Original Article

A Review On Brushless Dc Motor Control Techniques

Bokam Divakar[1] , Dr.R.S.R.Krishnam Naidu[2] , G Divya[3], SYugandhar[4], G Mani Deepak[5], D Sindhusha[6]

[1]Assistant Professor of Electrical and Electronics Engineering Nadimpalli Satyanarayana Raju Institute of Technology

[2]Associate Professor of Electrical and Electronics Engineering Nadimpalli Satyanarayana Raju Institute of Technology

[3,4,5,6] Students of Department of Electrical and Electronics Engineering Nadimpalli Satyanarayana Raju Institute of Technology
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Abstract

This paper deals with the different control strategies used in the operation of Brushless motors, which generally refer to Permanent-Magnet Motors. These motors are becoming increasingly popular in industrial applications due to their high-efficiency, fast dynamic response and compact size. Until recently, programming and implementation costs of high-performance control algorithms for these motors have been prohibitive. However, great strides have been made by manufacturers such as Microchip, Freescale, IRetc to facilitate these algorithms in the architecture for their processors. This has brought down the development costs significantly and opened up whole new avenues for Brushless Motor.

KEYWORDS : Brushless Motors, Permanent Magnet Motors, Trapezoidal Control, Sinusoidal Control, Field Oriented Control, Pulse Width Modulation

1.INTRODUCTION:

A Brushless Motor consists of a Permanent Magnet which acts as the rotor. The rotor is

surrounded by three equally spaced fixed stator windings as shown in figure 1. The current flow in each winding produces a magnetic field vector which sums up with each other to form a resultant magnetic field. Torque is produced in the motor by the attraction or repulsion between this net stator magnetic field and the magnetic field produced by the permanent magnet, i.e. rotor. By controlling the current flow in the three windings, a magnetic field of arbitrary direction and magnitude can be produced by the stator and thereby, the torque produced can be controlled. The conventional Brushed motors commutate itself with the use of a mechanical commutator whereas brushless motors need electronic commutation for the directioncontrol of current through the windings[1].

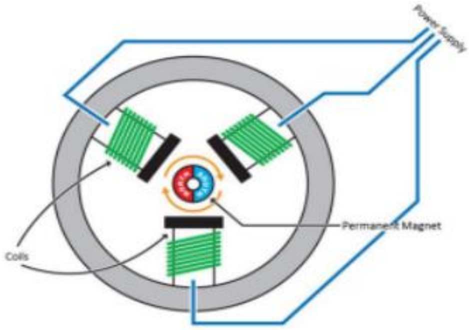

Fig 1 : Brushless Motor Construction

Brushless dc (BLDC) motor drives are becoming widely used in various consumer and industrial systems, such as servo motor drives, home appliances, computer peripherals, and automotive applications. Consequently, many machine design and control schemes have been developed to enhance the performance of BLDC motor drives. In general, the overall system consists of threeparts: (i) power conversion PWM inverters, (ii) BLDC motor and load, and (iii) speed, torque, and current controller. Therefore, exact understanding of each part is a prerequisite for analysis and prediction of the overall system operation. Before now, several simulation models have been proposed for the analysis of BLDC motor drives. These models are based on state-space equations, Fourier series, and the d-q axis model . In this paper we propose a simulation model for an entire BLDC motor drive to obtain controlled speed and also to analyze the stability of the complete system[1]

2.CONTROL TECHNIQUES :

A. TRAPEZOIDAL CONTROL:

One of the simplest and common methods for controlling Brushless DC motors (BLDC) is Trapezoidal Control. The stator consists of three stator windings which act as terminals. In this method, current is controlled through two terminals at a time, during which the third terminal electrically disconnected from the source. To measure the rotor position, Hall Effect sensors are usually embedded into the motor. At any instant of time, current of equal magnitude is flowing in two of windings while the third one is zero. Due to this, the current space vector can be one of six different possible directions[2]

Trapezoidal control is suitable for motors with Sinusoidal Back-EMF as the produced torque is not constant but made up from portions of a sine wave as shown in the figure 6.
This is due to the application of a Trapezoidal Control strategy for a motor with sinusoidal Back-EMF.

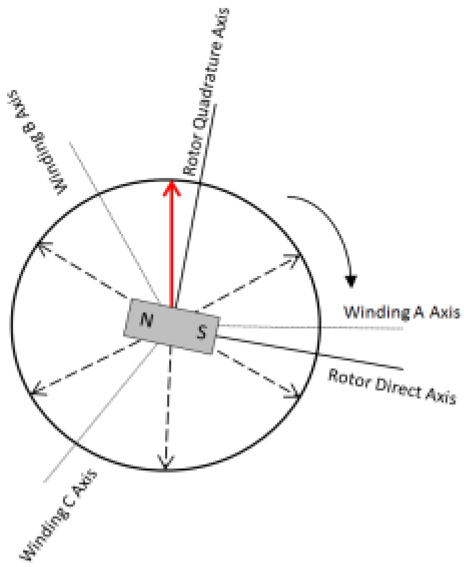

Fig.2 .Possible directions of current space vector in trapezoidal control

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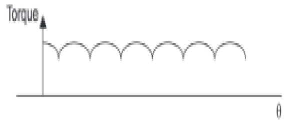


Torque Ripple when Trapezoidal Control is applied to Sinusoidal Back-EMF motor

The main advantage of this scheme is that it is relatively simple and cheap to implement since only one phase current needs to be controlled. Due to this, it is found to be ideal for low-cost applications which do not demand high performance.

B. SINUSOIDAL CONTROL:

The principle of Sinusoidal Control is to drive all the three motor windings with three currents that vary smoothly and sinusoidally as the motor rotates. This requires modulation of the three winding currents such that the resulting space vector is always in the quadrature direction with respect to the rotor and has constant magnitude. In order to achieve this, accurate measurement of rotor position is required which can be provided by Resolver or Quadrature Pulse Encoders. Since the windings are star connected, the current in one of the windings is the negative sum of the currents in the other two windings. Hence, this scheme requires a current control loop for the first two windings. The typical block diagram of a sinusoidal control scheme.[3]

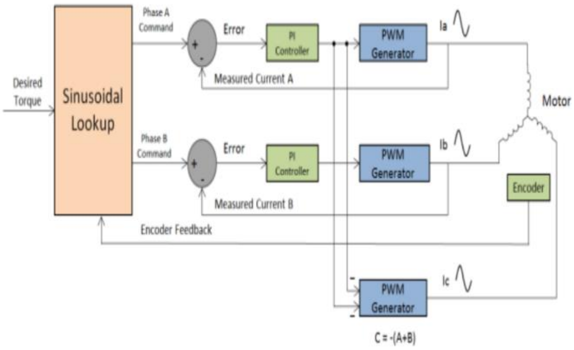
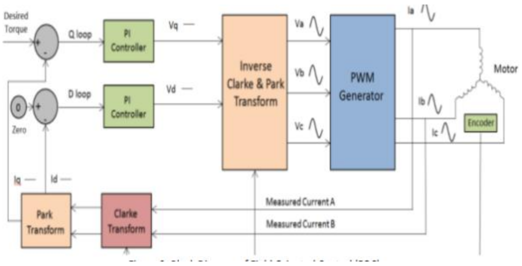


Fig.3. Block Diagram of Sinusoidal Control

Sinusoidal Control overcomes some of the drawbacks of Trapezoidal Control by eliminating Torque Ripple and offering smooth rotation with higher efficiency at low speeds.However, the PI controllers have limited gain and frequency response. As the speed increases, the frequency of the sinusoidal signals increase, making it more difficult for the controllers to track the reference current command signals. The lag and gain error in the current loops, which is inconsequential at low speeds, cause the current space vector to shift away from the desired quadrature direction producing unwanted torque in the direct axis direction. This leads to a reduction of useful torque by a given amount of current. The efficiency fades as more current is required to maintain the torque at the desired value. The speed can also only be increased up to a certain point, after which the phase shift in the current space vector exceeds 90o leading to negative torque. The Sinusoidal Control scheme is used for both BLDC and PMSM motors in low speed-medium speed applications but unsuitable for operations that require high speed.[3]

C.FIELD- ORIENTEDCONTROL:

The Field Oriented Control algorithm shares lot of common ground with Sinusoidal Control. However, some fundamental differences allow it to achieve better efficiency at high speeds. The main drawback of Sinusoidal Control arises due to the fact that this control scheme tries to control the motor currents whose magnitude and direction varies with time. As the speed and frequency increase, the PI controllers are incapable of handling the operation due to their limited bandwidth. This problem can be overcome by representing and controlling the current space vector in the two axis d-q.



The FOC algorithm is able to offer numerous advantages.Such as

• High Efficiency

•Smooth operation at low and high speeds   resulting in a wide range of speed •Transformation of a complex and coupled AC model into a simple linear system

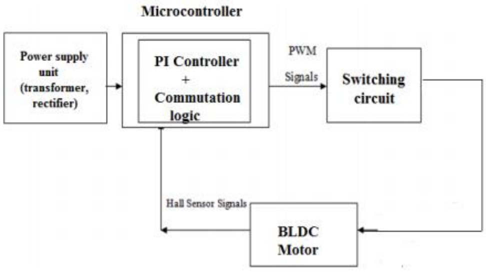
•Fast dynamic response and good transient and steady state performance

D. PWM CONTROL METHOD :

The permanent magnet motor technology has considered as an efficient option due to its high energy generation by PMs which increases the efficiency and also the trade-off which exists between the growth of the

manufacturing technology and the decrease in PM costs [4]. The quick growth of variable-speed drives in the automotive industry based on the hybrid drives is a major industry demand in variable-speed PM drives as well [5]. BLDC motors, also known as permanent-magnet DCsynchronous motors, are more popular and appealing than other PM motors in energy saving as a result of their better features and performance. Hence, it will be worthwhile to categorize the different controlling

strategies of driving these motors and also evaluate the inherent advantages and drawbacks of each method by a comparative analysis and finally, introduce the applications of each. BLDC motors with a two-phase and/or three-phase supply system, have many advantages over conventional motors; such as better speed versus torque racteristics,high dynamic response, high fficiency and reliability, long operation life, noiseless performance, high speed range, and low electromagnetic interference (EMI) over induction and DC motors. The last but not the least, they have higher power to weight and torque to current ratios compared to induction, DC, and PM synchronous motors (PMSMs). It should be mentioned that control of BLDC motor is simpler than induction and PMSM. Thanks to these substantial advantages, BLDC motors are widely utilized in various applications such as industrial automation, aerospace, military, medical, computer, automobile (EV, HEV), and transportation industries, information technology equipment, public facilities equipment, audio-visual equipment, toys, and home appliances in different powers ranging from microwatts to megawatts.



The general structure of a BLDC motor with a six-stepinverter is shown in Fig. 1. As seen in Fig. 1, the control structure of this motor is divided into two independent components.

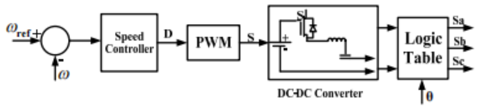


Fig. 2. Speed control with variable dc link voltage

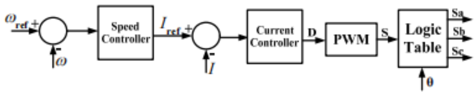


Fig. 3. Cascade current control with PWM method

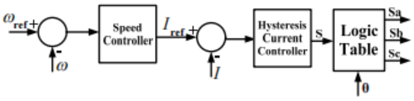


Fig. 4. Cascade current control with hysteresis controller

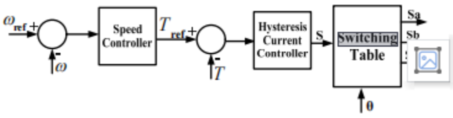
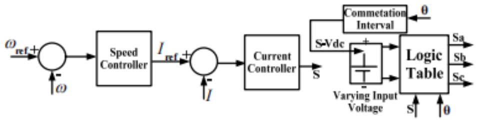
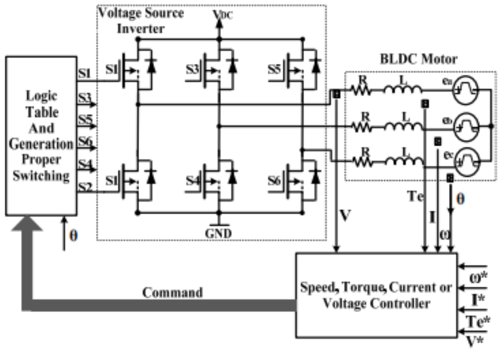


Fig. 5. Cascade torque control with hysteresis controller





General structure of the BLDC motor drive with a six-step inverter

The first provides the rotor and stator flux synchronism which is done every 60 electrical degrees by using the rotor position data obtained by a sensor or sensorless techniques and the correct selection of a pair of inverter switches. The second is responsible for producing necessary signals in order to provide desirablecontrol in any of 60 degrees ranges using different controlling strategy such as speed, voltage, current and torque. Speed, current, voltage, or torque can be the aim of controlling strategies in BLDC motorsThe closed loop speed control is used for attenuating speed variations caused by pulsating torques or any other source of disturbance which affects motor desirable speed [6]. In this paper, all the control methods are considered to be equipped with speed control in order to attain a correct comparison and analysis of the mentioned controlling strategies. A speed controller may directly determine the duty cycle of a pulse width modulator (PWM) of a DC-DC convertor as shown in Fig. 2 or be used in a cascade control with an outer speed loop and a current or torque control inner loop. The inner current control may be a PI controller with a PWM or ahysteresis controller as shown in Figs. 3 and 4, respectively. In addition to current control, hysteresis control is also used for torque control, as shown in Fig. 5. The first category of the mentioned controlling
strategies is voltage control and the second and third categories are current and torque control, respectively. It should be noted that there is another controller called varying input voltage control which is a complementary controller for torque ripple reduction at high speeds. This control scheme is used with different control
methods, in particular, current control as shown in Fig. 6.

This type of controller is placed in the first category due to the direct effect of voltage on motor performance improvement during commutation. Among the mentioned classification, there is a wide variety for current control category both in reference current generation and PWM algorithms and the type of feedback current extraction. The simplest solution in using feedback current I , is using dc-link current which will not be discussed in this paper due to the following
reasons:

- In power inverters, flat cooper plates are generallyused between transistors and electrolyte capacitors in order to reduce the inductance between power transistors and dc-link to prevent excess voltages on the switches, which can be dangerous. Thus, it is very hard to connect the current sensor in the dc-link [7].
- Use of a current sensor in a dc-link cannot detect the motor phase currents while they are conducting (during commutation), which results in a greater commutation ripple [8].
- Since the dc-link current is small, it may cause some problems during startup and low speeds, even with high motor currents [9].

- Certain PWM techniques cause floating phase current circulation. These currents result in undesirable utilization of the single current sensor in dc-link [10].
- Dc-link current requires to be sampled according to the switches conduction data; therefore, the system needs complicated calculations with regard to its
hardware.

3. CURRENT CONTROL STRATEGIES

Current control strategies are the general drive structure for BLDC motors. The main current control strategies can be categorized into three groups based on the controller type, the way of utilization of the sensed
currents, and reference currents generation. The controller type group includes two parts: PWM and hysteresis current control approach. The way of utilization of the sensed currents group also includes two parts: direct exploitation of the sensed
currents and exploitation for producing virtual dc-links. To have a better understanding and comparison between the current control strategies, the aforementionedcategorizations are considered moregeneral as PWM and hysteresis current control with and without reference current shaping, minimum copper losses, and current control by exploitation of virtual dclink.
BLDC motors voltage inverters switching is made by six PWM switching approaches: H-ON-L-PWM, ONPWM, PWM-ON, PWM-ON-PWM, and H-PWM-LPWM. PWM operation mode for BLDC motors acts so that the supply voltage is chopped in a constant frequency and a duty cycle dependent on the current error.

All the switching modes are for the 120 electrical degree conduction mode of the motor; i.e. at any instant of time only two phases of the motor conduct and thethird phase is off.
In this approach, the switching command is
considered as a design parameter and simple filtering of the electromagnetic and acoustic noises and constant switching losses in variable load and speed are the advantages. A drawback of this approach is that triangular wave is hard to produce. In the PWM
approaches, H-PWM-L-PWM is called bipolar PWM and considered as hard switching due to the inverter output voltage switch between dc-link voltage and that of the inverse polarity. Other PWM approaches are called unipolar PWM and considered as soft switching since
their output voltage switches between dc-link voltage and zero. Since in bipolar PWM approach the two switches under conduction are switched with the desired frequency, the switching losses and current oscillation are
twice that of unipolar approach, but it has faster current dynamic ranging and also its power electronic board design is simpler and cheaper .
There exist a linear relationship between current and torque since the back-EMF in BLDC motors is trapezoidal; thus, the current ripple and oscillation in these motors cause ripple and oscillation in torque. The torque ripple is the main cause of vibration and noise in BLDC motors which results in stabilitydegradation and decrease in reliability and also make them useless for the applications in which exact position control is required.
Therefore, it is worthwhile to analyze the current
dynamic response in different PWM approaches. Hence, the torque ripple in two regions is studied: during the commutation and when conduction occurs. These regions are called commutation region and non-commutation region, respectively

4.COMPARISON OF SENSORS AND SENSORLESS TECHNIQUES:

All the control techniques mentioned above require the real time position information of the motor in order to function effectively. There are numerous ways to obtain the rotor position information, either by using sensors or by deducing the information through some other means.

The sensor-based techniques employ electromechanical sensors coupled to the rotor to provide the speed and position of the rotor. The most prevalent ones used today are Optical Encoders, Resolvers and Hall Effect sensors. Resolvers and Optical Encoders are externally mounted on the motor, while Hall sensors are mounted on the rotor itself. Hall Sensors are the most common sensors used in low-cost applications. Three hall-effect sensors are mounted on the rotor, which provides digital signals for every 60o of rotation of the rotor.

The resolver is the most accurate and also the most expensive among all the available sensors. It is essentially a rotary electrical transformer which generates analog signals that can be used to determine absolute position. Due to its high resolution, it is the preferred choice in industrial servo applications. While not as precise as the Resolver, the Optical Encoders still offer fairly high resolution. It consists of an
incremental rotating disk with a slot pattern on its periphery. A LED is mounted on one side of the disk and a phototransistor is mounted on the other side, opposite to the LED. The arrangement produces a set number of pulses for
every 360o of rotation

Position and Speed Sensors

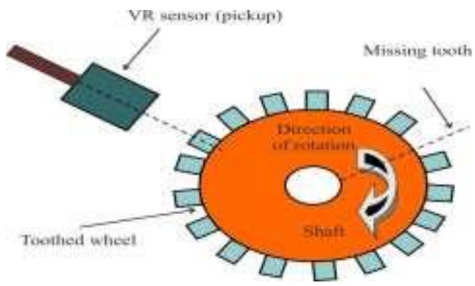
As clarified previously, probably the regularly utilized gadgets in position and speed applications are Hall-impact sensors, variable hesitance sensors and accelerometers. every last one of these sorts of gadgets is
talked about further beneath.

Hall-effect sensors

These Types of devices are based on Hall-effect theory, which states that if an electric current- carrying conductor is kept in a magnetic field, the magnetic field exerts a transverse compel on the moving charge bearers that will in general push them to the other side of the conductor. A increase of charge at the sides of the conductors will balance this magnetic influence producing a quantifiable voltage between the two sides of the conductor. The existence of this measurable transverse voltage is called the Hall-effect because it was discovered by Edwin Hall in 1879. Unlike a brushed DC motor, the commutation of a BLDC motor is limited electronically. stator windings ought to be empowered in an arrangement to pivot the BLDC motor. It is essential to know the rotor position in order to recognize which winding will be energized following the energizing sequence. Rotor position is sensed using Hall-effect sensors embedded into the stator

Variable Reluctance (VR) Wheel Speed Sensors

This type of sensor is used to measure position and speed of moving metal components, and is often referred as a passive magnetic sensor because it does not require to be powered. It consist of a permanent magnet, a ferromagnetic pole piece, a pickup coil, and a rotating toothed wheel, as Figure 15 illustrates. Construction of this device is basically a permanent magnet with wire wrapped around it. It is generally a basic circuit of just two wires where as a rule extremity isn't vital, and physics behind its operation include magnetic induction



5. CONCLUSION

The control strategies detailed in this paper each have their own advantages and drawbacks. Trapezoidal Control is relatively simple and offers smooth operation at high speed but causes torque ripple at low speeds. Sinusoidal Control eliminates torque ripple and provides efficient operation at low speeds but the limitations of a PI controller make it unsuitable for high speed applications. Field Oriented Control

(FOC) combines the best aspects of the previous two methods, offering smooth and efficient operation with fast dynamic response at both low and high speeds. The decision to implement sensors also depends on various factors. Excluding sensors will reduce the cost and size of the system but increase the complexity as rotor information needs to be deduced from other means. It is up to the designer to choose the most appropriate control technique that meets his requirements while minimizing the cost.

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