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DESIGN OF BLDC MOTOR FOR ELECTRIC TROLLEY

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Electric vehicles with higher energy efficiency, low maintenance cost and pollution free operation, are offering great alternative to popular conventional IC engine vehicles. Also, with the advancement in technology, electric vehicle manufacturers are able to overcome the traditional drawbacks of electric vehicles, making it more and more suitable for modern day transportation. A motor in an electric vehicle provides the necessary force for the propulsion of a vehicle, which makes it the heart of electric vehicles. Different types of electric motors are compared on the basis of certain parameters which should be considered for selecting a particular motor type for electric vehicle application.

Therefore hybrid and electric vehicles are going to be popular due to sustainability, energy saving and zero emission. Electric motors play significant role in In-wheel motor technology is being used in modern electric vehicles to improve efficiency, safety and controllability of vehicle nowadays. BLDC motor have been demanding as in-wheel motor in electric vehicles because of high efficiency, desired torque versus speed characteristics, high power density and low maintenance cost. In this paper BLDC motor with ideal back-EMF is modeled and simulated in MATLAB/SIMULINK. Simulation model of the controller and BLDC drive are presented. In order to validate the model various simulation models are studied. Simulations results depict from developed model are satisfactory and show performance of model.

Keywords—MATLAB/SIMULINK;BRUSHLESS DC MOTOR,SIMULATION TECHNIQUES,MODELING,

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I. INTRODUCTION

BLDC have been used in different applications such as industrial automation, automotive, aerospace, instrumentation and appliances since 1970's. BLDC motor is a novel type of DC motor which commutation is done electronically instead of using brushes. Therefore it needs less maintenance. Also its noise susceptibility is less, looking forward to have integral motor. Electronic commutation technique and permanent magnet rotor cause BLDC to have immediate advantages over brushed DC motor and induction motor in electric vehicle application.In-wheel technology is using a separate motor mounted inside tire for each wheel instead of one central drive train propelling two or all four wheels in conventional electric vehicles.

It increases controllability of vehicle and decreases chassis weight. With using in- wheel and by-wire technologies instead of mechanical, hydraulic and pneumatic control systems; idea of an Intelligent Fully Electronically Controlled Vehicle (IFECV) approaches to reality.

in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. BLDC motors have many advantages over brushed DC motors and induction motors. A few of these are:

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges

In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors. In this application note, we will discuss in detail the construction, working principle, characteristics and typical applications of BLDC motors.

BLDC has more complex control algorithm compare to other motor types due to electronically commutation. Therefore accurate model of motor is required to have complete and precise control scheme of BLDC. To design of BLDC motor drive system, it is necessary to have motor model gives precise value of torque which is related to current and back-EMF. Different simulation models have been presented to analyze performance of BLDC motor. Lots of various modeling techniques according to different applications of BLDC motor have been used. Although all the previous works made a great contribution to modeling BLDC motor, but there is no simple model appropriate for in-wheel motor application. Hence in this paper model of 3 phases, 4 poles, Y connected, trapezoidal back-EMF type of BLDC motor for automotive industry application is modeled and simulated in MATLAB / SIMULINK.

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II .BASIC STRUCTUTRE OF BLDC MOTOR

The construction of modern brushless dc motor is very similar to the ac motor, known as permanent magnet synchronous motor. Figure 1 illustrates the structure of a typical three phase brushless dc motor. The stator windings are similar to those in a poly phase ac motor, and the rotor iscomposed of one or more permanent magnets. Brushless dc motors are different from ac synchronous motors in that the former incorporates some means to detect the rotor position or (magnetic poles) to produce signals to control the electronic switches as shown in figure 2. The most common position/pole sensor is the hall element, but some motors use optical sensors7.

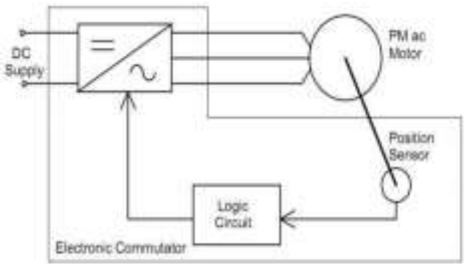

Fig. 2.1. Brushless DC motor block diagram

Although the most outerbox and efficient motors are three phases but two phases brushless dc motor are also very commonly used for simple construction and drive circuits. Figure 3 shows the cross sections of a two phase motor having axiliary salient pole

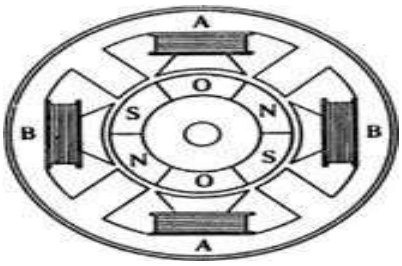

Fig. 2.2. Two phase brushless dc motor.

2.2. PROPOSED DESIGNS OF BRUSHLESS MOTOR

The proposed design of brushless dc motor will made with two phases. The two phases are phase A and phase B. Considering the figure2.4, for phase A the current is entering via FA and current leaving via SA. In the case of phase B current entering via SB and leaving via FB. If the two phase current in same direction then there is neutral pole will be created. If the two current are in opposite direction then thereis a pole must be created. So in between SA and SB South Pole is created. As a result North Pole of therotor will try toalign with South Pole of the stator winding.

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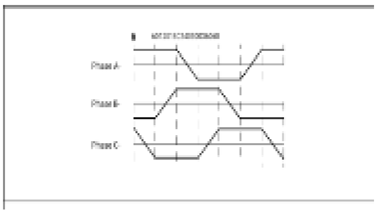
Fig.2.3: Brushless DC Motor(Phase A as reverse,Phase B reverse)

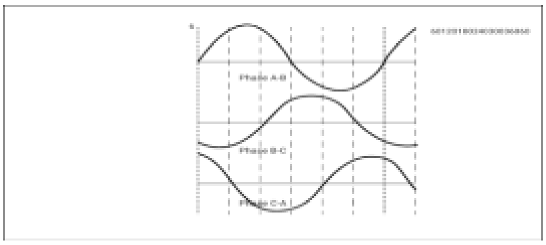
Now from the figure 2.3, for phase A the current entering issame of the figure 4. In case of phase B the current is entering via SB and leaving via FB. So the south pole will shift to the new postion in between SB and FA. Also in between SA and SB neutral pole will be created. So the rotor will try to align with this new postion. Hence the rotor will move clockwise 45 degree .

Taking account the figure 6, for phase B the current is entering is same of the figure 5. In case of phase A the current is entering via SA and leaving via FA. So the south pole will shift to the new position in between FA and FB. In between SB and SA neutral pole will be created. So the rotor will try to align with this new position. Hence the rotor will move another 45 degree. Now at this moment the total rotation is about 90 degree.

Similarly in the figure 2.4, for phase A the



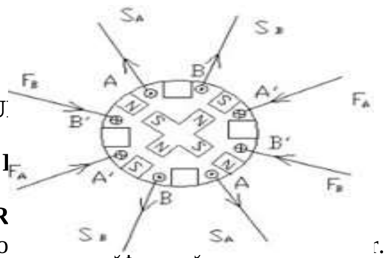
current is entering as same of the figure 5. For phase B the current is entering via SB and leaving via FB. So the south pole of the rotor will shift to the new position. Hence the rotor



will move clockwise another 45 degree. In this way the rotor wil lrotate clockwise.

Fig. 2.4. Brushless DC motor (Phase A as before, Phase B reverse)

For counter clockwise rotation the sequence of the switching will betarts form figure4 then figure 3, figure 2..



III. CONSTRU

WORKING I

3.1.CONSTR

BLDC mo r.
This means themagnetic field generated by the stator and the magnetic field generated by the rotor rotate at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motorsmotors.BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the mos popular and widely used.This application note focuses on 3-phase motors.

STATOR

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery (as shown in Fig 10). Traditionally, the stator resembles that ofan induction motor; however,the windings are distributed in a differnt

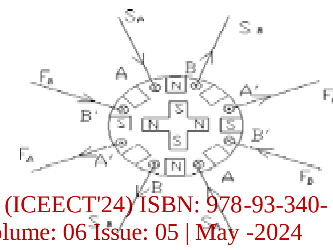
interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even numbers of poles.

There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF). Refer to the “What is Back EMF?” section for more information.

Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen. Forty-eight volts, or less voltage rated motors are used in automotive, robotics, small arm movements and so on. Motors with 100 volts, or higherratings, are used in appliances, automation and in industrial applications.

Fig:3.1 Trapezoidal Back EMF

Fig:3.2 Sinusoidal Back EMF



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3.1.2 ROTOR

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles.

Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the samesize motor using ferrite magnets.

(NdFeB) are some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to compress the rotor further.

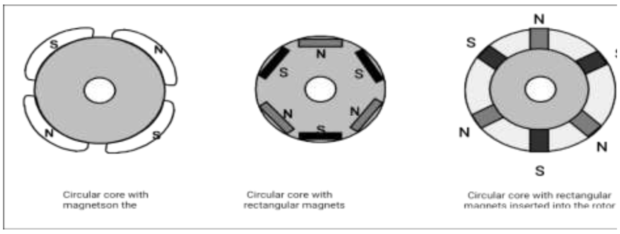

Fig.3.4 Rotor Magnet Cross section

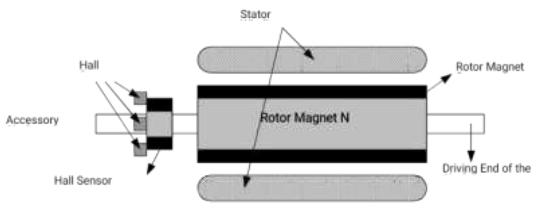

Fig.3.5: BLDC Transverse Connection

3.2 OPERATION OF BLDC MOTOR

BLDC motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that whenever a current carrying conductor placed in a magnetic field it experiences a force. As a consequence of reaction force, the magnet will experience an equal and opposite force. In case BLDC motor, the current carrying conductor is stationary while the permanent magnet moves.

Based on this signal from sensor, the controller decides particular coils to energize. Hall-effect sensors generate Low and High level signals whenever rotor poles pass near to it. These signals determine the position of the shaft.

Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exitsthe winding) and the third is in a non- energized condi-tion. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets. Ideally, the peak torque occurs when these two fields are at 90° to eachother and falls off as the fields move together. In orderto keep the motor running, the magnetic field

producedby the windings should shift position, as the rotor moves to catch up with the stator field. What is known as “Six-Step Commutation” defines the sequence of energizing the windings. See the “Commutation Sequence” section for detailed information andan example on six-step commutation.

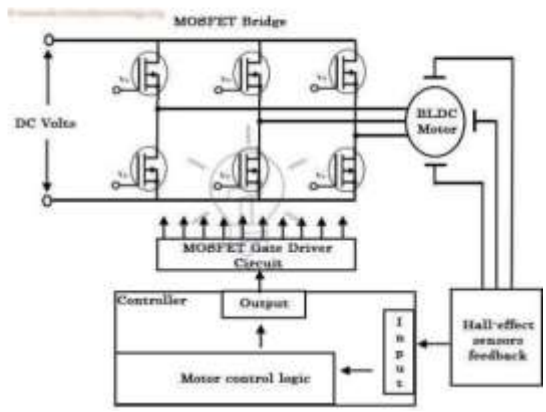

Fig.3.7: Brushless Motor

drive 3.2.1.TORQUE/SPEED

CHARACTERISTICS

Figure 3.7 shows an example of torque/speed character-istics. There are two torque parameters used to definea BLDC motor, peak torque (TP) and rated torque.Dur-ing continuousoperations, the motor can be loaded upto the rated torque. As discussed earlier, in a BLDC motor, the torque remains constantfor a speed range up to the rated speed. The motor can be run upto the maximum speed, which can be up to 150% of theratedspeed, but the torque starts dropping.

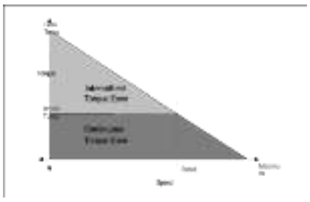

Fig 3.8:Torque speed characteristics of BLDC.

Applications that have frequent starts and stops and frequent reversals of rotation with load on the motor, demand more torque than the rated torque. This requirement comes for a brief period, especially when the motor starts from a standstill and during accelera- tion. During this period, extra torque is required to over- come the inertia of the load and the rotor itself. The motor can deliver a higher torque, maximum up to peaktorque, as long as it follows the speed torque curve. Refer to the "Selecting a Suitable Motor Rating for the Application".

IV. COMPAIRING BLDC MOTOR WITH OTHER MOTORS

In this section, the advantages and disadvantages of different electric motors are discussed

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 mush 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 contant power region

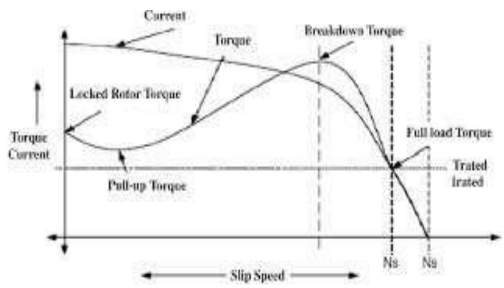

Fig.4.1. Torque speed Characteristics of induction motor

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 Proceedings of the 2008 International Conference on Electrical Machines.

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

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induction motors to have excellent performance at low speeds and reducing rotor winding losses at the design stage.

TABLE II [1]
EVALUATION OF DIFFERENT TRACTION SYSTEMS FOR ELECTRIC VEHICLES

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

PERMANENT MAGNET SYNCHROUS (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.b). To widen the speed range and increase the efficiency of PMS motors, conduction angle of the power converter can be controlled at speeds higher thanthe base speed.

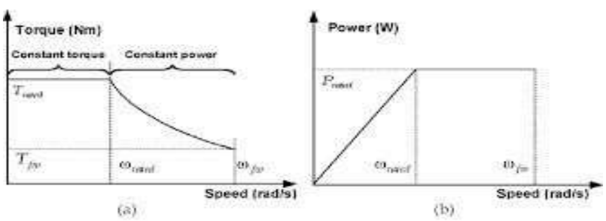

Fig 4.2 Torque speed characteristics

BRUSHLESS DC MOTOR

These motors are conceptually the outcome of reversing the stator and rotor of permanent magnet DC motors. They are fed by rectangular waves in contrast to BLAC motors which are fed by sinusoidal waves. Their main advantages are the deletion of the brushes, their compactness, high efficiency and high energy density. In table I, common EVs and their propulsion systems have been shown. In [1], the traction systems commonly used in EVs are evaluated based on six factors. As shown in table. II, a score out of 5 is given for each point to each motor. It is concluded that based on these factors, the 1M and PM motors are more suitable. However, in the following section the DC and SRM motors are not taken into consideration due to their disadvantages.

Fig.4.4.Common EVs and their propulsion Systems

In this part, three major electric vehicles, namely 1M, PM and BLDC, are studied by simulation software Advisor. Simulation is performed under three different driving cycles, namely: CYC-UDDS, Constant Speed,to compare the fuel consumption and the air pollution of the vehicle if these motors are used. The characteristics of these cycles are listed.

The below graph shows the efficiency of BLDC motor

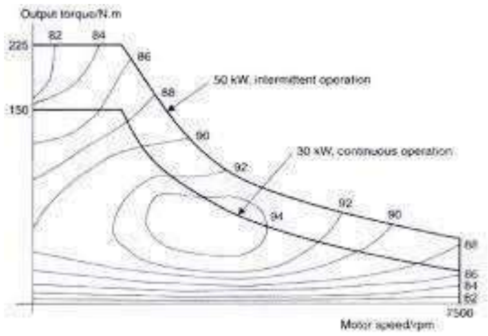

Fig.4.5.Efficiency Map for a BLDC motor

Compared to brushed DC motors and induction motors, BLDC motors have many advantages and few disadvantages. Brushless motors require less maintenance, so they have a longer life compared with brushed DC motors.

BLDC motors produce more out- put power per frame size than brushed DC motors and induction motors. Because the rotor is made of permanent magnets, the rotor inertia is less, compared with other types of motors. This improves acceleration and deceleration characteristics, shortening operating cycles. Their linear speed/torque characteristics pro- duce predictable speed regulation. With brushless motors, brush inspection is eliminated, making them

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ideal for limited access areas and applications where servicing is difficult. BLDC motors operate much more quietly than brushed DC motors, reducing Electromagnetic Interference (EMI). Low-voltage models are ideal for battery operation, portable equipment or medical applications.

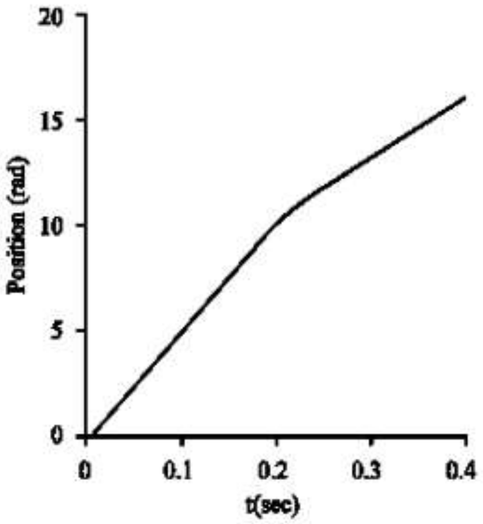

Fig. Position of the BLDC M

Conclusion:

Therefore hybrid and electric vehicles are going to be popular due to sustainability, energy saving and zero emission. Electric motors play significant role in In-wheel motor technology is being used in modern electric vehicles to improve efficiency, safety and controllability of vehicle nowadays. BLDC motor have been demanding as in-wheel motor in electric vehicles because of high efficiency, desired torque versus speed characteristics, high power density and low maintenance cost. In this paper BLDC motor with ideal back-EMF is modeled and simulated in MATLAB/SIMULINK. Simulation model of the controller and BLDC drive are presented. In order to validate the model various simulation models are studied. Simulations results depict from developed model are satisfactory and show performance of model.

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