Pedagogical study of electric go-karts: Technological choices, instrumentations, characteristics, challenge

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Abstract: - Electric vehicles are very good educational aids because they can be used by every student with lower costs compared to building a classic car. The International Pedagogical electric go-kart Meeting that take place in France motivates students and help them to implement different technological choices. These choices are often difficult because they mean saving the energy aboard, in accordance with new technologies. Indeed, these future vehicles represent a difficult compromise between weight, volume, power, autonomy, and price. The evolution of electric go-karts was made possible thanks to motors running on low voltage and new Lithium batteries. This article will outline the resisting power depending on the vehicle speed, accelerating torque, types of motors and controllers used, energy sources and chargers. Finally, one educational application will be presented as this kind of vehicles uses many aspects of electrical engineering: power converter, battery, motor, controller, control, electronics, lights, instrumentation, sensor, mathematics, mechanics...

Key-words: - go-kart challenge, motor electric control, Lithium battery, project-based teaching, battery charger, super capacity, instrumentation.

1 INTRODUCTION

Building an electric vehicle means finding a compromise between power, energy consumption, weight, volume, price and autonomy [1]. Electric go-kart is a good teaching tool to implement these compromises. Students will have the opportunity to show their ideas and achievements participating in International Pedagogical Meeting of electric go-kart in France. This challenge has been organized every year by the e-Kart Association [11] since 2006 and has brought together 40 go-karts technologically very different [4].

We will present in this article the evolution of the power needed by a kart depending on the speed and torque accelerator in order to start as fast as possible. The different types of motors, inverters and batteries will be studied, as well as chargers and instrumentations to measure electrical, thermal and mechanical variables.

Technologies used in these go-karts were transferred to small electric vehicles, for example golf cars or indoor go-karts, but also in forklift trucks used in industry.

Electric go-karts have a low noise level and are increasingly used on indoor tracks to be rented, so some companies sell electric go-karts such as Speedomax, Sodikart, Swiss Hutless… Since 2009, most of these go-karts are competing with petrol ones in terms of performance [2]. So, what are the mains characteristics of competition petrol go-karts and what are the electric motors equivalent?

1.1 Competition petrol go-karts

Competition petrol go-karts have 125 cm^3 engines which develop a maximum power of about 22 kW without gearbox, and up to 32 kW, with a gearbox. Go-karts are devices that have no suspension and no differential. The wheel diameter is set at 25 cm (10 inches). The acceleration time is about 4.5 s to cover 50 m and 6.5 s for 100 m. Petrol engines speed is 18,000 rpm which causes a high wear of the mechanical parts, intensive maintenance and a lot of noise. The mass of a petrol go-kart with the driver is about 170 kg.

We are going to quantify mathematically electric go-karts to study their characteristics: maximum speed, acceleration, weight, volume... For the sake of simplifying, we will not go into details on the mechanical losses of the motor, control, electronics power…

First, we are going to shortly present the resistant power depending on the speed of a go-kart.

2 RESISTIVE POWER VS SPEED

The resisting force of the vehicle depends on the kind of tire, their width and the road surface. They are represented by the coefficient $k_{friction}$.
This resisting force is very low compared to the air friction which depends on the air surface you go through, on turbulence so on aerodynamics.
On a non-horizontal track, a slope coefficient has to be taken into account. This coefficient depends on the mass of the vehicle and the percentage of the road slope.

To calculate the resistive power of a vehicle, it is easier to use the speed S in km/h with the following equation:

$$P_{resistive}(W) = k_{aero} \cdot S^3 + (k_{friction} + k_{slope}) \cdot S(km/h) \quad (1)$$

with $k_{Slope}(Watt/(km/h)) = M(kg) \cdot g \cdot Slope(\%)/3.6$ and k_{aero} in $Watt/(km/h)^3$.

Power versus speed in steady state can be observed in the following picture [1, 2]. It takes 17 kW to drive at 120 km/h on a flat road. This figure is experimental, taking into account the losses of the motor.

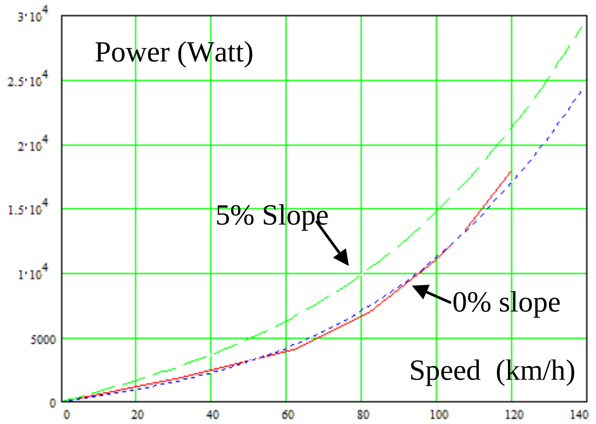

Fig. 1. Power traction vs speed. M = 250 kg, k_{aero} =0,0067 W/(km/h)^3, k_f=45 W/(km/h)

The aerodynamic coefficient can be limited thanks to a composite fiber streamlining as shown in figure 2. When you reduce the aerodynamic coefficient, you can reduce the size of the motor or increase the autonomy of the vehicle.

Fig. 2. Electric go-kart with thick plastic strip.

In the previous figure, we can see a very thick plastic strip around the go-kart in case of crash. Safety is essential with students and it also helps to protect the equipment.
Now let see what accelerating torque an electric go-kart must have.

3 ACCELERATION TORQUE

Because of batteries, an electric go-kart is heavier than a petrol go-kart. Its mass with a driver is around 250 kg. To reach a speed of 100 km/h in 4 s, the accelerating force of the motor must be higher than the value given by the following equation:

$$F_{motor} = M\frac{dv}{dt} + F_{Resistive} = 1736N + F_{Resistive} \quad (2)$$

The acceleration force the motor will develop depends on the value of the speed reduction so on the choice of the maximum speed. There is a compromise to be done between the maximum speed (4) and the accelerating force (3) that can provide the motor and controller.

$$T_{motor}(N.m) = (F_{wheel} \cdot radius_{wheel}) \cdot Gear \quad (3)$$

$$V_{max}(m/s) = N_{maxmotor} \cdot 2 \cdot \pi \cdot Gear \cdot radius_{wheel} / 60 \quad (4)$$

$$N_{max\ motor}(rpm) = U_{battery\ max} \cdot 60/(k \cdot 2 \cdot \pi) \quad (5)$$

$$T_{motor}(N.m) = k \cdot Intensity_{motor} \quad (6)$$

The choice of the gear transmission favors acceleration or the maximum speed. We will see how to optimize it.

3.1 How to choose the right speed

Electric motors generally have a maximum speed of approximately 4000 rpm. Therefore, a reducer must be put between the motor and the transmission shaft that adjusts the speed of the go-kart and allows a better accelerator torque. Toothed belts are used between the motor and the transmission shaft. With the level of the accelerating torque, tension of the toothed belt must be important in order that it remains engaged with the rings. This causes significant losses. As an alternative, it is possible to use chain transmissions: they are noisier but use far less energy.

The table 1 show an example of two values of transmission pulleys in a twin-motor-go-kart whose current is limited to 200 A per motor by the controller supply. Motors have a constant torque or speed of k = 0.17 Nm/A or V/rad/s eq. (5)(6). They provide a maximum torque of 65 Nm per motor.
The following table gives the maximum speed, inertia reduced to the motor shaft, time to reach 50 m, and the current in steady state speed.

U_{batt}	I_{limit} motor	Gear D_m/D_a	Inertia $kg.m^2$	S_{max} km/h	t(50m)	$I_{battery}$ (A) steady state
72V	2 x 200A	25/44	1.26	112	5.3 s	210 A at 112 km/h
72V	2 x 200A	17/44	0.58	75	4.4 s	70 A at 75 km/h

Table 1. Go-kart characteristics depending on the reduction ratio of the gear.

The speed reduction level to reach a distance in a minimum of time is determined by the equation:

$$Gear = \left[Distance \cdot \frac{(Torque_{motor} - Torque_{load})}{N^2 \cdot (\frac{2 \cdot \pi}{60})^2 \cdot radius^3 \cdot Mass} \right]^{\frac{1}{3}} \quad (7)$$

To simplify the calculation, the load torque is neglected compared to the motor torque.
We need a reduction of 13/44 for a go-kart on an indoor track with straight lines of 50 m maximum. So we need a gearbox to optimize the transmission. Besides, this is why the “taper lock” is selected with a variety of gear. With the change gear, the engine mount should be adjustable for a right tension of the belt or chain.
According to the previous table with a reducer of 17/44, the figure 3 shows the acceleration and speed of the motor versus time. Braking torque is less than or equal to what the engine can do. So this kind of electrical braking is relatively long and is not used in competitions. Indeed, on a racetrack, it is better to brake late and strongly.

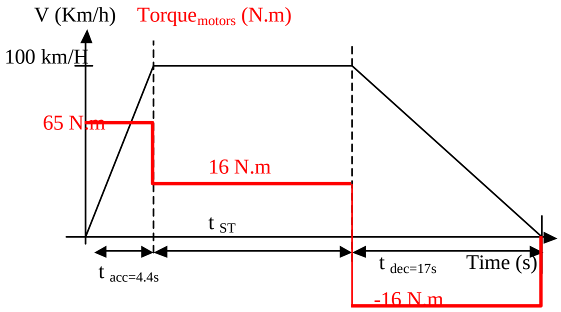

Fig. 3. Evolution of the speed and torque of a motor with a 17/44 gear.

Now we will see the impact of speed on the motor temperature.

3.2 How to choose the right current limiting

Therefore, we must determine the equivalent thermal current of the motor during one lap from the following equation:

$$I_{m\ equ} = \sqrt{\frac{\sum_{i=1}^{n} (I_n)^2 \cdot t_i}{\sum_{i=1}^{n} \cdot t_i}} \quad (8)$$

I_n is the motor current during the time t_i. The equivalent thermal current must be lower than the rated motor current.
Because of the successive accelerations and electrical braking, you can quickly exceed the rated current and destroy the motor. Motors used on competition go-karts require forced ventilation which consumes hundreds of watts.
Now that the motor power required and the choice of the gear is known, we will see the different kind of motor drives.

4 MOTORS AND CONTROLLERS

The dilemma of electric motors is to have outputs power from 10 to 20 kW with low voltage batteries from 48 V to 96 V, for relatively important current. In order to use industrial controllers that operate at 400 V DC, voltage boost converters can be used to increase the battery voltage. These voltage boost converters have never been developed because industrial motors are radial flow in-runner and relatively large. Motors must not have a too high speed to minimize the gearbox size, so they rather be axial flow and out-runner to have more torque. Out-runner motors are easier to cool. Three technologies of motors used on go-karts and presented in Table 2.

Technology of the motor	Max. voltage	I_{rate} A	I_{max} A	P_{max} kW	Mass kg	Length×Ø = volume cm^3	Price in 2014	N_{max} rpm	protection ingress
DC brush	72 V	190	400	14	11	11×20 = 690	2100 €	4000	IP 22
DC brushless	48 V	300	400	14	2	8.5×11 = 290	1300 €	8000	IP 22
Asynchronous	28 V	150	300	10	20	30×18 = 1700	2000 €	4500	IP 55

Table 2. Comparison of different go-kart electric motors.

DC motors are associated with DC choppers or H bridge converters which limit the starting current. DC motors are smaller and allow operating with 2 motors on the same shaft in order to add the torque. 2 choppers are often used to provide the motors supply with the same torque depending on the acceleration throttle.
The following experimental curve presents the voltage and current of an electric twin-motor-go-kart according to time, with adjustment of the motor current at 250A for each motor.
In the following figure, the motor torque is 80 Nm at 500A because the constant torque of our motors is 0.17 Nm/A. Torque mechanical losses are about 2.5 Nm with a no-load current of 15 A. Therefore, the torque loss is negligible compared to the starting torque of the two motors.

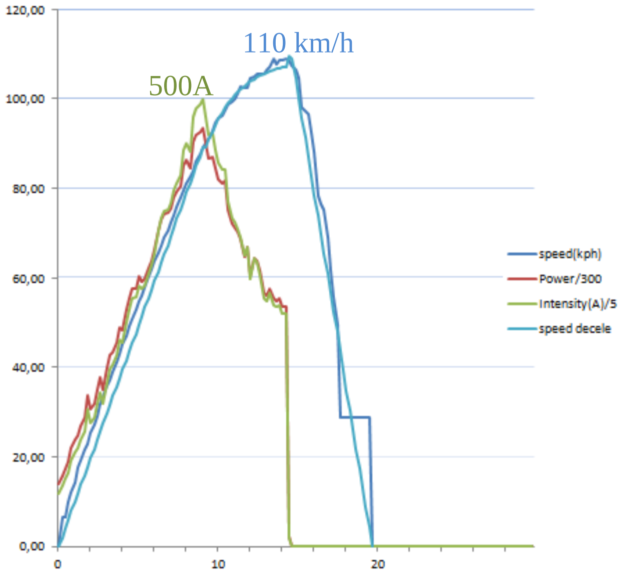

Fig. 4. Speed and intensity with twin-motor-DC 28 kW rating power with a battery voltage of 70 V and a gear 30/44. Start at 100 % throttle and mechanical brake stop after 13 s.

Although the differential equations (1) and (2) are not linear, the change in speed according to time can be simply modeled by the equation (9).

$$\text{Speed}(t) = \text{Speed}_{\text{steadystate}} + (\text{Speed}_{\text{initial}} - \text{Speed}_{\text{steadystate}}) \cdot e^{\frac{-t}{\tau}} \quad (9)$$

τ is the time constant.

If the initial speed is zero, the time constant τ is calculated for 63% of the final speed of 110 km/h, so for 70km/h. The response time is τ = 6.5 s.

DC motors require a lot of maintenance and are increasingly replaced by smaller out-runner brushless motors. But inverter controllers are more complex than choppers. Indeed, you need a three-phase inverter to supply the coils according to rotor position sensors.
The induction motor in Table 2 is larger so it is not easy to install two motors. The drive of the asynchronous motor is a vector control: This allows a maximum starting torque and holds the vehicle at zero speed without using a parking brake. The asynchronous motor is protected against water jets (protection ingress IP 55) and is ideal for go-kart rental or industrial applications.
Every drive can return energy to batteries, but may damage the batteries if the energy is too high. We will now see some batteries technologies commonly used on electric go-karts.

5 BATTERIES

The standard power supply solution for electric go-kart is to use four 12 V lead acid batteries in order to obtain 48 V with 48 Ah for example. With a 10 kW motor, the operating time of a go-kart is about 10 minutes, with a charging time of less than 20 minutes at 80 A. Twin-motor go-karts need 54 kW to start and only 10 kW to 30 kW are supplied at 72 V, in order to minimize the intensity from batteries. In Table 3, we can observe that the higher the discharge rate is, the higher the price of the battery will be. Similarly, we can observe the

size, weight and power capacity depending on the energy source.
Figure 5 shows two go-karts with the same twin motors but with 2 different batteries technologies. With Litihum LiFePo batteries, weight is divided by 2 while autonomy is increase by 4. This Lithium electric go-kart has an operating time of about 30 minutes at 110 km/h.
For example, a 400V batteries can be done with 100 cells of 20 Ah in series for a battery cost of 5,000 €. Then the use of industrial motor and controllers is possible [6]. The main disadvantages are electrical security due to high voltage, the battery volume and the Battery Management System (BMS) to manage the Lithium cells.
The following table shows a discharge rate which causes a significant increase in the price of the battery and shortens its life time [3]. The price and the weight of a go-kart will mostly depend on the technology of the battery.

Fig. 5. Electric Go-Karts, rating motors 28 kW :
48V lead-acid batteries on the left and 72V LiFePo batteries on the right. International e-Kart Challenge in Vierzon (France) 2011.

Battery technology for 72 V	Assembly	Energy Wh	Size in cm & Volume in dm^3	Mass kg	Price in 2014	Max charge rate	Max discharge rate
Lead acid 48 Ah	6S	1440	6 × 20×17.5×24 = 50 dm^3	102 kg	1600 €	100 A = 5 C	400 A = 8 C
LiFePo 90 Ah	22S	6480	22 × 14×6×22 = 41 dm^3	68 kg	2800 €	90 A = 1 C	300 A = 3 C
Li-Po 100 Ah	18S	7200	18 × 45.5×32.5×0.8 = 22 dm^3	49 kg	7000 €	100 A = 1 C	500 A = 5 C
Super capacity 3,000 F	36S	66	36 x Ø6.4×13.8×36 = 23 dm^3	18 kg	1800 €	147 A	2165 A

Table 3. Some technologies of batteries for electrical go-kart [4].

As a result, finding the good compromise for an electric go-kart is not easy because all the elements specifications are related.
For example, if you want to go faster, the traction power will be more important, so the motor will be heavier and more expensive. That is the same for batteries. You will use more energy or more efficient technologies so your budget will increase too. The volume of the embedded energy is limited on this type of vehicle as shown in the following figure.

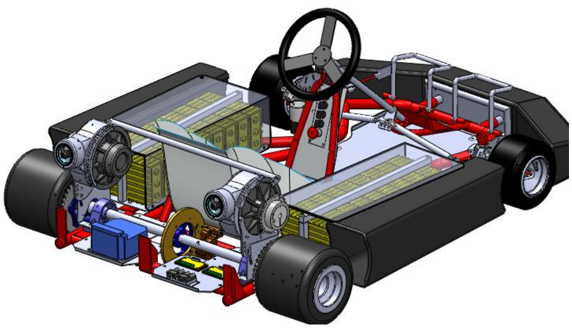

Fig. 6. Study of gravity center, aerodynamics, volume, cooling and mechanical protections on SolidWorks before building.

The mass of the batteries involve additional pressures on the frame (straight lines and bends). Every force and pressure study on the frame are done with the SolidWorks software.

The deformation simulation of the frame in a bend can be observed in the following figure. Purple arrows correspond to the masses of the batteries and the driver, the green squares correspond to the blocking of the chassis.

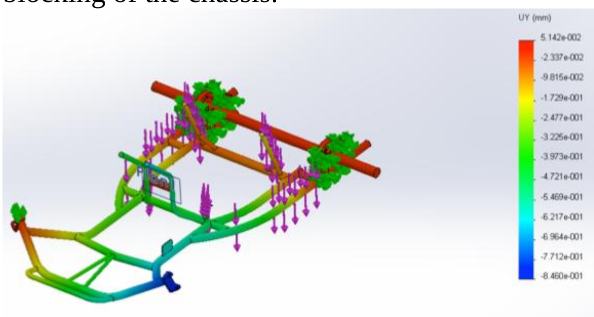

Fig. 7. Study of deformation in a right bend on the frame of a go-kart – Red ⇔ +514 Nm – Blue ⇔ -86.4 Nm.

A competition go-kart requires high acceleration but also late braking (important deceleration). If the rear hydraulic braking is conventional with ventilated brake disc, front brake discs have been made floating on special hubs.

Fig. 8. Study of floating front brake by the students of Mechanical Engineering IUT of Aisne.

6 HOMOGENISATION OF THE TECHNICAL OPTIONS

The first go-kart made in 2011 was composed of two 14 kW motors with 24 LiFePo 90 Ah Lithium cells. Both motors are controlled by two 100 V controllers that can provide during one minute a maximum current of 600 A and a nominal current of 300 A. Limiting the current of the controllers is not a problem because it is beyond what can bear the motors. 90 Ah batteries can provide a discharge current of 800 A during 1 minute. In addition, a constant discharge rate of 9C can't be withstand by the battery. But with this current, the acceleration is so important that the tires lack grip and it is difficult to control the go-kart. We have seen that homogenization of techniques is very important to build an electric vehicle. It is not worth having overpowered engines if batteries cannot provide the needed current. Indeed, that is why the voltage of batteries has increased from 48V to 72V and 96V in 2014.

Petrol go-kart races last for about 10 to 15 minutes and there is time to recharge between each round (more than one hour). At the International Pedagogical Electric Go-kart Meeting, the race lasts for 4 hours with 2 electric go-karts. So, another problem is to have fast and safe battery chargers.

7 BATTERY CHARGER

This part of the challenge means that while one of the go-karts is running, the other one is being charged. Battery autonomy and especially their ability to be fast charged are very important for this event. Indeed, batteries should be charged as much as they consume and chargers must provide important currents. The more the chargers can provide an important current, the more expensive and difficult to build they are.
Batteries are charged at a constant current and then at constant voltage, as shown in the following figure.

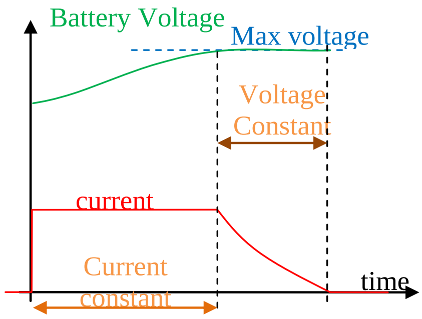

Fig. 9. Main steps of a battery charger [8].

Each team have a 240 V single-phase plug with a 32 A fuse, or a 400 V three-phases plug with a 6 A fuse which allows you to charge a 72 V battery with a current near 95 A (≈ 7000 W) if the charger have a unity power factor.
The structure of the power electronics stage of the charger is presented in the following figure.

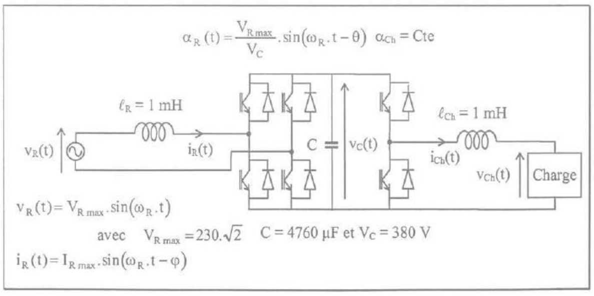

Fig. 10. Power electronics stage of a non-insulated single-phase power factor correction charger [7].

With a three-phase supply, the structure is more difficult to understand and to realize. Furthermore, control is not easy to do knowing that there are many control strategies in analog or digital means [5]. Developing a reliable charger takes time and a lot of study.
Many works on this topic have been published: rapid charging and reducing the volume of a high power charger embedded in an electric car (7kW to 22kW) [7, 8, 9].
Reducing the size and weight of a charger is a priority so that it can be easily moved and will be cheaper than one with a 50 Hz transformer.
Concerning Lithium batteries, it is necessary to check that the voltage of each cells never exceeds threshold of 3.70 V for LiFePo and to monitoring their temperature. These are control by the Battery

Management System (BMS). The charging current must decrease to a lower value in order to maintain all the cells voltage under the voltage threshold. If one cell is 100% charged and current becomes zero, the other elements may be charged under 100% and there will be an unbalanced charge.
So every 10 charges, elements should be charged independently in order that they would all be 100 % charged (well balanced). Since there are a large number of cells, you need a lot of independent and insulated chargers, but it is possible to charge slowly with a current of C/10 to C/20 of the energy capacity, so the charger current is about 5 A. This solution is still quite expensive, so many manufacturers have made balancers with resistance that discharge the most charged cells. But the discharge current is only 0.3 A to 0.5 A and it will take a lot of time to well balance all the cells.
The figure 11 shows the disparity between the voltages of each elements according to time: one element is charged to the threshold voltage of 3.7 V (100% charge), and the other elements are unbalanced. LiFePo elements, after being charged up to 100%, decrease to 3.30 V, so there is the phenomenon of "floating charge" (trickle charge) as on a lead-acid battery.

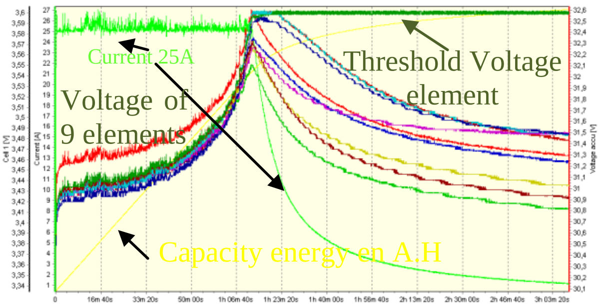

Fig. 11. Charging of 8 LiFePo cells 40 Ah at 25 A – Voltage, current, energy versus time [13].

BMS must protect each cells of the battery against:
- Over-Voltage during charging,
- Over-Voltage during braking,
- Under-Voltage during discharge (useless because you can no longer ride, but useful if you forget to turn off the drive).

In fact, if a battery is 100% discharged, the Lithium cell get in short circuit and will be destroyed. BMS must switch off the battery when the power capacity is less than 15%.
BMS must measure the temperature rise of each battery cells, but the number of sensors and the monitoring of the temperature is complicated. In addition, thermal time constant does not allow having a good protection and safety against thermal divergences.
Building a BMS is not an easy thing and costs between 25% and 50% of the price of a battery. We will study the need for the BMS functions:

- If the drive does not brake electrically, there is no need to embed the detection of the high voltage of the cells, because it is possible to integrate the monitoring of all cell voltages to the charger. Therefore, the threshold voltage of each element cannot be exceeded and the charger performs the balancing.

- On the contrary, with a battery charger without any balancing, a BMS will be necessary to discharge the cell that will be charged up to 100%. But in general, current deflected by BMS is only 0.3 A.

- Go-kart prototypes often use different voltages taken on intermediate cell battery for signaling and instrumentation for example. This unbalances the elements and requires the BMS to balance the cells.

- During electrical braking if the battery is charged between 100% and 95%, as the current deflected by BMS is low, then BMS will cut the battery. This disconnection is dangerous for the driving because the electric brake no longer functions.

- If the battery is at 100% charged at a temperature of 20° C, an increase of 30° C (exposition to direct sunlight for example), then the voltage of the cells will increase and may exceed the threshold voltage: the battery may catch fire. So BMS must discharge the cells before this can happen.

- If a cell is at the end-of-life and becomes thermally unstable, BMS can disconnect through numerous temperature sensors and prevent your battery from catching fire.

- BMS can communicate with controllers in order to limit the rate of discharge of the battery, if one cell is at a low voltage level.

From Table 3, we can see that the rate of discharge of batteries is low compared to the current that can be supported by motor-drives.
Using super-capacitors can be considered to provide the pulse current required for each accelera-

tions, as well as getting back the current from braking.

8 SUPER-CAPACITORS

Super-capacitors presented in Table 3, are used to provide high transient current but they have a low energy ability compared to the battery. Another advantage of this component is to have a number of cycles of charging and discharging 1000 times greater than the one of a battery. They are quite expensive despite decreasing prices in recent years.
It is therefore interesting to combine electrical advantages of super-capacitors to the ones of batteries. But a compromise between size, weight and price must be found.

Price and size of super-capacitors do not allow yet a sustainable use for an electric go-kart.

After having presented technical solutions, we will see how electric go-karts can be pedagogically exploited.

9 EDUCATIONAL APPLICATION

We need to examine all the possible motor technologies, different solutions for drives, batteries, chargers, issues about on-board power saving, Battery Management Security and how to make technical choices.
Indeed, the electric vehicle is an excellent teaching aid to develop electric converter and programming the micro-controller that controls the motor or the charger.
The French International Pedagogical Meeting e-Kart provides a high motivation to students in order to study, perform, improve and get on podiums.
While building an electric vehicle, every aspects of electrical engineering is used:

- Energy saving with embedded batteries.
- Power electronics via chargers, controller, BMS, wiring, LED drivers...
- Electronics with embedded instrumentation to measure speed, distance, energy capacity, temperature and send data to the pits.
- Computer science to run the data.
- Micro-computing to program microcontrollers, converters, BMS, chargers…
- Automatic engineering to regulate motor currents, to limit the voltage of chargers.
- Mechanics in the study of dynamic systems, brakes, composite streamlining to minimize aerodynamics...
- Thermal science with the study of the overheating of electric go-kart components.

Temperature instrumentation is very important on motors, converters and batteries. During competition, equipment is taken to extreme. So a large panel of temperature sensors can be used as well as thermograph cameras. Thermograph science detects any hot spot on the vehicule.
Moreover, on the following figure, we can see that connectivity, drives and motors have a relatively moderate increase in temperature.

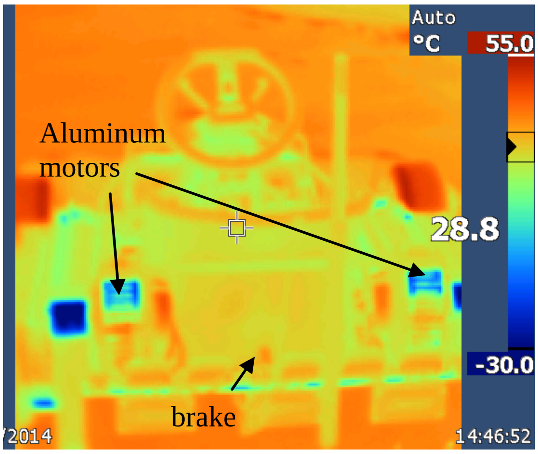

Fig. 12. Electric go-kart thermograph after 15 minutes running, ambient temperatures 22°C,

Currents are so important on motors that they generate many electromagnetic disruptions. So wiring and electronics must be paid a special attention to electromagnetic compatibility (EMC).
We have seen that mechanics are very important even though many parts are accessible in catalogs. Adapting a double electric motor on a petrol go-kart chassis is not so easy. In the latter, direction and seat are not in the axis of the go-kart. Therefore, it is necessary to cut every part and weld them back being sure the welds will bear vibrations and the battery weight.
Studying a chassis with its twists, stress forces, is not so easy even with the latest software tools.
Some parts are made with 3D printers and coated with carbon fiber to improve their rigidity such as motor ventilation racks, dashboard...
On some electric twin-motor go-karts, a differential on the rear axle is added. This differential offers better road-holding qualities in curves and energy saving.

Building crankcase and fiber composite streamlining is important: they prevent from electric shocks and allow driving even when it is raining.

One can observe that the list of technological and educational opportunities is very broad and is not exhaustive. It allows making multi-technological lessons.
Making posters and websites to communicate takes also lot of time and allows evaluating the understanding of students [12, 13]. This communication helps to increase promotion and recognition from universities.

During the challenge, motors are pushed to their thermal limits, and it is the same for controllers and batteries. So students must make many tests to set controllers in order to have a reliable electric go-kart and make sure they won't destroy it until the end of the race.

10 EXAMPLE OF TESTS

On a 2-motors go-kart, both motors must work identically. However, both motors have very slight differences concerning their internal electromotive forces and their resistance. Therefore, controllers must be set to solve this problem.
You can see in the following figures motors bearing several accelerations. Measurements of currents of both motors were nearly identical.

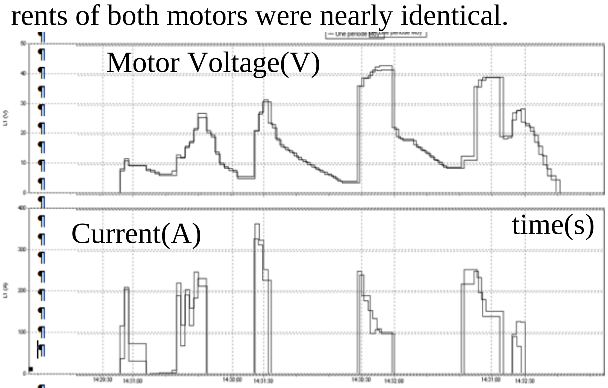

Fig. 13. DC motors voltages ant currents of the two motors vs time during a test tracks.

Electrical devices will work and be cooled differently according to straight lines, bends and also in terms of chosen gears.
Therefore, setting the maximum current will depend on the necessary cooling and forced ventilations required. On the table 4, we can observe the different values of the time constants according to the current limitation and the speed gear reducer.

U_{max} 72V $I_{limitation}$ (A)	Gear reducer	Inertia kg.m^2	S_{max} km/h	Time (s) 63% S_{max}
250A	44/30	1.9	110	11.2 s 70 km/h
500A	44/30	1.9	110	5.5 s 70 km/h
1000A	44/30	1.9	110	2.7 s 70 km/h
500A	44/15		56	1.36 s 35 km/h

Table 4. Dynamics measures of 28 kW electric go-kart.

The number of tests can be very important to check the dynamics of a vehicle. There are also the braking tests depending on the quality of tires. Students must be methodical while testing and understand the issues about motors and their limits.

11 CONCLUSION

Designing and building an electric go-kart is a very good teaching project for students in Electrical and Mechanical Engineering.
This article shows that electric go-karts have the same dynamics as competition petrol go-karts, with an honorable autonomy of 20-30 minutes. Similarly, the charging time is relatively short, less than an hour to charge a battery.
Each year, the French International Pedagogical Meeting e-kart brings together 30 teams with 40 electric go-karts and 220 participants.
Organizing a challenge is not so easy. You have to deal with registrations, hotels, restaurants, make a racetrack on a car park, set up pits, install electrical terminals for each team, register the teams' times, recruit race commissioners, handling and manage spectator's safety. 40 go-karts require three-phase AC power supply of 400 V 125 A 150 kVA.
Teams are awarded for 50m-race starting-stop and run and the best lap times. There are also two mains races: the 2 hours with 2 go-kart per team and the other one of 4 hours 4 ho-kart per team.
Each team is awarded with one or more prizes by a Pedagogical Jury: for example the Battery Award, the Signaling Award, the Motor Controller Award, the Mechanical Design Award, the Onboard Instrumentation and Supervision Award, the Educational Work Award, the Safety Award,

the Best Poster Award, the Best Website Award and the best promotional video [15].

An electric go-kart costs between 4000 € and 9000 € depending on the technology used. 9000 € is the price for a competition petrol go-kart.
Power consumption cost is 5 times lower with electric go-kart. In addition, electric go-karts require less maintenance than petrol ones.
Students are highly motivated by this kind of project because they feel helpful in answering a society need to minimize our impact on the planet and improve our energy future.

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Fig. 14. go through technical inspection with weighing (2014)

Fig. 15. Ready for start (electric go kart 2014)

Fig. 16. picture of together and on the race track (2013)

Fig. 17. Many cups and podium