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Design Considering Operation States and Control Strategy of Plug-In Hybrid Electric Vehicles with Full Performance

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Abstract

This paper discusses about the relative analysis of permanent magnet motors and switched reluctance motors (SRM) capability of electric vehicles (EVs) and hybrid electric vehicles (HEVs) system. Nowadays the pollution of the environment is increasing due to conventional vehicles. Hence, to reduce the pollution electric motors are very beneficial. Presently use of high power density magnetic motors like, brushless DC (BLDC) motors and permanent magnet synchronous motors (PMSM) have been the primary choice in the EVs and HEVs. But these motors have problems with demagnetization, high cost and fault tolerance. Therefore, in future permanent magnet motors will be replaced with SRM for EVs and HEVs. Because of SRM have no permanent magnets on the rotor, higher torque to power ratio, low losses and low acoustic noise compare to BLDC motors and PMSM. This paper is based on the properties of the special electric motors for example performance analysis, power density control, torque ripple control, vibration control, noise and efficiency. In this paper, special aspects of the BLDC motors, PMSM and SRM based drive systems for the EVs and HEVs are offered and reviewed. Also explained why permanent magnet motors are replaced with SRM for applications in EVs and HEVs.

Keywords: Brushless DC (BLDC) motors, electric vehicles (EVs), hybrid electric vehicles (HEVs), power electronics converters (PEC), permanent magnet synchronous motors (PMSM), switched reluctance motors (SRM) and special electric motors (SEM).

1. Introduction

Nowadays conventional vehicles produce air pollution throughout their life, during the vehicle operation. The most important pollutants from conventional vehicles are sulfur dioxide, Hydrocarbons, Carbon monoxide, Greenhouse gases and Nitrogen oxides. So, prevent to produce these types of gases in the environment, researchers are working on electric vehicles (EVs) and hybrid electric vehicles (HEVs). Therefore, nowadays people are going to replace conventional vehicles by EVs and HEVs. The EVs and HEVs are made by special electric motors (SEM).

The permanent magnet (PM) machines have beneficial that makes suitable for EVs and HEVs. But, the available resources of PM materials are limited and cost effective. Therefore, there is an increasing attention in PM free electric motor such as SRM [1]. Due to their strong construction and little cost, SRM is considered as physically powerful candidates for EVs and HEVs [2]. The SEM has gained popular recognition in the EVs and HEVs market due to high power density control, torque to inertia ratio control, speed range and reliability. Presently we are using permanent magnet synchronous motors (PMSM) and brushless DC (BLDC) motors in electric vehicles. But, these motors used permanent magnet material for production of a torque. Consequently, other technologies have been introduced and demanded for rare-earth-free motors. The introduced and demanded new motor is switched reluctance motors (SRM) are recognized to have a simpler and stronger construction exclusive of any windings and permanent magnets on the rotor [3].

The SRM provides a longer examination time in unkind environments and a supplementary cost effectual motor drive operation than BLDC motors and PMSM [3]-[4]. The SRM has lots of reward like, good efficiency, good reliability and more starting torque in early accelerations, excellent fault tolerance ability. So as to progress the SRM structure, reliability, position sensor less control techniques [4]-[5] and fault acceptance techniques [6]-[7] are developed for security significant applications. A most important factor for the selection of EVs and HEVs are: cost, weight and efficiency [8]. Bulky motors will increase the weight of the overall system and resulting in lower acceleration and reduce overall performance of the vehicles. Special electric motors are the best choice for the EVs and HEVs as they are comparatively inexpensive, strong and can be considered to have a least amount weight [9].

The advancement in region for example power electronics and control systems, there is a command for superior electric motors so as to meet the necessary performance indices of an EVs and HEVs at a lesser cost [10]. The required specifications for an ideal EVs and HEVs can be higher efficiency achievement, higher power density control, higher specific torque, lower noise, extensive constant power, wide speed range, improved dynamic response, ruggedness and robustness and cost [11]- [12]. The motivation of this paper is to offer a comparative analysis of permanent magnet motors and SRM capability for EVs and HEVs. The demerits of permanent magnet motors and major advantages of SRM for EVs and HEVs are explained. Finally, three types of motors are compared in the relevance of the EVs and HEVs.

The paper is structured as follows: Section II will discuss about the types of electric vehicles, while section III will discuss about electric motors for EVs and HEVs, section IV will discuss about power electronics and control system for SRM drives, section V will discuss about challenges and opportunity for power sector and last section VI concludes the paper.

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2. Types of Electric Vehicles

Hydrogen powered fuel cell, batteries and super capacitors are generally used to store electrical energy. Nowadays, SRM, PMSM, BLDC and induction motors (IM) are used in EVs and HEVs applications. The HEVs is acting as a generator and thus produce electric power which can be utilized later. In EVs and HEVs, series and parallel connection-based transmission system are used between electric motor and internal combustion engines (ICE). Power electronic semiconductor switches such as BJT, MOSFET and IGBT used and different types of control techniques along with linear and non-linear controllers are used in the control system. The controllers are implemented with various types of control platforms such as DSP, microcontrollers and others. The major difference between HEVs and ICE vehicle are as follows. a) a system which converts electrical power into appropriate mechanical torque on the wheels b) a system to store good amount of electrical energy c) a modified ICE system to adopt in HEVs application and d) a transmission system between two different control techniques. The main motivation is the use of renewable energy sources (RES) in EVs and HEVs applications such that system efficiency is improved.

2.1 Plug-in electric vehicles

The main components of plug-in electric vehicles are battery, power electronic converter, motor and gear system. The simple construction of plug-in electric vehicles is shown in Fig. 1. The energy stored in the battery is converted into AC based on the system used to drive the vehicles. The functional advantages of EVs are pollution free and environmental friendly. The major drawback of the plug-in EVs is fast discharging of the battery. Hence, it is not useful for large scale travel applications.

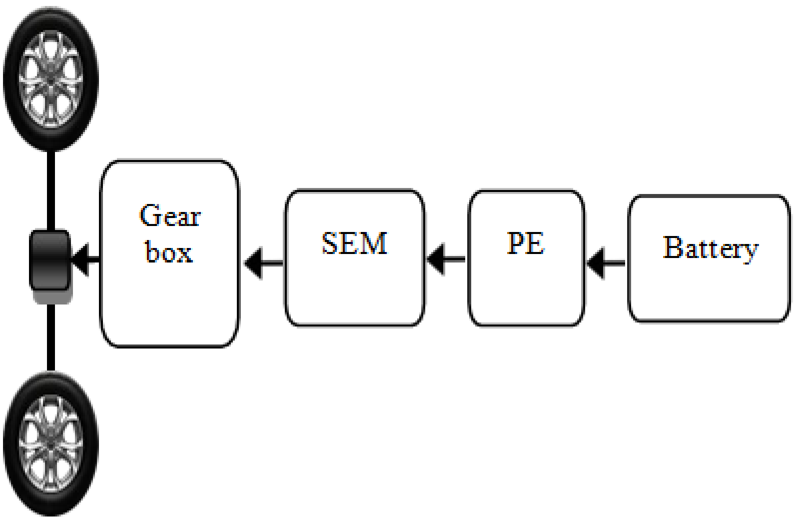

Figure 1 Plug-in electric vehicles

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2.2 ***Hybrid electric vehicles***

In HEVs, electric and other energy systems are incorporated together to drive the vehicles. Electric drive and different types of motor supplies to the power train of vehicles with various types of energy resources along with additional power sources such as ICE to drive the vehicle is generally called as HEVs. Toyota and Honda are the major car companies which already started production of HEVs which are now fetching very popular among the consumers for their mileage and less pollution.

3. Electric Motors for Electric and Hybrid Electric Vehicles

Configuration of different type of electrical motors which used in EVs and HEVs are shown in fig. 2. Application of each machine has their own merits and demerits which make them attractive different types of hybrid vehicle concepts. Schematic layout of electric and hybrid electric vehicles is shown in fig. 3. The schematic layout of EVs and HEVs are become combinations of power electronics components, batteries and control logic.

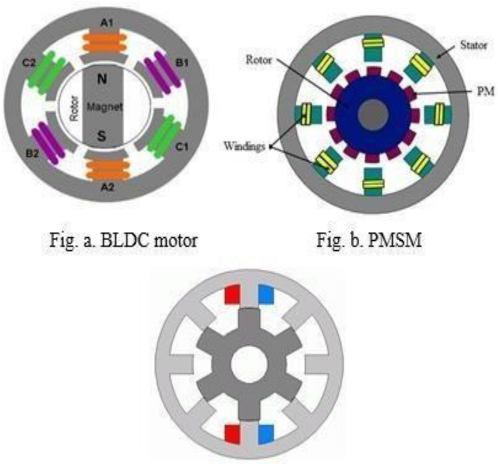

Figure 2. Basic stator and rotor configurations: (a) BLDC motor, (b) PMSM and (c) SRM

3.1 BLDC motor and PMSM

The excitation required for PMSM and BLDC motors are generated by PM in the rotor part of the system. Due to high energy density of the PM, these motors get more advantages such as PM requires less space. During the nominal speed, the overall efficiency of the BLDC motor and PMSM are high due to zero excitation current in the system. Iron losses in one of the important losses in the PMSM and BLDC motors. These losses are easily dissipated under the use of case cooling system. But cost of the magnet is high and field weakening is done by using a current component which is a drawback in the BLDC motor and PMSM which increase the stator loss and decrease the efficiency during high speed condition. The overload capacities of BLDC motor and PMSM are limited by using magnetic characteristics.

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Fig. 4 shows the torque speed curve of PMSM used in EVs. Different ranges of speed and torque variation are given as constant torque, constant power and high-speed region. During the constant torque region of the PMSM, rated speed is not reached, and constant torque is exerted. When speed meets the rated motor speed, torque reduces proportionally which leads to constant output power. When the speed increases further, constant power section ends. Furthermore, motor torque reduces proportionally with respect to square of the speed.

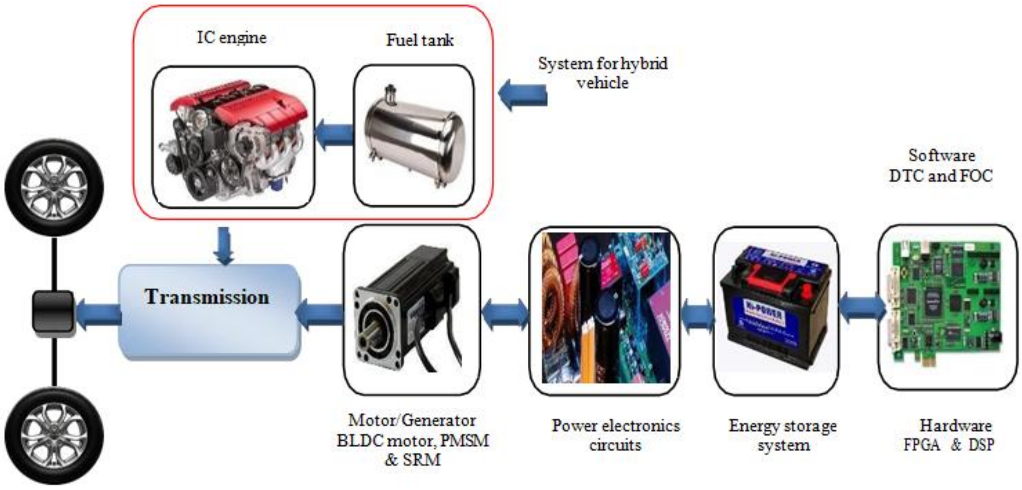

Figure 3 Schematic layout of electric and hybrid electric vehicles

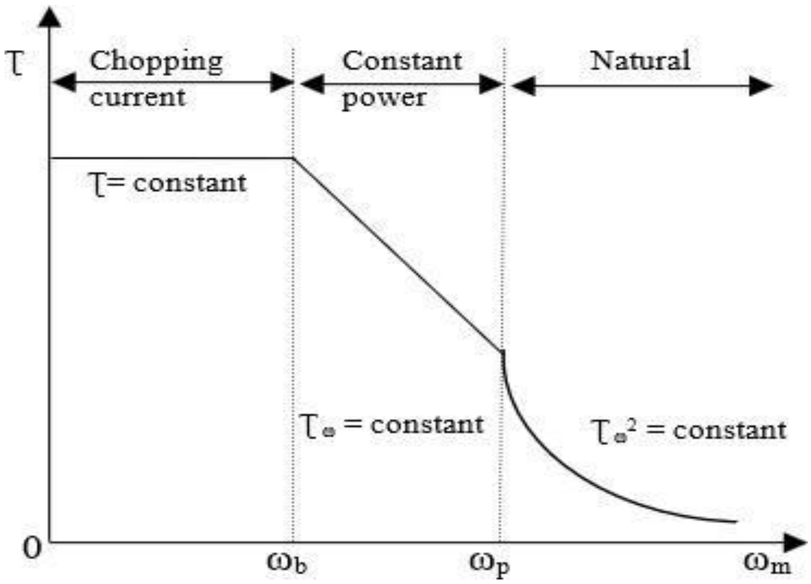

Figure 4 Torque speed characteristics of PMSM

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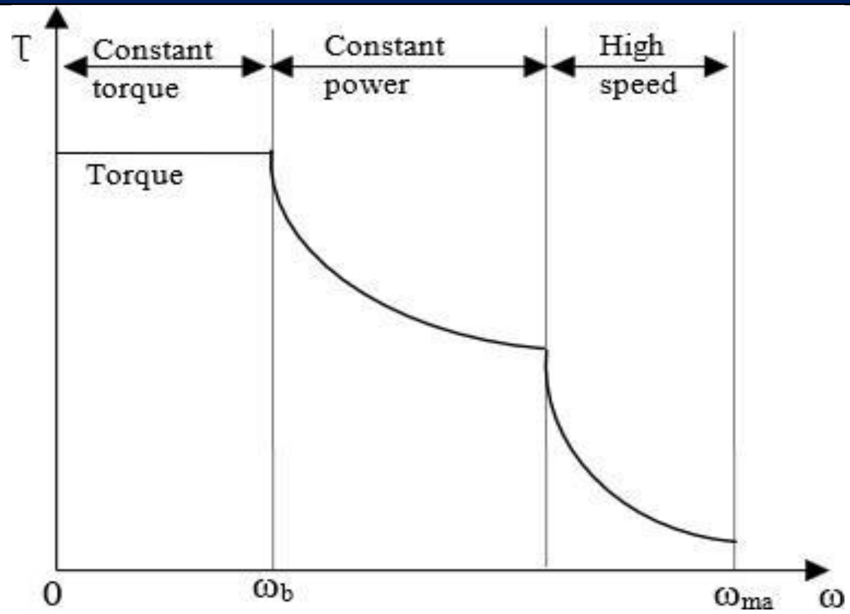

Figure 5 Torque speed characteristic of SRM

3.2 SRM

The basic understanding of SRM is used for a long time. However, this principle is not applied in the advancement in the power electronic applications. Compare to conventional motors, SRM shows improved power density and also it has good efficiency. The construction of SRM is very simple such that it has concentrated stator winding without any rotor winding. This type of construction achieved better charges. However, identification of current switching angle is highly non-linear such that control of SRM is more difficult than other three-phase machines. The torque speed characteristics of SRM are shown in Fig. 5. Based on the rotor position, the current in the stator winding are switched ON and OFF. The natural region is the one which have constant frequency and constant switching angles. Here ωb is called as base speed and it is defined as the speed at which peak current can be provided to the motor rated voltage with constant switching angle. The synchronization of battery and IC engines at different speed are shown in Fig. 6. Based on the speed changes, the battery and IC engine can work jointly or work separately in order to get better steady state and starting performance. Base speed (ωb) is defined as the maximum speed at which maximum current can be provided to the motor (Imax) at rated voltage, with fixed switching angles. At a specified speed the flux is directly proportional to the voltage V, and the torque differs with the current squared. The chopping voltage control is intelligent to control an SRM drive only in the mode under rated speed where the generated voltage, being greater than the back-EMF, forces the drive states on the sliding surface [3]. If fixed switching angles are continued at speeds above ωb, the torque falls as 1/ω. This is the second significant mode of operation, when the machine speed is beyond the base speed (ωb).

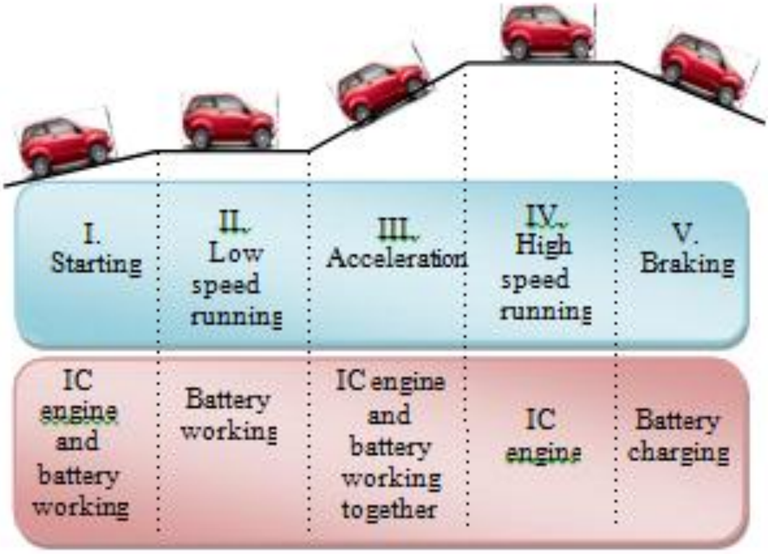

Figure 6 Coordination of the IC engine and the battery working in different speed conditions

As per speed variation of vehicles battery and IC engine operate at a different speed region or some time it will work individually rendering to the speed changes, to recover the starting, acceleration, and steady-state enactments. The multilevel voltage as well as the fast excitation and fast demagnetization are both accomplished in IC engine and battery driving modes for torque proficiency developments. Table I and table II shown the advantages and disadvantages of electric vehicles and comparison between permanent magnet motors and switched reluctance motor respectively.

Table 1 Advantages and Disadvantages of Electric Vehicles

Sl. No.	Advantages	Disadvantages
1	No gas required	Charging points
2	No emission	Electricity is not free
3	Safe to drive	A short driving range and speed
4	Cost effective	Not suitable for cities facing shortage of power
5	Low maintenance	Safety and security problems
6	Reduce noise pollution	High starting cost

From Table II, the best placed challenger is switched reluctance motor drives. Here higher number of digit is good for the selection of EVs and HEVs applications. After analysis that we selected a SRM because simple construction, ruggedness and manufacturability are very significant qualities for mass manufacture of motor drives for electric vehicles.

Table 2 Comparison of Special Electrical Motors

Items	Maximum	BLDC motor	PMSM	SRM
Power density	10	9	10	8
Overload	10	7	7	8
High speed range	20	9	10	8
Control	20	15	15	16
Noise	10	8	8	6
Torque ripple	10	6	8	5
Size and weight	10	8	9	7
Ruggedness	20	14	12	18
Maintenance	10	8	8	9
Manufacturing	20	14	12	18
Cost	30	20	18	26
Total	180	128	135	146

4. Power Electronics and Control System for SRM Drive

The SRM is a voltage source inverter based rotating machine in which controller and drive system is essentially required for the operation. The controller includes, drive mechanism, PEC and also with different types of sensors for sense the mechanical and electrical signals (phase current, phase voltage, rotor position and torque).

4.1 Converter Selection

The excitation phase current polarity is completely independent to the torque of SRM system. This idea makes it most advantage to drive the motor system with many circuit topologies. The asymmetric bridge type inverter for per phase SRM drive is shown in Fig. 7. The semiconductor switch with bidirectional capability is achieved by connecting a diode D1 and D2 parallel with switches S1 and S2. The detailed review of power electronic converters used for SRM application is given in [19]. In the asymmetric bridge type inverter, two switches are turned on simultaneously to magnetize the phase which converts electrical power into torque.

4.2 Control of SRM

The speed control of SRM is a based-on PI controller, which is mostly used in industry [18]. The desired torque is transformed to the motor's electrical references by additional method which depends on the system configuration and motor type.

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Based on the expected torque, phase currents are determined in the SRM motor. Up to conventional speed, PWM method is used to regulate the phase currents and this is one of the basic control system used in SRM. During high speed, due to dynamic characteristics of motor currents, it is difficult to control the phase currents. However, such methods are not used in the real-time applications. The noise control is one of the major challenges in the SRM control-based system. Hence, good amount of research work must be done in this area.

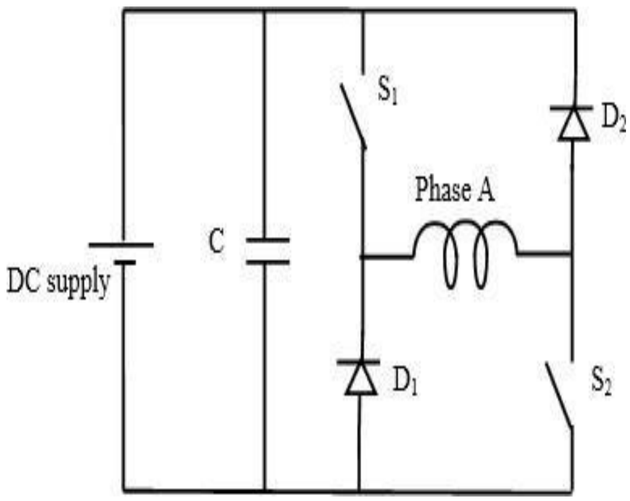

Figure 7 Asymmetric bridge converter for one phase of a SRM

4.3 Sensor less Control of SRM

In EVs and HEVs, the rotor position in sequence is required by operation of SRM based drive system. Sensor is used to sense the position and more precise phase details are required when number of phases are increased in SRM based drive system. However, sensor less control is one of the most effective than sensor-based control system. The sensor-based control system has more initial cost and installation is also tough. The speed torque uniqueness of a SRM drive is classified as low speed area, high speed area, ultra-high-speed area, and constant torque area and standstill condition. The complete information about various methods is detail discussed in [23]. Many types of estimation techniques are proposed in each speed range and sometimes combined method also help to achieve more benefits.

5. Challenges and Opportunities for the Power Sector

In order to ensure the quality of service and satisfactoriness, electrical system is used. The development in EVs will depend upon electrical circuit topologies, control techniques and charging methods. The electric car is charged various places which include home and possible public areas. Therefore, efficiency improvement, safety control and integration of software tools reduce the cost of circuit components and reduce the weight of energy storage elements [24]- [25]. These are immediate requirements for EVs and HEVs development.

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Conclusions

To determine the most suitable electric motors for electric vehicles (EVs) and hybrid electric vehicles (HEVs), several motors were compared. The characteristics of the motors like the power density, efficiency and their advantages and disadvantages were compared regarding their applicability in EVs and HEVs. The switched reluctance motor (SRM) is fine acknowledged for their easy construction, less cost, rigid design, and fault tolerance. The SRM migrates the advantages of a brushless DC (BLDC) motor and permanent magnet synchronous motors (PMSM) though considerably developing its high-power density, high torque, low vibration and low acoustic noise compared to other motors. Based on a comprehensive relative study, it has been shown that SRM can meet and go above the highest torque to power performance. Based on a complete relative study, it has been shown that SRM is better compare to BLDC motors and PMSM in applications of EVs and HEVs.

Acknowledgement

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