ideal.

Figure 8. Electric Vehicles Recharging Stations in South America, in September 2018 [10].

This paper aims to develop a medium size electric motorcycle, with power and energy spent per hour calculated based on a highway use. To do so, it will be necessary to estimate a few parameters, using as baseline existing electric motorcycles and data from specialized literature, which shall be then adjusted, for any other specific use.

The following parameters will be used in the calculations:

1. V limit: 200km/h (56m/s)
2. V cruse: 170km/h (47m/s)
3. W moto: 230kg
4. W total: 310kg
5. Acceleration time 0-100km/h: 4 seconds
6. Af: 0,697m²
7. Cd: 0,60 [15]
8. ρa: 1,225 kg/m³
9. g: 9,81m/s²

Initially, it is necessary to understand what is the aerodynamic resisting force that will be applied against this vehicle, which can be defined as the air resistance to a quick displacement, generated by the pressure difference between the front and the rear portion of the motorcycle. The two main factors that influence this force are: frontal area and the aerodynamic coefficient [11].

Ideally the product design shall aim for a smaller frontal area and a design that allows the air to be cut in a way that the molecules slowly move, close to the external surface of the motorcycle [11].

To calculate the aerodynamic resisting force (Fa), it will be used the following equation [1]:

$$Fa = Cd\ \rho a\ Af\ Vlimit^2\ \frac{1}{2}$$
$$Fa = 790{,}6\ N \qquad (1)$$

According to Newton's second law, the more mass a body has, more force shall be necessary to move it; based on that principle it will be calculated the force necessary to break the inertia and put the vehicle in motion, the rolling resistance force (Fr). For a precise calculation, it shall be obtained experimental values and then propose a correlation that represents the given vehicle. The SAE standards J1296, J1270, J1379, and J1380, define the procedures to obtain such correlation.

In this project, it will be used the following equation, where K1 = 0,108m/s² and K2 = 0,000099 1/s [1].

$$Fr = (K_1 + K_2\ V_{\text{cruse}})\ W_{total}$$
$$Fr = 34{,}9\ N \qquad (2)$$

As an initial parameter, it will be calculated the initial acceleration (ai), given as constant, to move the vehicle from 0 to 100km/h in 2.9 seconds. To do so, it will be used the following equation:

$$a_i = \frac{velocity}{0{,}725\ time}$$
$$a_i = 9{,}6 m/s^2 \qquad (3)$$

For motorcycle applications, it is crucial that the acceleration decreases over time, avoiding the detachment of the front wheel from the ground, thus increasing the frontal area, and potentially losing directional control. For such it will be used a gradient descent in the acceleration calculation [1].

$$a = a_i \exp\left(-\frac{a_i}{Vlimit}\ t\right)$$

(4)

From the above expression, one can define the velocity function [1]:

$$v = Vlimit\,[1 - \exp(-\frac{a_i}{Vlimit}\,t)] \tag{5}$$

Both equations are valid only for 0 ≤ t ≤ ta, being ta, the acceleration time until cruse speed is reached, and it is defined by the equation below [1].

$$ta = \frac{Vlimit}{a_i}\ln(\frac{Vlimit}{Vlimit - Vcruse})$$
$$ta = 11\ seconds \tag{6}$$

Considering the input data of this application, the ta is equal to 11 seconds, which means, it is the time needed by the motorcycle to reach the cruse speed of 170 km/h (56 m/s).

With these expressions in hand, one can calculate the acceleration and velocity at each fraction of time since the departure until the moment the motorcycle reaches cruse speed.

Another important factor can be calculated using the acceleration and velocity, which is the required inertial power at each moment. For such, it follows the expression, where the peak of 41.2 kW can be identified at 4.02 seconds, when reached the 100 km/h (27.8 m/s) speed and 4.79 m/s² acceleration [1].

$$PI = W_{total}\,a_i\,Vlimit\,\exp(-\frac{a_i}{Vlimit}\,t)\,[1 - \exp(-\frac{a_i}{Vlimit}\,t)] \tag{7}$$

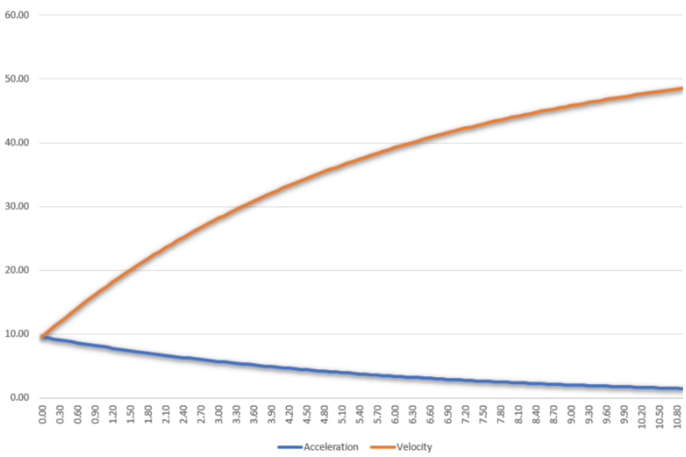

Figure 9. Chart Showing Acceleration versus Velocity. Source: Author

From this, it can be calculated the necessary power to put the vehicle in motion, using the aerodynamic, rolling, and inertial powers, plus the desired limit velocity [1].

$$P_t = \{(K_1\,W_{total}) + [W_{total}\,a_i\,\exp(-\frac{a_i}{V_{limit}}\,t)]\}\{[1 - \exp(-\frac{a_i}{V_{limit}}\,t)]\,V_{limit}\} + \{(\frac{1}{2}\,\rho a\,Cd\,Af)\,V_{limit}^3\,[1 - \exp(-\frac{a_i}{V_{limit}}\,t)]\}$$
$$P_t = 66387\ Watts \tag{8}$$

This value represents the total power, during the acceleration of an electric motorcycle weighting 310 kg (230 kg motorcycle + 80 kg driver), from 0 to 170 km/h in 11 seconds.

To determine the battery pack capacity, it is necessary to understand: amount of energy required to put the motorcycle in motion up to the cruse speed and the amount of energy to keep it moving for a given distance.

The equation below will be used to determine the acceleration energy [1].

$$Ea = \frac{Wtotal\,Vcruse^2}{2} + V_{limit}\,[(K_1\,W_{total} + \frac{1}{2}\,\rho a\,Cd\,Af\,V_{limit}^2)\frac{Vlimit}{ai}\ln(\frac{Vlimit}{Vlimit - Vcruse}) - (K_1\,W_{total} + 3\,\frac{1}{2}\,\rho a\,Cd\,Af\,V_{limit}^2)\,\frac{Vcruse}{ai} + \frac{3\,\frac{1}{2}\,\rho a\,Cd\,Af\,Vlimit^2\,Vcruse}{2\,ai}\,(2 - \frac{Vcruse}{Vlimit}) - \frac{\frac{1}{2}\,\rho a\,Cd\,Af\,Vcruse^3}{3\,ai}(1 - \frac{3\,Vlimit}{Vconstant}(1 - \frac{Vlimit}{Vconstant}))]$$
$$Ea = 843829\ Joule/departure \tag{9}$$

An important factor to understand is the traveled distance during the acceleration. To perform such calculation, it will be used the following equation [1].

$$Da = V_{limit}\,(Ta - \frac{V_{cruse}}{a_i})$$
$$Da = 337\ meters \tag{10}$$

With the motorcycle already in cruse speed, it is necessary to calculate the amount of energy to keep it moving per meter [1].

$$Ec = K1\,W\text{total} + \frac{1}{2}\,\rho a\,\text{Cd}\,Af\,V\text{cruse}^2$$
$$Ec = 605\,Joule/meter \tag{11}$$

With this information in hand, one can determine the battery pack capacity. To do so it will be considered the following scenario:

1. acceleration time from 0 to 100 km/h: 4 seconds
2. total time traveled: 1 hour
3. velocity during travel: 170 km/h
4. distance traveled: 170 km

To determine the amount of energy needed, it will be used the equation shown below.

$$E\text{total} = \frac{\{[(3600 - t\text{a})\,V\text{cruse}]\,E\text{c}\} + E\text{a}}{3600}$$
$$E\text{total} = 28701\,\frac{Watt}{hour} \tag{12}$$

Expanding the scenarios, one can draw the following chart. It is noted, for example, that a 13.4 kWh battery pack, is capable of providing energy enough to move the motorcycle for 1 hour, at 130 km/h. With that, it can be concluded that with the same battery pack capacity, but moving in a lower velocity, would enable a total distance traveled greater than 130km, with a single full battery charge.

For comparison purposes, according with the technical data from the OEM, the electric motorcycle Zero SR/F d2020 delivers 190N.m of torque at 5000 RPM, with an 82 kW motor, while in this proposed project, with a motor of approximately 66 kW, it would deliver 126 N.m of torque.

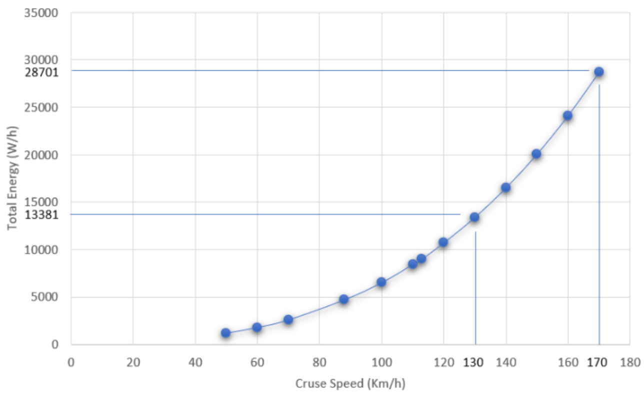

Figure 10. Chart Total Energy versus Cruse Speed. Source: Author

As last parameter, it will be calculated the motor torque, considering the 66387 Watts of power previously calculated in Pt. For such task, it will be used the following equation, where n represents the number of revolutions per minute [12].

$$Torque = \frac{9{,}549\,Pt}{n} \tag{13}$$

One of the characteristics of an electric motor is to provide effective torque at 0 speed, as can be seen in the chart below.

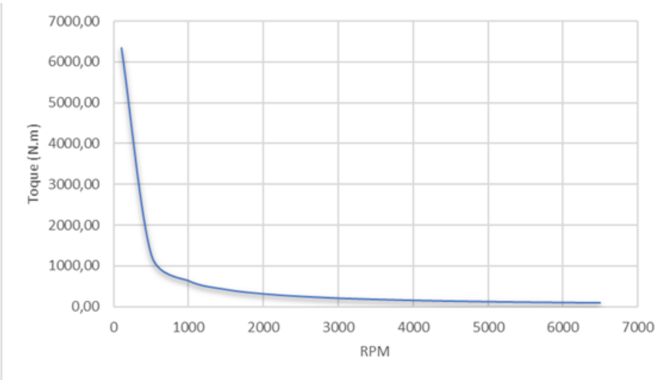

Figure 11. Chart Toque versus RPM Source: Author

SUMMARY/CONCLUSIONS

Aligned with the main objectives of the GHG emission reduction, mainly by the transportation sector, this paper aims to calculate the basic technical requirements for an electric motor and battery pack to be used in a medium size motorcycle with medium/high performance.

It is known that the calculations established down are theoretical and don’t take into account losses inherent to the systems but are sufficient to guide the first steps in the development of an electric motorcycle.

It was identified that, for use in Brazilian highways, without uphill and downhill, where the speed limit is 110 km/h, it would be necessary an electric motor of at least 66 kW, with battery pack of 8.5 kW/h, so that the motorcycle can travel a distance up to 110 km, with a battery single full charge.

Considering the same motorcycle characteristics, but now for urban use, and with a speed limit of 60 km/h, it can be derived that the autonomy range that a single battery charge would provide is significantly bigger.

The frontal area and the drag coefficient are two parameters that shall be carefully studied and tuned so that there is the maximum use of the energetic capacity of the motorcycle, since a difference in the battery pack impacts, among other aspects, in the final cost of the motorcycle, its center of gravity, weight, and drivability

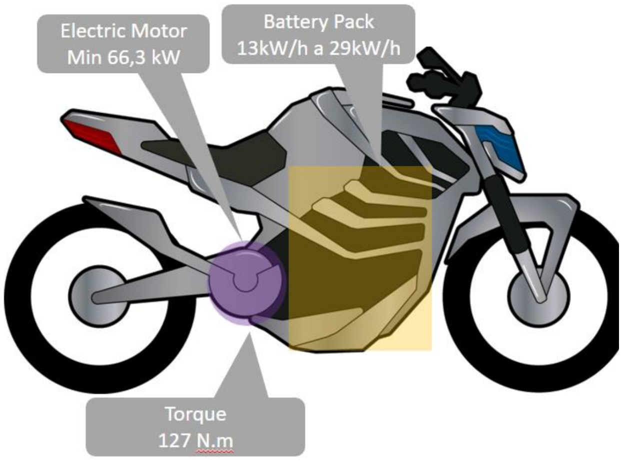

Figure 12. Basic Specifications. Source: Image given by designer Romulo Leão

Given the number of motorcycles, in most cities, exceeds the cars, the raising interest of the feminine public for two-wheeler vehicles, and the lack of medium size electric motorcycles in the market, one can assume this market niche has potential of growth and shall be studied in detail.

During the development of this paper, it was noted the need of a deep dive into a few subjects, which could be matter of different future studies.

1. Equation of rolling resistance specific for this application
2. Determine the operating current and voltage of the system
3. Definition of the type of electric motor
4. Amount and type of battery cells
5. Modeling the energetic need in an urban cycle.

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DEFINITIONS/ABREVIATIONS

Af	Vehicle frontal area, considering the driver
BEV	Battery electric vehicles
Cd	Aerodynamic coefficient
CO2	Carbon dioxide
EIA	U.S. Energy information administration
FHEV	Full hybrid electric vehicles
G	Gravity acceleration
GDP	Gross domestic product
GHG	Greenhouse gases
km	Kilometer
hm/h	Kilometers per hour
kg/m^3	Kilogram per cubic meter
kW	Kilowatt
mHEV	Mild-hybrid electric vehicles
m/s	Meters per second
m^2	Square meter
m/s^2	Meters per square second
N	Newton
N.m	Newton times meter
OECD	Organization for economic cooperation and development
ρa	Specific mass of air
PHEV	Plug-in hybrid electric vehicles
RPM	Revolutions per minute
V cruse	Cruse velocity
V limit	Limit velocity
W moto	Motorcycle weight, considering standard equipment and all fluids
W total	Motorcycle total weight, considering standard equipment, all fluids, and 80 kg driver
WRI	World resources institute
μHEV	Micro-hybrid electric vehicles