SYSTEMIC DESIGN OF ELECTRIC VEHICLES POWER CHAIN OPTIMIZING THE AUTONOMY

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Abstract: *A computer tool permitting to solve the design problem of the electric vehicle power chain maximizing the autonomy is developed. This tool rests on the modeling of the power chain taking in account of the interactions that exists between the design and the control. A descriptive model of the behavior of the vehicle is developed and is coupled to the average model of the autonomy has permitted to fix the parameters influencing the middle autonomy on a mission of circulation, what drove to a dynamic optimization problem to several variable and constrained. This problem solved by the method of genetic algorithms drove to encouraging results. The vehicle conceived around an optimal autonomy on a circulation mission using a motor to permanent magnets to axial flux and to weak cost of manufacture present an interesting solution thus encourage their production in big set.*

Key words: *Losses, Electric Vehicle, Autonomy, Engine, Converter, Optimization.*

1. Introduction

The major problem of the electric vehicles is the storage of the energy directly bound to their autonomy. Indeed the production in big sets of the electric vehicle (EVs) is essentially hampered by the weak storage capacity leading to a weak autonomy and the problem of battery load infrastructure since the technology of the batteries to fuel is difficult to put in work for problems of hydrogen installation [1]. Otherwise, another not negligible point influencing the autonomy of the EVs is the efficiency of the traction chain [2]. In this setting, we fix like objective to maximize the efficiency of the traction chain since the phase of its design. The methodology proposed to arrive to this objective consists in a first time in mathematically expressing the problem of design of the traction chain maximizing the efficiency or the autonomy, in a second time to apply the method of the genetic algorithms to solve it [6], [7], [8], [9], [10].

2. Electric vehicle power train structure

The structural diagram of the power chain is illustrated in figure 1.

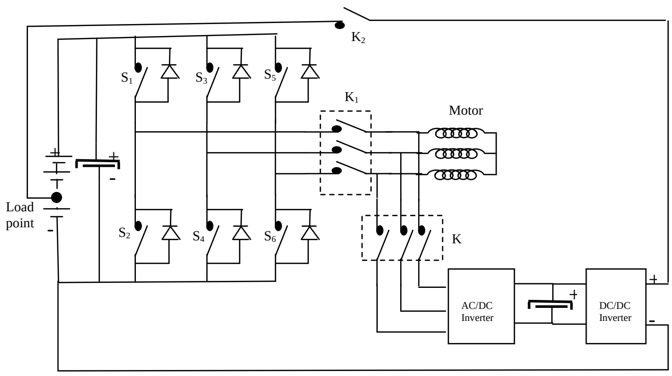

Fig.1. Structure of the power chain

During the phases of acceleration and constant speed operation, the motor is driven by the static converter with electromagnetic switches according trapeze or sinus control strategy which maintains the motor's phase electric current in phase with the electromotive force, which leads to a minimization of the energy consumption. In this case the switches K and K2 are open by action of their generating coils. However, during deceleration phases that relate to a recoverable energy, K1 is opens and K, K2 are closed and this triggers the operation of the energy recovery. In this case the motor operates as a generator. In fact, the three electromotive forces induced by the inertial force of the vehicle are transformed into a high DC voltage by an optimized DC-DC converter in order to maximize the recovered energy by the storage battery in the electric vehicle. This voltage is applied to the battery at the reload node. This node is selected in a way to maximize energy recovery.

3. Dimensioning torque

The back electromotive force (E.m.f) stage level is given by the following expression:

$$E = n \times N_s \times \left(\frac{D_e^2 - D_i^2}{4} \right) \times \Omega \ \times B_e \qquad (1)$$

The instantaneous electromagnetic power $P_e(t)$ is expressed by the following relation

$$P_e(t) = \sum_{i=1}^{m} e_i(t) \times i_i(t) \quad (2)$$

Two phases are powered simultaneously and the currents of phases have the same wave-form as the electromotive force with a maximum value of motor phase current I. Consequently, for a constant speed, the electromagnetic power developed by the motor takes the following form:

$$P_e = 2 \times E \times I \quad (3)$$

The electromagnetic torque developed by the motor is expressed by:

$$C_m = 2 \times \frac{E \times I}{\Omega} \quad (4)$$

The electromagnetic torque developed by the motor results:

$$T_m = 2 \times n \times N_s \times \left(\frac{D_e^2 - D_i^2}{4} \right) \times B_e \times I \quad (5)$$

The electromagnetic torque which the motor must develop so that the vehicle can move with a speed v is deduced from the dynamics fundamental relation related to the electric vehicle dynamic:

$$C_m = \frac{P_f}{\Omega} + C_d + \left(C_b + C_{vb} + C_{fr} \right) + \frac{C_r + C_a + C_c}{r_d} + \left(\frac{J}{R_w} + \frac{M_v \times R_w}{r_d} \right) \times \frac{dv}{dt} \quad (6)$$

The different torques are expressed by the following equations:

$$C_b = s \times \frac{v}{|v|} \quad (7)$$

$$C_{vb} = \chi \times v \quad (8)$$

$$C_{fr} = k \times v \times |v| \quad (9)$$

$$C_r = R_w \times f_r \times M_v \times g \quad (10)$$

$$C_a = R_w \times \frac{(M_{va} \times C_x \times A_f)}{2} \times V^2 \quad (11)$$

$$C_c = M_v \times g \times \sin(\lambda) \quad (12)$$

The phase current becomes:

$$I = \frac{C_m}{2 \times n \times N_s \times \frac{D_e^2 - D_i^e}{4} \times B_e} \quad (13)$$

The dimensioning current is expressed as follows:

$$I_{dim} = \frac{C_{dim}}{2 \times n \times N_s \times \frac{D_e^2 - D_i^e}{4} \times B_e} \quad (14)$$

C_{dim} is the dimensioning torque. This torque is found by the genetic algorithm method on a standardized circulation mission in order to not exceed the limiting temperatures and to minimize the motor mass.

Several methods were proposed to define dimensioning sizes of the motor-reducer torque, based on simplified statistical tools. A first method is based on the determination of the effective torque for a circulation mission in order to take into account the thermal aspect. A second more elaborate approach consists in defining zones of strong occurrences and to take the sizes resulting from these zones like dimensioning sizes. Finally, a last simpler method consists in dividing the torque-speed plan into 4 zones, to take the gravity center of each zone then to consider the gravity center of these four points balanced by the number of each zone points as dimensioning point. These methods have the advantage of quickly providing useful sizes for dimensioning and simulation, nevertheless they do not take into account the problem of electric vehicle consumption minimization. For our approach, the dimensioning torque will be iteratively calculated by the genetic algorithms method in order to satisfy a global optimization of autonomy while respecting the dimensional thermal stresses relating to our application specified by the schedule of conditions. To guide the algorithm to converge towards a powerful solution and in order to limit the space of research, the motor dimensioning torque must satisfy the following condition extracted inequality:

$$(1-\varepsilon) \times R_w \times \left(\frac{\frac{J}{R_w^2} + \frac{M_v}{r_d}}{t_d} \times V_b + \frac{M_v \times g \times \sin(\lambda)}{r_d} \right) \le C_{dim} \le (1+\varepsilon) \times R_w \times \left(\frac{\frac{J}{R_w^2} + \frac{M_v}{r_d}}{t_d} \times V_b + \frac{M_v \times g \times \sin(\lambda)}{r_d} \right) \quad (15)$$

The adjustment coefficient of the torque ε generally does not exceed 0.25 and will be adjusted by simulations of the propulsion system on normalized circulation missions.

4. Design of the traction motor

The desired configuration must be with reduced manufacturing cost, mass and volume and to high power. It must also be modular to cover a wide range of power and reduce maintenance costs. In this context, we paid particular attention to the permanent magnet synchronous motor with axial flux because it adapts well to our specifications.

The chosen configuration illustrated by figure 2 is with four pairs of poles, and trapezoidal electromotive force waveforms, it provides a good compromise high performance and low weight, it is therefore chosen to solve the problem of the electric vehicle motorization.

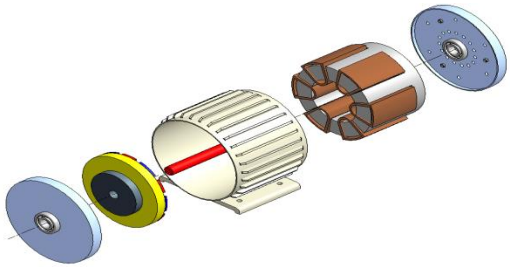

Fig.2. Permanent magnet synchronous motor with axial flux

The slot width of these structures is given by the following equation:

$$L_{enc}=\left(\frac{D_e+D_i}{2}\right)\times\sin\left(\frac{1}{2}\times\left(\frac{2\times\pi}{N_d}-\alpha\times\beta\times\frac{\pi}{p}\times\left(1-r_{did}\right)\right)\right) \quad (16)$$

For the configurations with trapezoidal waveforms the height of a tooth is given by the following equation:

$$H_d=\frac{3\times2\times N_s}{2\times N_d}\times\frac{I_{dim}}{\delta}\times\frac{1}{K_f}\times\frac{1}{L_{enc}} \quad (17)$$

This electric current is given by the following equation:

$$I_{dim}=\frac{C_{dim}}{K_e} \quad (18)$$

The magnet height is expressed by the following equation:

$$H_a=\mu_r\times\frac{B_e}{B_r-\dfrac{S_d\times B_e}{S_a\times K_{fu}}}\times e \quad (19)$$

To avoid demagnetization of the magnets, the phase electric current must be less than the demagnetization electric current I_d:

$$I_d=\left(\frac{B_r-B_c}{\mu_r}\times H_a-B_c\times K_{fu}\times e\right)\times\frac{p}{2\times\mu_0\times N_s} \quad (20)$$

The heights of the rotor yoke and the stator yoke are derived by applying the theorem of conservation of flux between a magnet and the rotor yoke, and between the main tooth and the stator yoke:

$$H_{cr}=\frac{B_e}{B_{cr}}\times\frac{\mathrm{Min}\left(S_d,S_a\right)}{2\times\left(\dfrac{D_e-D_i}{2}\right)}\times\frac{1}{K_{fu}} \quad (21)$$

$$H_{cs}=\frac{B_e}{B_{cs}}\times\frac{\mathrm{Min}\left(S_d,S_a\right)}{2\times\left(\dfrac{D_e-D_i}{2}\right)} \quad (22)$$

5. DC bus voltage

The DC bus voltage is calculated in such a way that the vehicle can reach a maximum speed with a low torque undulation and without weakening. This voltage is calculated assuming that the motor runs at a stabilized maximum speed. At this operating point the electromagnetic torque to be developed by the motor is expressed by the following equation:

$$T_{Udc}=\frac{P_f}{\Omega}+C_d+\left(C_b+C_{vb}+C_{fr}\right)+\frac{C_r+C_a+C_c}{r_d} \quad (23)$$

At this operating point, the phase current of the motor is expressed by the following eclectic equation:

$$I_p=\frac{T_{Udc}}{K_e} \quad (24)$$

The electric constant is defined by:

$$K_e=2\times n\times N_s\times\frac{\left(D_e^2-D_i^2\right)}{4}\times B_e \quad (25)$$

To reach this eclectic current value with a low ripple factor (r = 10% for example), the DC bus voltage must be a solution of the following equation:

$$r=\frac{t_m}{t_p}=10\% \quad (26)$$

$$t_m=-\frac{L}{R}\times\ln\left(1-\frac{2\times R\times I_p}{U_{dc}-K_e\times\Omega_{max}}\right) \quad (27)$$

The holding time of the electric current for a maximum speed (corresponding to 120 electrical degrees) is given by the following expression:

$$t_p=\frac{1}{3}\times\frac{2\times\pi}{p\times\Omega_{max}} \quad (28)$$

The DC bus voltage can be deduced from equations (26), (27) and (28):

$$U_{dc}=\frac{2\times R\times I_p}{1-\exp\left(-\dfrac{2\times\pi\times r}{3\times p\times\Omega_{max}\times\dfrac{L}{R}}\right)}+K_e\times\Omega_{max} \quad (29)$$

The converter’s continuous voltage for sinusoidal control is expressed as follow:

$$U_{dc}=\frac{\pi}{2}\times\sqrt{\left(R\times I_p+E_{phi}\right)^2+\left(L\times p\times\Omega_{max}\times I_p\right)^2} \quad (30)$$

E_{phi} is the maximal value of electromotive force.

$$E_{phi}=\frac{2}{3}\times K_e\times\Omega_{max} \quad (31)$$

6. Gear ratio

The insertion of a gear speed reducer with r_d ratio aims to enable the vehicle to reach the maximum speed of 80 km / h in our application. This ratio also helps ensure proper interpolation of reference voltages in order to have a good quality of electromagnetic torque.

$$r_d = \frac{2 \times \pi \times R_r \times F_{ri}}{n_{qTA} \times V_{max} \times p \times n_{iTR}} \quad (32)$$

7. Phase inductance

From the distribution of the flux at a stator pole, we deduce the value of the total inductance from the following equations:

$$L = \mu_0 \times 2 \times \frac{N_s^2}{4} \left(\frac{\frac{S_d}{2}}{2 \times (e + H_a)} + \frac{\left(\frac{D_e - D_i}{2}\right) \times H_d}{L_{enc}} \right) \quad (33)$$

The principle of the calculation of the mutual inductance is based on the supply of a coil for the calculation of the flux sensed by the adjacent coil. The flux path determines the total reluctance of the magnetic circuit modeling this mutual inductance.

$$M = \mu_0 \frac{\frac{S_d}{2}}{2 \times (e + H_a)} \frac{N_s^2}{4} \times 2 \quad (34)$$

8. Inverter losses modelling

8.1. Case of sinusoïdal control

The structure of converter's arm with IGBTs is illustrated by the following face:

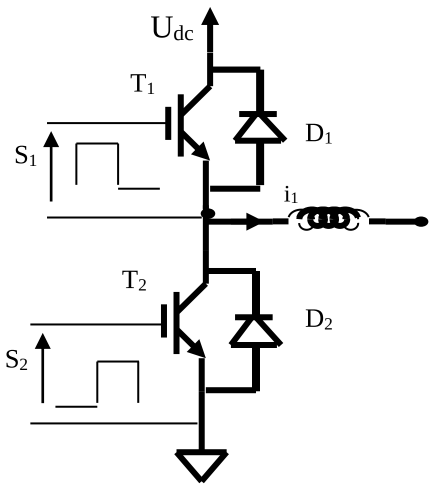

Fig.3. Structure of converter's arm with IGBTs

The sequences of working of converter's arm with IGBTs are illustrated by the following face [3]:

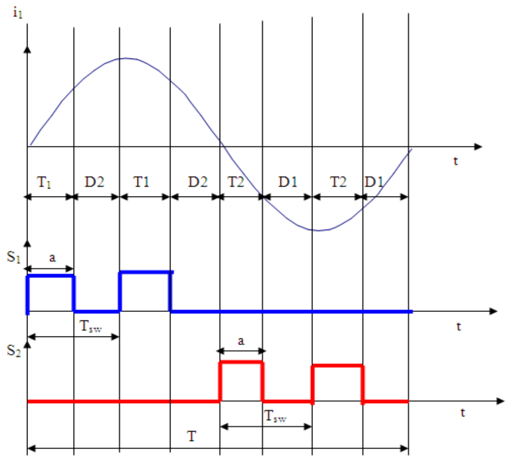

Fig.4. Working sequences of converter's arm with IGBTs

According to this strategy of control, we deduce the middle model of the conduction losses of the transistors:

$$P_{conT} = \frac{6}{2} \times \rho \times V_{ce}(I_m) \times I_m \quad (35)$$

$$\rho = \frac{a}{T_{sw}} \quad (36)$$

I_m is the middle phase current on a half period:

$$I_m = \frac{I_{max}}{\pi} \quad (37)$$

The commutation losses of transistors are also deducted by the following relation:

$$P_{comT} = \frac{6}{2} \times f_{sw} \times \frac{U_{dc}}{E_w} \times \left(E_{on}(I_m) + E_{off}(I_m)\right) \quad (38)$$

The conduction losses in the diodes are also estimated by the following relation:

$$P_{conD} = \frac{6}{2} \times (1 - \rho) \times V_d(I_m) \times I_m \quad (39)$$

The electromagnetic torque that the motor must develop so that the vehicle can move to the V speed is given by the following expression [3]:

$$C_{em} = \frac{P_f}{\Omega} + C_d + (C_b + C_{vb} + C_{fr}) + \frac{C_r + C_a + C_c}{r_d} + \left(\frac{J}{R_r} + \frac{M_v \times R_r}{r_d}\right) \times \frac{dv}{dt} \quad (40)$$

The current of phase is given by the following relation:

$$I_m = \frac{2}{\pi} \frac{C_{em}(t)}{K_e} \quad (41)$$

This expression allows the calculation of the copper losses and losses in the IGBTs converter.

8.2. Case of trapezoïdal control

For the structures of motor to shape of trapezoidal wave, the motor is powered by a reversible three-

phase converter while running to assure the recuperation of the energy during the phases of deceleration. It is energized by gaps of current of 120° electric degree (figure 3). The energizing of the motor presents itself then in a succession of sequences of 60° electric degree during which two phases are powered in series by a constant current. The resulting torque appears like a simple juxtaposition of the relative torque to the different coils.
The regulating of the current in the motor is assured by PWM modulation. Two types of modulation are possible, modulation by two transistors and modulation by only one transistor [4].

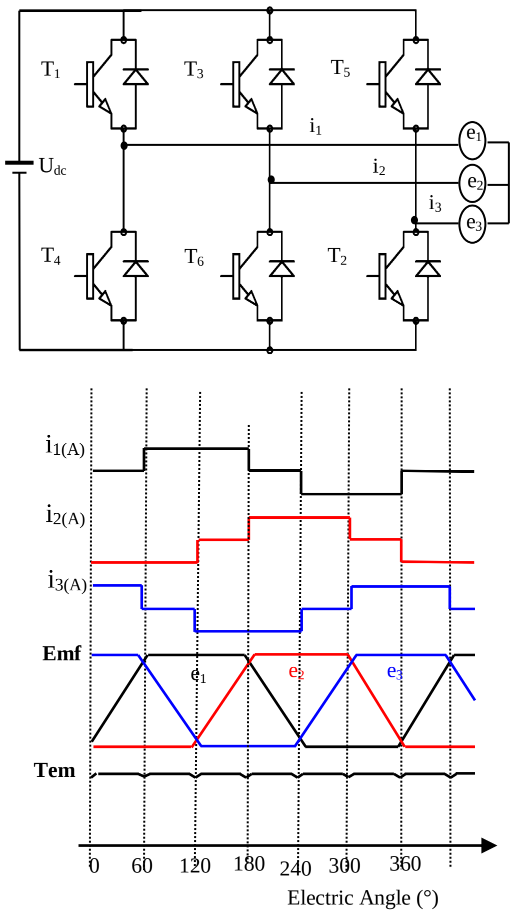

Fig.5. Principal of the motor powering

- **Modulation by two transistors**

Lasting one period of modulation, the working sequences of the converter are represented by the faces 6 and 7.

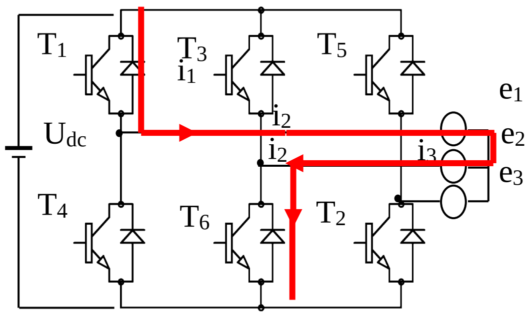

Fig.6. Sequence of working during the first half period of modulation

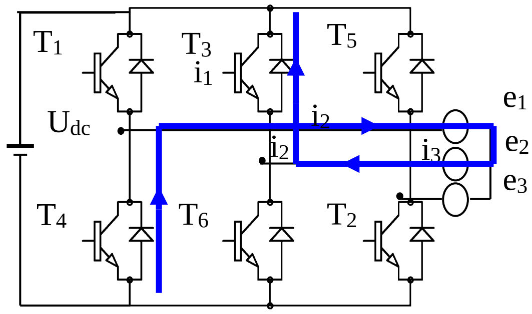

Fig.7. Sequence of working during the second half period of modulation

If we assume that the phases 1 and 2 is powered then during the first half period of modulation the T_1 transistors and T_6 drive and the two phases of the motor are powered by an increasing current. During the second half period of modulation, these two transistors are forced to the blockage and consequently the D_4 diodes and D_3 drive and the two phases of the motor are powered by a decreasing current.
To this fashion of working the losses by conduction P_c are expressed by the following formula [4]:

$$P_c = 2(\rho V_{ce}(I)I + (1-\rho)V_d(I)I) \quad (42)$$

The losses by commutation P_{com} are given by the following expression [4]:

$$P_{com}=2(K_{Eon}E_{on}(I)+K_{Eoff}E_{off}(I))f_{sw} \quad (43)$$

where K_{Eon} and K_{Eoff} are worth:

$$K_{Eon}=K_{Eoff}=\frac{U_{dc}}{E_w} \quad (44)$$

- **Modulation with only one transistor**

During the first half period of modulation, the T_1 transistors and T_6 drive and the motor is powered therefore by an increasing current (Face 8). During the second half period of modulation the T_1 transistor is forced to the blockage, therefore the D_4 diode starts itself and the T_6 transistor remains driver, the motor is powered therefore by a decreasing current (Figure 9).

The losses by conduction deducted from this fashion of working are expressed like follows [4]:

$$P_c = (1+\rho)V_{ce}(I)I + (1-\rho)V_d(I)I \quad (45)$$

and the losses by commutation are expressed by the following formula [4]:

$$P_{com} = (K_{Eon}E_{on}(I) + K_{Eoff}E_{off}(I))f_{sw} \quad (46)$$

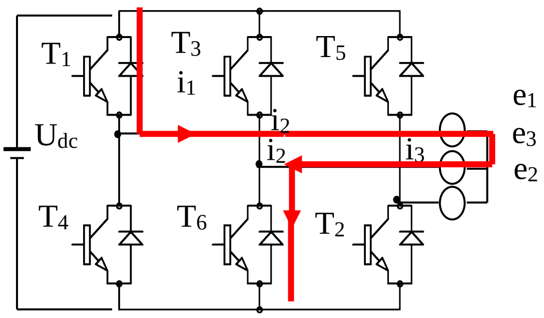

Fig.8. Sequence of working during the first half period of modulation

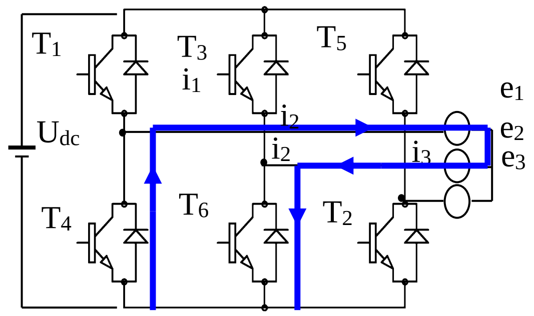

Fig.9. Sequence of working during the second half period of modulation

9. Modelling of the autonomy on a normalized mission of circulation

The middle autonomy on a mission of circulation is given by the following expression:

$$Au = \frac{(W_b - |W_r|)\frac{1}{T}\int_0^T \eta(t)\,dt}{P_{um1}} V_m \quad (47)$$

The available useful power on the driving wheels is given by the following expression:

$$P_u = \left(C_r + C_a + C_c + \left(\frac{r_d J}{R} + M R_r^2 \right) \frac{dV(t)}{dt} \right) \frac{V(t)}{R_r} \quad (48)$$

Where J is the moment of inertia of the motor:

$$J = \frac{1}{2}(M_{cr} + M_a)\frac{(D_e^2 - D_i^2)}{4} + \frac{1}{2}M_{ar}\frac{D_a^2}{4} \quad (49)$$

P_u is the sum of two power, one is positive (P_{u1}) and in this case it is produced by the motor and the other is negative (P_{u2}) and be recover to the level of the batteries.

P_{um1} is the middle power available to the driving wheel:

$$P_{um1} = \frac{1}{T}\int_0^T P_{u1}(t)\,dt \quad (50)$$

$\eta(t)$ is the efficiency at t:

$$\eta(t) = \frac{P_{u1}(t)}{P_{u1}(t) + P_c(t) + P_{com}(t) + P_m(t) + P_j(t) + P_{fer}(t) + P_r(t)} \quad (51)$$

The middle speed of the vehicle is given by the following expression:

$$V_m = \frac{1}{T}\int_0^T V(t)\,dt \quad (52)$$

The load voltage of the energy accumulator for a motor to sinusoidal control is expressed by the following relation:

$$U_r = \frac{2}{3} \times K_e \times \Omega \times 3 \times \frac{\sqrt{3}}{\pi} \times \frac{1}{1-\alpha} \quad (53)$$

This quantity for the motor to trapezoidal control is expressed by the following relation:

$$U_r = \frac{2}{3} \times K_e \times \Omega \times \frac{1}{1-\alpha} \quad (54)$$

To this phase of working, the recovered power for the motor to sinusoidal control is expressed as follows:

$$P_{rec} = -\frac{2}{3} \times K_e \times \Omega \times 3 \times \frac{\sqrt{3}}{\pi} \times \frac{1}{1-\alpha} \times \left(\frac{2}{3} \times K_e \times \Omega \times 3 \times \frac{\sqrt{3}}{\pi} \times \frac{1}{1-\alpha} - U_{batt} \right) \times \frac{1}{R_{batt}} \quad (55)$$

and for the motor to trapezoidal control:

$$P_{rec} = -\frac{2}{3} \times K_e \times \Omega \times \frac{1}{1-\alpha} \times \left(\frac{2}{3} \times K_e \times \Omega \times \frac{1}{1-\alpha} - U_{batt} \right) \times \frac{1}{R_{batt}} \quad (56)$$

We deduce the expression of the recovered energy:

$$W_r = \int_0^T P_{rec} \times dt \quad (57)$$

10. Inverse model of the traction chain

The general structure of the inverse model is presented by the figure 10.

This model permits to calculate the torque necessary to the wheels to follow the chosen circulation mission like entry for this model from the equation describing the movement of the electric vehicle. Then, it estimates the electromagnetic torque of the motor while taking into account the torques due to the losses in the different elements of the vehicle (reducing + electric motor). The current of the motor necessary to the calculation of the copper losses and losses in the converter is found while dividing this torque by the electric constant of the motor (K_e). The sense of resolution is reversed therefore in relation to the direct model [5].

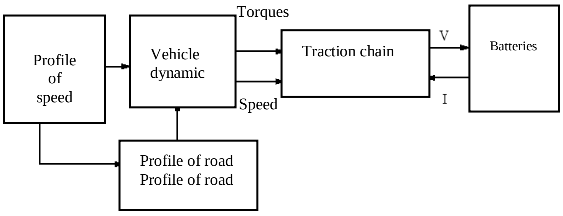

Fig.10. General structure of the inverse model

The electromagnetic torque that the motor must develop so that the vehicle can move to the V speed is given by the following expression:

$$C_{em}(t) = \frac{P_f}{r_d \frac{V(t)}{R_r}} + C_{red}(t) + \left(C_b(t) + C_{vb}(t) + C_{fr}(t)\right) + \frac{C_r(t) + C_a(t) + C_c(t)}{r_d} + \left(\frac{J}{R_r} + \frac{MR_r^2}{r_d}\right)\frac{dV(t)}{dt} \quad (58)$$

Where C_{red} is the torque due to the reducer rubbing strength.

For structures to shape of trapezoidal wave and for an energizing by currents in phase with electromotive forces, the current will be given by:

$$I(t) = \frac{C_{em}(t)}{K_e} \quad (59)$$

For structures to shape of wave sinusoidal and for an energizing by currents in phase with electromotive forces, the current will be given by:

$$I(t) = \frac{C_{em}(t)}{\frac{3}{2}K_e} \quad (60)$$

11. Problem of autonomy optimization

Our choice carried itself on the inverse model by what it integrates easily to the program of optimization, since the time of simulation is a lot less weak than the one of the direct model, in more this last present the inconvenience of the possibility to diverge while varying the design parameters of the traction chain that require a regulating of the parameters of the regulator.

This model shows good that the autonomy depends on the following variables: ray of the wheel (R_r), report of reduction (r_d), external diameter (D_e), interior diameter (D_i), induction in the air-gap (B_e), density of current in the slots (δ), stator yoke thickness (B_{cs}), and rotor yoke thickness (B_{cr}) and of the number of spires by phase (N_{sph}).

The problem of optimization sums up by:

$$\begin{cases} \text{Maximize the autonomy} \\ I_m > I_d \\ 0.25 \le R_r \le 0.35(m) \\ 1 \le r_d \le 8 \\ 50 \le d_m \le 350(mm) \\ 120 \le L_m \le 300(mm) \\ 0.1 \le B_e \le 1.0575\ (Tesla) \\ 2 \le \delta \le 7 \\ 0.2 \le B_{cs} \le 1.6\ (Tesla) \\ 0.2 \le B_{cr} \le 1.6\ (Tesla) \\ 20 \le N_{sph} \le 400 \\ U_{dc} \le 100\ \text{Volt} \end{cases} \quad (61)$$

Where :

$L_m=(D_e-D_i)/2$ (62)

$d_m=(D_e+D_i)/2$ (63)

It is to noted that the thermal constraints are held in account and in the cases where the algorithm of resolution to develop doesn't converge naturally toward a solution respecting these constraints, the forks of variation of these last will be modified because of the possibility to integrate a system of cooling in the chains traction.

12. Resolution of the optimization problem by the method of the genetic algorithms

The model of the losses is coupled to a program of optimization by the method of the genetic algorithm. The progress of the program of optimization with constraints of the autonomy, chosen as the objective function is described by this organization diagram [6], [7], [8], [9], [10], [11], [12]:

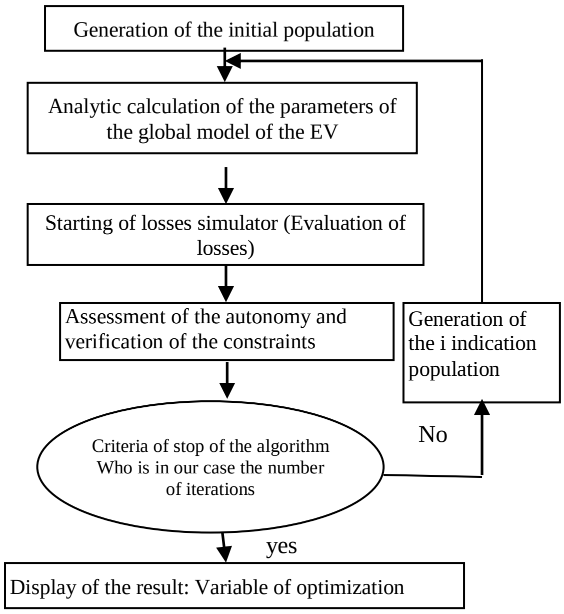

Fig.11. Progress of the optimization program

The first stage consists in define and in code suitably the problem. To each variable of optimization x_i ($x_i \in \{R_w, r_d, D, L_m, B_g, \delta, B_{sy}, B_{ry}, N_{sph}\}$), we make correspond a gene. Each device is represented by an individual (chromosome) endowed with a genotype constituted several genes. We use in our algorithm a binary coding. That is to say that a gene is a long whole (10 bits). An individual is a table of genes. The population is a table of individuals.

We consider a finished space of research:

$$\forall k \in [1; N]\ S_k = [x_{k1}, x_{k2}, ..., x_{k9}] \quad (64)$$

So as to code our real variables in binary, we discretize the research space. Thus a coding on 10 bits implies a discretization of intervals in $g_{max} = 2^{10} - 1 = 1023$ discreet values. To each real variable x_i we associates therefore a long whole g_i:

$$0 \leq g_i \leq g_{max} \quad \forall\ i \in [1 ; 9] \quad (65)$$

Where:

$$g_i = \sum_{j=0}^{10} b_j \times 2^j \quad (66)$$

Coding and decoding formulae are then following:

$$g_i = \frac{x_i - x_{i\,min}}{x_{i\,max} - x_{i\,min}} \times g_{max} \quad (67)$$

$$x_i = x_{i\,min} + (x_{i\,max} - x_{i\,min}) \times \frac{g_i}{g_{max}} \quad (68)$$

The algorithm begins with a generation of the initial population. This population is constituted by N individuals characterized each by a chromosome and a fitness function. The initial population is constituted by the selection of N best solutions among Z generated admissible solutions of the next manner:

$$\forall\ k \in [1 ; Z] \quad S_k = [x_{k1}, x_{k2}, ..., x_{k9}] \quad (69)$$

$$x_{ki} = x_{ki\,min} + \frac{k}{Z}(x_{i\,max} - x_{i\,min}) \quad (70)$$

The optimization program based on Genetic Algorithms method was programmed in MATLAB 7.0 and was run on a Pentium IV, 2.0 GHz, 128 MB RAM machine [6-10].

Several simulations showed that the sinusoidal control presents the most elevated autonomy. For this reason, we only present the relative results to this control law.

The curve of the autonomy and the curve of the average of the autonomy for every generation are given by the following face:

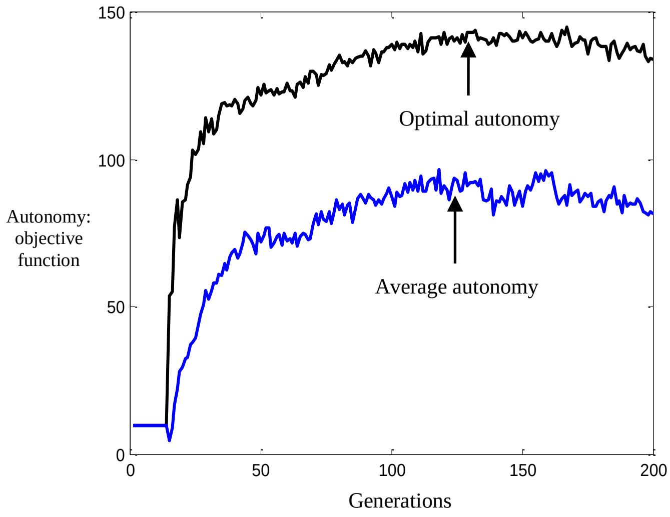

Fig.12. Curve of the autonomy and curve of the average of the autonomy for every generation

When the autonomy takes the value 10, the algorithm doesn't find any solutions.

The following table illustrates the solution found for 200 generations relative to the motor to sinusoidal shape of wave:

Table 1: Optimal solution to 200 iterations

R_r (m)	r_d	d_m (mm)	L_m (mm)	B_e (Tesla)	δ (A/mm^2)	B_{cs} (Tesla)	B_{cr} (Tesla)	N_{sph}	Autonomy (km)
0.270	1.109	52.052	120.879	0.461	2.259	0.316	0.757	21	139.4

13. Conclusion

In this paper, we present a systemic and parameterized model of electric vehicles power chain coupled to a model of the middle autonomy. Indeed, three types of control laws held into account by this model are to knowledge:

- Sinusoidal control law.

- Two trapezoidal control laws.

The different types of losses in the converter for these types of control laws are modeled in order to select the most economical law. The Developed model poses a problem of optimization of the autonomy with constraints. This problem is solved by the genetic algorithms method [6-9]. The gotten results encourage the industrialization of these kinds of vehicles [10].

List of symbols

D_i Internal diameter
D_e External diameter of the stator
B_e Flux density in the air-gap
N_s Number of phase spire
Ω Angular speed
n Module number
$e_i(t)$ Back electromotive force of the phase i.
$i_i(t)$ Current of the phase i
r_d Reduction ratio
M_v Vehicle mass
R_w Vehicle wheel radius
J Motor moment of inertia
v Vehicle velocity
P_f Iron losses
C_d Torque due to the loss in the reducer
C_b Torque due to the forces dry rubbing
C_{vb} Torque due to the viscous rubbing forces
C_{fr} Torque due to the fluid rubbing forces
C_a Aerodynamic torque
C_r Torque of rolling resistance
C_c Torque of gravity
C_{red} Torque due to the reducer rubbing strength
s Dry friction coefficient
χ Viscous friction coefficient
k Fluid friction coefficient
λ Angle that the road makes with the horizontal
M_{va} Density of the air
C_x Aerodynamic drag coefficient
r_p Coefficient taking account of the mechanical losses in the motor and the transmission system
A_f Vehicle frontal area
α Report between the width of a main tooth and the width of a magnet
β Report between a magnet and the polar step
N_d Number of main teeth
r_{did} Angular relation between an interposed tooth and a main tooth
K_f Filling factor of the slot
δ Allowable current density in the slot
I_{dim} Current sizing the copper conductors
K_{fu} Coefficient of flux losses
μ_r Relative permeability
e Air-gap thickness
S_d Tooth section
S_a Magnet section
B_c Induction of demagnetization
B_r Remanent induction of magnets
μ_0 Permeability of air
α Cyclic report of the control voltage of the DC-DC elevator converter with IGBT transistor
K_e Electromotive forces constant
R_{batt} Resistance of the energy accumulator
U_{batt} Middle voltage of the energy accumulator
ρ Cyclic report of the transistors control signals
t_p Time for mainting the eclectic current at a maximum speed
t_m Time of current increasing from zero to I_d
R Motor phase resistance
L Motor phase inductance
M Mutual inductance
Ω_{max} Maximum angular velocity of the motor
I_{max} Maximal phase current of the motor
V_{ce} Collector-emettor voltage
U_{dc} Voltage of the continuous bus
fsw Switching frequency
E_{on} Energy dissipated to closing
E_{off} Energy dissipated to the opening
E_w Continuous voltage descended of the constructors tests at the time of the determination of the energy dissipated to the opening and closing
V_d Diode voltage
I Current to the point of working given
W_b Energy stocked in the batteries
W_r Energy recovered during the phases of decelerations
P_u Power to the wheels
η Efficiency of the traction chain
M_a Mass of the magnets
T Length of the circulation mission
P_c Conduction losses
P_{com} Commutation losses
P_j Copper losses
P_r Reducer losses
n_{iTR} Reference voltages interpolation coefficient
p Number of pair poles
n_{qTA} Coefficient of quality of the food voltage
F_{ri} Switching frequency
V_{max} Maximum speed of the vehicle
H_d Height of the slot
H_a Height of the magnet
L_{enc} Width of the slot
A_{encm} Average width of the slot
A_{dentm} Average width of the main tooth
A_{dentim} Average width of the tooth interposed
H_{cr} Height of the rotor yoke
H_{cs} Height of the stator yoke

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