An Electrical Bike For Project Based Learning Platform

Arnaud Sivert*, IEEE Reviewer E-mail : arnaud.sivert@iut.u-picardie.fr
Franck Betin*, IEEE Member, E-mail : franck.betin@u-picardie.fr,
*Laboratoire des Technologies innovantes (L.T.I)
*Institut Universitaire de Technologie de l'Aisne, I.U.T, 13 av. F.Mitterrand, 02880 Cuffies, France
Jean-Paul Bécar IEEE ToE Reviewer, E-mail : jean-paul.becar@univ-valenciennes.fr
Institut Universitaire de Technologie de Valenciennes, Le Mont-Houy, 59300 Valenciennes

Abstract: *This paper deals with the electrical bike (e-bike) seen as a project based learning tool. The e-bike offers the students a real system to learn many concepts. Some subjects as forces determination, electrical drives, power electronics, speed variations, energy saving and instrumentation can be treated in experimented in real time using this friendly educational tool. In this article, the educational tool is serving one objective that is to know how is it possible to represent the human mechanics as reliable as possible into an electrical motor system. The work presented here is done by a team composed by a teacher in electrical engineering domain supervising four students in the second grade of bachelor of technology course with electrical engineering as their speciality. The group is welcome in an Institute of Technology. After some theoretical calculation, the team fixed the choice of an e-bike and realized this educational platform. A special electronic equipment is installed on a test bench in order to make some laboratory experimentations.*

The e-bike is setting an interface between the theoretical, practical and experimental knowledge. It represents a complete electro mechanical system and can be also viewed as another research platform.

Keywords: electrical bike, sustainable development, electro mechanical system, strategies controller

1. Introduction

This paper deals with the electrical bike seen as a project based learning tool. The e-bike offers the students a real system to learn many concepts. Some subjects as forces determination, electrical drives, power electronics, speed variations, energy saving and instrumentation can be treated in experimented in real time using this friendly educational tool. In this article, the educational tool is serving one objective that is to know how is it possible to represent the human mechanics as reliable as possible into an electrical motor system.

The work presented here is done by a team composed by a teacher in the field of electrical engineering supervising four students in the second grade of bachelor of technology course with electrical engineering as their speciality. The group is welcome in an Institute of Technology. After some theoretical calculation, the team fixed the choice of an e-bike and realized this educational platform.

A special electronic equipment is installed on a test bench in order to carry out laboratory experimentations.

The e-bike is setting an interface between the theoretical, practical and experimental knowledge. It represents a complete electro mechanical system and can be also viewed as another research platform.

The second section of the paper is concerned with the material configuration. After some calculation of the power required to move the e-bike according to a specifications sheet, the section presents the results of the sizing of an e-bike. It includes a comparative table motivating the choice of an e-bike. This last section deals with a test bench. Some additional equipment is fixed to the e-bike to supervise the main parameters as the voltage and current battery, the energy, the speed of the wheel speed. A few strategies to control the motor for speed limitation are ending the section.

2. Material configuration

2.1 Features of the man-machine interface

To understand how a reacts motorization, or to choose one, you need to identify yourself to it.
Then, the electrical bike allows you to add a muscular power to the engine power.
The e-bike points out to any biker a way to substitute his human power to the engine in order to apply :
-an acceleration torque due to the system inertia
-the power drives
-the mechanical transmission as speed reducer or mechanical torque increasing
-the reviews of electrical power and energy consumption,
-the thermal studies of motor
-the torque breaking for energy recovery
-the technical choices and compromises.
The electrical bike allows you to apply all of these fundamentals to understand the problems of all mechanical engines systems, and all our Industrial and Home motorized environment.
More-over, the electrical bike turns a new actor in the transportation activity especially inside the traffic congested cities.
Today, there is the French Legislation which slows down the electrical bike expansion. Because the speed limit does not exceed 25km/h and the power should be lower than 250W. These bikes of low power have sensor pedal so named electrical assisted bike.

To discover the pedagogical part done with an electric bike support we will, firstly, show some examples of unusual Electric bikes. Then we will discuss the resistive power in function of the speed, the forces needed during the transient, the current needs for the batteries, to finally derive the consumption and driving autonomy.
Then we will show the advantages of the pedagogical use of this system and the curriculum covered.

2.2 Presentation of the electrical bikes

To create interest and impress our student, our electrical bikes can reach 50km/h, on a flat road, but also on a 5% steep road.
The acceleration needs 4 seconds to reach 36km/h with a cyclist and bike of 100 kg. The maximum current, the maximum speed and the acceleration time can be set in the controller.
In 2010, the cost of our bikes was € 1400 with the instrumentation. In 2011, the cost has been reduced to € 1000. These bikes aren't using a sensor pedal technology, only a twisting accelerator handle.

Figure 1: The 2010 edition of two electrical bikes of 500 and 1000W.

All our bikes are 26 inches wheels with disc brake. The bike frame and the wheel support are really robust. The bikes are the property of the students association so there are not the responsibility of school.
The e-bikes can only be used on private’s roads. It is possible to drive them on a road while paying from 200 till € 300 per year. For a show or a challenge you need a € 8 registration fees per week to insure a recreation motorized bike with under 50cm^3 engine.

The e-bikes engines are hub motor brushless, and have a really important power for a low mass. They can be really easily described and explained because the speed depends on the electric voltage and the motive force of the current.
The only problem for self taught persons, the speed controller of theses engines is a relatively complex system.

The controller speed (1000W, 60V, 40A max), allows you to break electrically and load the batteries downward.
Our "home made" battery charger can load our bike at 10A and equilibrate the Li-Po batteries.

We will now mathematically qualify the electric bike to understand theses characteristics and understand these controls.

For the sake of simplicity, we will not go into show details of the mechanical losses of the engine and command systems (speed and current regulation), the power electronic or internal resistance of batteries. The reader can download the study in details that our students have done on the website: http://aisne02geii.e-kart.fr/

2.3 Force and power of the engine in a steady state speed.

In a steady state speed, the engine force is equal to the resistive force. This force depends on the ball bearings, the tires, the step of the road slope, and air resistance.
Their respective equations are:

$$F_{resistive}(N) = F_{Road} + F_P + F_A \quad (0)$$
$$F_P(N) = M(kg) \cdot g \cdot slope(\%) \quad \text{with } g=9.81 \quad (1)$$
$$F_A(N) = f \cdot [V(Km/h) + V_{wind}] \quad (2)$$

The F_{road} depends on the kind of wheel, the kind of pavement, and the bicycle driver weight. It is negligible compared to the air resistance F_A. The power needed can be observed in a steady state speed on figure 2.

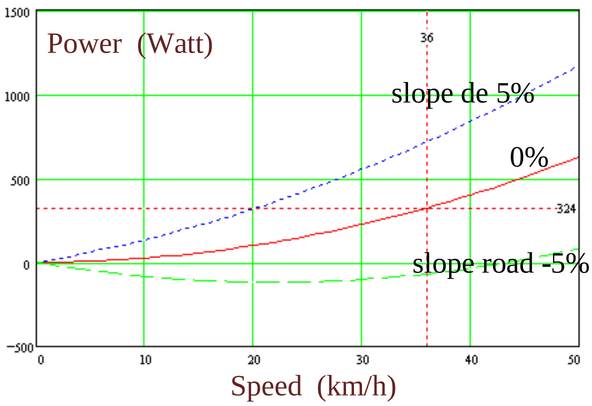

Figure 2: Motive power vs speed for different slopes (M=100kg, f=0.25 N/km.h^{-1})

It corresponds in a steady state speed to the following equation: human

$$P_{resistive}(W) = F_{resistive}(N) \cdot \frac{V(km/h)}{3,6} = P_{humane} \quad (3)$$

The average human power is setting from 150W to 300W for a pedaling rate from 10 to 100 rpm. The cyclist is always adjusting the gear ratio to the relief in order to obtain the same human power and a constant pedaling rate due to the resistance power.

For a VTT of 26 inches, the force of pedaling is:

$$F_{pedal} = \frac{teeth_{pedal}}{teeth_{whell}} \bullet \frac{Power_{humane} \cdot 0.0254}{\frac{V(km/h)}{3.6} \bullet Radius_{pedal}} \bullet \frac{26}{2}$$

$$F_{pedal} = \frac{teeth_{pedal}}{teeth_{whell}} \bullet \frac{Force_{resistive}}{Radius_{pedal}} \bullet 0.33 \quad (4)$$

Once known the resistive power, the accelerative power is required to start moving the bike.

3 Force and power in speed dynamic

A trapezoid speed profile (fig 3) is used to determine the accelerating power [3].
The acceleration and deceleration times can be set in the controller. The motor force F_m corresponds to the following mechanic fundamental equation:

$$F_m = M\frac{dv}{dt} + F_{Resistive} \quad (5)$$

We can observe on the fig 3 that the acceleration will need a motor force at 280 N at the beginning and the deceleration will need break strength of -220N.

During acceleration, the speed dynamic is determined by the equation differential (5):

$$v(m/s) = \frac{(F_m - F_{resistive})}{M} \cdot t + v(t=0) \quad (6)$$

Energy is determine by integration of power

$$Energie(W.H) = \int \frac{Puissance(t)}{3600} \cdot dt \quad (7)$$

We can notice that the energy we get back from breaking nearly match with the acceleration, the resistive forces subtracted.

The speed controller commands the engine's speed with the accelerative handle. The electro mechanicals relations of the engine are:

$$v(m.s^{-1}) = U_m / k = \alpha . U_{Batt} / k \quad (8)$$
$$F_m(N) = I_m \cdot k \cdot \eta_{motor} \quad (9)$$

With U_m and I_m the motor voltage and current, η the efficiency.
The α coefficient varies from 0% to 100%. It's delivered by the controller to vary Um for motor brushless. So the controller commands the speed.

The mechanic and electric power is determined by this equation:

$$P(W) = F_{resitive} \cdot v(t) = \alpha \cdot U_{Batt} \cdot I_{Batt} \cdot \eta_{motor} \quad (10)$$

With U_{batt} and I_{batt} the batteries tension and current.

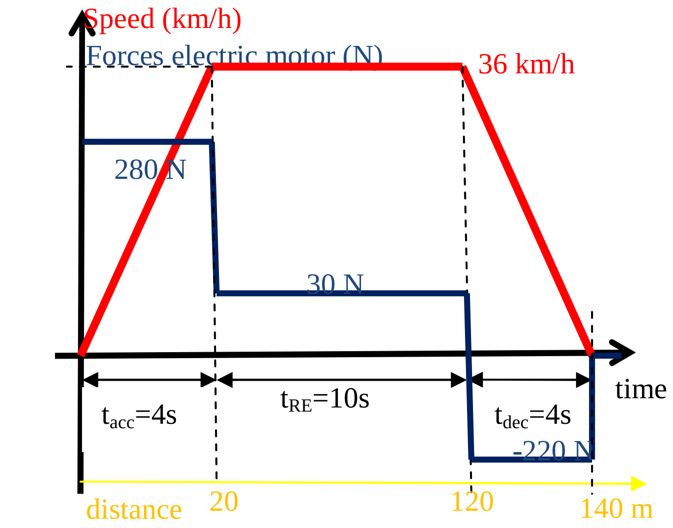

Fig 3: speed and force motor resultant vs time
for a mass M=100 kg, $F_{Resistive}$ =30N.

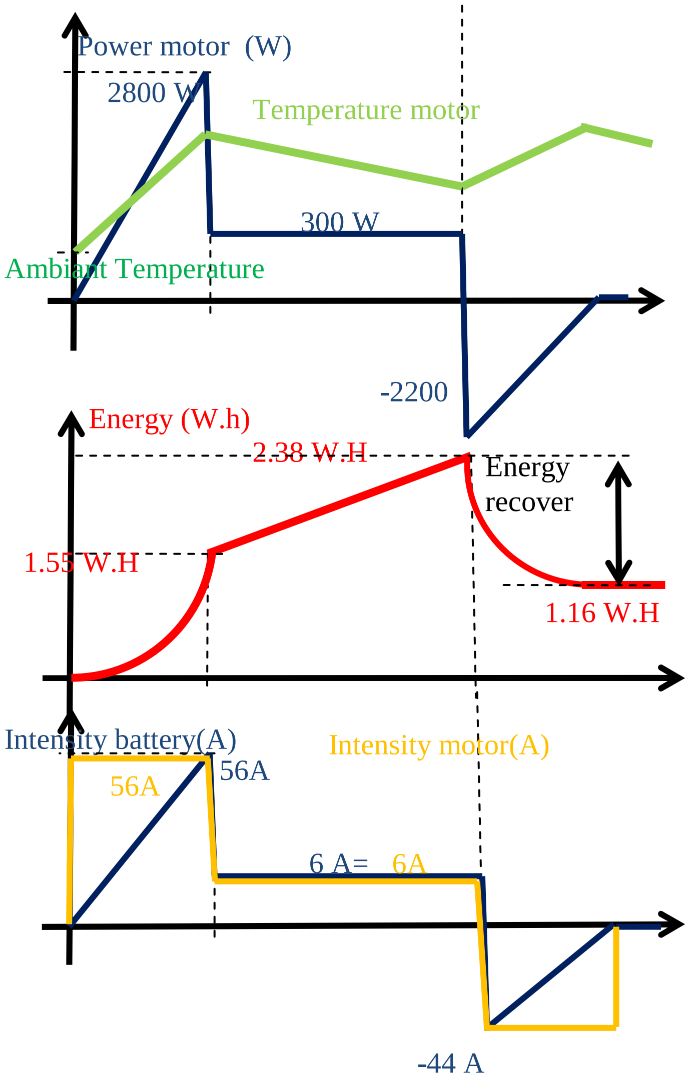

Fig 4: force, power, energy and intensity
according to speed profil trapezoidal
for a battery of 50V.

The k term in (N/A) or (V/m.s) depends on the engine construction (numbers of the spires in the magnetic field of the magnets, poles numbers...). In the case of fig 3, the maximum speed is reached at 36 Km/h with a battery tension of 50V. Consequently, from the equation (9), it is easy to determine the k coefficient which is 5.

Notice that, the bigger the k term is, the faster will be the engine for the same voltage of the battery, but the motorized force will be lower for the start for the same limitation current. The motorized force of an electric engine can be really strong when starting. So, it doesn't need to have gearbox as a thermal engine needs.

To simplify studies, the efficiency of motor is considered as a constant function of the speed. The electric power of the engine is:

$$P_{abs\,motor}(W) = (U_{Batt} \bullet \alpha) \bullet I_m(A) = \frac{P_{resistive}}{\eta_{moteur}} \quad (11)$$

The engine rentability is a consequence of the mechanic losses but also of the engine warming, caused by the current in the « spires » .This heating phenomenon can be damageable for the engine if the winding temperature goes up to a 100°C. The motor efficiency is around 70%. We consider a perfect rentability of controller (Approximate efficiency of 95%, so negligible)
Consequently, the electric power of the batteries corresponds to the following equation:

$$P_{batt}(W) = U_{batt} \bullet I_{Batt} = P_{abs\,motor} / \eta_{controller} \quad (12)$$

From (11) and (12), the electric current corresponds to the following equation:

$$I_{Batt}(A) = \alpha \cdot I_m \quad (13)$$

The time bikes autonomy C_E (A.H) correspond to the following equation:

$$t_f(H) = \frac{C_E(A.H).U_{Batt}(V)}{\text{Power abs motor}(W)} = \frac{C_E}{I_{BAtt}(A)} \quad (14)$$

The bicycle is a compromise between power, autonomy, technology battery, price…
We will see these compromises and technical choice.

Technical choices and compromises

The choice of the engine depends on the power that it can deliver and on the speed. The speed is given by the k term in equation (8) according to the voltage battery. The choice of the controller is determined by the engine current in the steady state and also by the maximal current during the accelerating process. Then the choice of the batteries will depend on the number of elements, the volume, the mass, the cost and the discharge rate that battery can offer. Each type of batteries has a specified voltage. Thus, a 50 V battery has a number of electrochemical elements denoted by S. The charge and discharge current in an electrochemical element is also limited. This is due to its manufacturing. And the choice is really important for the discharge of the batteries. In addition, when the charge and discharge current are high, the accumulator is warming up. Some elements can be destroyed and the lifetime of the battery is getting low.

The following table shows the technology in 2010 of a 50V, 10 A.H batteries:

Type de battery	Volume cm^3	Mass	Price 2010	Price 2011	charge rate max	discharge rate max	Internal Resistance
Plomb 4 S	6000	20 kg	200 €	200 €	2A	10 A	?
Ni MH 40S	2500	8 kg	550 €	550 €	5 A= 0.5C	10 A =1C	?
li-po 12S	1500	3 kg	450 €	220 €	10 A= 1C	100 A =10C	2 mΩ

This table indicates that only the li-po Batteries are a good choice for an electric bike. A faster e-bike runs so the higher voltage is required. Therefore, the large number of elements is increasing the battery cost. This implies that the bigger is the given voltage for a fixed resistance power and the lower is the current delivered by the battery. In that case, a lower discharge rate is obtained.

The parameters of the controller must be settled in order to limit the discharge current of the battery, to obtain a maximum power at start and a minimal current during the braking and accelerating times. A good compromise for a 1000W electric motor is a battery voltage in the range [48V, 72V] with energy in the range [10A.H, 15A.H]. The li-po batteries can support from 500 to 2500 charge discharge cycles. The range is 40 km without pedaling upgraded to 80 km with pedaling. The e-bike could run 20 000 km in the worst case and 100 000 km in the best case with the same power supply battery. As the controller is limiting the discharge current, a battery security management is not used here. The battery charger is monitoring all electrochemical element voltages. It balances these elements to obtain 100 % of the charge without overtaking the maximal voltage. As the French rate for home electricity costs 0.08 Euros per 1kWH, the 100km run with an e-bike cost 0,1 Euros.

Taking account of the lifetime batteries and their prices the cost to run 100km grows to 1.2 for 500 cycles of charge and discharge until 0.2 Euros for 2500 cycles.

Now this cost can be compared to other types of energy

5. Energy costs for some modes of transportation

The electrical power can be compared to the energy coming from oil or food. Thus, a 40 km e-bike run at 40 Km/h requires a 500W power. As 500W.H corresponds to 433Kcal that is equivalent for example to 250g of bread or 150g of cheese or 3 bananas. This corresponds to 0.18 gasoline liter for a thermal engine with efficiency equals to 30%.

An active human should consume 2600 kCal a day. He needs three lunches that cost 15 Euros each. That gives 0,006 Euros/Kcal.

Only 30% energy consumed by a human being muscle is transformed in to power, the rest is heat consumption. Therefore, the human power is a low efficiency system and human food is rather expensive. The following table compares the energy cost to run 100km with a bike, an e-bike or a motorcycle equipped of a 50 cm^3 engine. It shows the low cost of an e-bike despite the battery high prices.

Vehicle	insurance	maintenance	Consumption	cost / 100km
bike	x	muscular	0,006 €/kcal	6,5 €
e-bike	x	220 € /20 000km	0,08 €/kW.H	1,2 €
50 cm^3 motorcycle **5000km by year**	400 €	Change oil	5 liter/100km 1 liter =1€	13 €

A test bench [2] is built in order to identify and measure the motor power involved in e-bikes.

6. A test bench for e-bikes

The choice of rear motor is motivated by a way to reload the battery thanks to the human muscle strength. A pinch roller is installed on the device. A generator is connected on the pinch roller to test the motor (see on figure 5). Some embedded instruments are measuring the voltage, the current, the wheel speed and calculating the power and the energy of the battery. A LCD monitor displays all parameters values:

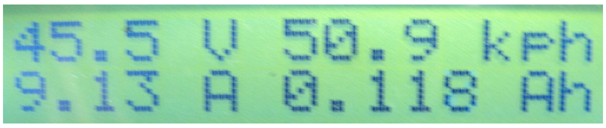

Figure 5: elec bike and testbed

An oscilloscope and a wattmeter recorder are used to measure the dynamic of the current, voltage and speed of the e-bike.

In order to control the current motor, there are more strategies:
- limiting only the motor current and used the acceleration/deceleration times based on section 3 examples.
- controlling the speed and limiting the current motor,
- limiting the current from the battery and limiting the speed.

The first solution provides a high motive force. The second strategy is interesting because it can use a security sensor to be installed on the chain ring with the following features:
-If the pedaling frequency vanishes or is equal to 0.1 rd/s, the motor runs as a freewheel and the speed set-point is 0 km/h, whatever any action on the twist handle throttle
-If the pedaling frequency is lower than 0.15 rd/s, the speed set-point equals 13km/h even if the throttle is getting up to 100%,
-If the pedalling frequency is greater than 0.15 rd/s, the speed set-point matches with a ratio of the twist throttle,
-An electrical breaking will occur when the throttle is at its start position when the bike is getting over 13 km/h. Below this speed the motor looks like a free wheel.

The figure 6 shows an example of this strategy.

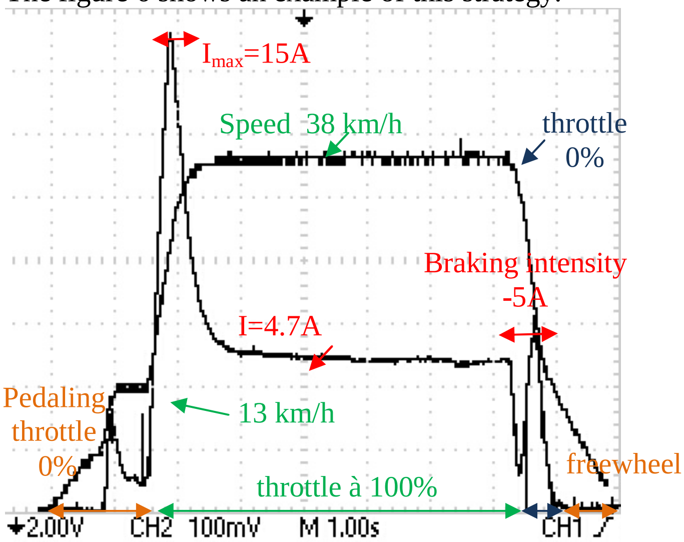

Fig 6: speed and intensity battery versus time without load (F_R 23N, wheel mass 7kg)

We have found again approximately the acceleration and deceleration times given by the equation (5) and (9) using the test bench.

$$F_{motrice} = K \bullet I_{moteur} = 5 \bullet (15A) = 75N$$

$$t_{dema} = \frac{(V_{final} - V_{init}) \cdot M}{3{,}6 \cdot (F_m + F_R)} = \frac{(38-13) \cdot 7kg}{3{,}6 \cdot (75-23)} = 0{,}9s$$

$$t_{decel} = \frac{(V_{final} - V_{init}) \cdot M}{3{,}6 \cdot (F_m + F_R)} = \frac{(13-38) \cdot 7kg}{3{,}6 \cdot (-25-23)} = 0{,}8s$$

The third strategy offers the limitation of the discharge rate of the battery. Nevertheless, as starting power is constant, the acceleration turns lower than in the two previous strategies.
After some measurements, all the parameters of an e-bike are well identified tor understand the e-bike dynamics understanding.

The specification sheet given by the motors and controller by the manufacturers does not meet our requirements.
And the teachers should invest efforts to use the e-bike as a teaching support. An e-bike challenge should be proposed to the community as it has been done since six years in the electrical go-kart background www.e-kart.fr . That means that all knowledge should be shared by the use of a website.

Conclusion

The e-bike as a teaching support is used in technical field activity as electrical engineering or mechanical engineering and also in theoretical field activity as physics and mathematics. The use of this teaching support is also adequate with the syllabus of undergraduate students and bachelor of technology students. The e-bike teaching tool turns all mechanical or human parameters such as forces and powers into their electrical analogy representation. The e-bike allows to understand some facts. The heavier is a vehicle with large tyres, the more power is required and the more energy is consumed. The e-bike cancels the ideas that it is possible to charge the batteries while a cyclist runs at a 30km/h speed on a horizontal road. Some e-bike challenges are existing in France in order to add a motivation for students. The Alpes Mountain crossing and now the e-bike challenge in Vierzon are a few examples. The e-bike is turning as a smart and funny tool to improve the learning process. The low cost of the system is contributing to its success.

Acknowledgement

The authors warmly thank the Institute of Technology for its technical support.

References

References

[1] http://aisne02geii.e-kart.fr/ réalisation de vélo électrique, mai 2009

[2] Benoit Rozel, Wilfried Frelin, Emmanuel Hoang, Gilles Feld, “ charge simulator for Home Trainer”, CETSIS'2005, Nancy, 25-27 octobre 2005

[3] Guide for calculating mechanical and electrical engineering technician guide hatchette technical editor

[4] our engineering students and drivers, Elektor magazine, september 2010, n°387

Figure 6: electrical vehicles of I.U.T

Arnaud.sivert was born in France.
He received the Ph.D. degree from the University of Picardie Jules Verne, Soissons, France, in 2000.
In 1994, he joined an Institute University of Technology in the Department of Electrical Engineering, as an Assistant Professor. His major research interest is the control of electrical machines
I.U.T produces electric vehicles since 2008 and participates in the national challenge of electric kart [4].