Selection of Motor and Motor Drive System for Electric Auto-Rickshaw

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***Abstract*- In this paper, we propose that electric vehicle is much more efficient than gasoline vehicles and it can reduce emissions, it is cost effective, and reduces noise pollution and less maintenance cost. Though many electric motors are available, BLDC motor was the most suitable electric motor for electric vehicle due to greater efficiency, its compatible for all speed vehicles. BLDC motor has been selected by considering all the parameters and by comparing with other motors. As BLDC motor has been selected, Hall effect sensors are in this to determine the position of rotor in BLDC motor and control the speed of the motor. In this paper, the basic working principle of Hall-Effect sensors has been explained and the stages of commutation of 3-phase BLDC motor has been described briefly. Different drive systems are available. PWM Inverter based and SEPIC converter based control for drives have been studied.**

I. INTRODUCTION

As quoted by the CEO of Renault, Carlos Ghosn "The time is right for electric vehicles – in fact the time is critical", electric vehicles play a vital role in today's world with reference to many aspects.

The pollution of environment is increasing due a very large numbers of conventional vehicles present today. To reduce pollution, the electric and hybrid electric vehicle are very beneficial. As the decade of low cost fuel is coming to an end the electric vehicle or hybrid electric vehicle is a good alternative to the conventional vehicles. Adding to this, electric vehicles have significance in improving the country's economy as well.

It is known that electric vehicle (EV) technology has been gaining importance at both military and commercial vehicle systems for the last decades. Despite they have higher cost, their higher energy efficiency, lower emissions, regenerative braking and silent mode drive capabilities are major advantages over conventional vehicles.

There are three main types of electric vehicles (EVs), classed by the degree that electricity is used as their energy source. BEVs, or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs, or hybrid electric vehicles. Only BEVs are capable of charging on a level 3, DC fast charge.

HEVs: They are powered by both gasoline and electricity. The electric energy is generated by the car's own braking system to recharge the battery. This is called 'regenerative braking', a process where the electric motor helps to slow the vehicle and uses some of the energy normally converted to heat by the brakes. HEVs start off using the electric motor, then the gasoline engine cuts in as load or speed rises. The two motors are controlled by an internal computer, which ensures the best economy for the driving conditions. Ex: Toyota Prius Hybrid.

PHEVs: They can recharge the battery through both regenerative braking and "plugging in" to an external source of electrical power. While "standard" hybrids can (at low speed) go about 1-2 miles before the gasoline engine turns on, PHEV models can go anywhere from 10-40 miles before their gas engines provide assistance. Ex: Chevy Volt, Audi A3 E-Tron, Porsche Cayenne S E-Hybrid

BEVs: They are more frequently called EVs, are fully-electric vehicles with rechargeable batteries and no gasoline engine. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all onboard electronics. BEVs do not emit any harmful emissions and hazards caused by traditional gasoline-powered vehicles. BEVs are charged by electricity from an external source.

Any Electric vehicle will have the following basic components:

Charging port or vehicle inlet: It is a connector present on the electric vehicle to allow it to be connected to an external source of electricity for charging.
Power electronic converter: A power electronic converter is made of high power fast-acting semiconductor devices, which act as high-speed switches. Different switching states alter the input voltage and current through the use of capacitive and inductive elements. The result is an output voltage and current, which is at a different level to the input.
On-board charger: It is an AC-to-DC power electronic converter (often referred to as a rectifier) that takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. Using the battery management system, it regulates the battery characteristics such as voltage, current, temperature, and state of charge.
Traction battery pack: It is a high voltage battery used to store energy in the electric car and provide power for use by the electric traction motor.
Battery power converter: It is a DC-to-DC power electronic converter that converts the voltage of the traction battery pack to the higher-voltage of the DC-bus used for power exchange with the traction motor.
Motor drive: It is a DC-to-AC (often referred to as inverter or the variable frequency drive) or at times a DC-to-DC power electronic converter, used to convert power from the high voltage DC bus to AC (or at times DC) power for the operation of motor. The converter is bidirectional for operating in both driving and regenerative braking mode.
Traction electric motor/generator: It is the main propulsion device in an electric car that converts electrical energy from the traction battery to mechanical energy for rotating the wheels. It also generates electricity by extracting energy from the rotating wheels while braking, and transferring that energy back to the traction battery pack.
Transmission: For an electric car, usually a single gear transmission with differential is used to transfer mechanical power from the traction motor to drive the wheels.
Power electronics controller: This unit controls the flow of electrical power in the different power electronic converters in the electric car.
Battery (auxiliary): In an electric drive vehicle, the auxiliary battery provides electricity to start the car before the traction battery is engaged and is also used to power the vehicle accessories.

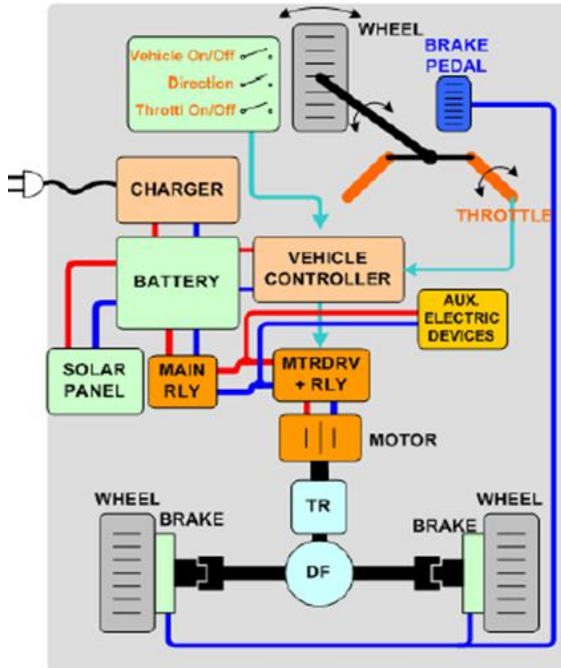

Fig-1: Block diagram pure electric vehicle

Power electronic converters in EV's:
Power semiconductor devices are widely used in automotive power electronic systems, and often dictate the efficiency, cost, and size of these systems. Active power semiconductor switches such as MOSFETs and IGBTs serve as load drivers for motors (ranging from 75 kW AC traction motors to 1W DC motors), solenoids, ignition coils, relays, heaters, lamps, and other automotive loads. Diodes are used in automotive systems to rectify AC current generated by the alternator, provide freewheeling current path for IGBTs or MOSFETs in DC/AC inverters and DC/DC converters, and suppress voltage transients. An average vehicle nowadays has over 50 actuators, which are often controlled by power MOSFETs or other power semiconductor devices.In addition, there are power integrated circuits (ICs) and smart power devices that monolithically integrate power switching devices with logic/analog control, diagnostic, and protective functions.
In the past decades, power device technology has made a tremendous progress. These power devices have grown in power rating and performance by an evolutionary process. The evolution of power

converter topologies normally follows that of power devices, aiming to achieve high power density, high efficiency, high controllability, and high reliability. The power converter topologies dependon the motors to be driven. The selection criteria of motor drives (including the motors and their power converters) for EVs can be divided into the mandatory requirements and the preferable requirements. The mandatory ones are that the motor drive can offer the torque-speed requirements of the EV driving profile without involving variable gearing or gearbox, and the motor drive can provide the capability of bidirectional power flow to recover the regenerative braking energy. In general, the DC, AC or SR motor drives can offer the desired torque-speed requirements under proper motor design.

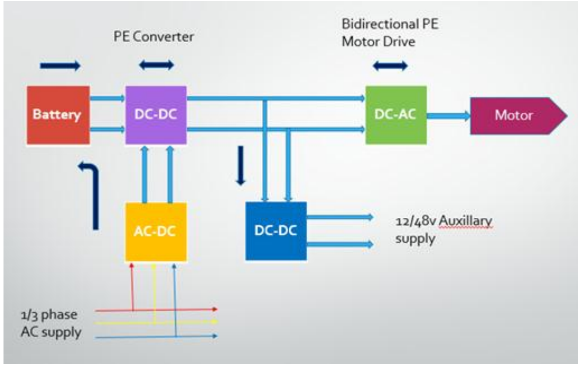

Fig-2: Power converters block diagram

II. SELECTION OF MOTOR

Selection of the traction motor for an electric vehicle system is a crucial step in designing the overall system. Many criteria such as efficiency, cost, reliability, power density, maturity of technology and controllability must be taken into consideration. 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. 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.

In the industrial application point of view, the most common motors used in the hybrid electric vehicles (HEV) and pure electric vehicles (PEV) are: DC motors, induction, permanent magnet synchronous, switched reluctance and brushless DC motors.

COMPARITIVE STUDY:

DC Motors: Although DC motors have been the subject of interest since old time because of simple control and decoupling of flux and torque, their construction (having brushes and rings) poses maintenance problems. Therefore, after the growth of vector control for AC motors (synchronous and induction), the DC motors' attraction in traction applications diminished. Of course, DC motors are still good candidates for low power applications. The commutator actually acts as a robust inverter; Therefore, power electronics devices can be much simple and inexpensive. The Peugeot factory of France has introduced a HEV named "Dynavolt" in which, DC motor has been used as traction motor.

Induction Motors: Squirrel cage induction motors have already been the most important candidate because of their reliability, robustness, less maintenance and the ability to work in hostile environments. The induction motors have the most mature technology among all other AC competitors. the main characteristics of an induction motor have been shown. Torque and field control can be decoupled using vector control methods. Speed range may be extended using flux weakening in the constant power region.

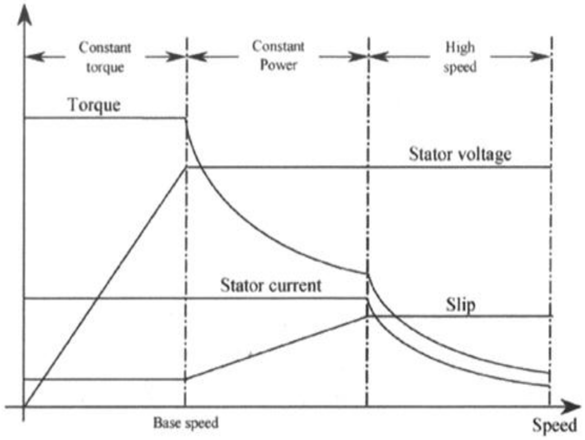

Fig-3: Characteristics of Induction motor

Existence of break-down torque in the constant power region, reduction of efficiency and increment of losses at high speeds, intrinsically lower efficiency in comparison to permanent magnet motors due to the presence of rotor winding and finally low power factor are among the shortcomings of induction motors. Many efforts have been made by researchers to solve these problems, such as: usage of dual inverters to extend the constant power region, incorporating doubly- fed induction motors to have excellent performance at low speeds and reducing rotor winding losses at the design stage. For high power, high speed applications like electric cars, induction motors are the best choice there is. For example, Tesla Model S uses a 3 phase induction motor for traction. But, for low power applications like electric two and three wheelers, induction motors are not used.

Permanent magnet synchronous (PMS) motors: PMS motors are the most serious competitor to the induction motors in traction applications. Actually, many car manufacturers (such as Toyota, Honda and Nissan) have already used these motors in their vehicles. These motors have several advantages: higher power density, higher efficiency and the more effective distribution of heat into the environment. However, these motors have intrinsically a narrow constant power region (Fig.3a). To widen the speed range and increase the efficiency of PMS motors, conduction angle of the power converter can be controlled at speeds higher than the base speed. Fig. 3-b shows the torque speed of a PMS motor with conduction angle control. Speed range can be extended to three of four times the base speed. A shortcoming of these motors is that they can be demagnetized due to the heat or armature reaction.

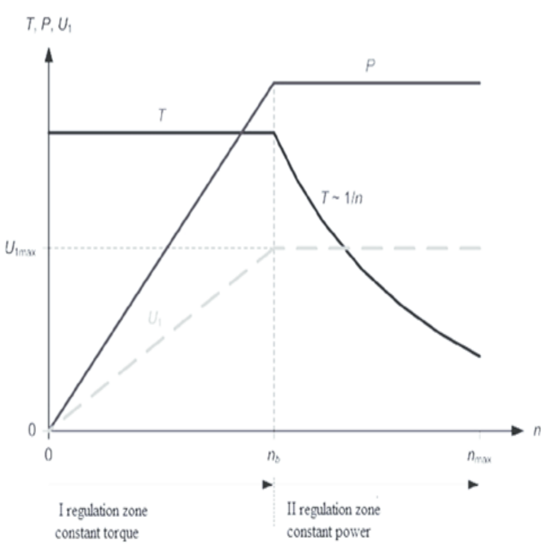

Fig-4: Torque speed characteristics of PMS motors

Switched reluctance motors (SRM): A switched reluctance motor is an electric motor in which the torque is produced by the tendency of its moveable part to move to a position of least reluctance, which corresponds to the position of maximum inductance It is a doubly salient, singly excited motor. That is, the SRM has salient poles on both the rotor and the stator, but only the stator poles carry windings. The rotor tries to get to a position of minimum reluctance by aligning itself with the stator magnetic field. In the presence of a rotating magnetic field, the rotor tries to rotate along with the rotating magnetic field to be always in a position of minimum reluctance. Thus, exciting the stator phase windings of the motor in a particular sequence and consequently, controlling the rotating magnetic field, the movement of the rotor can be controlled

Switched reluctance motors are receiving much attraction in HEV systems every day. Among the advantages of these motors are: simple and rigid construction, fault tolerance, simple control and excellent torque-speed characteristic. A switched reluctance motor can intrinsically operate under a wide constant power region. Several disadvantages such as high noise, high torque ripple, special convertor topology and electromagnetic interference have been mentioned for this motor. Both the advantages and disadvantages of this motorare important in the EV applications. A conventional torque speed characteristic of a SRM has been depicted in the Fig. The PMAR motor using Ferrite magnets exhibits a very limited overload capability, due to the risk of an irreversible demagnetization. Therefore, the synchronous reluctance motor only can be chosen when a high overload capability is requested, as frequently happens for a traction motor.

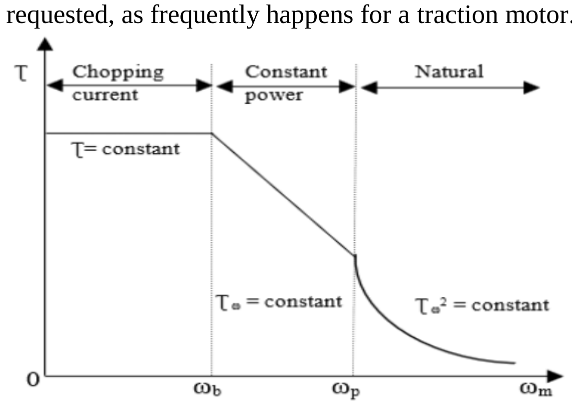

Fig-5: Characteristics of SRM

Brushless DC motors (BLDC): They are mostly used and most suitable motors for EVs as they possess excellent speed torque characteristics, better speed range, higher power densities and most importantly low maintenance. As the magnetic field produced by stator and rotor magnetic rotates at same frequency, so BLDC falls under the umbrella of synchronous motor. As said it is type of synchronous motor so it does not have slip which is normally found in induction motor.

In BLDC motor permanent magnets are fixed on the rotor and armature winding are permanently fixed on the stator which uses laminated steel core. Rotation is started and maintained by energizing opposite pairs of pole in a sequential manner. This makes the BLDC motor:

- Simpler to maintain,
- More durable,
- Smaller,
- 85%–90% more efficient,
- Able to respond faster and at higher operating speeds,
- Simpler to control in regard to speed control and reversing,
- Lighter
- Less prone to the failures that brushed motors experience, and
- Able to self-start.

The composition of the BLDC motor also keeps the machinery inside a vehicle cooler and thermally resistant. Plus, because the motor is brushless, there is no dangerous brush sparking.

All of today’s hybrid vehicles use a BLDC motor. Green car manufacturers often prefer BLDC motors over the alternatives because the peak point efficiency is higher and rotor cooling is simpler. The motors can also operate at “unity power factor,” meaning the drive can operate at its maximum efficiency levels.

Batteries and brakes. One of the most important components of the BLDC motor drive system is the batteries. In addition to supplying energy to the engine, they allow the electrical receivers to function. Therefore, it’s important that the batteries in green cars be as efficient as possible.

Whenever a battery gets used, an irreversible change in the chemical structure occurs. As a result, a rechargeable battery is most efficient when maintained close to full charge. Thanks to the permanent magnets in the brushless DC motor and the ability for the external torque to work as a generator, a person operating a green car can pulse-charge the battery by applying the brakes. It’s important to note, however, that braking alone won’t fully charge an electric car’s battery.

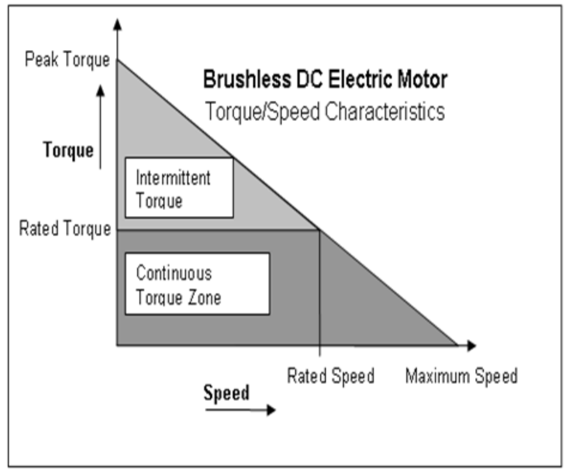

Fig-6: Torque speed characteristics of BLDC motors

There are BLDC motors available with standard ratings and they are selected based on the requirement. For a low power electric vehicle with the following assumptions:

Seating Capacity: 4+1+(40 kg Luggage) – Approximately 1500kg

The motor specifications will be as follows:

Parameters	Values
1. Holding torque	4.78 Nm
2. Peak torque	14.33 Nm
3. Rated speed	3000 rpm
4. No-load speed	4200 rpm
5. Rated voltage	48V-DC
6. Rated current	39.06A
7. Rated power	1.5 KW
8. Max power	4.5 KW

Table-1: Specifications of the required motor for an ideal low power three-wheeler

III. DRIVES

MODELING OF BLDC MOTOR DRIVE

The equivalent circuit of three-phase, 4-pole BLDC motor fed from a PWM inverter is modelled and shown in Fig. 10. The three phase current waveforms with ideal trapezoidal back EMF voltages of a BLDC motor is shown in Fig-8.The BLDC machine is operated under 1200 conduction mode where the system efficiency can be optimum. For the current analysis, it is assumed that the motor is unsaturated, armature reaction is negligible, stator winding is symmetrical, the resistances and inductances of the motor windings are constant and motor exhibits no cogging torque

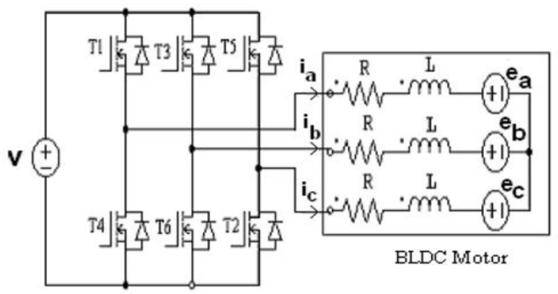

Fig-7: PWM Inverter and equivalent circuit of BLDC Motor

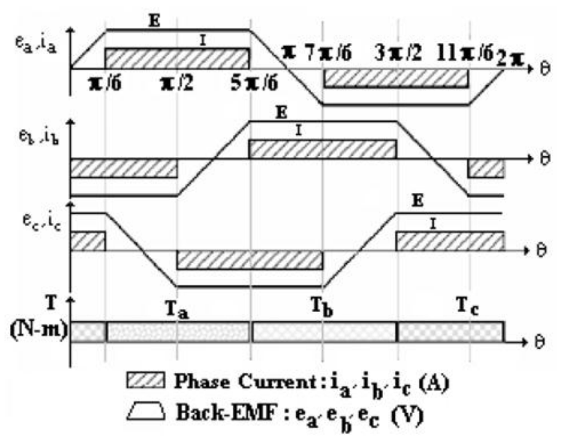

Fig-8: Signal waveforms of BLDC Motor

BLDC motor operation is dependent on the rotor position which is detected by hall sensors. Necessary switching is done based on the hall signal. Three hall sensors are provided in the motor for position sensing and they have 120° phase difference. The power section of the controller is nearly identical to the Vector Inverter and uses a PWM method of current control but the similarity stops there. The currentis not controlled sinusoidally, but trapezoidly. Current is also only conducted in two of the three motor wires at a time instead of being conducted in all three of the wires at a time vectorially. Brushless DC is very simple compared to a Vector Drive.

PWM control

PWM duty cycle control technique enable greater efficiency and versatility of the Brushless DC motor to provide flexible control and novel cyclic operation, as well as better protection schemes for the motor and control circuits. The high efficiency, higher power densities and reliability make BLDC motors an ideal choice for battery-operated motor applications because the combination of power electronics and innovative control techniques provide a high performance, efficient, compact and low cost solution.

Hardware Implementation

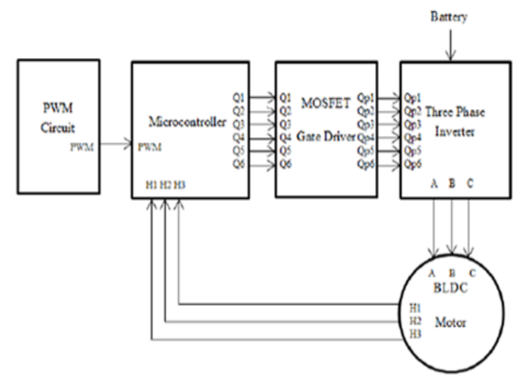

Fig-9: Block diagram of Hardware setup

The overall hardware set up is shown in Fig-9. The microcontroller is coded to generate the required switching based on the inputs PWM, H1, H2 and H3. The output of the microcontroller is given to the gate driver circuit which is used to provide isolation between the control and main power circuit (inverter).

Comparisons of efficiency, torque, currents

In the low power range and in applications requiring variable speed control, adopting BLDC motor can lead to efficiency improvements of up to 10% to 15% when compared with AC induction motors, and allow the possibility of 90% operating efficiency.

At the same time, BLDC motors are more energy efficient than induction motor. This arises because the motors eliminate the excitation circuit losses and does not suffer from friction due to the brushes.

In addition, BLDC motor for the same mechanical work output will always be smaller than an AC induction motor. This arises because the motor inherent construction facilitates better thermal efficiencies, thus the motor body has less heat to dissipate.

IV. CONCLUSION

To design an electric vehicle there are many factors that are to be taken into consideration. Among these the motor and the controller are the ones which require more attention. Initially, based on the required type of the vehicle the load on the motor is decided after which the rating and other parameters of the motor are determined. After a literature survey it is in our best knowledge that a permanent magnet BLDC motor is the best fit for the requirement. For the functioning of this motor certain sensors will be employed. For this application hall effect sensors are appropriate as they would make the system simpler and avoid the usage of several other voltage and current sensors. A voltage source will be used to supply the required input to the motor.

This supply is received by the motor through a motor drive circuit, which consists of a 3 phase inverter which employs IGBT's. From the survey 120degree conduction mode is observed to be more efficient. All the above parameters were determined assuming the electric vehicle to be a three wheeler.

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