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Modelling and Simulation of a Solar Racing Car under MATLAB Simulink

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ABSTRACT: in this article we present the dimensioning the modelling and a simulation study of a solar car race with its traction chain and its energy system. The most important components in addition to the chassis and the body of the vehicle are the motor drive system and the on-board power supply. The management of the energy flows is an important task to guarantee the best possible autonomy. The solar system with the MPPT technique and the storage battery are modelled to power a DC motor. Simulations are made for different loads and speed profiles.

KEYWORDS: Solar car, Solar Ennery, MPPT Solar race

I. INTRODUCTION

Solar energy is a topical issue; it's used on a large scale. Individual, collective, connected and unconnected installations are highly developed. On the other side, mobile installations such as solar vehicles, Dependent on many parameters and require a detailed study and better management to guarantee efficiency and profitability.In this article, we treat the modelling of a solar car and the forces which oppose to normal progress and create a resistant torque. We present the study of the energy chain, the solar panels, the converter with MPPT charging technique, the storage battery and the speed controller. The responses in speed and torque of the electric traction allow to evaluate the performances of the vehicle and to predict the autonomy in energy.The weight of the vehicle constitutes an obstacle to the advancement. This weight becomes a resistant force in case of a positive slope. The forward speed which is a characteristic performance constitutes the most resistant aerodynamic force, hence the need to reduce this force by opting for a shape with a reduced frontal surface.

II. MATHEMATICAL MODELLING OF THE RACING CAR

The forces exerted on a moving car are: the aerodynamic resistance forces, acceleration force, slope and resistance to movement forces. These forces are illustrated in Fig (1) [3,12,13]:

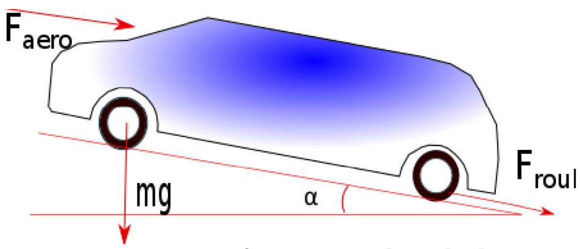

Fig 1: forces on a solar vehicle

At the equilibrium the sum of forces is zero:

$$\sum F_x = 0 \tag{1}$$

$$F_{tot} = F_{roul} + F_{aero} + F_{pente} + F_{acc} \tag{2}$$

$$F_{roul} \approx g M_v C_{rr} \tag{3}$$

$$F_{aero} = \frac{1}{2}\rho S_f C_{px}(V_{veh} - V_{vent})^2 \quad (4)$$

When the wind speed is negligible, this relationship becomes:

$$F_{aero} = \frac{1}{2}\rho S_f C_{px} {V_{veh}}^2 \quad (5)$$

$$F_{acc} = M_v \frac{dV_{veh}}{dt} \quad (6)$$

$$F_{pente} = g M_v sin\,(\alpha_p) \quad (7)$$

$$F_{tot} = g M_v C_{rr} + \frac{1}{2}\rho S_f C_{px} {V_{veh}}^2 + M_v \frac{dV_{veh}}{dt} + g M_v sin\,(\alpha_p) \quad (8)$$

With:
F_{tot} : total force
F_{roul} : rolling resistance force
F_{aero} : aerodynamic force
F_{acc} : Acceleration force
F_{pente} : Slope force
g : gravity
M_v : vehicle mass
C_{rr} : rolling resistance coefficient
S_f : frontal surface of the vehicle
C_{px} : coefficient of penetration in air
V_{veh} : Vehicle speed
V_{vent} : wind speed
α_p : road slope

The analysis of these forces shows the big influence of the force of aerodynamic resistance, the acceleration force, the slope of the road and especially the total weight of the vehicle.

A simplified model on simulink has been developed to evaluate the forces (Fig. 2 and 3), and the required motor power.

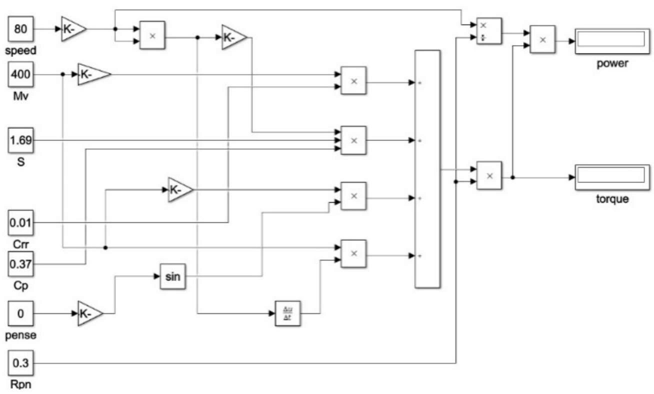

Fig 2 : Model simulink of forces on a solar vehicle

The simulation makes it possible to calculate the power required for traction with wheels and tires with a radius 'Rpn'. For a solar car of 400 kg, and 80km / H of speed, the necessary power of traction is 4kW.

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Fig 3 :simulink model of a solar vehicle with acceleration forces

The accelerating forces impose a very strong torque and disappear when the speed reaches its final value (8) (Fig 4).

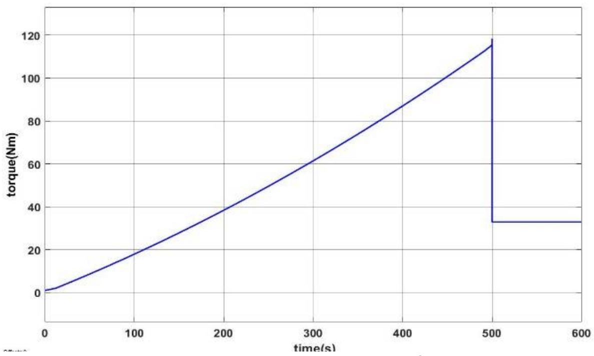

Fig 4 : acceleration torque depending for positive acceleration

Solar racing cars must respect a canvas imposed by the organizers of competitions. An example of constraints is:

Maximum length=4.5m; Maximum width=1.8m; Surface of solar panels≤6m²; Storage battery Capacity ≤5kWh

For an example of parameters, we can take (Fig5) :6m² of PV, 23% 1300W,Battery : 25AH, 120V,Total weight : 250kg,DC Motor,Body with composite.

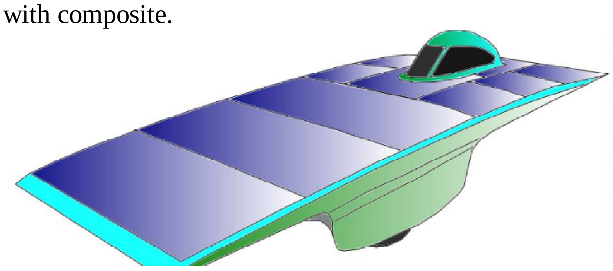

Fig 5: example of design for solar car

The motorization is made by a motor wheel, two rear wheels and a system of control and variation of speed (Fig 6). The motor can be DC one or a Brushless based technique. The drive acts on the speed of the motor, the control is made by the accelerator pedal.

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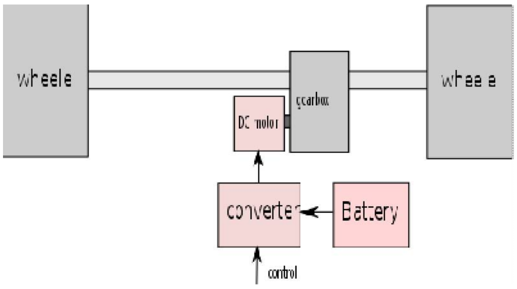

Fig 6: Single-engine model with mechanical gearbox

The Vehicle speed "*Vveh*" in km/h is related to the motor speed by the following relation:

$$V_{veh} = \frac{D_{pn}}{2}\Omega_{roue} \quad (9)$$

Vehicle speed: V_{veh} (m/s)
Tire diameter: D_{pn} (m)
Tire speed :Ω_{roue} (rd/s)

$$\Omega_{roue} = k_r \Omega_{Mot} \quad (10)$$

Gearbox coefficient: k_r
Motor speed: Ω_{Mot} (rd/s)

$$\Omega_{Mot} = N_{mot}\frac{2\pi}{60} \quad (11)$$

N_{mot}(tr/min)
The vehicle speed in km/h is expressed as:

$$V_{Veh} = D_{pn} k_r N_{mot}\frac{3.6\pi}{60} \quad (12)$$

Vehicle speed in km/h :V_{Veh} (km/H)

III. MODELING OF THE ENERGY SOURCE

The power source consists of:

- Solar panels
- Battery charger
- Battery
- DC converter
- DC motor
- Mechanical gearbox
- Control, measurement and signalling system

The PV array is a five-parameter model using a current source I_L (current generated by light), a diode (parameters I_0 and nI), a series resistor R_s and a shunt resistor R_{sh} representing the current and voltage characteristics (I-V) of the panels [11].

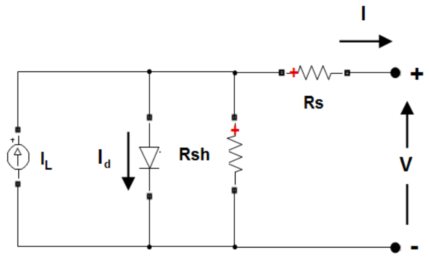

Fig 7 : Equivalent model of a photovoltaic panel

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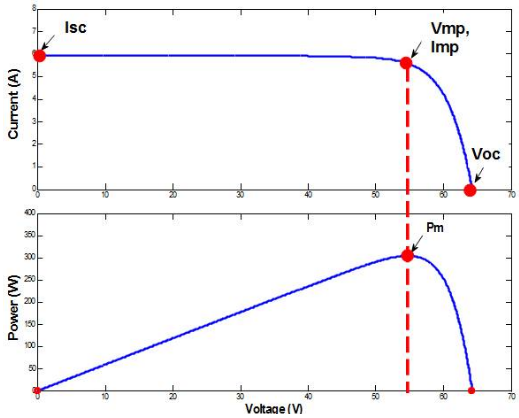

Fig 8: Characteristics I (V) P (V) of a Solar Panel

The voltage-current characteristic of the solar panel is given as follows:

$$I_d = I_0(\exp\left(\frac{V_d}{V_T}\right) - 1) \quad (13)$$

$$V_T = \frac{KT}{q} \times nI \times Ncell \quad (14)$$

with:
I_d= diode current (A)
Vd= diode voltage (V)
I_0= diode saturation current (A)
I_L=light current (A)
nI= diode ideality factor, a number close to 1.0
k= Boltzmanconstant = 1.3806e-23 J.K-1
q= electron charge = 1.6022e-19 C
T= cell temperature (K)
Ncell= number of cells connected in series in a module

The solar car in motion must absorb the maximum energy of the solar panels. The flow direction and orientation of the panels requires the use of a fast MPPT algorithm. The solar energy must be completely transmitted to the battery and the motor.

The solar panels of 6m² can generate 1200W. Serial, parallel or mixed mounting depends on the type of the used DC-DC converter (Fig. 10 and 11). The power developed depends on the irradiations and the temperature (Fig 8 and 9)

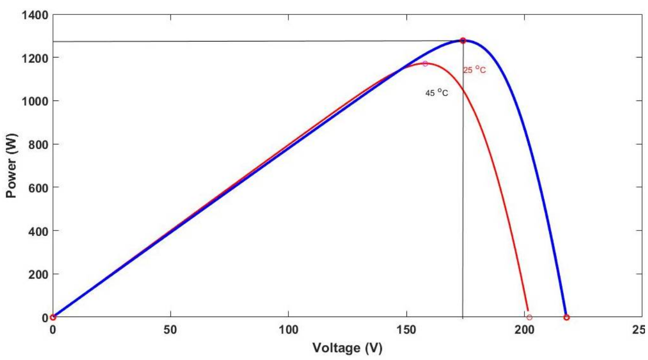

Fig 9: Dependence of the maximum power point of the temperature

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The search for the MPPT [1] is made by the same DC-DC converter and controlled with the "perturb and observe" (P&O) algorithm of the Fig (12).

The current and voltage of the PV are measured, the sign of dP (derivative of the power) gives an indication of the position of the MPPT, a decision is taken subsequently to increase or decrease the duty cycle(D).

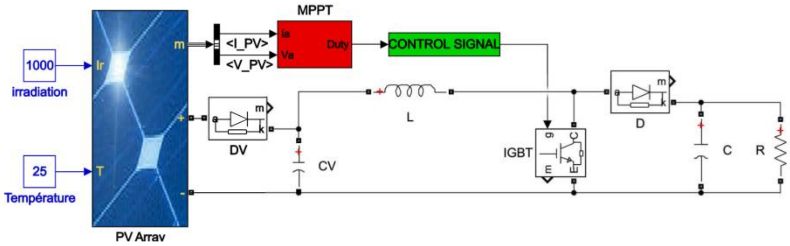

Fig10: boost MPPT converter

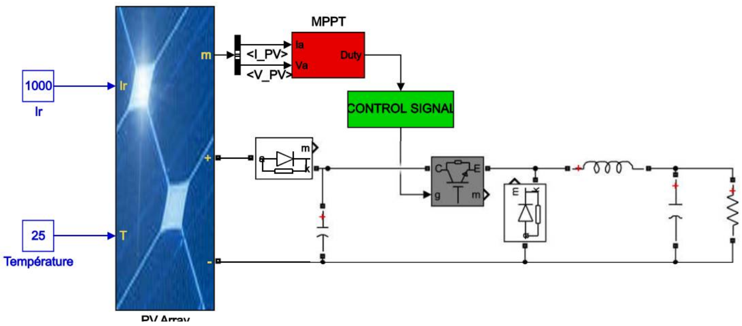

Fig 11: buck MPPT converter

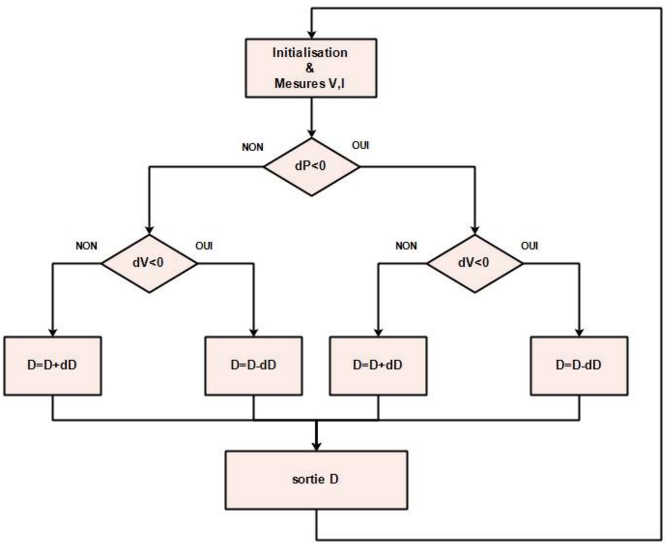

Fig 12: P&O MPPT Algorithm

For a battery as a load of a buck converter, we have:

$$V_{bat} = \alpha V_{pv} \quad (15)$$

The maximum power point is obtained for.

$$V_{pv\_opt} = \frac{V_{bat}}{\alpha} \quad (16)$$

Fig 13 shows the pursuit of the MPP (maximum power point) for a ramp step for a setting with a low dD.

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Fig 14 shows the power response of the P&O method for two dD settings (0.0001 and 0.001). The high value of dD gives a fast response with oscillations for high powers. A low value of dD gives a slow response but with very low power oscillations [2,7,8].

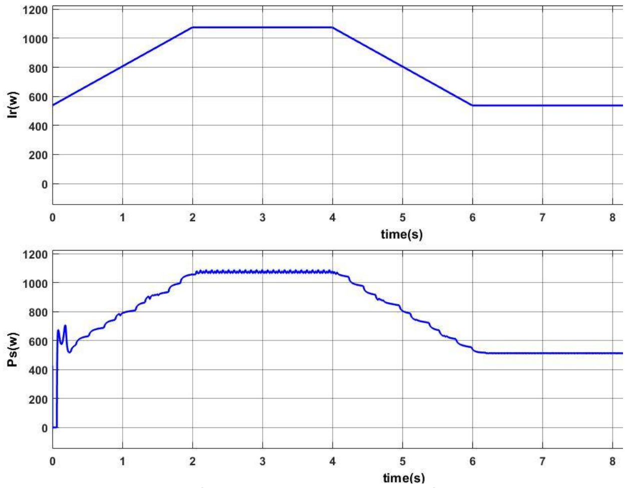

Fig 13 : Power response of the MPPT (bottom) for an irradiation ramp Ir (w) (top)

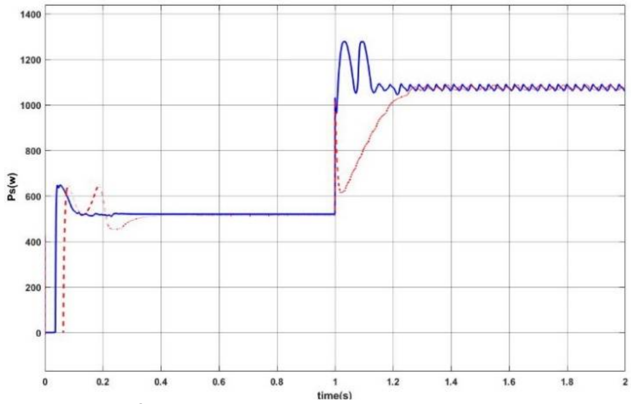

Fig *14: Solar panel power for an irradiation step; For low dD (dashes) and large dD (solid line)*

For the MPP point, the current of the battery is maximum and must be switched off in case of overcharging of the battery (battery protection)[4,6].

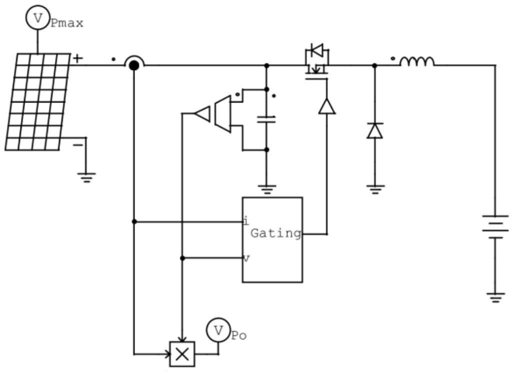

Fig 15 : diagram of a buck chopper MPPT and battery charger

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IV. MODEL OF THE MOTORIZATION CHAIN

The motorization chain can be represented by the following diagram (Fig 16) [5].

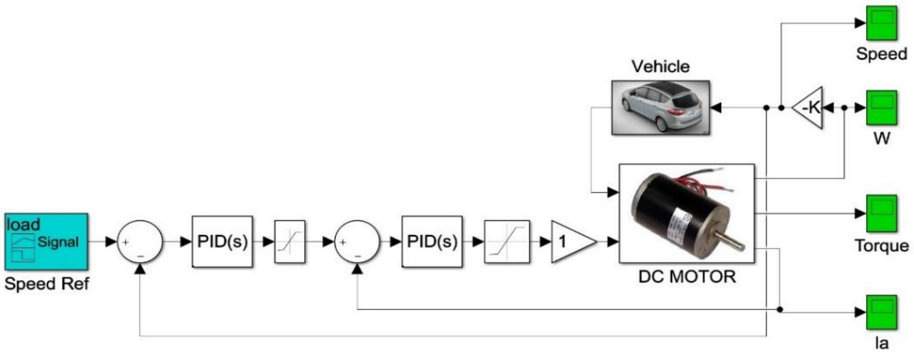

Fig 16: Single-engine model with current limitation

The electromagnetic torque is related to the speed and to the resistive torque by the following relation:

$$j\frac{d\Omega}{dt} = \text{Tem} - \text{Tres} \quad (17)$$

with :
J : moment of inertia,
Ω:rotation speed,
Tem : electromagnetic torque,
Tres : resistant torque

The speed changes according to the following relationships:

$$\frac{d\Omega}{dt} = \frac{Tem - Tres}{j} \quad (18)$$

$$\Omega = \frac{1}{j}\int Tem - Tres \quad (19)$$

$$Tem = j\frac{d\Omega}{dt} - Tres \quad (20)$$

We must act on the torque to modify the speed, current must be limited to protect the machine and be well managed with the supply constituted of the battery and the solar panel with the MPPT technique (Fig 15).

During starting or changing of the speed set point, a high current is required to overcome the acceleration torque.
We have (Fig 17):

$$I_{mot} = I_{pv} + I_{bat} \quad (21)$$

During the starting phase, the current of the battery supplies the motor in addition to the current from the solar panel [9,10] (Fig 18)

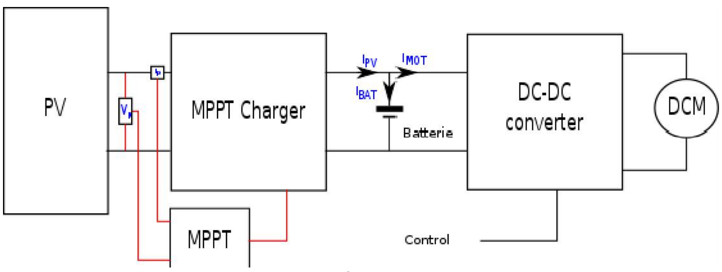

Fig 17 : Currents called for a PV-Battery and motor system

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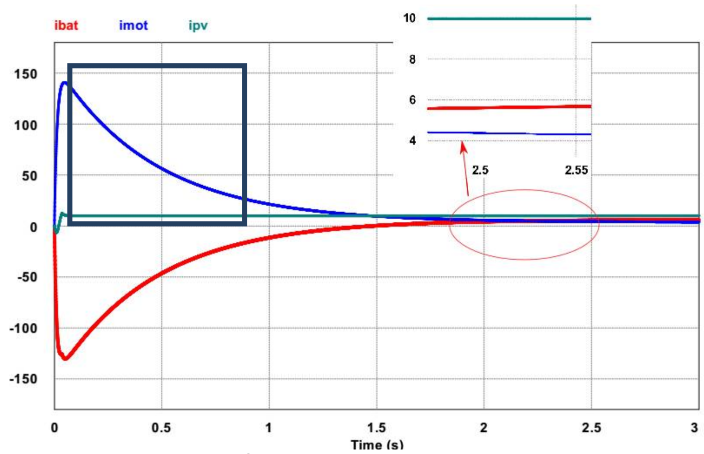

Fig 18 : Currents at the starting of the DC motor: Motor (blue), Battery (Red) and Solar (green)

V. CONCLUSION

In conclusion, this work focuses on the evidence of controlling the energy flow in a solar car. The driving force must overcome the resisting torque by guaranteeing an important motor torque for the acceleration sequences or by facing an important slope of the road. For a given area of solar panels, energy management is imperative to guarantee a better autonomy by reducing the losses and taking maximum advantage of the solar energy and by reserving the energy in the battery for the accelerations and the final phases of a solar car race.

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