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COMPARISON OF ELECTRIC MOTORS USED FOR ELECTRIC VEHICLES PROPULSION

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Abstract: *At present, interest in electric vehicles road reached a very high level. Undoubtedly, these vehicles will be part of the main means of transport of the future but for them to dominate the market of road vehicles, there is still much research efforts dedicated to this purpose. Also, new industries will be created and will have trained many professionals in the fields of electric propulsion systems and components of these systems. Rotary motors are the main components of electric propulsion systems of road vehicles (scooters, cars, buses). There are several types of electric motors can be used in vehicle propulsion systems: DC motors, synchronous motors with permanent magnets or electromagnetic excitation, switched reluctance synchronous motors, squirrel cage induction motors. Performance of these engines, with performance electric batteries or other energy storage mobile units, largely conditions techno-economic performance of electric vehicles, which require careful consideration of their choice. In this paper we present a comparative analysis of electric motors that are currently used in road vehicle propulsion systems.*

Keywords: *electric vehicles, propulsion systems, rotary motors.*

1. INTRODUCTION

Electric vehicle was converted mainly from the existence of an internal combustion vehicle by replacing the internal combustion engine and fuel tank with an electric drive motor and a battery unit while retaining all other components as shown in Figure 1. Disadvantages such as heavy load, reduced flexibility, and performance degradation caused electric vehicle using this type of use out of. In its place, modern electric vehicle is deliberately built models based on the original frame and body. This unique structure satisfies the requirements of the electric vehicle and makes use of a more flexible electric propulsion.

A modern electric drive system is conceptually illustrated in Figure 2. Drive propulsion system consists of three major subsystems: propulsion electric motor, power supply, and auxiliary. Electric propulsion subsystem consists of vehicle controller, electronic power converter, electric motor, manual transmission and driving wheels.

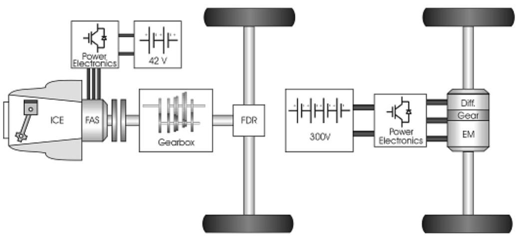

Figure 1. Primary propulsion system of the electric vehicle [8]

Power supply subsystem includes: power supply, power management unit, and unit energy recharge. Auxiliary subsystem consists of drive power steering, climate control room and auxiliary power unit.

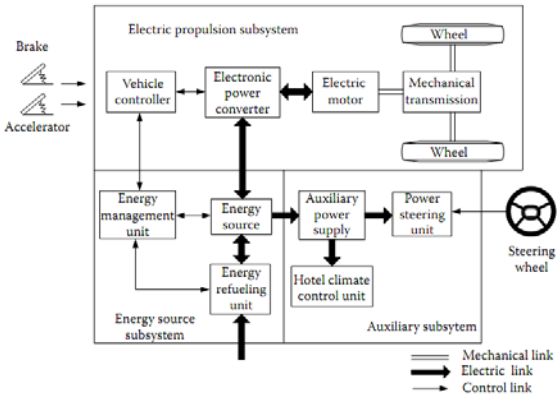

Figure 2. Conceptual illustration of the general configuration of an electric vehicle [2]

2. ELECTRIC PROPULSION SYSTEM

It consists of electric motors, power converters, and electronic control (Figure 3). The electric motor converts electrical energy into mechanical energy for propulsion of the vehicle or vice versa, to enable regenerative braking or charging energies to generate electrcitate stored on board. Power converter is used to power the electric motor with the proper voltage and current. Electronic controller can be further subdivided into three functional units: sensor interface circuits and processor.

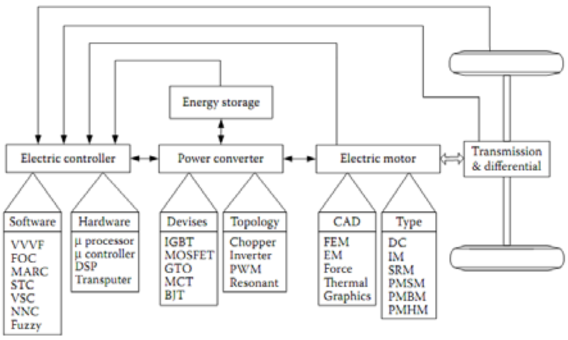

Figure 3. Functional block diagram of a typical electric propulsion system [2]

The sensor is used to translate the measured quantities such as voltage, current, temperature, speed, torque, and flow in electrical signals through interface circuits. These signals are conditioned to the appropriate level before being introduced into the processor. Processor output signals are usually amplified through interface circuits act of power semiconductor devices power converter. Energy source refers to batteries, fuel cells, ultracapacitor, flywheel, and different hybrid sources. Drive motors for electric and hybrid vehicles can be classified into two main groups, namely switching engines and motors without commutation, illustrated in Figure 4. Switching engines are basically traditional DC motors, including excitations series, shunt excitation, excitation compound, separate excitation and excitation permanent magnet motors. DC motors switches and brushes need to enter armature current, thus making them less reliable and unfit for maintenance-free operation and high speed.

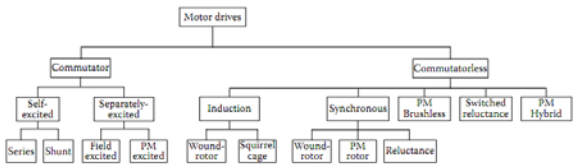

Figure 4. Classification of motor units for electric and hybrid vehicle applications [2]

Recent technological developments have pushed electric motors without switching into a new era. Benefits include increased efficiency, increased power density and low operating costs. They are also more reliable and maintenance-free compared with switching, so those without switch became more attractive. Induction motors are widely accepted as a type of engine without switching to electric vehicle propulsion. This is due to the low cost, high reliability and maintenance-free operation. However, conventional control of induction motor such as variable voltage, variable frequency can not provide the desired performance. With the advent of power electronics and microchip age, principle as field oriented control or vector control of induction motor have been accepted to overcome the complexity of control because of their nonlinearity. However, these control methods suffer from low efficiency in light load and limited range of operating at constant power. By replacing the field winding permanent magnet synchronous motor classic, permanent magnet synchronous motors can remove conventional brushes, slip rings, and field copper losses (Figure 5). In fact, the permanent magnet synchronous motors are also known as brushless motors with permanent magnet or permanent magnet sinusoidal AC and brushless configuration (BLDC). Variable reluctance synchronous motors (SRM) were recognized to have great potential for applications in electric and hybrid vehicles (Figure 6).

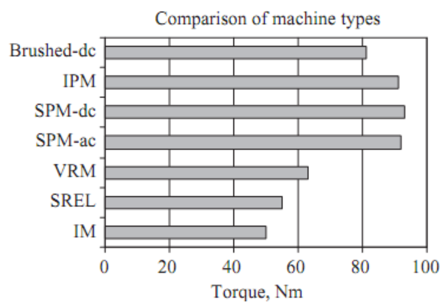

Figure 5. Relative ranking based on maximum torque at the same volume [1]

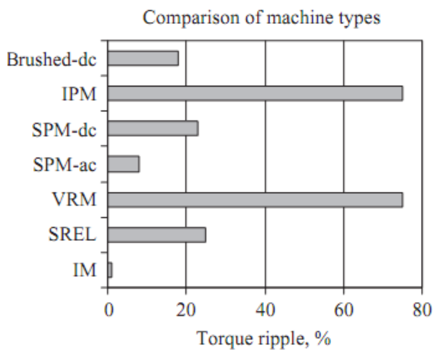

Figure 6. Comparison based on cutting torque ripples at the same volume [1]

3. ADVANTAGES AND DISAVANTAGES OF VARIOUS TYPES OF ELECTRICAL MACHINES

Selection traction motors for hybrid propulsion systems is a very important step that requires a special attention. In fact, the automotive industry is still searching for the electric propulsion system suitable for hybrid vehicles and even electric vehicles. In this case, the key features are efficiency, reliability brushless motors powered sinusoidal due to

and cost. Choice of electric propulsion systems for electric vehicles depends primarily on three factors: expectations driver, vehicle constraints, and energy source. Among the various types of electric motor drives, different types are considered viable powertrain electrification, namely those with DC motor, induction motor (induction motor), wound rotor synchronous motor, switched reluctance motor and motor brushless permanent magnet (Figure 7).

	DC motor	Asynchronous (induction) motor	Synchronous wound rotor machine	Synchronous permanent magnet machine	Synchronous permanent magnet machine	Switched reluctance machine
Field orientation	Radial	Radial	Radial	Radial	Axial	Radial
Torque	+	-	-	++	++	+
Efficiency	-	-	+/-	++	++	+
Max speed	-	+/-	-	+/-	+/-	+
Cooling	-	-	+/-	+	-	+
Field weakening	+	+	+	+/-	+/-	+/-
Reliability	-	+	-	+	+	+
Economic potential	+	++	-	-	+/-	+

Figure 7. Overall comparison of different types of motors for traction propulsion system [8]

Given the above table, topology selection electric machines for traction vehicles was restricted inside and concentration flux permanent magnet synchronous motors with radial flow but also axial flux machines with permanent magnets. Permanent magnet machines are becoming more common in traction applications due to high power density, compactness and current availability of power electronics needed for effective control. Despite recent increases in the price of permanent magnets, they are still profitable. Machines axial flux permanent magnet, axial length have particularly short, which could be a considerable advantage to incorporate machine drive system of the vehicle. Moreover, axial flow impellers machine can replace the engine flywheel and flywheel housing is available in the engine. Induction machines are also selected because they are recognized as a mature technology and is widely accepted in traction applications (Figure 8). DC machines were excluded from the selection list for the well known problems associated with mechanical switching. Switched reluctance machines also have been considered a candidate for electric vehicle applications. However, they are less common and therefore are not considered in this study. The same observation can be made on the wound rotor synchronous machine. This machine is not selected for now, because copper losses rortor difficult to extract, but it would be relevant in the future for a car that does not use permanent magnets, and is profitable for future applications (Figure 9).

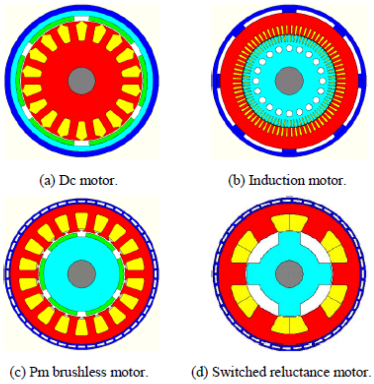

Figure 8. Industrial engines and traction [10]

For the applications drive electric cars, multiphase system could meet the potential demand for electric drives great power, which are both robust and energy efficient.

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
Σ Total	**22**	**27**	**25**	**23**

Figure 9. Systems evaluation of electric propulsion [10]

High number of phases drives have several advantages over 3 phase drives such as: reducing the amplitude and increasing the frequency of torque pulsation, reducing rotor current harmonics, reducing the current per phase without increasing the voltage per phase, reducing the DC link current harmonics, a increased reliability and greater power in the same frame. In a multiphase system drive the car more than three windings are located in the same state of electric machine, and the machine phase currents is thus reduced.

All multiphase variable speed drives share a number of common features:

- For output power of the machine time, the use of more than 3-phase power split to allow a greater number of connections to the inverter, allowing use of semiconductor switches at low levels.
- Due to a larger number of phases, multiphase machines are characterized by a much better fault tolerance than the phase.

Independent control of flux and torque requires means for independent control of two currents. This is impossible in a car if a phase-phase becomes open circuit, but does not present a problem for a multiphase machine as long as no more than three phases are not defective.

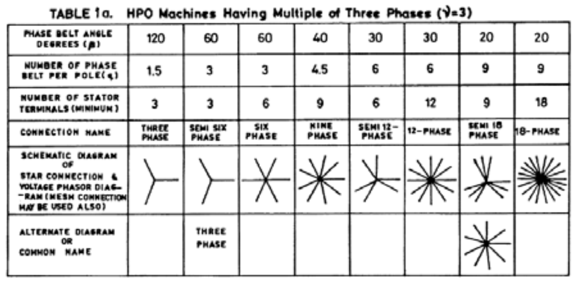
TABLE 1a. HPO Machines Having Multiple of Three Phases (ν=3)

PHASE BELT ANGLE DEGREES (β)	120	60	60	40	30	30	20	20
NUMBER OF PHASE BELT PER POLE(q)	1.5	3	3	4.5	6	6	9	9
NUMBER OF STATOR TERMINALS (MINIMUN)	3	3	6	9	6	12	9	18
CONNECTION NAME	THREE PHASE	SEMI SIX PHASE	SIX PHASE	NINE PHASE	SEMI 12-PHASE	12-PHASE	SEMI 18 PHASE	18-PHASE
SCHEMATIC DIAGRAM OF STAR CONNECTION & VOLTAGE PHASOR DIAGRAM (MESH CONNECTION MAY BE USED ALSO)								
ALTERNATE DIAGRAM OR COMMON NAME		THREE PHASE						

Figure 10. Multiphase machine models [9]

3. ACKNOWLEDGMENT

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