Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study

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***Abstract*—This paper describes a comparative study allowing the selection of the most appropriate electric propulsion system for a parallel Hybrid Electric Vehicle (HEV). This study is based on an exhaustive review of the state of the art and on an effective comparison of the performances of the four main electric propulsion systems that are the dc motor, the induction motor, the permanent magnet synchronous motor, and the switched reluctance motor. The main conclusion drawn by the proposed comparative study is that it is the cage induction motor that better fulfils the major requirements of the HEV electric propulsion.**

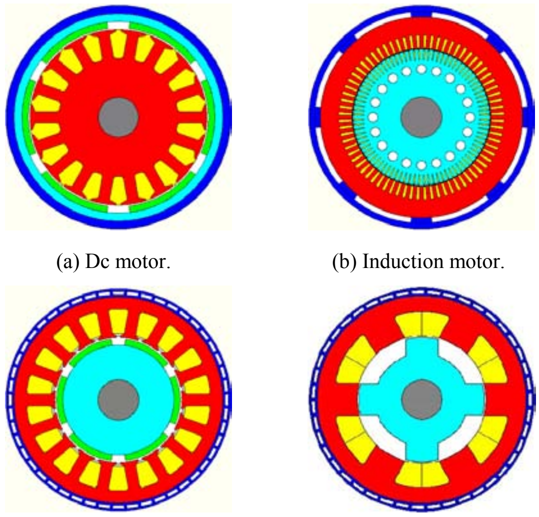
***Index Terms*—Hybrid electric vehicle (HEV), electric propulsion, comparison.**

I. INTRODUCTION

Selection of traction motors for hybrid propulsion systems is a very important step that requires special attention. In fact, the automotive industry is still seeking for the most appropriate electric propulsion system for HEVs and even for electric vehicles. In this case, key features are efficiency, reliability and cost. The process of selecting the appropriate electric propulsion systems is however difficult and should be carried out at the system level. In fact, the choice of electric propulsion systems for HEVs mainly depends on three factors: driver expectation, vehicle constraint, and energy source. With these considerations, it is obvious that the overall motor operating point is not tightly defined [1]. Therefore, selecting the most appropriate electric propulsion system for a HEV is a challenging task.

In an industrial point of view, the major types of electric motors adopted or under serious consideration for HEVs and also for electric vehicles include the dc motor, the induction motor, the permanent magnet synchronous motor, and the switched reluctance motor [2]. Cross-sections of each of these four motor types are provided in Fig. 1. Moreover, according to an exhaustive review of the state of the art related to electric propulsion systems, it is observed that investigations on cage induction motors and the permanent magnet motors are highly dominant, whereas those on dc motors are dropping while those on switching reluctance motors are gaining much interest [3-6].

In this paper, potential candidates of traction motor, for parallel HEVs, are presented and evaluated according to the major requirements of a HEV electric propulsion system. Conclusions are then drawn to identify the most potential candidate of traction motor for parallel hybrid propulsions.



(a) Dc motor. (b) Induction motor.

(c) Pm brushless motor. (d) Switched reluctance motor.

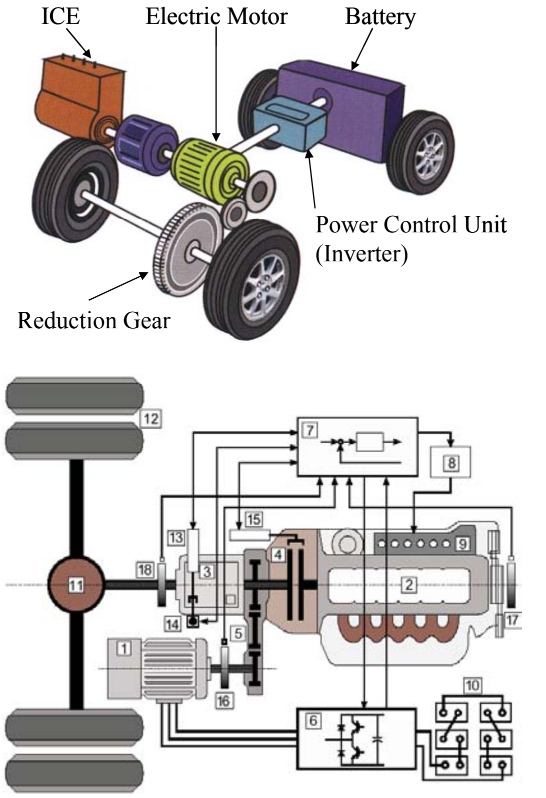
Fig. 1. Industrial and traction motors.

II. HEV MAJOR REQUIREMENTS

A. HEV Configuration

The proposed comparative study has been done on the parallel HEV configuration (Fig. 2). In fact, differing from the series hybrid, the parallel HEV allows both the Internal Combustion Engine (ICE) and the electric motor to deliver power in parallel to drive the wheels. Since both the ICE and electric motor are generally coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by the ICE alone, by the electric motor or by both. Conceptually, it is inherently an electric-assisted ICE for achieving lower emissions and fuel consumption. Better than the series HEV, the parallel hybrid needs only two propulsion devices, the ICE and the electric motor. Another advantage over the series case is that a smaller ICE and a smaller electric motor can be used to get the same performance until the battery is depleted. Even for long-trip operation, only the ICE needs to be rated for the maximum sustained power while the electric motor may still be about a half [3], [7].

Sizing the electric motor is a key point in a HEV to improve fuel economy and dynamic performances. The ratio between the maximum power of the electric motor (P_{EM}) and the ICE (P_{ICE}) is characterized by the Hybridization Factor (HF) that is defined as



1. Electric motor, 2. ICE, 6. Inverter, 7. Controller, 10. Battery, 11. Differential gear.

Fig. 2. HEV parallel configuration.

$$HF = \frac{P_{EM}}{P_{EM} + P_{ICE}} = \frac{P_{EM}}{P_{HEV}}$$

Where P_{HEV} is the maximum total traction power to propel the HEV. It has been demonstrated that hybridization improves HEV fuel economy and dynamic performances up to a critical optimum point (*HF* = 0.3 to 0.5). After this point, increasing the electric propulsion system capacity will not improve the HEV performances [8-9].

B. Motor Characteristics Versus Electric Traction Selection

The major requirements of HEVs electric propulsion, as mentioned in past literature, are summarized as follows [1], [3].

- High instant power and high power density.
- High torque at low speeds for starting and climbing, as well as high power at high speed for cruising.
- Very wide speed range including constant-torque and constant-power regions.
- Fast torque response.
- High efficiency over wide speed and torque ranges.
- High efficiency for regenerative braking.
- High reliability and robustness for various vehicle-operating conditions.
- Reasonable cost.

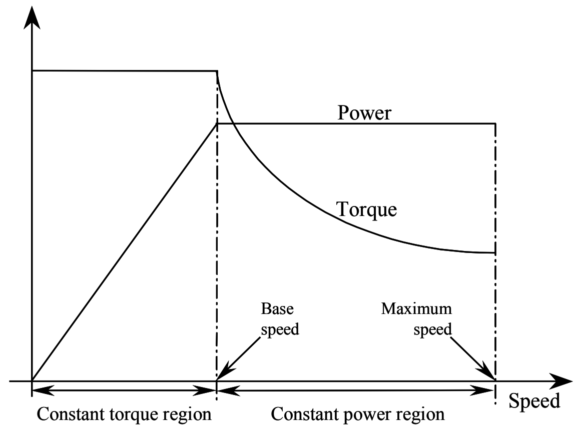
Moreover, in the event of faulty operation, the electric propulsion should be fault-tolerant [10-11]. Finally, in an industrial point of view, an additional selection criterion is the market acceptance degree of each motor type, which is closely associated with the comparative availability and cost of its associated power converter technology [4].

Figure 3a illustrates the standard characteristics of an electric motor used in EVs or HEVs. This characteristic corresponds to the profile of the tractive effort versus speed on the driven wheels (Fig. 3b). It should be noted that these characteristics depend on the Hybridization Factor (*HF*).

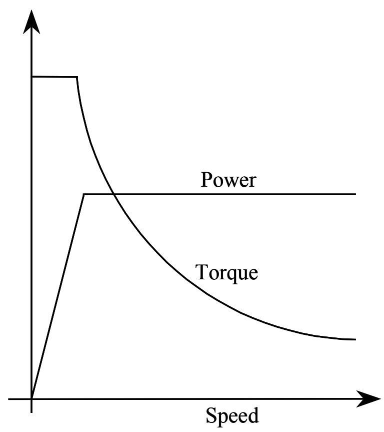
III. Comparative Study

A. Dc Motors (DC)

Dc motors have ever been prominent in electric propulsion because their torque-speed characteristics suit traction requirement well and their speed controls are simple. However, dc motor drives have bulky construction, low efficiency, low reliability and need of maintenance, mainly due to the presence of the mechanical commutator (brush) even if interesting progress have been done in slippy contacts. Moreover, the development of rugged solid-state power semiconductors made it increasingly practical to introduce ac induction and synchronous motor drives that are mature to replace dc motor drive in traction applications.



(a) Electric traction.



(b) Tractive effort versus speed.

Fig. 3. HEV typical characteristics.

In fact, the commutatorless motors are attractive as high reliability and maintenance-free operation are prime considerations for electric propulsion. Nevertheless, according to the cost of the inverter, ac drives are used generally just for higher power. At low power ratings, the dc motor is still more than an alternative. Improvement of existing cars (“re-engineering”) without changing the mechanical part can be achieved by new dc chopper power electronics. The commutator, if used in proper operation, is a very rugged “inverter”, therefore the power electronics circuit can be kept relatively simple and thus with low costs. This is the case of the French automaker PSA Peugeot Citroën that has introduced the HEV version of the well-known Berlingo, called Dynavolt, with a dc motor as an electric propulsion (Fig. 4) [12].

B. Induction Motor (IM)

Cage induction motors are widely accepted as the most potential candidate for the electric propulsion of HEVs according to their reliability, ruggedness, low maintenance, low cost, and ability to operate in hostile environments. They are particularly well suited for the rigors of industrial and traction drive environments. Today, induction motor drive is the most mature technology among various commutatorless motor drives [3-4]. For illustration, Fig. 5 shows industrial traction induction motors.

Figure 6 shows the typical characteristics of an induction motor drive. Vector control of induction motors can decouple its torque control from field control.

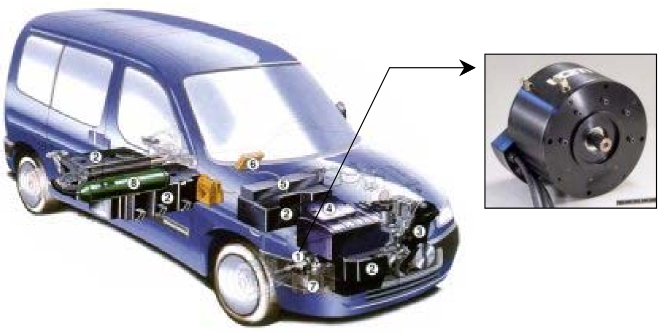
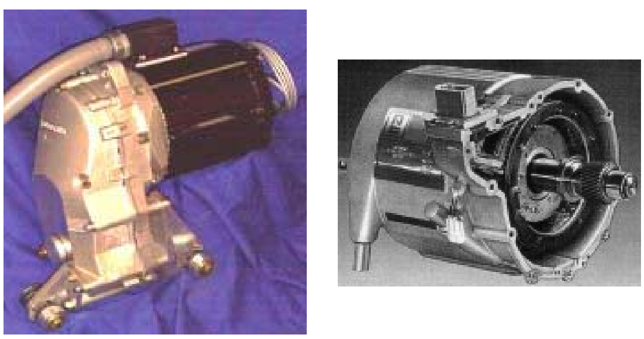


Fig. 4. Dc motor in the Hybrid Citroën Berlingo [© Citroën].



(a) (b)

Fig. 5. Industrial induction motors. (a) External view of an induction motor traction drive [© Solectria]. (b). Water-cooled induction motor [© Delco].

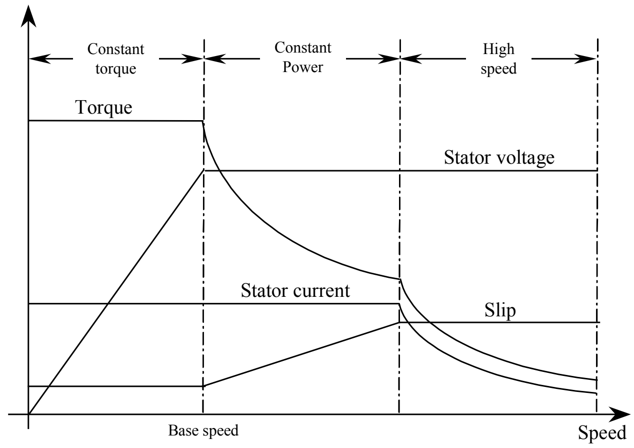


Fig. 6. Induction motor characteristics.

Extended speed range operation with constant power beyond base speed is accomplished by flux weakening. However, the presence of breakdown torque limits its extended constant power operation. At the critical speed, the breakdown torque is reached. Moreover, efficiency at high-speed range may suffer in addition to the fact that induction motors efficiency is inherently lower than that of permanent magnet motors due to the absence of rotor winding and rotor copper losses [1].

In general, induction motor drives were facing a number of drawbacks that pushed them out from the race of HEVs electric propulsion. These drawbacks are mainly: high loss, low efficiency, low power factor, and low inverter usage factor, which is more serious for high speed and large power motor. Fortunately, these drawbacks are taken into consideration according to the available literature. Some researches propose to take into account these problems in the design step of the induction motor used for HEVs [13-15].

To improve induction motor drives efficiency a new generation of control techniques has been proposed [16-17]. Some of the proposed techniques are particularly devoted to HEV applications [18-19], which constitute a progress compared to the study made in [20].

To extend the constant power region without oversizing the motor (to solve the problem of breakdown torque), it has been proposed the use of multi-phase pole-changing induction motor drive especially for traction application (Figs. 7 and 8) [21-22]. In [21], the key was to propose a new sinusoidal PWM strategy in such a way that the two carriers of the six-phase inverter are out of phase during four-pole operation, whereas they are in phase during two-pole operation. Another approach to enlarge the constant power region (up to 10:1) is to use dual inverters (Fig. 9) [23]. Finally, it should be noticed that certain research works tend to introduce the doubly-fed induction motor as electric propulsion, as they have excellent performance at low speeds (Fig. 10) [24].

C. Synchronous Motor (PM Brushless Motor)

PM brushless motors are most capable of competing with induction motors for the electric propulsion of HEVs. In fact, they are adopted by well-known automaker for their HEVs (Fig. 11).

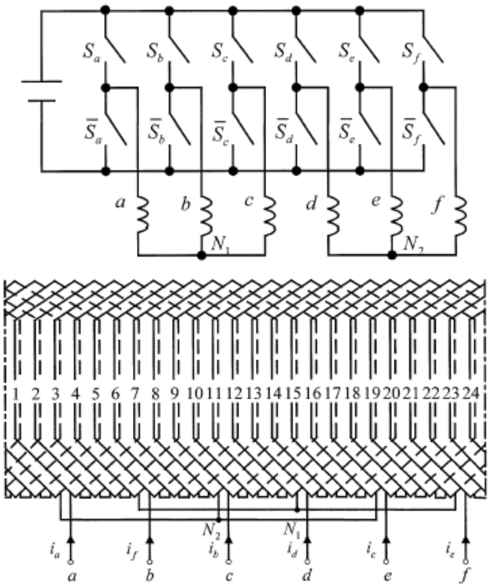
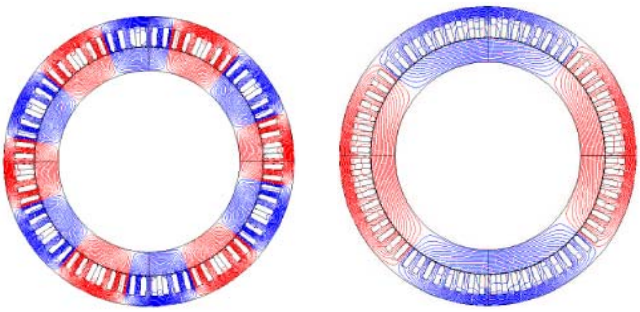


Fig. 7. Inverter-fed six-phase pole-changing induction motor drive [21].



(a) 12-pole configuration. (b) 4-pole configuration.

Fig. 8. Main flux of a pole-changing induction motor drive [22].

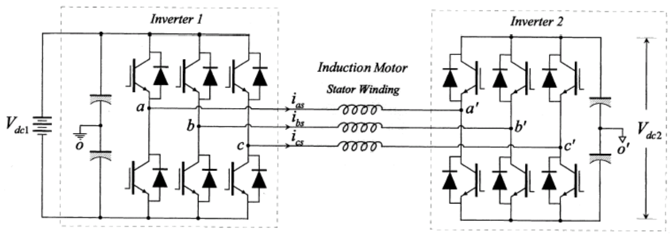


Fig. 9. Dual inverter system [23].

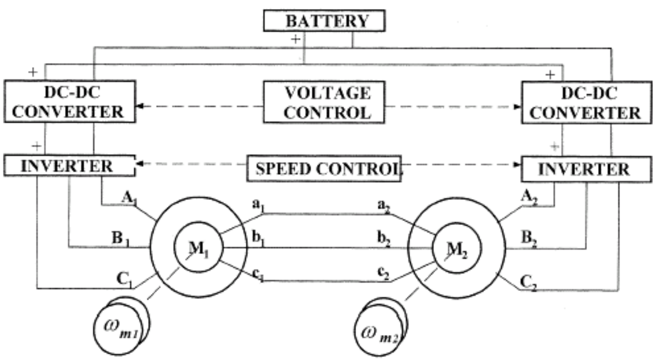
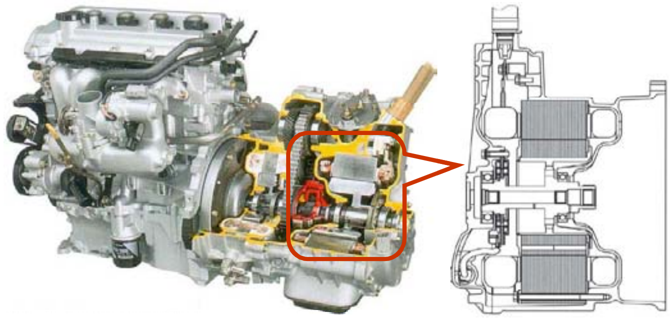


Fig. 10. Doubly-fed differential drive layout [24].

(a) 10-kW motor of the Honda Insight [25].

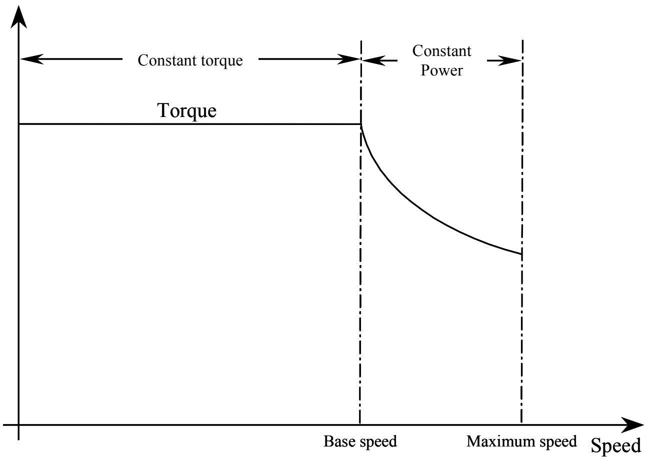


(b) 50-kW motor of the Toyota Prius [26].

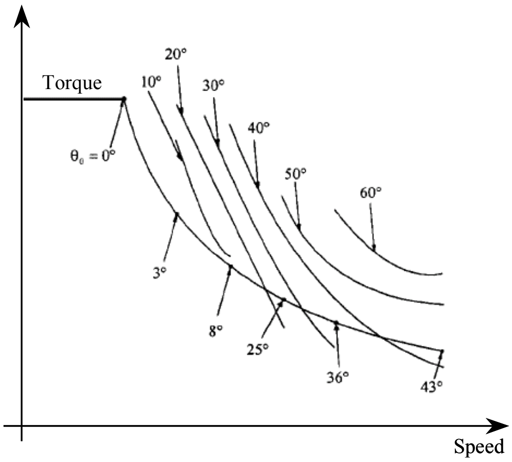
Fig. 11. Industrial permanent magnet synchronous motor.

These motors have a number of advantages, which are: *(a)* overall weight and volume significantly reduced for a given output power (high power density), *(b)* higher efficiency as mentioned above and *(c)* heat efficiently dissipated to surroundings. However, these motors inherently have a short constant power region (the fixed PM limit their extended speed range) (Fig. 12a). In order to increase the speed range and improve the efficiency of PM brushless motor, the conduction angle of the power converter can be controlled at above the base speed. Figure 12b shows the torque-speed characteristic of a PM brushless motor with conduction angle control. The speed range may be extended three to four times over the base speed. However, at very high-speed range the efficiency may drop, the motor may suffer from demagnetization.

There are various configurations of PM brushless motors. Depending on the arrangement of the PM, basically they can be classified as surface magnet mounted or buried magnet mounted, the latter being more rugged. The surface magnet designs may use fewer magnets, while the buried magnet designs may achieve higher air-gap flux density. Another configuration is the so-called PM hybrid motor, where the air-gap magnetic field is obtained through the combination of PM and field winding. In the broader term, PM hybrid motor may also include the motor whose configuration utilize the combination of PM motor and reluctance motor. PM hybrid motors offer wider speed range and higher overall efficiency but more complex construction [3]. Finally, the PM brushless motor is particularly privileged and suited for wheel direct-drive motor applications (Fig. 13) [27].



(a) Typical characteristic.



(b) With conduction angle control.

Fig. 12. Torque-speed characteristic of a pm brushless drive.

D. Switched Reluctance Motor (SRM)

Switched reluctance motors are gaining much interest and are recognized to have potential for HEV applications. These motors have the definite advantages of simple and rugged construction, fault-tolerant operation, simple control, and outstanding torque-speed characteristics (Fig. 14). SRM can inherently operate with extremely long constant power range. There are, however, several disadvantages, which for many applications outweigh the advantages. Among these disadvantages, acoustic noise generation, torque ripple, special converter topology, excessive bus current ripple, electromagnetic interference (EMI) noise generation. All of the above advantages as well as the disadvantages are quite critical for vehicle applications. Acceptable solutions to the above disadvantages are needed to get a viable SRM-based HEV [28-29]. Nevertheless, SRM is a solution that is actually envisaged for light and heavy HEV applications (Figs. 15 and 16) [30-31].

E. Industrial Applications

Table 1 briefly reviews the electric propulsion adopted in the automotive industry.

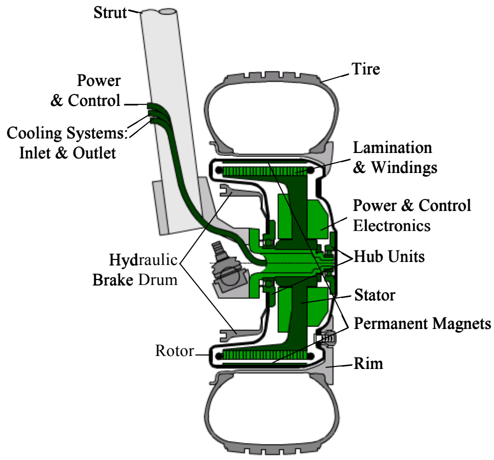


Fig. 13. In-wheel pm brushless motor layout [© TM4].

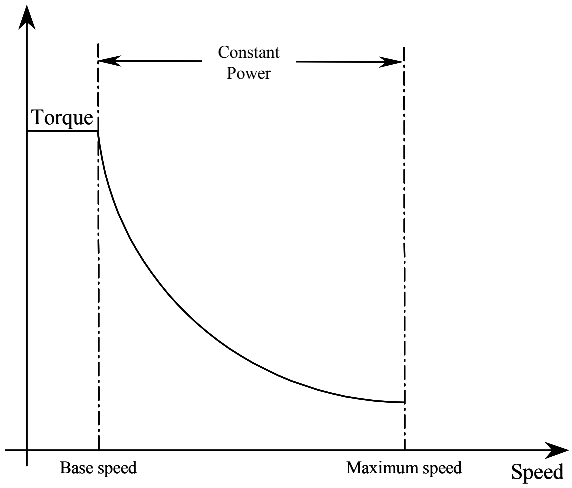


Fig. 14. Typical torque-speed characteristic of a switched reluctance motor.

F. Preliminary Conclusions and Perspectives

The induction motor seems to be the most adapted candidate for the electric propulsion of urban HEVs. In fact, this solution is a consensual one as illustrated by the evaluation summarized in Table 2 and based on the main characteristics of the HEV electric propulsion, each of them is graded from 1 to 5 points, where 5 points means the best. Indeed, this evaluation is an update of the one done in [3].

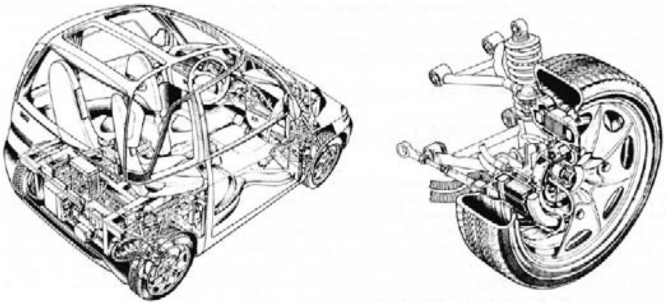


Fig. 15. In wheel switched reluctance motor in the Fiat "Downtown" [30].

Fig. 16. A 50-kW switched reluctance motor
in an experimental HEV bus" [31].

However, among the above-mentioned motor electric propulsion features, the extended speed range ability and energy efficiency are the two basic characteristics that are influenced by vehicle dynamics and system architecture. Therefore, the selection of traction drives for HEVs demands special attention on these two characteristics. Moreover, the issue of extended speed range is significant to a vehicle's acceleration performance, which is a design criteria usually determined by user's demand. However, in real time driving, the vehicle rarely operates in extreme conditions (i.e. high speed and acceleration). Thus, the issue of energy efficiency of the system becomes important [1], [3]. From this analysis, a conclusion that should be drawn is that PM brushless motor is an alternative (Table 2). This is why competition remains hard between the induction and PM motors. In this context, some automakers try to combine the advantages of these two motors. In fact, on the GM HEV, called Sequel, an induction motor is used in the vehicle front and two PM brushless motors are used as wheel hub motors (Fig. 17a).

Recently, a new induction motor technology has been developed for traction application requiring flat or hub style motors (pancake or hub motor). The developed motor can produce the torque of a PM motor without using permanent magnet material. Other features include reduced manufacturing costs, and operation at higher temperatures and higher speed (Fig. 17b) [32].

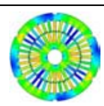
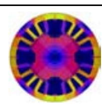
IV. SUMMARY

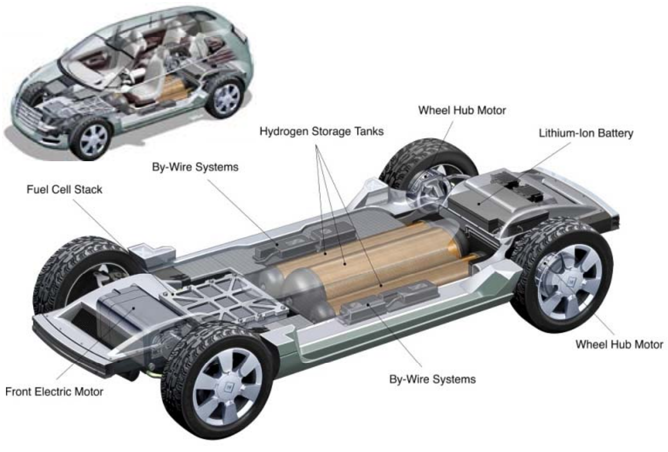
In this paper, potential candidates of traction motor, for parallel HEVs, have been presented and evaluated according to major requirements of a HEV electric propulsion system.

Table 1 Electric propulsion adopted in the automotive industry.

HEV Model	Propulsion System
 PSA Peugeot-Citroën / Berlingo (France)	Dc Motor
 Holden /ECOmmodore (Australia)	Switched Reluctance Motor
 Nissan/Tino (Japan)	Permanent Magnet Synchronous Motor
 Honda/Insight (Japan)	Permanent Magnet Synchronous Motor
 Toyota/Prius (Japan)	Permanent Magnet Synchronous Motor
 Renault/Kangoo (France)	Induction Motor
 Chevrolet/Silverado (USA)	Induction Motor
 DaimlerChrysler/Durango (Germany/USA)	Induction Motor
 BMW/X5 (Germany)	Induction Motor

Table 2. Electric propulsion systems evaluation.

Propulsion Systems / *Characteristics*	 DC	 IM	 PM	 SRM
Power Density	2.5	3.5	5	3.5
Efficiency	2.5	3.5	5	3.5
Controllability	5	5	4	3
Reliability	3	5	4	5
Technological maturity	5	5	4	4
Cost	4	5	3	4
∑ Total	 **22**	 **27**	 **25**	 **23**



(a) Sequel concept [© GM].

(b) Symetron™ induction motor [32].

Fig. 17. New concepts for HEVs.

The comparative study has revealed that the induction motor is the solution that makes the consensus even if competition remains hard with PM brushless motors. Moreover, this study consolidates other comparative investigations [33-34].

REFERENCES

[1] Z. Rahman et *al.*, "An investigation of electric motor drive characteristics for ev and hev propulsion systems," *SAE Technical Paper Series*, Paper # 2000-01-3062.

[2] L. Eudy et *al.*, "Overview of advanced technology transportation, 2004 Update," *NREL*, DOE/GO-102004-1849, August 2004.

[3] C.C. Chan, "The state of the art of electric and hybrid vehicles," *Proceedings of the IEEE*, vol. 90, n°2, pp. 247-275, February 2002.

[4] T.M. Jahns et *al.*, "Recent advances in power electronics technology for industrial and traction machine drives," *Proceedings of the IEEE*, vol. 89, n°6, pp. 963-975, June 2002.

[5] C.C. Chan et *al.*, "An overview of power electronics in electric vehicles," *IEEE Trans. Industrial Electronics*, vol. 44, n°1, pp. 3-13, February 1997.

[6] K. Rajashekara, "History of electric vehicles in General Motors," *IEEE Trans. Industry Applications*, vol. 30, n°4, pp. 897-904, July-August 1994.

[7] A. Emadi et *al.*, "Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations," *IEEE Trans. Vehicular Technology*, vol. 54, n°3, pp. 763-770, May 2005.

[8] S.M. Lukic et *al.*, "Effects of drivetrain hybridization on fuel economy and dynamic performance of parallel hybrid electric vehicles," *IEEE Trans. Vehicular Technology*, vol. 53, n°2, pp. 385-389, March 2004.

[9] Z. Rahman et *al.*, "A comparison study between two parallel hybrid control concepts," *SAE Technical Paper Series*, Paper # 2000-01-0994.

[10] D. Diallo et *al.*, "A fault-tolerant control architecture for induction motor drives in automotive applications," *IEEE Trans. Vehicular Technology*, vol. 53, n°6, pp. 1847-1855, November 2004.

[11] A.G. Jack et *al.*, "A comparative study of permanent magnet and switched reluctance motors for high-performance fault tolerant applications," *IEEE Trans. Industry Applications*, vol. 32, n°4, pp. 889-895, July-August 1996.

[12] G. Dancygier et *al.*, "Motor control law and comfort law in the Peugeot and Citroen electric vehicles driven by a dc commutator motor," *in Proceedings of the 1998 IEE Power Electronics and Variable Speed Drives Conference*, pp. 370-374, September 21-23, 1998.

[13] T. Wang et *al.*, "Design characteristics of the induction motor used for hybrid electric vehicle," *IEEE Trans. Magnetics*, vol. 41, n°1, pp. 505-508, January 2005.

[14] G. Pugslay et *al.*, "New modeling methodology for induction machine efficiency mapping for hybrid vehicles," *in Proceedings of the 2003 IEEE International Electric Machines and Drives Conference*, vol. 2, pp. 776-781, Madison, WI (USA), June 1-4, 2003.

[15] D.H. Cho et *al.*, "Induction motor design for electric vehicle using niching genetic algorithm," *IEEE Trans. Industry Applications*, vol. 37, n°4, pp. 994-999, July-August 2001.

[16] M.E.H. Benbouzid et *al.*, "An efficiency-optimization controller for induction motor drives," *IEEE Power Engineering Letters*, vol. 18, n°5, pp. 43-45, May 1998.

[17] M.E.H. Benbouzid et *al.*, "Fuzzy efficient-optimization controller for induction motor drives," *IEEE Power Engineering Letters*, vol. 20, n°10, pp. 43-44, October 2000.

[18] H.D. Lee et *al.*, "Fuzzy-logic-based torque control strategy for parallel-type hybrid electric vehicle," *IEEE Trans. Industrial Electronics*, vol. 45, n°4, pp. 625-632, August 1998.

[19] B. Kou et *al.*, "Operating control of efficiently generating induction motor for driving hybrid electric vehicle," *IEEE Trans. Magnetics*, vol. 41, n°1, pp. 488-491, January 2005.

[20] G. Brusaglino et *al.*, "Advanced drives for electrically propelled vehicles," *in Proceedings of the 1999 IEE Colloquium on Electrical Machine Design for All-Electric and Hybrid-Electric Vehicles*, pp. 4/1-4/12.

[21] S.Z. Jiang et *al.*, "Spectral analysis of a new six-phase pole-changing induction motor drive for electric vehicles," *IEEE Trans. Industrial Electronics*, vol. 50, n°1, pp. 123-131, February 2003.

[22] J.W. Kelly et *al.*, "Control of a continuously operated pole-changing induction machine," *in Proceedings of the 2003 IEEE International Electric Machines and Drives Conference*, vol. 1, pp. 211-217, Madison, WI (USA), June 1-4, 2003.

[23] J. Kim et *al.*, "Dual-inverter control strategy for high-speed operation of ev induction motors," *IEEE Trans. Industrial Electronics*, vol. 51, n°2, pp. 312-320, April 2004.

[24] M.S. Vicatos et *al.*, "A doubly-fed induction machine differential drive model for automobiles," *IEEE Trans. Energy Conversion*, vol. 18, n°2, pp. 225-230, June 2003.

[25] K. Aoki et *al.*, "Development of integrated motor assist hybrid system: Development of the 'Insight', a personal hybrid coupe," *SAE Technical Paper Series*, Paper # 2000-01-2216.

[26] H. Endo et *al.*, "Development of Toyota's transaxle for mini-van hybrid vehicles," *JSAE Review*, vol. 24, n°2, pp. 109-116, 2003.

[27] M. Terashima et *al.*, "Novel motors and controllers for high-performance electric vehicle with four in-wheel motors," *IEEE Trans. Industrial Electronics*, vol. 44, n°1, pp. 28-38, February 1997.

[28] J. Malan et *al.*, "Performance of a hybrid electric vehicle using reluctance synchronous machine technology," *IEEE Trans. Industry Applications*, vol. 37, n°5, pp. 1319-1324, September-October 2001.

[29] K.M. Rahman, et *al.*, "Advantages of switched reluctance motor applications to ev and hev: Design and control issues," *IEEE Trans. Industry Applications*, vol. 36, n°1, pp. 111-121, January-February 2000.

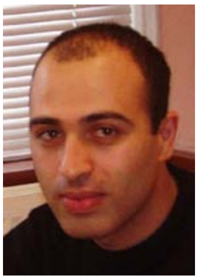
[30] G. Brusaglino, "Energy management optimization by an auxiliary power source," *dans les Actes du Symposium Véhicules Propres*, pp.223-230, La Rochelle, France, Novembre 1993.

[31] S. Wang et *al.*, "Implementation of 50-kW four-phase switched reluctance motor drive system for hybrid electric vehicle," *IEEE Trans. Magnetics*, vol. 41, n°1, pp. 501-504, January 2005.

[32] Symetron™ P-2 AC Motor Technology, "AC induction motor design for "Pancake" or "Hub" motor applications," *http://www.rasertech.com/*.

[33] J.G.W. West, "Dc, induction, reluctance and pm motors for electric vehicles," *IEE Power Engineering Journal*, pp. 77-88, April 1994.

[34] L. Chang, "Comparison of ac drives for electric vehicles – A report on expert's opinion survey," *IEEE AES Magazine*, pp. 7-11, August 1994.



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