Design of electric powertrains for vehicles using driving cycles

E. de Cecco, G. Krebs, C. Marchand
Laboratoire de Génie Electrique de Paris (LGEP, CNRS UMR 8507, Supelec, UPMC-P6, Univ. Paris-Sud 11)
11 rue Joliot Curie, F 91192 Gif-Sur-Yvette CEDEX.
Guillaume.krebs@lgep.supelec.fr

Abstract — This paper proposes an approach to design electric powertrains. The driving cycles, represented in torque-speed space, are divided in regions affected with weights that depend on the utilization rate of each region. The optimization of the powertrain, built around an axial flux motor, is then realized using a reduced number of points.

I. INTRODUCTION

The reduction of greenhouse gas emissions has become an important priority nowadays. The use of electromechanical converters in addition or instead of combustion engines in passenger vehicles, allows a significant reduction of these gases. The electromechanical conversion is then subject to several operating points (for example: start, generator, boost, brake …). These conditions require consequently the following constraints: large torque-speed features, high global efficiency and good power-mass ratio. Permanent magnet synchronous motors are the best structures to fulfill these conditions [1] and axial configurations are particularly interesting in terms of power-mass ratio [2].

For an operating point, the design of such structures is simplified due to computational capabilities and mathematical tools (based on finite element method for example). However, a powertrain designed for only one operating point, will not necessarily fulfill all the requirements in terms of efficiency for example. On the other side, it is not realistic to consider all operating points simultaneously.

In this paper, a design methodology based on different driving cycles is proposed. The principle of the proposed approach is to work with a division in areas of the power-speed space. The designed structure is then expected to offer a best compromise on performances.

In a first part a description of driving data (Artemis cycles [3]) is performed. It shows the multiple operating points during an urban trip. To reduce the number of operating points to consider only some areas are defined. In the second part, the axial flux motor driving the powertrain is given. In the third part, a sensitivity analysis is firstly performed to reduce computation time. The significant geometrical and electrical parameters are identified and only used. The description of the objective function and optimization algorithm is then presented. Finally, results are given and discussed.

II. DRIVING CYCLES AND ENVELOP CURVE

Torque and speed applied on a rear axle of vehicles with thermal engine during a rural driving cycle ("Artemis Rural"[3]) are used in this paper. Operating points, such as traction or braking, are easily observable. Although these data's has been extracted from conventional vehicles, such cycle can be adapted for hybrid or full electrical vehicle due to the short distance covered.

The power train has to be sized considering all the working points. To take into account these ones, it is easier to work in a torque-speed space inside envelop curves, see Fig.1. Using a constant step time for the sampling of the cycle, the areas where the converter is mostly used can be highlighted (see Fig.1).

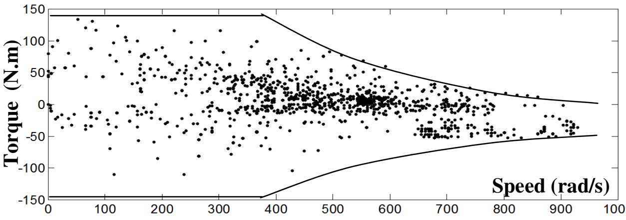

Fig. 1. ARTEMIS and envelop curves in torque-speed space

For each operating points, a converter can be theoretically designed. However some of ones would no be able to reach extreme torque or speed values. Furthermore the computation times would be unreasonable.

The approach is here to design a power train taking into account firstly the two operating points (T_n, Ω_n), (T'_n, Ω_n), (T_d, Ω_d), and (T'_d, Ω_d), see Fig.3. To work with the best global efficiency, masse-power ratio and compactness on the other points, the torque-speed space is separated in some chosen regions (six colored regions in the example 3). Each one is represented by a sole point which is its barycenter, attached with a weight that is the ratio between the number of points in the region and the number of points describing the whole curve (Fig.2). The constant step sampling implies that these weights are directly proportional to the duration where the structure works in. Now, the space is approximated by ten points (in this example) instead of one thousand.

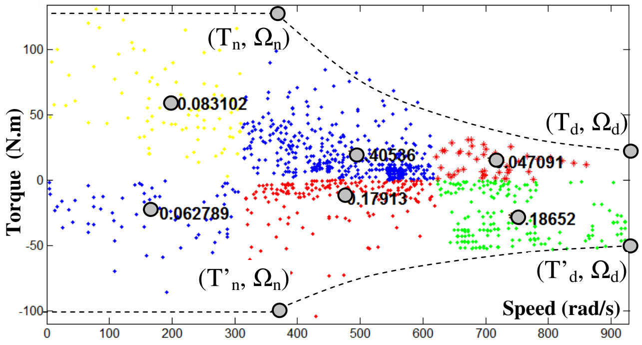

Fig. 2. ARTEMIS curve in torque-speed space with the operating points.

III. DESCRIPTION OF THE ELECTRICAL MOTOR

For the sake of clarity, only a short description of the powertrain is given in this abstract. It is built around an axial flux structure [4] presented in Fig.3.

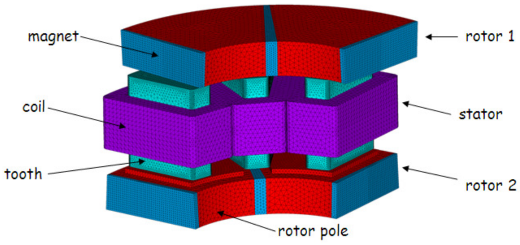

Fig. 3. Geometry of the axial motor used in the powertrain (1/4 of the total geometry).

The motor is composed of two rotors with inserted magnets. The stator has 9 coils, connected in order to create a three phase system. The rotor poles and stator teeth are made of iron powder. A 2D equivalent model [5] is used to reduce the computation times, see Fig.4.

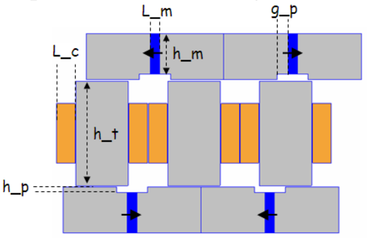

Fig. 4. 2D model of the axial flux motor.

The 2D problem is solved by means of a finite element calculation code. Flux, fem and torque are calculated. Iron, mechanical and inverter losses are calculated a posteriori.

IV. DESIGN METHODOLOGY

A. Sensibility analysis

Reducing the number of parameters allows limiting computational time, for optimization steps. So, a fractional factorial design was used, by means of Taguchi method which does not need to improve all the 5^6 experiments, but only 25; however limiting errors of interpretation. This design contains the six parameters identified of the geometry, each one taking five levels of variation in its own chosen interval. On Fig. 5, for each level in abscissa, is given the effect, on the objective function (1), of each factor, in ordinate. Note that the effects are normalized by the maximum value among effects calculated. This allows determining easily the most significant parameters which will be used in optimization process.

$$F_{obj} = \left|C - C_n\right|_{\Omega=\Omega n} + \left|C - C_d\right|_{\Omega=\Omega d} + \left|V - V_n\right|_{\Omega=\Omega n} \tag{1}$$

On the same principle, another objective function is also studied for energetic criterions (looses in converter and motor).

In the case shown above, no factor could be excluded for optimization process, because of absence of weak value effect in the considered intervals.

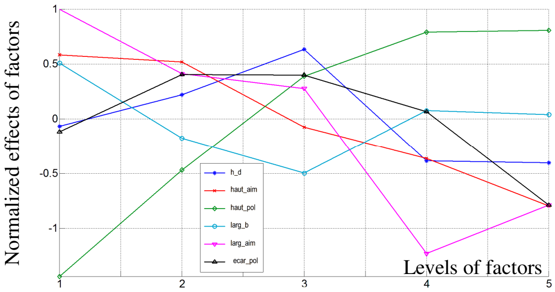

Fig. 5. Results of factorial design for envelop curve and voltage.

B. Optimization of power train

Finally, the structure is optimized with a simplex method with the most significant parameters. It uses an objective function (2) taking into account energetic criterions on simplified driving cycle, weighted by the value obtained in part II for barycenters; and a constrained function for the respect of the simplified envelop curve (3).

$$Fobj = \sum_{i=1}^{6} k_i \left|\eta\right|_{\Omega=\Omega i} \tag{2}$$

$$F_{constr} = \left|C - C_n\right|_{\Omega=\Omega n} + \left|C - C_d\right|_{\Omega=\Omega d} + \left|V - V_n\right|_{\Omega=\Omega n} \tag{3}$$

Where *ki* is the weight of each barycentre and η the performance.

V. CONCLUSION

In this paper an optimization methodology applied on an electric powertrain for vehicles is described, using only four noteworthy points of the envelop curve and an approach to take into account driving cycles. This structure is studied by Taguchi fractional factorial design to conserve the most significant parameters and so it is optimized by a simplex algorithm.

The approach used to model the transient behaviour of the structure and the method implemented to avoid local minimums will be developed in full version.

VI. ACKNOWLEDGEMENTS

Theses works were realized within the project M2EI (Electrical Machine and Integrated Electronic, Ademe).

VII. REFERENCES

[1] M. Zeraoulia, M.El Hachemi Benbouzid and D. Diallo, “Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study”, *IEEE Trans. on Vehicular Technology*, vol. 55, no.6, pp.1756-1764, november 2006.

[2] S. Huang, J. Luo, F. Leonardi and T.A. Lipo, “A comparison of power density for axial flux machines based on general purpose sizing equations”, *IEEE Trans. on Energy Conversion*, vol. 14, no.2, pp.185-192, June 1999.

[3] “Impact of the gearshift strategy on emission measurements”, Artemis 3142 report, Report n° LTE 0307 March 2003.

[4] Patent EP1276213, “Machine discoide”, inventors : J. Saint Michel, A. Abou-akar, Applicant: Leroy-Somer, publication : 2003-01-15.

[5] O. Maloberti, C. Marchand, Y. Choua, D. Condamin, L. Kobilansky, E. Bomme, “Multi-Physical quasistatic modelling of an axial flux permanent magnet machine”, *International Conference on Electrical Machines (ICEM)*, September 2010.