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Major Project

Report On

DESIGN AND DEVELOPMENT OF SUITABLE ELECTRIC VEHICLE MOTOR FOR URBAN TRANSPORTATION

Submitted for partial fulfillment of the requirements for the award of the degree

of

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ENGINEERING

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CERTIFICATE

This is to certify that the project work entitled **"DESIGN AND DEVELOPMENT OF SUITABLE ELECTRIC VEHICLE MOTOR FOR URBAN TRANSPORTATION"** is a bonafide work carried out by **Mr. A. Sai Charan(17911A0202), Mr. Y. Sai Raghunath (17911A0248), Mr. M. Dayakar(17911A0228), Ms. A. Joshna(1791A0201)** in partial fulfillment of the requirements for the award of degree of **BACHELOR OF TECHNOLOGY IN ELECTRICAL AND ELECTRONICS ENGINEERING** to be awarded by the **JAWAHARLAL NEHRU TECHNOLOGICALUNIVERSITY,** Hyderabad.

The content in this report has not been submitted to any other university or institute for the award of any degree or diploma.

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DECLARATION

This is to certify that the work reported in the present project entitled **Design And Development of Suitable Electric Vehicle Motor for Urban Transportation** is a record ofwork done by us in the Department of **Electrical and Electronics Engineering,** Vidya Jyothi Institute of Technology (Autonomous), Jawaharlal Nehru Technological University, Hyderabad. The reports are based on the project work done entirely by us and not copied fromany other source.

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ABSTRACT

Abstract-In this paper, different electric motors are studied and compared to see the benefits of each motor and the one that is more suitable to be used in the electric vehicle (EV) applications. There are five main electric motor types, DC, induction, permanent magnet synchronous, switched reluctance and brushless DC motors are studied. It is concluded that although the induction motors technology is more mature than others, for the EV applications the brushless DC and permanent magnet motors are more suitable than others. The use of these motors will result in less poUution, less fuel consumption and higher power to volume ratio. The reducing prices of the permanent magnet materials and the trend of increasing efficiency in the permanent magnet and brushless DC motors make them more and more attractive for the EV applications.

This paper also deals with the advantages and uses of BLDC Motor in urban transportation.It also consists of a detailed study of motors and it also consists of how BLDC Motor is different from other motors.

Automotive Industry is targeting sustainable transportation in near future. Therefore hybrid and electric vehicles are going to be popular due to their sustainability, energy saving and zero emission. Electric motors play significant role in EV’s. 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 also presented. In order to validate the model various simulation models are studied. Simulations results depict from developed model are satisfactory and show correct performance of model.

Growing need for high productivity is placing new demands on mechanisms connected with electrical motors. The demand for low cost Brushless DC (BLDC) motor has increased in industrial applications. A simple BLDC motor control algorithm for low cost motor drive applications using general purpose microcontrollers has been created and presented in this paper. Proposed design will allow the user to rotate the motor either clockwise or counter clockwise direction. Depending on the rotor position the sensor will give response to the controller circuit. Then the controller circuit will fix the direction of current following to the stator. The design controller circuit is also implemented. The overall design consists of microcontroller circuit, logic gates, switching devices (MOSFET/BJT), BLDC motor, sensors.

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Chapter-1

INTRODUCTION

1.1. 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.

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used 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.

A Brushless dc (BLDC) motor is a synchronous electric motor which is powered by direct-current electricity (DC) and which has as electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related. In BLDC motor the electromagnets do not move, instead the permanent magnets rotate and the armature remains static. This gets around the problem how to transfer current to a moving armature. In order to do this, the brush systems assembly is replaced by an electronic controller. The controller performs the same power distribution found in a brush dc motor, but using a solid state-static circuit rather than a commutator/brush system.

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. 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.

AC motor drives have some distinct advantages over their DC counterparts, such as: higher efficiency, higher power density, effective regenerative braking, robustness, reliability and less need of maintenance. DC motors are losing their attraction while switched reluctance motors are "the dark horse in the race". In, a survey and comparison of characteristics of motor drives used in the EVs are presented. Regarding the proportion of research, the other three types including the induction, brushless DC and permanent magnet synchronous motors are greatly dominant. Therefore, in this paper these motors are used in EV applications and the vehicles with same characteristics but various motors are simulated by Advisor® software in different driving cycles to see and compare them in terms of pollution, fuel consumption, and power to volume ratio.

Chapter-2

CONVENTIONAL BLDC MOTOR STRUCTURES

2.1 .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.

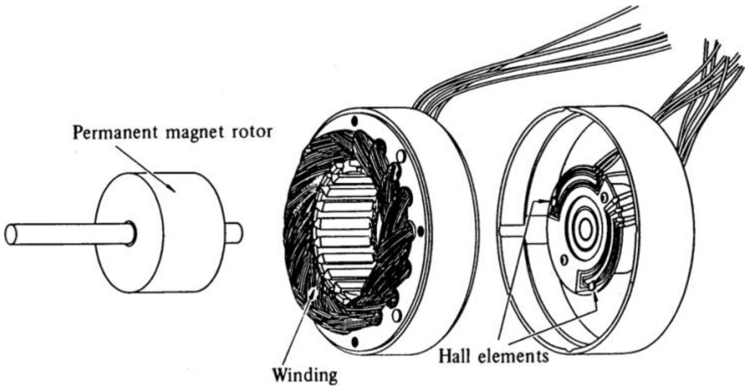


Fig. 2.1. Disassembled view of a brushless dc motor

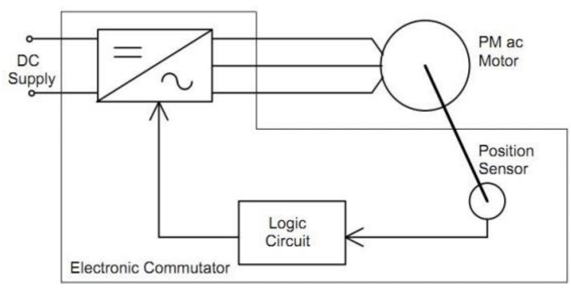


Fig. 2.2. Brushless DC motor block diagram

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

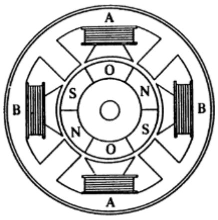


Fig. 2.3. Two phase brushless dc motor

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 figure 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 the rotor will try to align with South Pole of the stator winding.

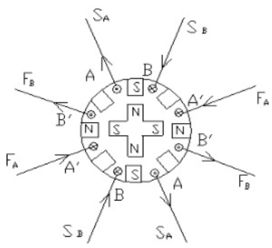


Fig.2.4:Brushless DC Motor

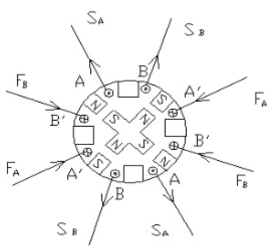


Fig.2.5: Brushless DC motor
(Phase A as before, Phase B reverse)

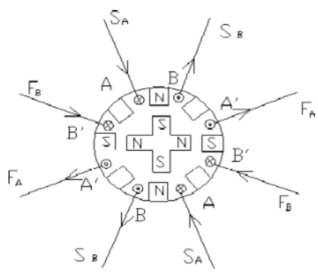


Fig.2.6: Brushless DC Motor
(Phase A as reverse,Phase B reverse)

Now from the figure 5, for phase A the current entering issame of the figure 4. In case of phase B the current isentering 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 rotorwill move another 45 degree. Now at this moment the total rotation is about 90 degree.

Similarly in the figure 7, 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 willrotate clockwise.

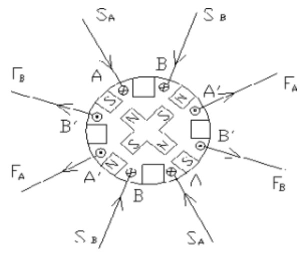


Fig. 2.7. Brushless DC motor (Phase A as before, Phase B reverse)

For counter clockwise rotation the sequence of the switching will be starts form figure7 then figure 6, figure 5, figure 4.

Chapter-3

CONSTRUCTION AND OPERATING PRINCIPLE

3.1. CONSTRUTION OF BLDC

BLDC motors are a type of synchronous motor. This means the magnetic 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 motors.

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 most popular and widely used. This application note focuses on 3-phase motors.

3.1.1. 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 of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils 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.

As their names indicate, the trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal motor's back EMF is sinusoidal, as shown in Figure 1 and Figure 2. In addition to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. This makes the torque output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on the stator periphery, thereby increasing the copper intake by the stator windings.

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

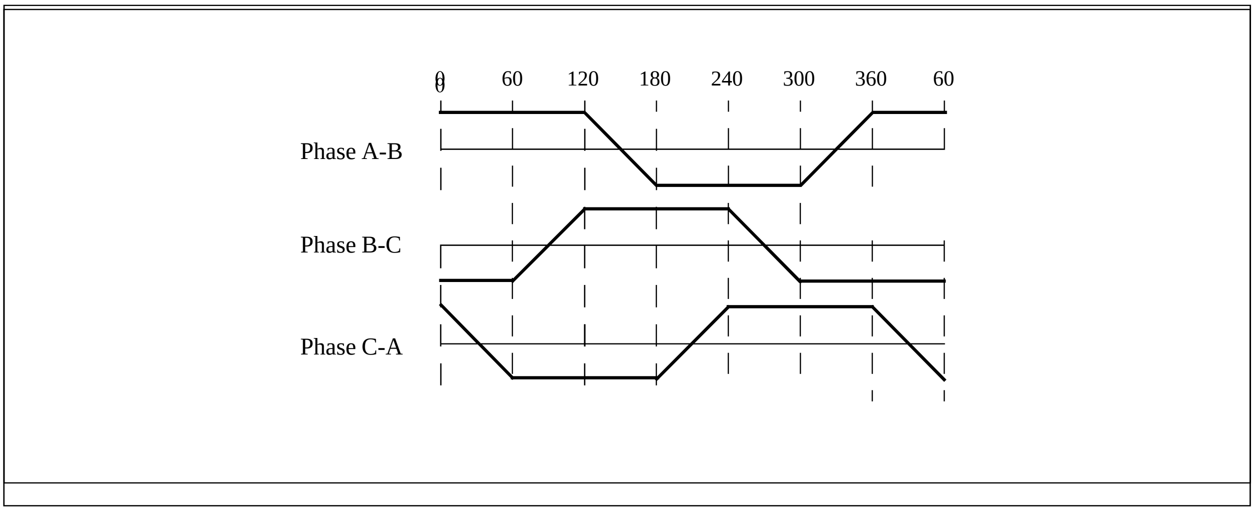
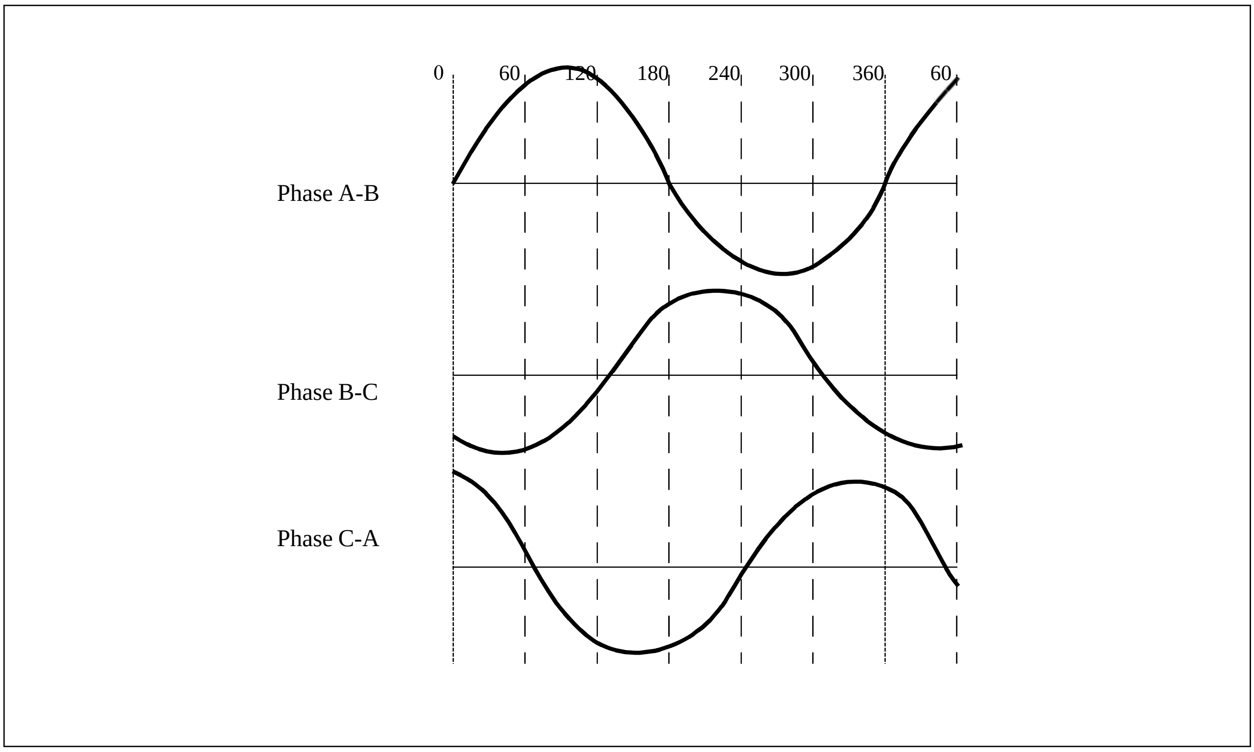


Fig:3.2 Sinusoidal Back EMF



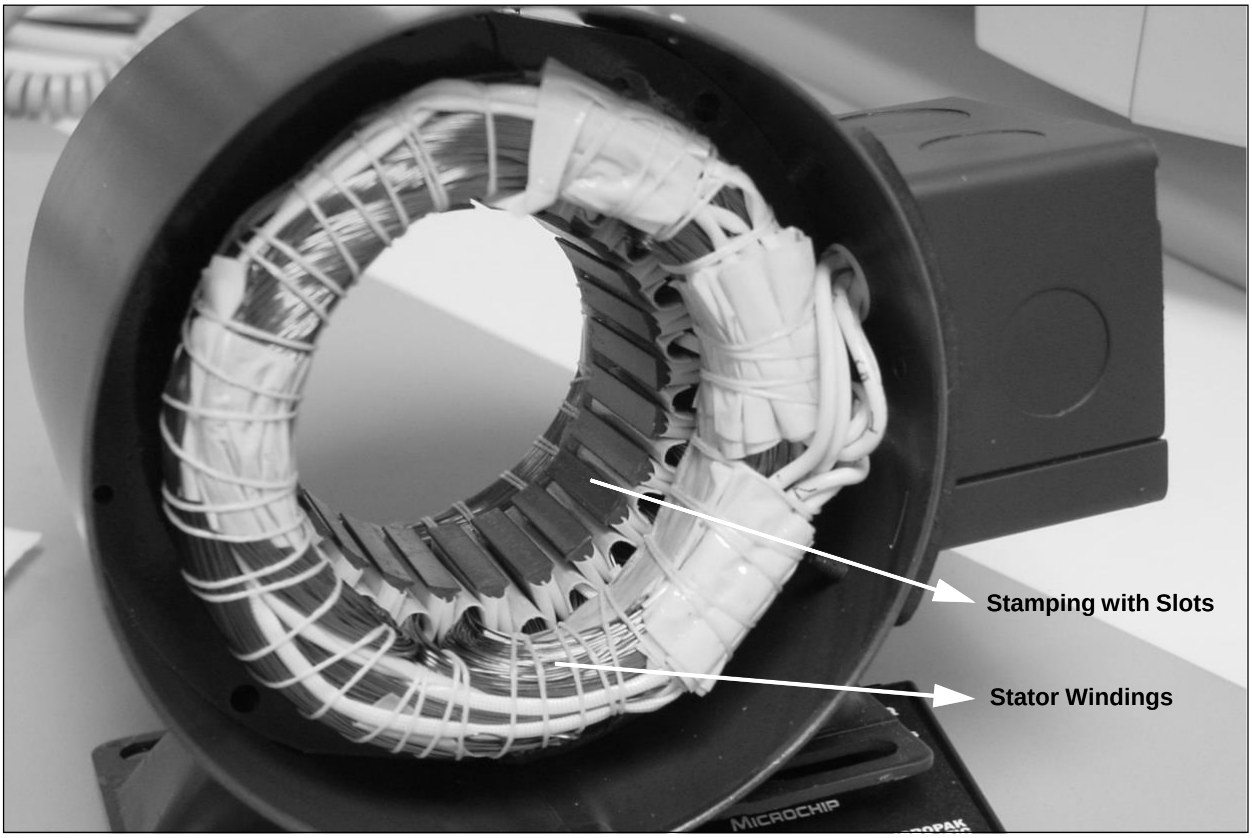


Fig:3.3 Stator of BLDC Motor

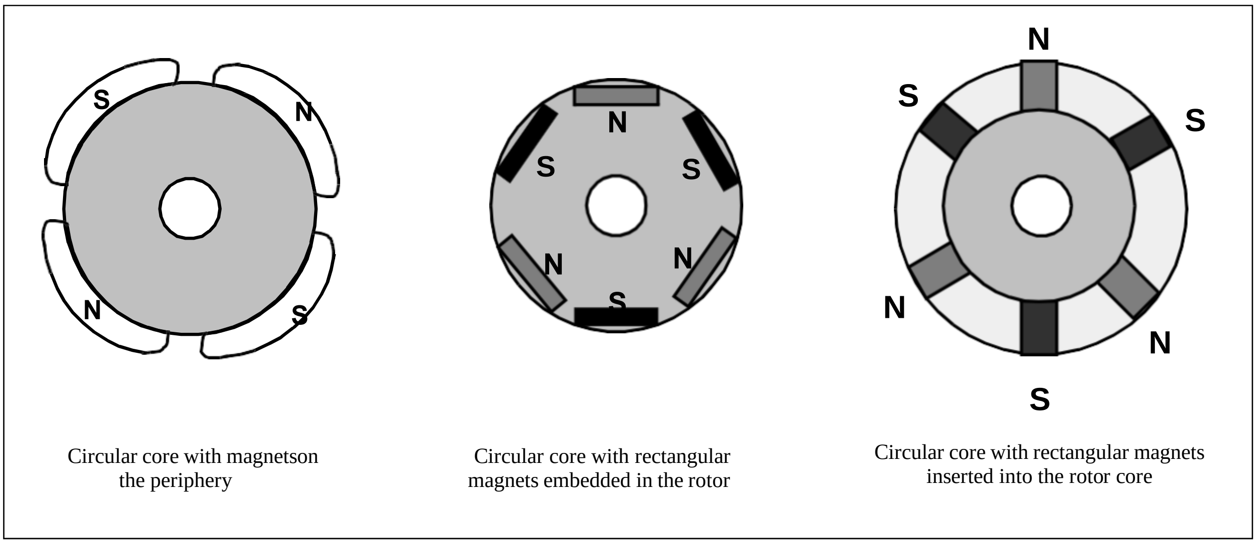
3.1.2 ROTOR

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) andSouth (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 makepermanent magnets. As the technology advances, rareearth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disad- vantage of low flux density for a given volume. In con-trast, 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 same size motor using ferrite magnets.

(NdFeB) are some examples of rare earth alloy magnets. Continu- ous research is going on to improve the flux density tocompress the rotor further.

Fig.3.4 Rotor Magnet Cross section



3.1.3 HALL SENSORS

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. It is important to know the rotor positionin order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall effect sensors embedded into the stator.

Most BLDC motors have three Hall sensors embeddedinto the stator on the non-driving end of the motor.

Whenever the rotor magnetic poles pass near the Hallsensors, they give a high or low signal, indicating the Nor S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

NOTE: *Hall Effect Theory: If an electric current carrying conductor is kept in a magnetic field, the magnetic field exerts a trans- verse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall effect after E. H. Hall who discovered it in 1879.*

Figure 5 shows a transverse section of a BLDC motor with a rotor that has alternate N and S permanent mag-nets. Hall sensors are embedded into the stationary partof the motor. Embedding the Hall sensors into the statoris a complex process because any misalignment in these Hall sensors, with respect to the rotor magnets, will generate an error in determination of the rotor posi-tion. To simplify the process of mounting the Hallsensors onto the stator some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets. These are a scaled down replica version of the rotor. Therefore, whenever the rotor rotates, the Hall sensor magnets give the same effect as the main mag-nets. The Hall sensors are normally mounted on a PC board and fixed to the enclosure cap on the non-driving end. This enables users to adjust the complete assem-bly of Hall sensors, to align with the rotor magnets, in order to achieve the best performance.

Based on the physical position of the Hall sensors, there are two versions of output. The Hall sensors may be at 60° or 120° phase shift to each other. Based on this, the motor manufacturer defines the commutation sequence, which should be followed when controlling the motor.

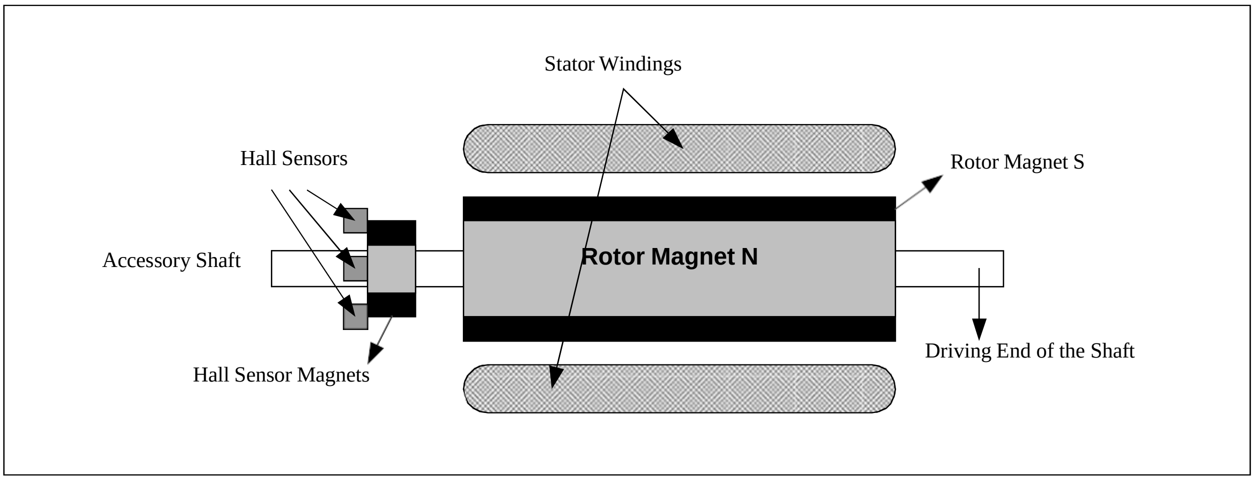


Fig.3.5: BLDC Tranverse Connection

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.

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

Motor stator is excited based on different switching states. With the switching of windings as High and Low signals, corresponding winding energized as North and South poles. The permanent magnet rotor with North and South poles align with stator poles causing motor to rotate.

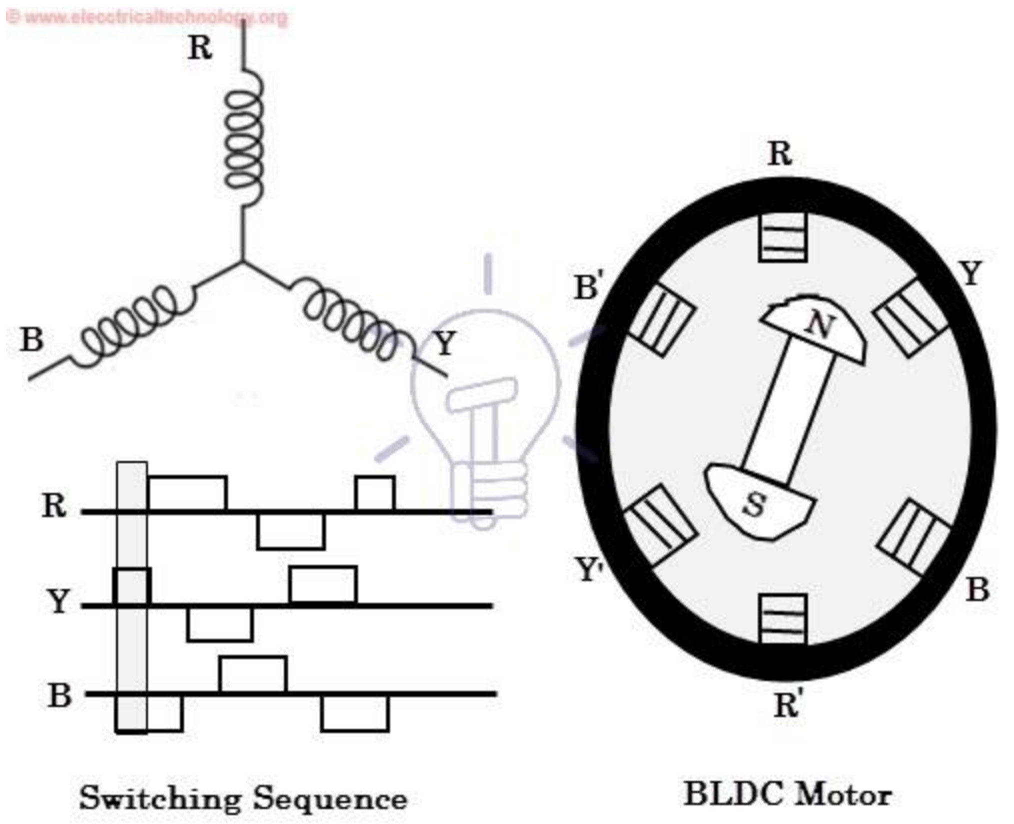


Fig.3.6 Switching sequence of BLDC Motor

Observe that motor produces torque because of the development of attraction forces (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment). By this way motor moves in a clockwise direction.

Here, one might get a question that how we know which stator coil should be energized and when to do. This is because; the motor continuous rotation depends on the switching sequence around the coils. As discussed above that Hall sensors give shaft position feedback to the electronic controller unit.

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 rotormoves to catch up with the stator field. What is knownas "Six-Step Commutation" defines the sequence of energizing the windings. See the **"Commutation Sequence"** section for detailed information and an example on six-step commutation.

As described above that the electronic controller circuit energizes appropriate motor winding by turning transistor or other solid state switches to rotate the motor continuously. The figure below shows the **simple BLDC motor drive circuit** which consists of MOSFET bridge (also called as inverter bridge), electronic controller, hall effect sensor and BLDC motor.

Here, Hall-effect sensors are used for position and speed feedback. The electronic controller can be a microcontroller unit or microprocessor or DSP processor or FPGA unit or any other controller. This controller receives these signals, processes them and sends the control signals to the MOSFET driver circuit.

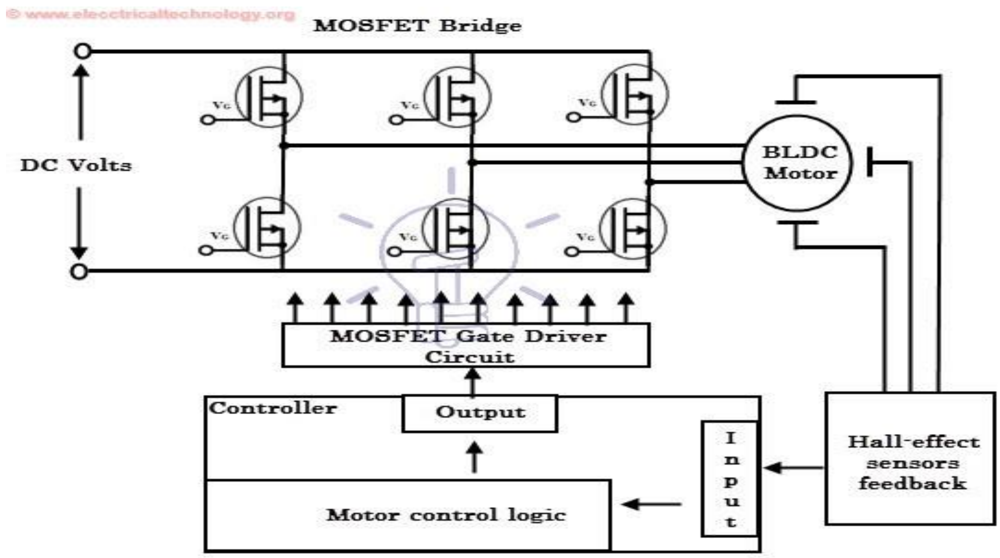


Fig.3.7: Brushless Motor drive

3.2.1.TORQUE/SPEED CHARACTERISTICS

Figure 14 shows an example of torque/speed character-istics. There are two torque parameters used to define a BLDC motor, peak torque (TP) and rated torque.Dur-ing continuous operations, the motor can be loaded upto the rated torque. As discussed earlier, in a BLDC motor, the torque remains constant for a speed range up to the rated speed. The motor can be run up to the maximum speed, which can be up to 150% of the ratedspeed, but the torque starts dropping.

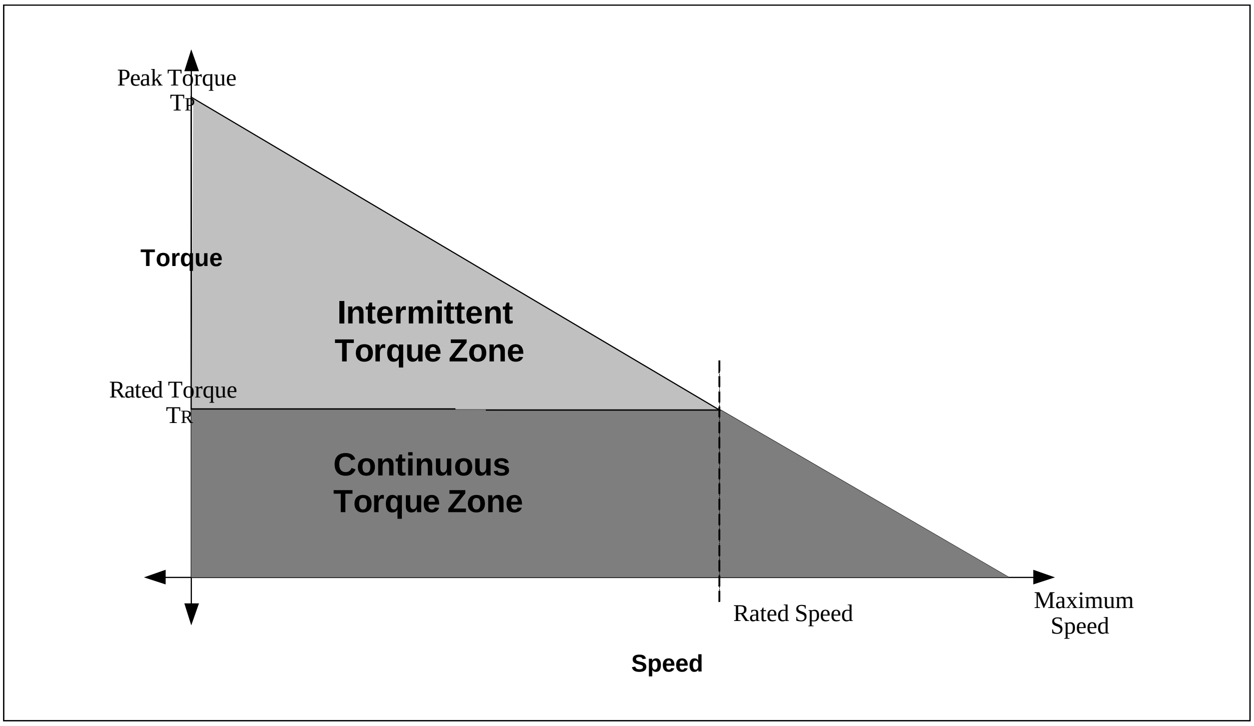


Fig 3.8:Torque speed characteristics of BLDC.

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”** section to understand how to select these parameters for an application.

Chapter-4

COMPARING BLDC MOTORS TO OTHER MOTOR TYPES

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 constant power region.

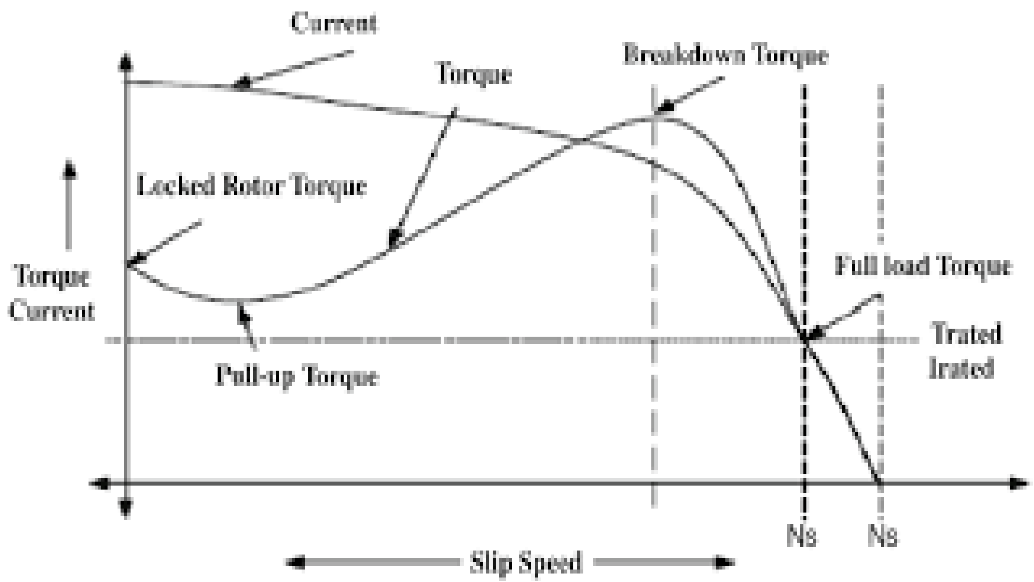


Fig.4.1. Torque speed Characteristics of induction motor

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

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 than the base speed. Fig. a 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.

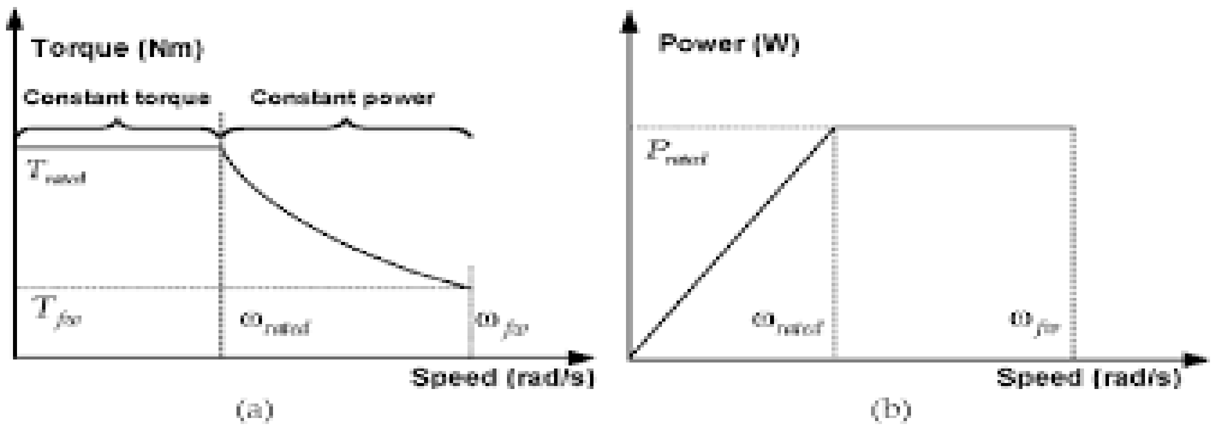


Fig.4.2 Torque,Power,Speed characteristics

SWITCHED RELUCTANCE MOTOR

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 motor.

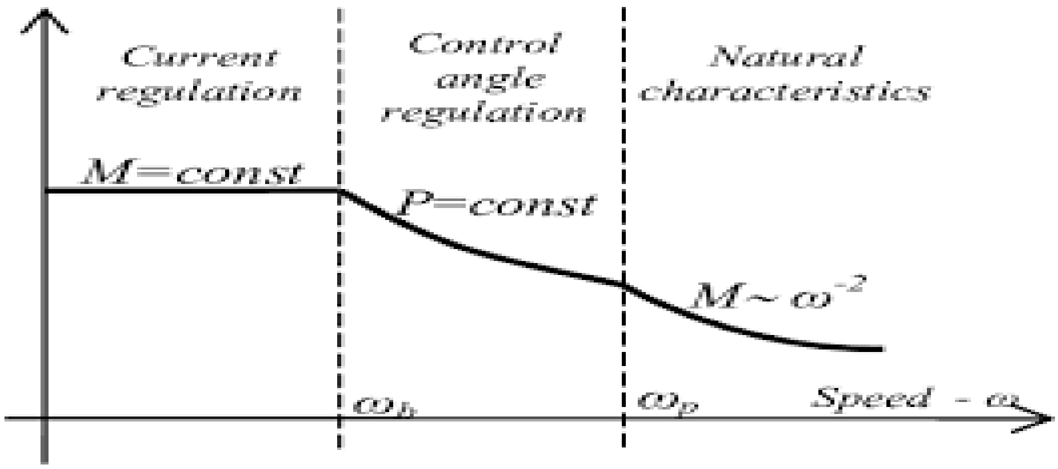


Fig.4.3. Torque speed Characteristics

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.

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

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

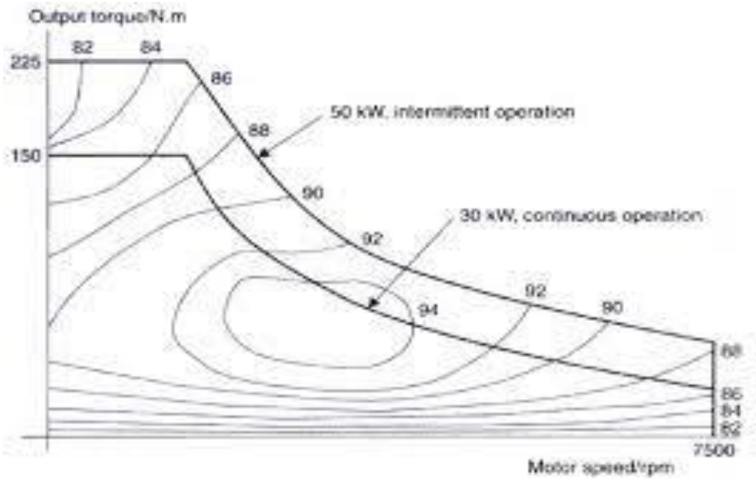


Fig.4.5.Efficiency Map for a BLDC motor

Compared to brushed DC motors and induction motors, BLDC motors have many advantages and fewdisadvantages. Brushless motors require less mainte-nance, 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 perma- nent 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 ideal for limited access areas and applications where servicing is difficult. BLDC motors operate much morequietly than brushed DC motors, reducing Electromagnetic Interference (EMI). Low-voltage models are ideal for battery operation, portable equipment or medical applications.

Feature	BLDC Motor	Brushed DC Motor
Commutation	Electronic commutation based on Hall position sensors.	Brushed commutation.
Maintenance	Less required due to absence of brushes.	Periodic maintenance is required.
Life	Longer.	Shorter.
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load.	Moderately flat – At higher speeds, brush friction increases, thus reducing useful torque.
Efficiency	High – No voltage drop across brushes.	Moderate.
Output Power/ Frame Size	High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better.	Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size.
Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response.	Higher rotor inertia which limits the dynamic characteristics.
Speed Range	Higher – No mechanical limitation imposed by brushes/commutator.	Lower – Mechanical limitations by the brushes.
Electric Noise Generation	Low.	Arcs in the brushes will generate noise causing EMI in the equipment nearby.
Cost of Building	Higher – Since it has permanent magnets, building costs are higher.	Low.
Control	Complex and expensive.	Simple and inexpensive.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.

Table 4.1.1:- Comparing BLDC Motor to BRUSHED DC Motor

Features	BLDC Motors	AC Induction Motors
Speed/Torque Characteristics	Flat – Enables operation at all speeds withrated load.	Nonlinear – Lower torque at lower speeds.
Output Power/ Frame Size	High – Since it has permanent magnets on the rotor, smaller size can be achieved for a given output power.	Moderate – Since both stator and rotor have windings, the output power to size is lower than BLDC.
Rotor Inertia	Low – Better dynamic characteristics.	High – Poor dynamic characteristics.
Starting Current	Rated – No special starter circuit required.	Approximately up to seven times of rated – Starter circuit rating should be carefully selected. Normally uses a Star-Delta starter.
Control Requirements	A controller is always required to keep the motor running. The same controller can be used for variable speed control.	No controller is required for fixed speed; a controller is required only if variable speed is desired.
Slip	No slip is experienced between stator and rotor frequencies.	The rotor runs at a lower frequency than stator by slip frequency and slip increases with load on the motor.

Table 4.1.2: Comparing BLDC Motor to AC Induction motor

モータ / 項目	AC motor			Universal motor	Brush DC motors	Brushless DC motor	Stepping motor	Servo motor	
	Single-phase	Three-phase (Induction)	Three-phase (Sync)					AC serv	DC servo
Power type	AC			AC/DC	DC	DC (including driver)/Driver	Drivers	Drivers	Drivers
Efficiency	40-60%	60-70%	70-80%	50-60%	60-80%	80%-	60-70%	50-80%	60-80%
Size (same output)	Large	Intermediate or large		Large	Small	Small	Intermediate	Small or intermediate	Small
Noise	Small			Large	Large	Small	Intermediate	Small	Large
Speed range	Narrow	Wide		Intermediate	Wide	Wide	Wide	Intermediate	Narrow
Response	Slow			Slow	Intermediate	Intermediate	Intermediate	Fast	
Service life	Long			Short	Short	Long	Long		Short
Price	Low		Intermediate	Low	Low	Intermediate or high	Intermediate	High	
Applications	Washing machines Air blowers Vacuum cleaners Pumps	Cranes Conveyors Air conditioners Industrial machinery	Compressors Dishwashers Washing machines	Vacuum cleaners Electric tools Juicers	Electric toys Electric tools Automobile electric components Small home appliances	Air conditioners Dishwashers Washing machines Small home appliances	Robots Small home appliances Air-conditioning equipment	Conveyors Robots Machine tools	Printers Plotters Working machines
Judgment	Cost focused	Versatility focused		Cost focused	Cost focused	Efficiency focused Versatility focused	Versatility focused	Performance focused	

Table 4.1.3 – Comparision of BLDC with all other motors

Chapter-5

BRUSHLESS SOLUTION

In brushless DC motors, an electronic servo system replaces the mechanical commutator contacts. An electronic sensor detects the angle of the rotor and controls semiconductor switches such as transistors which switch current through the windings, either reversing the direction of the current or, in some motors turning it off, at the correct angle so the electromagnets create torque in one direction. The elimination of the sliding contact allows brushless motors to have less friction and longer life; their working life is only limited by the lifetime of their bearings.

Brushed DC motors develop a maximum torque when stationary, linearly decreasing as velocity increases. Some limitations of brushed motors can be overcome by brushless motors; they include higher efficiency and lower susceptibility to mechanical wear. These benefits come at the cost of potentially less rugged, more complex, and more expensive control electronics.

A typical brushless motor has permanent magnets that rotate around a fixed armature, eliminating problems associated with connecting current to the moving armature. An electronic controller replaces the commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the commutator system.

Brushless motors offer several advantages over brushed DC motors, including high torque to weight ratio, increased efficiency producing more torque per watt, increased reliability, reduced noise, longer lifetime by eliminating brush and commutator erosion, elimination of ionizing sparks from the commutator, and an overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter.

Brushless motor commutation can be implemented in software using a microcontroller, or may alternatively be implemented using analog or digital circuits. Commutation with electronics instead of brushes allows for greater flexibility and capabilities not available with brushed DC motors, including speed limiting, microstepping operation for slow and fine motion control, and a holding torque when stationary. Controller software can be customized to the specific motor being used in the application, resulting in greater commutation efficiency.

The maximum power that can be applied to a brushless motor is limited almost exclusively by heat; too much heat weakens the magnets and will damage the windings' insulation.

When converting electricity into mechanical power, brushless motors are more efficient than brushed motors primarily due to the absence of brushes, which reduces mechanical energy loss due to friction. The enhanced efficiency is greatest in the no-load and low-load regions of the motor's performance curve.

Environments and requirements in which manufacturers use brushless-type DC motors include maintenancefree operation, high speeds, and operation where sparking is hazardous (i.e. explosive environments) or could affect electronically sensitive equipment.

The construction of a brushless motor resembles a stepper motor, but the motors have important differences due to differences in implementation and operation. While stepper motors are frequently stopped with the rotor in a defined angular position, a brushless motor is usually intended to produce continuous rotation. Both motor Brushless solutionSchematic for delta and wye winding styles. (This image does not illustrate the motor's inductive and generator-like properties) types may have a rotor position sensor for internal feedback. Both a stepper motor and a well-designed brushless motor can hold finite torque at zero RPM.

Chapter-6

SENSORS ELIMINATION AND REDUCTION TECHNIQUES

However, some of these sensors in PMBLDC motor drive may be reduced from the view point of size, cost, maintenance and reliability. Typically mechanical rotor position and speed sensors have the drawbacks of increasing the number of connections between motor and controller, increased interference, limitation in accuracy of sensors due to environmental factors such as temperature, humidity, vibrations etc., increased friction and inertia and additional space in motor housing. Because of these problems recently there has been wide interest and developments in the techniques for elimination of mechanical rotor position/speed sensing by estimating the rotor position and speed using sensed currents and voltages 40-57. Moreover, the number of voltage and current sensors may be reduced through using intelligent processors for the control of inverter feeding PMBLDC motors. Various techniques for these sensors elimination and reduction are briefly discussed in the following section.

6.1 Mechanical sensors elimination

One of the most recent developments in PMBLDC motor drives has been the rapid evolution of new techniques for eliminating the rotor angular position sensor. Elimination of the shaft-mounted position sensor is a very desirable feature in a number of applications since this sensor is one of the most expensive and fragile components in this drive. Some of the position sensorless schemes are classified in brief.

6.2 Back EMF based position estimation

The most common methods of rotor flux position sensing is based on deriving the back emf signals. There are many methods for rotor position estimation based on the back emf and are briefly discussed below.

6.2.1 Direct back EMF detection:

This method is quite popular for rectangular fed PMBLDC motors. In these PM motors, particular phase winding is excited for 2/3 of each electrical period and ideally there is always one phase which is not excited. The direct sensing of back emf of unexcited phases in sequence is used to generate discrete rotor position signal for current synchronization with rotor flux. It has been applied to many industrial applications including disk drives compact stereo player and room air conditioners.

6.2.2 Estimation of back EMF:

This method is applied to both sinusoidal fed and rectangular fed PMBLDC motors. This method is based on the reconstruction of the back emf by using voltage equation of the motor ($e = v - iR - L di/dt$). Reconstruction of the back emf involves either simulating this equation with operational amplifier 46 or solving this equation in on-line digital processor normally used for control 52. In this method, the terminal voltage and line current are measured directly and the above equation is used to achieve back emf and rotor position.

6.3 Third harmonic voltage detection based position estimation

In star-connected PMBLDC motors, the third harmonic voltage is measured between the star point and an artificial star point created by three high-value resistors which are connected to the motor terminals. Such a voltage gives six zero crossings in the 3-phase motor and results in rotor position for current synchronization with rotor flux.

6.4 By monitoring current or computation of the phase inductance

The basic concept of this method is that the rate change of current in a phase winding of the motor depends on the incremental inductance which is rotor position dependent. This phase winding inductance variation with rotor position is used to estimate the rotor position for electronic commutation of the inverter. This current sensing model for rotor position estimation is used by Lin et al 50.

6.5 Injecting diagnosis signal to the stator winding

This method uses a PWM carrier frequency and inductance bridge to measure the rotor flux path reluctance. The method operates on a bridge principle by monitoring the inductance difference in two phases, and is sensitive to small variations in reluctance.

6.6 Observer methods

In these methods, an observer reconstructs the rotor position which is directly measurable. Basically all these methods use the sensed phase and/or line currents to perform on-line compensation to derive the rotor position. A number of observer methods such as Kalman filter technique, discrete time observer, state observer and stator flux estimation method current and the voltage based observer method 56-57 as well as improved different types of motors, are reported.

6.7 By a special windings electromagnetic devices

A number of methods based on special winding such as search coils or an electromagnetic device 58 are used to sense the rotor position. The electromagnetic device consists of pickup coils around a special stator made of magnetically nonlinear material. The pick-up coils are excited by a high frequency sinusoidal current. The device detects the phase of the second harmonics component of the induced voltage in the pick-up coils.

6.8 Monitoring switching states in the inverter

This method is applied to rectangular fed PMBLC motor and ON/OFF states of inverter switching devices are used for rotor position estimation 51. The method is based on amotor with trapezoidal back-emf. The rotor flux position is obtained on the basis of the conducting state of free-wheeling diodes in an open phase at a particular time. In most of these methods, the rotor speed/velocity is estimated by using the time derivative of rotor position angle or by measurement of the period during the transition of alternating rotor position.

6.9 Elimination~reduction of current and voltage sensors

Intensive work is carded out to reduce the current and voltage sensors in the PMBLC motor drive to reduce the cost and enhance reliability. Normally two current sensors are required in 3-phase star connected motors, a technique used to estimate the 3-phase winding currents only using one current sensor in the dc link and switching states of the inverter devices. Since, in the intelligent inverter control, device-switching patterns are available in the processor, the 3-phase winding currents signals are constructed using measured dc link current and switching status of the inverter devices. Similarly, one voltage sensor is used at the dc link and three-phase terminal voltages are derived using the same switching states of the inverter devices. For rectangular fed PMBLDC motor drives, current sensors can be eliminated entirely using current sensors embedded in three Of the six inverter switches 59. MOS gated devices such as MOSFET and IGBTs in integrated modules from different manufacturers are available which incorporate current sensors integrated into monolithic power devices.

Chapter-7

RECENT TRENDS IN BLDC MOTORS & SENSORS

7.1 TRENDS IN BLDC MOTOR

Permanent magnet (PM) excitation has been used in place of dc excitation in different es such as dc machines, synchronous machines and new PMBL machines such as PM stepper motors, hybrid stepper motors and PMBLDC motors. High cost of PM materials has been a major bottleneck for use and development of these electric machines. Gradual growth of better PM materials, improved manufacturing technology, varying nature of construction of these motors to suit specific applications have brought them at a level where they are considered one of the best motors available nowadays. PM machines have a wide spectrum but this paper is restricted to PMBLDC motors. Presently PM materials used in PMBLDC motors are classified in the following three broad categories, namely Alnico (A1-Ni-Co-Fe), Ceramics also include ferrites and rare-earth materials such as samarium-cobalt (Sm-Co), neodymium-iron-boron (Nd-Fe-B). Alnico and ferrites have long been used in the development of PM motors as they are cheap and easily available. Rare-earth PM materials, namely SmCo, are used nowadays because of the high energy density caused by its high residual flux density, coercive force and low temperature coefficient. NdFeB is considered one of the best PM materials presently since it offers much higher residual flux density and coercive force. However, its only drawback is the temperature limit. Continuous efforts are being made to overcome this and it is hoped that this will enable PMBLDC motors to attain higher efficiencies and lower sizes along with other advantages. PMBLDC motors may be classified into different categories such as number of phases, radial or axial field, cageless or with cage bars, surface mounted PMs or buried magnets, sinusoidal or rectangular fed motors etc. Some of them are briefly discussed in this section.

7.1.1 Number of phases

PMBLDC motors are developed in single phase in low power (< 50W) for tube axial fans to cool electronics equipments. They are manufactured in two phase construction for home appliances such as solar PV fed refrigeration system, servo control etc. Most of the medium and high power rating motors are designed in three-phase construction similar to conventional ac motors. In some electric vehicles 22-24 and megawatt ratingmotors for submarine propulsion etc., designers have compelling reasons to increase the number of phases to five, six or more in order to reduce the per phase power handling requirements.

7.1.2 Radial and axial field motors

Most of the motors in the market are radial field type (cylindrical or salient pole construction). However, the axial field motors have some advantages over the conventional radial field construction in terms of power density, torque to inertia ratio, peak torque, less magnet weight, low inductance, short winding turns, compact design etc,. Axial field motors are designed in package, disk and sandwich type construction and have no iron in the rotor, resulting in low inertia. Axially directed magnetic field from rotor magnet interacts with radially directed currents in these axial field motors. The magnets are encapsulated in resin or plastic. Because of their construction, they are considered most suitable for robotics, computer equipments, machine tools etc.,

Radial field motors are also designed with varying desired flux linkage waveforms such as sinusoidal or trapezoidal, different shapes and positions of magnets in the rotor such as buried or surface mounted etc. They are widely used since stator design is similar to conventional ac synchronous or induction motors. Figure 9-10 shows the typical cross-sections of these two types of popular PMBLDC motors.

7.1.3 Shape and location of PM in rotors

Permanent magnets are placed in the rotor in PMBLDC motors.In axial field type of motors, the magnets are encapsulated in resin or plastic in disc form as shown in figure la. These magnets are placed in such a manner that induced back emf are either sinusoidal or trapezoidal waveforms. In radial field motors, the magnets are placed in different form such as surface mounted for low speed motors and interior radially oriented or interior tangentially oriented in high speed PMBL motors. Figure 11 shows such rotor geometries. They are also designed to achieve sinusoidal or trapezoidal back emfs depending upon applications.
of these rectangular currents they are also called switched PM motors, brushless dc motors and electronic commutated PMBLDC motors. Figure 13 shows the ideal current waveforms for these two types of motors. Position sensors requirement is accordingly changed to realize these ideal current waveforms in the motor windings in self synchronous control mode.

7.2 TRENDS IN SENSORS

In the control of PMBLDC motors, position, speed and current sensors are essentially required to regulate the phase currents in synchronization with rotor position. Moreover, sometimes, terminal voltage sensors are also required to estimate either position or speed. Voltage sensors are also needed to regulate dc bus voltage during braking or for front end converter control. In some typical attempts, flux sensors and torque sensors are also used in the precise control of these motors. Basic role of these sensors are already discussed in closed loop control of PMBLDCM drive. In the following section, the recent trends in sensors and their function are briefly discussed.

7.2.1 Position sensors

The rotor flux position in PMBLDC motors is defined by the mechanical angle of rotation, which is achieved from some form of rotor position sensors. Rotor flux position is required for phase current synchronization and rotor position is also required for position control. Rotor position is directly sensed using position sensors or indirectly estimated using other measured parameters. Hence, rotor position sensing is indispensable in current-controlled PMBLDC motor drives
Rotor position is sensed using resolvers, inductive modular absolute system (IMAS), hall effect position sensor, magnetoresistors, electronics and optical encoders, synchros and tachsyn. The tachsyn is an airgap reluctance sensitive 3-phase alternator with PM field and trapezoidal output waveforms. It is used for position and velocity sensing and signal outputs are analog. They are available in 4, 6 and 8 pole configurations. The encoders are characterised by number of pulses per revolutions (PPR) and nowadays

they are available in several thousands PPR. Interfacing ICs are also available to convert these sensor signals to digital form to feed digital processors used for intelligent control of PMBLDCM drives.

Indirect position sensing is achieved by estimating the rotor position using other measured parameters such as currents and voltages etc. There are many techniques for rotor flux position estimation which are much detailed in the next section.

7.2.2 Speed/velocity sensors

In the PMBLDC motor drive, speed or velocity signals are essentially required for speed control loops in position controlled drives and speed feedback for speed controlled drives. Speed measurement is carded out either using speed transducers/sensors or estimated using the rotor position information either obtained through direct position sensing or through estimation. In general dc tachogenerators and brushless tachogenerators are used to sense motor speed. They provide an analog dc voltage signal which is proportional to shaft speed. The polarity of this voltage signal in both types of tachogenerators results in the direction of rotation. Nowadays rotor velocity/speed is estimated more accurately by using high resolution position sensors or estimated rotor flux position. Sometimes, these sensors are different from the position sensors used for electronic commutation.

7.2.3 Current sensors

Fast torque control in high performance PMBLDC motor drives is implemented through closed loop regulation of phase winding currents in synchronization with rotor flux position information. Closed loop regulation of winding currents is realized through PWM or hysteresis current controllers of CC-VSI over the reference desired currents and sensed winding currents. Therefore, the sensing of winding currents becomes indispensable in PMBLDC motor drives.

The current sensing is generally carded out using hall effect current sensors. They detect the magnitude and direction of currents and are integrated to provide sensitive and accurate current sensing. Very fast response (less than 1 microsecond) and accurate current sensors are available from different manufacturers (ABB, LEM etc.) in wide range of current sensing (fractions of amperes to kiloamperes). These hall effect current transducers have galvanic isolation of several kilovolts which is a very desired requirement of these drives in high rating. Generally in 3-phase motors two current sensors are required and thirdphase current is estimated from other two-phase currents in star connected motors. These current sensing requirements for current regulated rectangular fed PMBLDC motor drive are typically reduced to a single current sensor in the dc link of the inverter. Current shunt resistors with low power dissipation are often used as the current sensor in low power drives for cost effectiveness. In the modem power devices such as MOSFET/IGBT a current sensing feature is provided by many manufacturers which also dispenses with the use of extra current sensors in the control of the inverter/converter feeding the PMBLDCM.

7.2.4 Voltage Sensors

Terminal voltage sensing in modem advanced PMBLDC motor drives is required to estimate the rotor position and speed for the control, resulting in mechanical sensorless drive with a view to reduce size, cost, maintenance and enhanced reliability. Voltage sensing is also required to regulate dc bus voltage during braking or for control of front end converter used for regenerative feature in high rating drives.

Terminal voltage sensing is carried out by using electronic isolation amplifier (AD202 Analog Devices make etc.) and hall effect voltage sensors (ABB make etc.) with galvanic isolation. In small rating drives, voltage is sensed using high valued resistor potential dividers to reduce the cost of the drive. Sometimes, induced voltage in the motor windings is achieved using special windings such as search coils etc. However, ac mains voltages for the control of front end convener are sensed using the potential transformers.

Chapter-8

APPLICATIONS OF BLDC MOTOR

Brushless motors fulfill many functions originally performed by brushed DC motors, but cost and control complexity prevents brushless motors from replacing brushed motors completely in the lowest-cost areas. Nevertheless, brushless motors have come to dominate many applications, particularly devices such as computer hard drives and CD/DVD players. Small cooling fans in electronic equipment are powered exclusively by brushless motors. They can be found in cordless power tools where the increased efficiency of the motor leads to longer periods of use before the battery needs to be charged. Low speed, low power brushless motors are used in directdrive turntables for gramophone records.

Transport

Brushless motors are found in electric vehicles, hybrid vehicles, personal transporters, and electric aircraft. Most electric bicycles use brushless motors that are sometimes built into the wheel hub itself, with the stator fixed solidly to the axle and the magnets attached to and rotating with the wheel. The same principle is applied in self-balancing scooter wheels. Most electrically powered RC models use brushless motors because of their high efficiency.

Cordless tools

Brushless motors are found in many modern cordless tools, including some string trimmers, leaf blowers, saws (circular or reciprocating), and drills/drivers. The advantages of brushless over brushed motors (low weight, high efficiency) are more important to handheld, battery-powered tools than to large, stationary tools plugged into an AC outlet, so uptake has been faster in that segment of the market.

Heating and ventilation

There is a trend in the heating, ventilation, and air conditioning (HVAC) and refrigeration industries to use brushless motors instead of various types of AC motors. The most significant reason to switch to a brushless motor is the dramatic reduction in power required to operate them versus a typical AC motor.While shaded-pole and permanent split capacitor motors once dominated as the motor of fans, many fans are now run using a brushless motor. Some fans also use brushless motors in order to increase overall system efficiency. In addition to the brushless motor's higher efficiency, HVAC systems (especially those featuring variable-speed and/or load modulation) use brushless motors because the built-in microprocessor allows for programmability, control over airflow, and serial communication. Some ceiling fan and portable fans also feature this motor. They advertise the motor being highly energy efficient and quieter than most fans.

Industrial engineering

The application of brushless DC motors within industrial engineering primarily focuses on manufacturing engineering or industrial automation design. In manufacturing, brushless motors are primarily used for motion control, positioning or actuation systems.

Brushless motors are ideally suited for manufacturing applications because of their high power density, good speed-torque characteristics, high efficiency, wide speed ranges and low maintenance. The most common uses of brushless DC motors in industrial engineering are linear motors, servomotors, actuators for industrial robots, extruder drive motors and feed drives for CNC machine tools.

Motion control systems

Brushless motors are commonly used as pump, fan and spindle drives in adjustable or variable speed applications as they are capable of developing high torque with good speed response. In addition, they can be easily automated for remote control. Due to their construction, they have good thermal characteristics and high energy efficiency. To obtain a variable speed response, brushless motors operate in an electromechanical system that includes an electronic motor controller and a rotor position feedback sensor.

Brushless DC motors are widely used as servomotors for machine tool servo drives. Servomotors are used for mechanical displacement, positioning or precision motion control. DC stepper motors can also be used as servomotors; however, since they are operated with open loop control, they typically exhibit torque pulsations.Brushless DC motors are more suitable as servomotors since their precise motion is based upon a closed loop control system that provides tightly controlled and stable operation.

Positioning and actuation systems

Brushless motors are used in industrial positioning and actuation applications. For assembly robots,brushless stepper or servo motors are used to position a part for assembly or a tool for a manufacturing process, such as welding or painting. Brushless motors can also be used to drive linear actuators.Motors that directly produce linear motion are called linear motors. The advantage of linear motors is that they can produce linear motion without the need of a transmission system, such as ballscrews, leadscrew, rack-andpinion, cam, gears or belts, that would be necessary for rotary motors. Transmission systems are known to introduce less responsiveness and reduced accuracy. Direct drive, brushless DC linear motors consist of a slotted stator with magnetic teeth and a moving actuator, which has permanent magnets and coil windings. To obtain linear motion, a motor controller excites the coil windings in the actuator causing an interaction of the magnetic fields resulting in linear motion.Tubular linear motors are another form of linear motor design operated in a similar way.

Aeromodelling

Brushless motors have become a popular motor choice for model aircraft including helicopters and drones. Their favorable power-to-weight ratios and wide range of available sizes, from under 5 grams to large motors rated at well into the kilowatt output range, have revolutionized the market for electric-powered model flight, displacing virtually all brushed electric motors, except for low powered inexpensive often toy grade aircraft. They have also encouraged growth of simple, lightweight electric model aircraft, rather than the previous internal combustion engines powering larger and heavier models. The increased power-to-weight ratio of modern batteries and brushless motors allows models to ascend vertically, rather than climb gradually. The low noise and lack of mass compared to small glow fuel internal combustion engines is another reason for their popularity.

Legal restrictions for the use of combustion engine driven model aircraft in some countries, most often due to potential for noise pollution—even with purpose-designed mufflers for almost all model engines being available over the most recent decades—have also supported the shift to high-power electric systems.

Radio-controlled cars

Their popularity has also risen in the radio-controlled (RC) car area. Brushless motors have been legal in North American RC car racing in accordance to Radio Operated Auto Racing (ROAR) since 2006. These motors provide a great amount of power to RC racers and, if paired with appropriate gearing and high-discharge lithium polymer (Li-Po) or lithium iron phosphate (LiFePO4) batteries, these cars can achieve speeds over 160 kilometres per hour (99 mph).

Brushless motors are capable of producing more torque and have a faster peak rotational speed compared to nitro- or gasoline-powered engines. Nitro engines peak at around 46,800 r/min and 2.2 kilowatts (3.0 hp), while a smaller brushless motor can reach 50,000 r/min and 3.7 kilowatts (5.0 hp). Larger brushless RC motors can reach upwards of 10 kilowatts (13 hp) and 28,000 r/min to power one-fifth-scale models.

CONCLUSION AND FUTURE SCOPE

Sustainable transportation is a need in near future due to reduce energy consumption and greenhouse gases emission in the world for solving global warming issue. Hybrid and electrical vehicles are the good solution in this case. Increase of safety, efficiency and controllability of a vehicle has been always one of the most important challenges in automotive industry. Design of intelligent fully electronically controlled vehicle (IFCEV) can be the solution for many of challenges in this field.

In conclusion, BLDC motors have advantages over brushed DC motors and induction motors. They have better speed versus torque characteristics, highdynamic response, high efficiency, long operating life, noiseless operation, higher speed ranges, rugged con-struction and so on. Also, torque delivered to the motorsize is higher, making it useful in applications where space and weight are critical factors. With these advan- tages, BLDC motors find wide spread applications in automotive, appliance, aerospace, consumer, medical, instrumentation and automation industries.

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