IOSR Journal of Engineering (IOSR JEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 42-55

Review on Speed Control Techniques of Brushless DC Motor

Khairnar Yogesh Keda[1], Shaikh Sameer[2] ,Muqueem Khan[3] , Sajid Shaikh[4] , Shah Faisal[5]
[1,2,3,4,5](Deptartment of Electrical Engineering, MMANTC, Mansoora, Malegaon, India)

Abstract: *There are typically two classes of dc motors utilized in industry. The primary one is the traditionnel dc motor where the flux is produced by the current through the field coil of the stationary pole structure. The secondary type is the brushless dc motor where the permanent magnet provides the essentail air gap flux instead of the wire-wound field poles. Brushless motor drive are becoming more popular in industrial , traction applications. This makes the control of BLDC motor in all aspects very vital. This paper deals with the review of sensor and sensorless speed control methods f BLDC motor .The performance and reliability of BLDC motor drives has been improved because the traditional control and sensing techniques have been improved through sensorless technology . Then ,in this paper sensor and sensorless advances are reviewed with their advantages and limitations .The study includes a deep overview of speed control method, PID controller and Fuzzy PID controller method, Method based on converter topology, Direct torque control method ,back EMF method, PWM techniques for speed control, Sensor based speed control techniques*

Keywords*: back-EMF,BLDC,EKF, FEM, PID,SMO.*

I. Introduction

For as far back as two decades a few Asian nations, for example, Japan, which have been experiencing tension from high vitality costs, have actualized variable speed PM motor drives for vitality sparing applications, for example, forced air systems and coolers [1]. Then again, the U.S.A. has continued utilizing shoddy acceptance motor drives, which have around 10% lower effectiveness than movable PM motor drives for vitality sparing applications. In this manner as of late, the expansion in vitality costs goads higher requests of variable speed PM motor drives. Likewise, late quick multiplication of motor crashes into the vehicle business, in view of half and half drives, creates a genuine interest for high productive PM motor drives, and this was the start of enthusiasm for BLDC motors. BLDC motors, likewise called Permanent Magnet DC Synchronous motors, are one of the motors types that have all the more quickly picked up prevalence, for the most part as a result of their better attributes and execution [2]. These motors are utilized in a lot of modern divisions on the grounds that their motoring is reasonable for any security basic applications. The brushless DC motor is a synchronous electric motor that, from a displaying point of view, looks precisely like a DC motor, having a straight connection among flow and torque, voltage and rpm. It is an electronically controlled recompense framework, rather than having a mechanical commutation, which is normal of brushed motors. Also, the electromagnets don't move, the changeless magnets pivot and the armature stays static. This gets around the problem of how to exchange current to rotating armature. So as to do this, the brush-system commutator get together is supplanted by intelligent electronic controller which plays out a similar power distribution as a brushed DC motor [3]. BLDC motors have numerous preferences over brushed DC motors and AC machines, for example, a superior speed versus torque qualities, high dynamic response, high productivity and unwavering quality, long working life (no brush disintegration), silent operation, higher speed ranges, and decrease of electromagnetic impedance (EMI). Moreover, the proportion of conveyed torque to the size of the motor is higher, making it helpful in applications where space and weight are basic elements, particularly in aerospace applications.

The control of BLDC motor should be conceivable in sensor or sensorless mode, however to diminish in general expense of sensing dvices, sensorless control procedures are typically utilized. The upside of sensorless BLDC motor control is that the detecting part can be discarded, and in this manner overall expenses can be significantly diminished. The disadvantages of sensorless control are higher requirements for control algorithms and more complex electronics [3]

II. Techniques And Advances In Sensorless Control

Position sensors can be totally disposed of, in this way decreasing additionally cost and size of motor assembly , in those applications in which just variable speed control (i.e, no positioning) is required and system elements isn't especially requesting (i.e, slowly or, at least, predictably varying load). Truth be told, some control strategies, for example, back-EMF and current sensing , give, by and large, enough data to measure or estimate with adequate accuracy the rotor position and, along these lines, to work the motor with synchronous phase current. A PM brushless drive that does not require position sensors but rather just electrical estimations is known as a sensorless drive [4].

The BLDC motor gives an appealing possibility to sensorless operation on the grounds that the idea of its excitation naturally offers an ease approach to extricate rotor position data from motor terminal voltages. In the excitation of a three-stage BLDC motor, aside from the stage commutation periods, just two of the three phase windings are leading at once and the no conducting phase conveys the back-EMF. There are numerous classes of sensorless control methods [5]; be that as it may, the most well known classification depends on back electromotive force or back-EMFs [6]. Sensing back-EMF of unused phase is the most cost competent method to obtain the commutation sequence in star wound motors. Since back-EMF is zero at standstill and proportional to speed, the measured terminal voltage that has huge signal-to-noise ratio cannot sense zero crossing at low speeds. That is the motivation behind why in all back-EMF-based sensorless techniques the low-speed execution is constrained, and an open-loop starting strategy is required [7]. In this paper, ordinary and late progression of back-EMF detecting techniques for the PM BLDC motors and generators are introduced

2.1 PID and Fuzzy PID Control

BLDC motor drives are comprehensively used for variable speed drive systems of the mechanical applications what's increasingly, electric vehicles. In practice, the design of the structure of the BLDCM drive includes a complex procedure, for example, modeling, control scheme selection , simulation and parameters tuning and so forth. A specialist information of the system is required for tuning the controller parameters of servo framework to get the ideal execution. As of late, different modern control solutions are proposed for the speed control method of BLDC motor[8[9][10]. Be that as it may, Conventional PID controller calculation is basic, steady, simple modification and high reliability, Conventional speed control system utilized in regular PID control [11][12]. However, truth be told, most mechanical procedures with various degrees of nonlinear ,parameter fluctuation and vulnerability of mathematical model of the system. Tuning PID control parameters is troublesome, poor robustness, in this way, it's hard to accomplish the ideal state under field conditions in the real production. Fuzzy PID control strategy is a superior technique for controlling, to the complex and hazy model frameworks, it can give basic and compelling control, Play fluffy control robustness, great unique reaction, rising time, over strike characteristic.

Fuzzy Logic control (FLC) has demonstrated viable for complex, non-linear and loosely characterized procedures for which standard model based control methods are illogical or inconceivable [13][14][15][16]. Fuzzy Logic, deals with troubles that have vagueness, uncertainty and use membership functions with values varying between 0 and1. This implies if the a dependable expert knowledge isn't available or if the controlled system is too unpredictable to even think about deriving the required choice standards, improvement of a fuzzy logic controller progress toward becoming tedious and repetitive or sometime impossible. For the situation that the expert learning is accessible, calibrating of the controller may be tedious also [13][14]. Besides, an ideal fuzzy logic controller can't be accomplished by trial and error. These disadvantages have constrained the utilization of fuzzy logic control. Some efforts have been made to solve these troubles and simplify the task of tuning parameters and developing rules for the controller.

2.1.1 System of Speed Control of BLDC Motor

Fig.1 illustrate the whole block diagram of speed control of three phase Brushless DC Motor . Two control loops are utilized to control BLDC motor. The outside loop controls the motor's speed by varying the DC bus voltage .The internal loop synchronizes the inverter gates signals with the electromotive forces...The outer loop controls the motor's speed by varying the DC bus voltage.

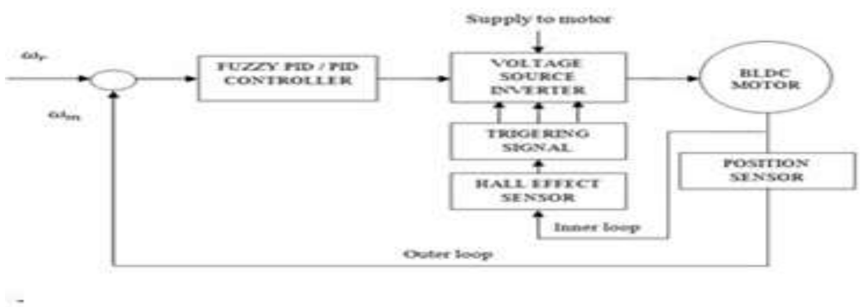


Fig.1: Block Diagram of speed control of BLDC Motor[17]

Motor Driving circuitry includes three phase electronics power modulators, which uses six power devices thyristors or transistors (generally MOSFET are used) to energizes two BLDC motor phases concurrently The rotor position, which decides the switching sequence of pair of the MOSFET transistors, is recognized by means of 3 Hall sensors mounted on the stator. With the help of Hall sensor information and the sign of reference current (produced by Reference current generator), Decoder block produces signal vector of back EMF. The basic idea of running motor in converse direction is by giving opposite current.

2.1.2 Controller Circuit (PID Controller)

A PID controller is basic three-term controller. The letter P,I and D represent P-Proportional, I-Integral, D-Derivative. The output transfer function of the most basic form of PID controller is

$$\mathrm{C(S)} \ = Ki + \frac{Kp}{S} + \mathrm{KdS}$$

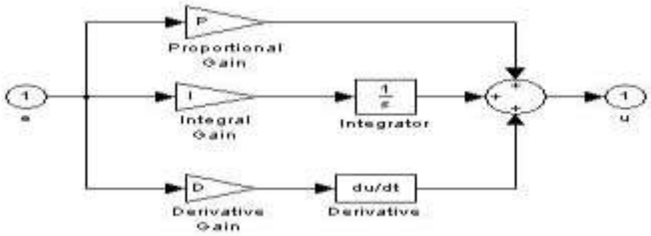


Fig.2: Simulation model of PID Controller[17]

For designing a PID controller are following steps are used ,
i) Check and determine what characteristics of the system needs to be improved.
ii) Use Kp to reduce the rise time.
iii) Use Kdto decrease the overshoot and settling time.
iv) Use Ki to eliminate the steady-state error.
The Values of Kp, Ki and Kd values of PID Controller is shown in below table I are obtained by using the ZN method.

Table 1. PID Values[17]

Controller	Kp	Ki	Kd
PID	0.8	48	0.01

2.1.3 Fuzzy PID Controller

In operation of the drive , the speed of the motor can be controlled operation can be achieved by indirectly by controlling the Voltage Source inverter. The speed is restricted by fuzzy logic controller whose output is the inner dc Voltage controller. The Voltage is controlled and regulated by varying the dc voltage. The drive execution of voltage source controller is enhanced by utilizing two arrangements of fuzzy logic controller. Fuzzy PID controller used in this paper is based on two input FLC structure with coupled rules

The overall arrangement of used controller is shown in Fig.3 from Fig. 4one set of fuzzy logic controller is used in the internal loop for controlling the torque of the motor which is proportional to DC link current Idc, and another set is used in the external loop for controlling the actual motor speed

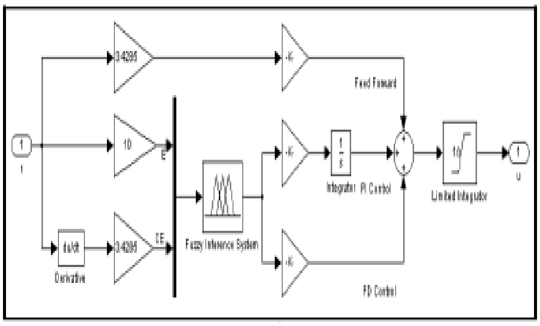
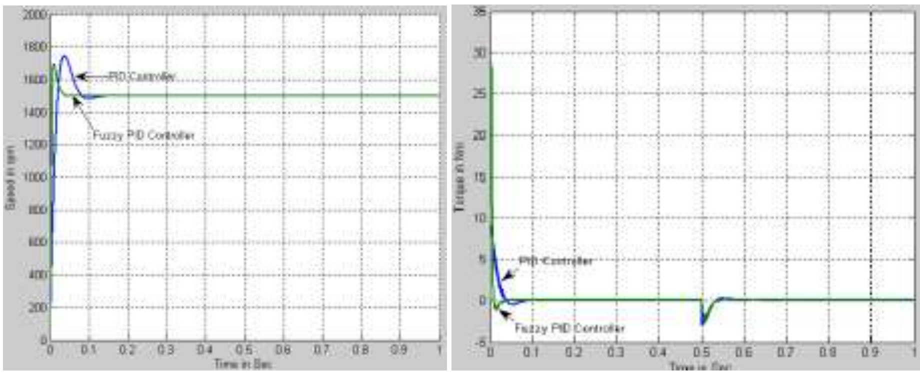


Fig.3: Simulation of Fuzzy PID Controller[17]

2.1.4 Performance of PID and Fuzzy controller

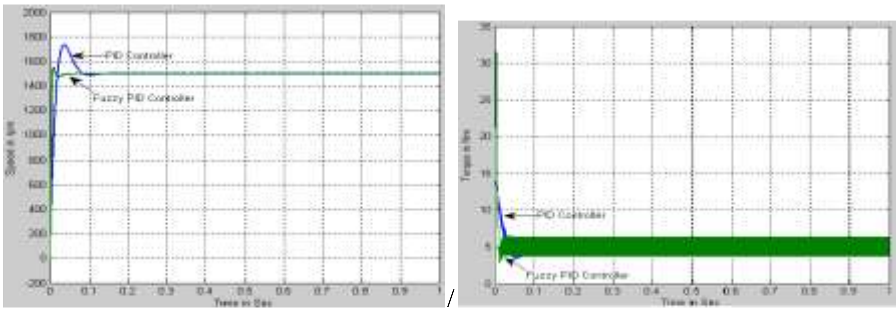
Performance of the Fuzzy PID controller and Conventional PID Controller of BLDC Motor on Reference speed of 1500rpm with no load condition of (a)speed and (b)Torque is shown in fig 4. The outcome demonstrate that traditional PID controller arrive at settling time is 0.35 sec, but in fuzzy PID controller reach the settling time of 0.10 sec..



a) b)

Fig. 4: Reference speed of 1500 rpm with no load (a)speed and (b) torque[17]

Performance of the fuzzy PID controller and Conventional PID Controller of BLDC Motor on Reference speed of 1500rpm with load condition of (a)speed and (b)Torque is shown in Fig 5. The load of 5 N.m is apply to BLDC motor, the results show that usual PID controller reach settling time is 0.40 sec, but in fuzzy PID controller reach the settling time of 0.15 sec.



a) b)

Fig. 5: Reference speed of 1500 rpm with load (a) Speed and (b) Torque[17]

With results got from simulation, obviously for a similar activity condition the BLDC speed control using conventional PID controller technique had poor and unsatisfactory performance than the Fuzzy PID controller (i.e. Fuzzy PID controller has better performance) , mainly when the motor was working at lower and higher speeds. In addition, the motor speed to be at steady state when the load varies.

2. 2 Direct Torque Control

Ozturk and Toliyat [18] extended traditional direct torque control (DTC) strategies for BLDC motor drive to direct torque control and indirect flux control method for sensor less BLDC motor drive. The proposed technique changes the quantities from a-b-c reference frame to d-q frame. The torque can be constrained by q-axis current and the flux can be controlled indirectly by d-axis current. The proposed strategy utilizes new2x2 line to line Park transformation matrix with the goal that the estimation of two line voltages are adequate to transform the quantities to d-q frame. In this manner the computations are decreased to least. In contrast to traditional strategies, this scheme utilizes OTC method with three phase conduction so that, the stator fluxes amplitude can be controlled without influencing the commutation. The framework utilizes look-into table for controlling the voltage vector rather than the PWM technique resulting in simpler control action and faster

Mourad Masmoudi et al. [19] have displayed an increasingly solid control technique for DTC. In the prior techniques the reliability of the drive is compromised because of the unequal exchanging of lower and upper switches in the inverter and the nearness of high CMV. In the proposed strategy, the above mentioned issues are dispensed with by applying proper null voltage vector. The two dimension hysteresis controllers in the torque loop is supplanted with a two dimension hysteresis controller to have three phase conduction mode during sector-to-sector commutation so that the torque ripple could reduce to minimum.

2.3. Method of zero crossing detection using back EMF

Back EMF estimation technique generally rely on the zero crossing detection of the EMF waveform. The technique of estimating back EMF by sensing the terminal voltages with respect to a virtual neutral point is proposed in [20]. The neutral point will not be constant during pulse width modulation (PWM) switching. Low pass filters have been used to remove the higher harmonics and to exchange the terminal voltages into triangular waveform signals. Delay is introduced in the detected signal due to heavy filtering, which also varies with the operating speed. Therefore, this method is well suitable only for a narrow speed range. Indirect back EMF sensing technique is proposed in [21] without the need of neutral or virtual neutral potential. The back EMF zero sensed with respect to the negative dc bus potential. In [22], Kim and Ehsani define a function depending on the measured voltages, currents, and the derivative of the currents, which indicates the switching instants. After prepositioning, Kim and Ehsani [22] advance the switching pattern by 60 electrical degrees and let their sensorless algorithm take over. Since their functions are dependent on the estimation of derivatives of currents, the technique requires digital realization and could be affected by sensor noise. Detecting the free-wheeling diode conduction in the open phase gives the zero-crossing point of the back EMF waveform[23]. Especially at lower speed this approach of rotor-position sensing works over a wide speed range,. The main disadvantage of this scheme is the prerequisite of six additional power supplies for the comparator circuits to detect current flowing through the free-wheeling diode.

Integrating the back EMF waveform of the unexcited phase is another method to extract the position information for the phase commutation [24]. Integration begins when zero crossing of the back EMF occurs and the integration stops when the threshold set value is reached, which gives the commutation instant. This methodology is less delicate to exchanging clamor yet low speed activity is poor. Further, this strategy needs the nonpartisan potential and experiences the balance mistake because of coordination.

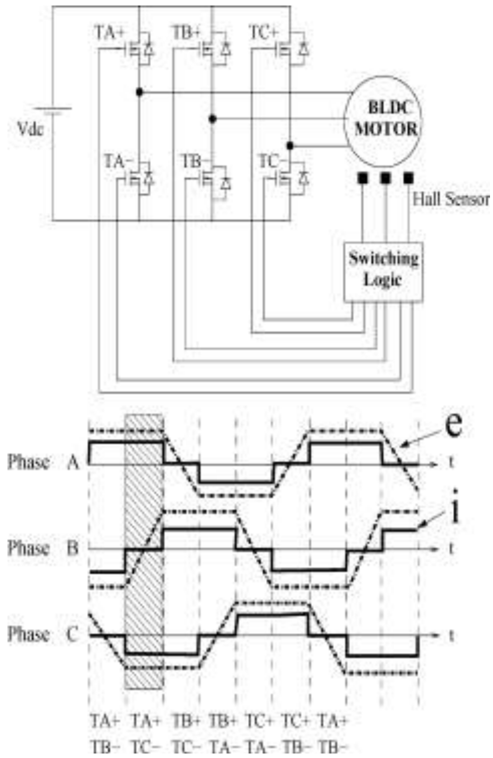


Fig. 6: BLDC motor drive along with typical phase current and back EMF.[24]

2.4. Converter Topology Used For BLDC Motor Drive

Electronic commutation is used to control BLDC motors; it makes the drive costlier when comparing with other electric motors. Conventionally for a three phase BLDC motor six switches are used to drive the motor [25] - [26], as shown in Fig.6 Nowadays many studies are focusing on how to reduce the cost of BLDC motor drive [27] [28] - [29] - [30] - [31] - [32]. Four switch topology is a way to reduce the cost of three phase

BLDC drive; where it reduces the number of switch by two , as shown in Fig.7. The main disadvantage of the four switch topology is speed restriction of BLDC motor. A usual four switch BLDC drive can operate only up to half of the rated speed. By combining two input dc-dc boost converter with four switch BLDC drive topology, a low cost three phase BLDC drive can be created for hybrid electric vehicle [33] - [36]. Two input dc-dc boost converter is utilized to supply the voltage to four switch converter. By directing the yield voltage of two info dc BLDC motor; the motor can keep running up to appraised speed.

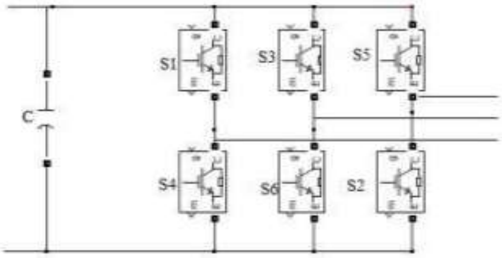


Fig. 7: Conventional six-switch converter topology[25]

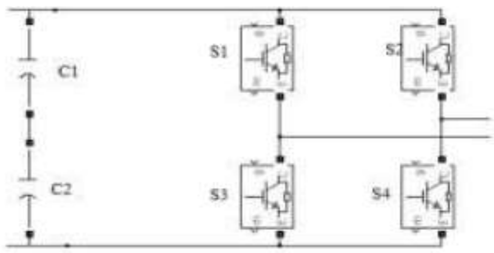


Fig. 8: Four-switch converter topology[25]

In four switch topology, four switches are used instead of six and one phase is directly connected to the common point of dc-dc capacitor [37]. The topology is shown in fig. 7.the desired back-emf and current profile are shown in Fig. 6. On account of the BLDC motor drive, for each mode one stage current will be zero.

2.5. Methods Based On PWM Strategies

There are numerous strategies dependent on PWM control plans, however the most pertinent are ordinary 120º, disposal of virtual impartial point.

2.5.1 Conventional 120° PWM Technique

The block diagram for a three-phase BLDC drive, which consists of a three-phase inverter and a BLDC motor, was shown in Figure 6. It can be controlled by the PWM technique to give proper commutations so that two of the three phases are with on states and the remaining one is with floating state. Moreover, the series of commutations is retained in suitable order such that the inverter performs the functions of brush and commutator in a traditional DC motor, to generate a rotational stator flux [38,39]. Figure 9 shows the PWM waveforms for this conventional approach [48], which has low switching losses in the inverter side at the cost of significantly high harmonic contents. This outcomes in increment of misfortune in the motor side [22].

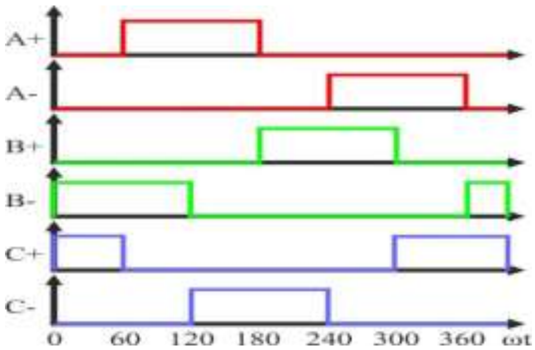


Fig. 9: PWM waveforms for a conventional approach [40].

2.5.2 Technique of Virtual Neutral Point Elimination

In a typical inverter configuration, as Figure 6 illustrates, two phases are always conducting current and one phase is only available to measure back-EMF. To measure the back-EMF across a phase, the conventional method requires monitoring the phase terminal and the motor neutral point [41], as shown in Figure 10 The zero crossing of the back-EMF can be gotten by contrasting the terminal voltage with the unbiased point. As a rule, the motor unbiased point isn't accessible. The most commonly used method is to build a virtual neutral point that will be theoretically at the same potential as the neutral point of the wye-wound motor [42]. The traditional sensing technique is quite simple and when a PWM signal is used to vary motor speed or torque/current, the virtual neutral point fluctuates at the PWM frequency. As a result, there is a very huge common-mode voltage and high-frequency noise. Voltage dividers and low-pass filters shown in fig 10 there are necessary to reduce the common-mode voltage and minimize the high-frequency noise [42]. By means of eliminating the virtual neutral point when measuring back-EMF, a low amount of filtering is required, and the zero crossing of the back-EMF voltage of the floating stage can be gotten specifically from the motor terminal voltage alluded to ground by legitimately choosing the PWM and detecting system. Additionally, the unbiased point potential will be capacity of each stage's back-EMF, and will not be affected by any external driven voltage. Also, in this method the PWM signal is applied on high side switches only, and the back-EMF signal is synchronously detected during the PWM off time [43], as illustrated in Figure 11. To commutate the phases of the motor low side switches are only switched. Then, the true back-EMF can be detected during PWM off time because the terminal voltage of the motor is directly proportional to the phase back EMF during this interval.

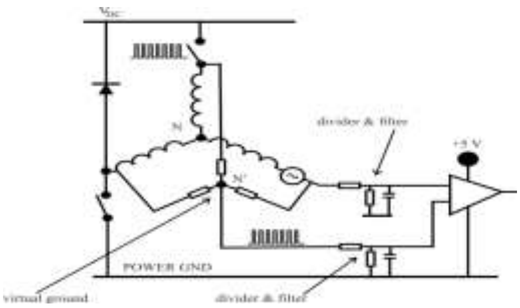


Fig.10 : Back-EMF sensing based on virtual neutral point [41].

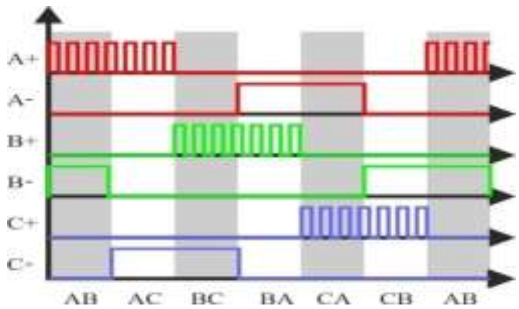


Fig. 11: PWM applied to high side switches of a typical inverter for BLDC motors [42].

2.5.3 Third Harmonic Voltage Integration Method

This technique uses the third consonant of the back-EMF to decide the substitution moments of the BLDC motor. It is based on the fact that in a symmetrical three phase Y-connected motor with trapezoidal air gap flux distribution, the summation of the three stator phase voltages results in the removal of all polyphase , that is fundamental and all the harmonics components like 5th, 7th, *etc*. The resulting sum is dominated by the third harmonic component that keeps a stable phase displacement with the fundamental air gap voltage for any load and speed.

An appropriate processing of the third harmonic signal allows the evaluation of the rotor flux position and a proper inverter current control. In disparity with indirect sensing methods based on the back-EMF signal, the third harmonic requires only a small quantity of filtering. As a result, this method is not responsive to filtering delays, achieving a high piece of performance for a wide speed range. A better motor starting performance is also achieved because the third harmonic can be detected at low speeds

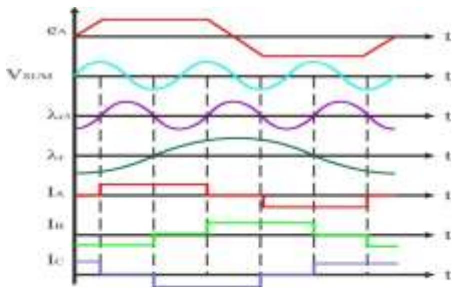


Fig. 12 : Back-EMF, third harmonic voltage, rotor flux and rotor flux fundamental components, and motor phase currents[40]

2.6. Comparison of Methods' Feasibility

Assuming a three-phase BLDC motor as a reference model, a six-step commutation with 120º conduction time allow/s for current to flow in only two phases at any one time, which leaves the third phase available for sensing back-EMF. Originally the method of sensing back-EMF was proposed in order to build a virtual neutral point, which, in theory, will be at the same potential as the center of the wound motor. However, when using a chopping drive, the PWM signal is superimposed on the neutral voltage, inducing a large amount of electrical noise on the sensed signal [42]. To reduce the switching noise, the back-EMF integration [53] and third harmonic voltage integration [54] were introduced. The coordination approach has the advantage of diminished sexchanging clamor affectability. Be that as it may, despite everything it has an exactness issue at low speed. A roundabout detecting of zero intersection of stage back-EMF by identifying the leading condition of free-wheeling diodes in the unexcited stage is entangled and exorbitant, while its low speed activity is an issue [55]. The back-EMF zero-intersection identification technique, which does not require the motor impartial voltage, allows the extraction of the valid back-EMF specifically from terminal voltage by appropriately picking the PWM and detecting procedure [41].As a result, this sensorless BLDC driver can give a much wider speed range from start-up to full speed than the traditional approaches.

The third harmonic based technique is one of most relevant back-EMF sensing techniques. It has a wider speed range and lesser phase delay than the terminal voltage sensing method [56]. However, at low speed, the integration process can cause a serious position error, as noise and offset error from sensing can be accumulated for a relatively long period of time [45]. At lower speeds, detection of both the third harmonic and the zero-crossing of the phase voltage become difficult due to the lower signal levels. In comparison, the traditional back-EMF control method is able to drive the motor from 6,000 rpm to about 1,000 rpm, but the third harmonic control technique is capable to run the motor from rated speed (6,000 rpm) down to about 100 rpm. This does not introduce as much phase delay as the zero-crossing method and needs less filtering. Then, the efficiency drop is more accentuated for the terminal voltage sensing technique, because the delay introduced by the low pass filter reduces with the motor speed. This phase delay introduced by the filter is accountable for the loss of field orientation and loss of the quadrature condition between rotor flux and stator current. The instant consequence is the reduction of the torque per current ratio of the motor, which implies in larger copper losses [40]. Also, the third harmonic back-EMF method is applicable for the operation in flux weakening mode, and the schemes based on zero-crossing of the back-EMF are simple. However, it is only applicable under normal operating conditions (commutation advance or current decay in free-wheeling diodes lower than 30 electrical degrees) [43].

III. Sensors Based Speed Control Of Bldc Motor

PM motor drives require a rotor position sensor to legitimately perform stage compensation or potentially current control. For PMAC motors, a steady supply of position data is vital; therefore a position sensor with high goals, for example, a pole encoder or a resolver, is regularly utilized. For BLDC motors, only the information of six phase-commutation instants per electrical cycle is required; therefore, low-cost Hall-effect sensors are usually used. Also, electromagnetic variable reluctance (VR) sensors or accelerometers have been extensively applied to evaluate motor position and speed. Actually precise movement sensors dependent on attractive field detecting standards emerge on account of their numerous natural points of interest and detecting benefits.

3.1. 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.

3.1.1 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 [57].

Most BLDC motors have three Hall sensors in the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors they give a high or low signal representing the N or S pole is passing near the sensors. In view of the blend of these three Hall sensor signals, the accurate arrangement of compensation can be resolved. Figure 13 shows a transverse section of a BLDC motor with a rotor that has alternate N and S permanent magnets. Hall sensors are mounted into the stationary part of the motor. Inserting the Hall sensors into the stator is a troublesome procedure in light of the fact that any misalignment in these Hall sensors as for the rotor magnets will create a blunder in assurance of the rotor position.

To make simpler the process of mounting the Hall sensors onto the stator some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets. Therefore, whenever the rotor rotates the Hall sensor magnets give the same result as the main magnets. The Hall sensors are usually mounted on a printed circuit board and fixed to the enclosure cap on the non-driving end. This enables users to adjust the whole assembly of Hall sensors to align with the rotor magnets in order to achieve the best performance [58].

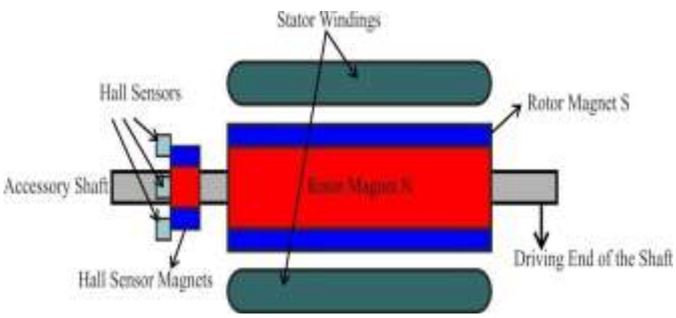


Fig. 13: BLDC motor transverse section [58].

These days, on the grounds that scaled down brushless motors are presented in numerous applications, new position sensors are being created, for example, a three branches vertical Hall sensor [11] portrayed in Figure 14a. The interfacing rule between the brushless motor and this sensor is reminiscent of the scaled down attractive rakish encoder dependent on 3-D Hall sensors. A permanent magnet is fixed at the end of a rotary shaft and the magnetic sensor is placed below, and the magnet creates a magnetic field parallel to the sensor surface. This surface corresponds to the responsive directions of the magnetic sensor. Three-stage brushless motors need three signals with a phase shift of 120° for control, so a closed loop control might be utilized to enhance the motor execution.

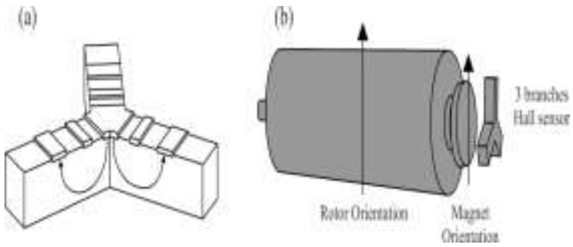


Fig. 14 : (a) Schematic depiction of a three branches Hall sensor. (b) Three branches vertical Hall device mounted as angular position sensor for brushless motor control [59].

Each branch could be translated as a half of a vertical Hall sensor and are turned by 120° in contrast with the other. Only a half of a vertical Hall sensor is use since small space is available for the five electrical contacts (two for the supply voltage and three to extract the Hall voltages). This sensor naturally makes three signals with a phase shift of 120°, which specifically relate to the motor driving signs, to rearrange the motor control in a closed loop arrangement. An illustration of this current gadget's utilization as precise position sensor for brushless motor control is given in Figure 14b. A first arrangement is between the rotor orientation and the changeless magnet, and a second arrangement is between the stator and the sensor. This arrangement will allow the motion information for the motor and the information about its shaft angular position.

3.1.2. 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 [60].

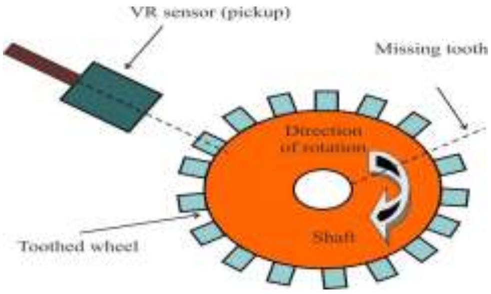


Fig. 15 : Variable Reluctance sensor that senses movement of the toothed wheel [60].

As the teeth go through the sensor's magnetic field, the measure of magnetic flux going through the permanent magnet fluctuates. At the point when the tooth gear is near the sensor, the flux is at most extreme. At the point when the tooth is further away, the flux drops off. The moving target results in a period differing flux that inducing a voltage in the coil, delivering an electrical analog wave. The frequency and voltage of the analog signal is corresponding to speed of the turning toothed wheel. Each passing intermittence in the objective makes the VR sensor produce a pulse. The repetitive pulse train or a computerized waveform made can be translated by the BLDC motor controller.

The benefits of the VR sensor can be abridged as pursues: ease, powerful demonstrated speed and position detecting innovation (it can work at temperatures more than 300 °C), self-producing electrical signal which requires no outer power supply, less wiring associations which add to superb unwavering quality, and a wide scope of yield, opposition, and inductance necessities with the goal that the device can be custom fitted to meet explicit control prerequisites [60].

Due to the fact that these sensors are very small, they can be fixed in spaces where other sensors may not fit. For instance, when sealed in protective cases they can be opposed to high temperatures and high pressures, as well as chemical attacks [61]. Through the observing of the strength of running motors, serious and surprising motor disappointments can be stayed away from and control framework unwavering quality and practicality can be progressed. If the VR was integrated in a motor case for an application in a harsh environment, sensor cables could be easily damaged in that environment. At that point, a wireless and feeble detecting arrangement ought to be connected utilizing electromagnetic pulses for going through the motor packaging to convey the sensor signal to the motor controller [62].

The Hall-effect sensor explained before is an alternative but more expensive technology, so VR sensors are the most suitable choice to measure the rotor position and speed.

3.1.3 Conventional Control Method Using Sensors

A BLDC motor is driven by voltage strokes attached with the rotor position. These strokes must be properly apply to the active phases of the three-phase winding system so that the angle between the stator flux and the rotor flux is kept near 90° to get the greatest produced torque. Subsequently, the controller needs a few methods for deciding the rotor's orientation/position (with respect to the stator loops, for example, Hall-impact sensors, which are settled in or close to the machine's air hole to detects the attractive field of the passing rotor magnets. Every sensor yields an abnormal state for 180° of an electrical turn, and a low dimension for the other 180°. The three sensors have a 60° relative balanced from one another. This partitions a turn into six stages (3 bit code) [9] The process of switching the current to flow through only two phases for every 60 electrical degree rotation of the rotor is called electronic commutation.

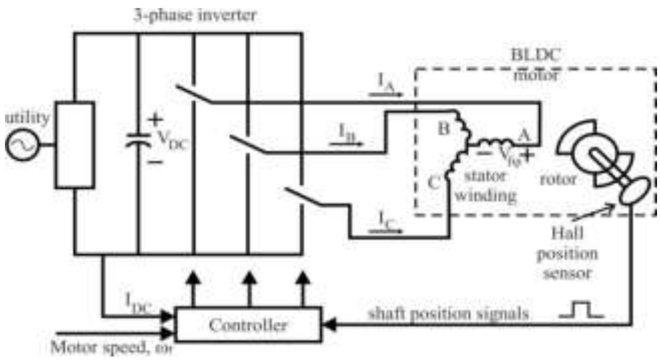


Fig. 16: Electronically commutated BLDC motor drive [63].

The motor is drive from a three-phase inverter, and the switching actions can be easily triggered by the use of signals from position sensors that are mounted at suitable points around the stator. At the point when settled at 60 electrical degree intervals and adjusted appropriately with the stator phase windings these Hall switches disseminate digital pulses that can be decoded into the favored three-phase switching succession [64].A BLDC motor drive with a six-step inverter and Hall position sensors is shown in Figure 16. Such a drive typically also has a current loop to vary the stator current, and an external speed loop for speed control . The speed of the motor can be restricted if the voltage across the motor is changed, which can be achieved easily varying the duty cycle of the PWM flag used to control the six switches of the three-stage connect. Such a drive typically also has a current loop to vary the stator current, and an external speed loop for speed control . The speed of the motor can be restricted if the voltage across the motor is changed, which can be achieved easily varying the duty cycle of the PWM signal utilize to control the six switches of the three-phase bridge. Only two inverter switches, one in the upper inverter bank and one in the lower inverter bank, are conducting at any time. These discrete switching occasions guarantee that the arrangement of directing sets of stator terminals is looked after . Figure 17 shows an example of Hall sensor signals with respect to back-EMF and the phase current. One of the Hall sensors changes the state every 60 electrical degrees of pivot. Given this, it finds a way to finish an electrical cycle. Be that as it may, one electrical cycle may not compare to a total mechanical revolution of the rotor. The quantity of electrical cycles to be rehashed to finish a mechanical turn is controlled by the rotor shaft sets. For every rotor shaft pair, one electrical cycle is finished. The quantity of electrical cycles/revolutions parallels the rotor post sets [58].

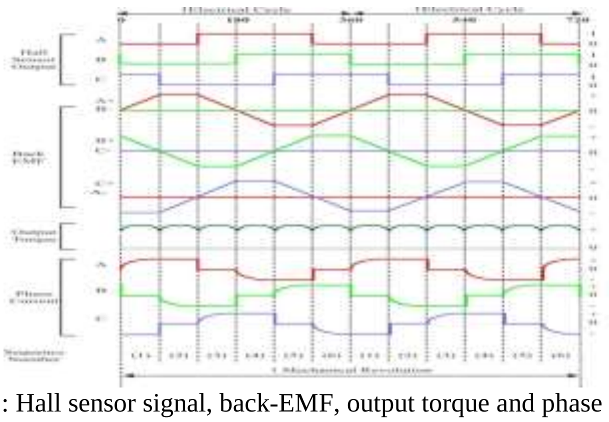


Fig. 17 : Hall sensor signal, back-EMF, output torque and phase current [58].

This grouping of directing sets is fundamental to the creation of a consistent output torque Such a drive typically also has a current loop to vary the stator current, and an external speed loop for speed control . The speed of the motor can be restricted if the voltage across the motor is changed, which can be achieved easily varying the duty cycle of the PWM signal utilize to control the six switches of the three-phase bridge.

Only two inverter switches, one in the upper inverter bank and one in the lower inverter bank, are conducting at any time. These discrete exchanging occasions guarantee that the succession of conducting pairs of stator terminals is looked after . Fig. 17 demonstrates a case of Hall sensor signals as for back-EMF and the stage current. One of the Hall sensors changes the express every 60 electrical degrees of revolution. Given this, it finds a way to finish an electrical cycle. In any case, one electrical cycle may not compare to a total mechanical rotation of the rotor. The quantity of electrical cycles to be rehashed to finish a mechanical rotation is controlled by the rotor post sets. For each rotor shaft pair, one electrical cycle is done. The quantity of electrical cycles/turns rises to the rotor post sets [58]. This grouping of directing sets is basic to the generation of a steady output torque.

In summary, permanent magnet motor drives needs a rotor position sensor to legitimately execute phase commutation, but there are several confinements when such kinds of position sensors are utilized.. The main drawbacks are the increased cost and large size of the motor, and a special arrangement needs to be made for mounting the sensors. Further, Hall sensors are temperature sensitive and hence the operation of the motor is limited, which could decrease the system reliability because of the additional components and wiring [65]. To reduce cost and improve reliability such position sensors might be wiped out. To this end, numerous sensorless plans have been accounted for position (and speed) control of BLDC

IV. Conclusions

In this paper a review of position control methods for BLDC motors has been presented. The fundamentals of various techniques have been introduced, mainly back-EMF schemes and estimators, as a helpful reference for preliminary investigation of conventional methods. Advances in the position control and applications were additionally talked about. To give knowledge in control method and their benefits a categorization of existing methods and newer methods were presented with their merits and drawbacks. From the above discussion, it is clears that the control for BLDC motors using position sensors, such as shaft encoders, resolvers or Hall-effect probes, can be enhanced by means of the reduction of these sensors to further reduce cost and improve reliability. Furthermore, sensorless control is the only option for some applications where those sensors cannot function reliably due to harsh environmental conditions and a superior performance is necessary, mainly back-EMF schemes and estimators, as a useful reference for preliminary investigation of traditional methods. advance in the position control and applications were also discussed.

References

[1]. Iizuka, K.; Uzuhashi, H.; Kano, M.; Endo, T.; Mohri, K. , Microcomputer Control for Sensorless Brushless Motor, IEEE Trans. Ind. Appl. 1985, IA-21, 595-601.

[2]. Becerra, R.C.; Ehsani, M, High-Speed Torque Control of Brushless Permanent Magnet Motors, IEEE Trans. Ind. Electron. 1988, 35, 402-406.

[3]. Hubik, V.; Sveda, M.; Singule, V. ,On the Development of BLDC Motor Control Run-Up Algorithms for Aerospace Application, In Proceedings of the 13th Power Electronics and Motion Control Conference (EPE-PEMC 2008), Poznan, Poland, September 2008; pp. 1620-1624

[4]. Bonfe, M.; Bergo, M, A Brushless Motor Drive with Sensorless Control for Commercial Vehicle Hydraulic Pumps, In Proceedings of the IEEE International Symposium on Industrial Electronics (ISIE 2008), Cambridge, England, July 2008; pp. 612-617.

[5]. Su, G.J.; McKeever, J.W, Low-Cost Sensorless Control of Brushless DC Motors with Improved Speed Range, IEEE Trans. Power Electron. 2004, 19, 296-302.

[6]. Shen, J.X.; Iwasaki, S, Sensorless Control of Ultrahigh-Speed PM Brushless Motor using PLL and Third Harmonic Back EMF, IEEE Trans. Ind. Electron. 2006, 53, 421-428.

[7]. Shen, J.X.; Zhu, Z.Q.; Howe, D, Sensorless Flux-Weakening Control of Permanent-Magnet Brushless Machines using Third Harmonic Back EMF, IEEE Trans. Ind. Appl. 2004, 40, 1629-1636

[8]. J.E Miller, Brushless permanent-magnet motor drives, Power Motorering Joumal,voI.2, no. 1 , Jan. 1988.

[9]. Q.D.Guo,X.MZhao, BLDC motor principle and technology application, [M]. Beijing: China electricity press,2008.

[10]. Uzair Ansari, SaqibAlam, Syed Minhaj un NabiJafri, Modeling and Control of Three Phase BLDC Motor using PID with Genetic Algorithm , 2011 UKSim 13th International Conference on Modelling and Simulation,pp.189-194..

[11]. K. Ang, G. Chong, and Y. Li, ,PID control system analysis, design and technology, IEEE Trans.Control System Technology, vol. 13, pp. 559-576, July 2005.

[12]. AtefSaleh Othman Al-Mashakbeh, Proportional Integral and Derivative Control of Brushless DC Motor, European Journal of Scientific Research 26-28 July 2009, vol. 35, pg 198-203.

[13]. ChuenChien Lee, Fuzzy Logic in Control Systems:Fuzzy Logic controller,–Part 1, 1990 IEEE

[14]. ChuenChien Lee, ,Fuzzy Logic in Control Systems : Fuzzy Logic controller Part 2, 1990 IEEE .

[15]. ZdenkoKovaccic and StjepanBogdan, ,Fuzzy Controller design Theory and Applications, © 2006 by Taylor & Francis Group. international, 2002.

[16]. R.Arulmozhiyal and K.Baskaran, ,Implementation of Fuzzy PI Controller for Speed Control of Induction Motor Using FPGA,Journal of Power Electronics, Vol.10, No.1, Jan 2010, pp.65-71.

[17]. R. Arulmozhiyal& 2R.Kandiban Design of Fuzzy PID Controller for Brushless DC Motor 2012 International Conference on Computer Communication and Informatics (ICCCI -2012), Jan. 10 – 12, 2012, Coimbatore, INDIA

[18]. Ozturk. S.B, Toliyat. H.A, ,Direct Torque and Indirect Flux Control of Brushless DC Motor, EEEIASME Transactions on Mechatronics, vo1.16, no.2, pp.351-360, April 2011.

[19]. Masmoudi. M, EI Badsi. B, Masmoudi, A, ,Direct Torque Control of Brushless DC Motor Drives With Improved Reliability, IEEE Transactions on Industry Applications, vo1.50, no.6, pp.3744-3753, Nov.-Dec. 2014.

[20]. K. Iizuka,H.Uzuhashi, M. Kano, T. Endo, andK.Mohri, ,Microcomputer control for sensorless brushless motor, IEEE Trans. Ind. Appl, vol. IA-21, no. 4, pp. 595–601, May/Jun. 1985

[21]. J. Shao, D. Nolan,M. Teissier, and D. Swanson, ,A novelmicrocontrollerbasedsensorless brushless DC (BLDC) motor drive for automotive fuel pumps, IEEE Trans. Ind. Appl, vol. 39, no. 6, pp. 1734–1740, Nov./Dec. 2003.

[22]. T.-H. Kim and M. Ehsani, ,Sensorless control of BLDC motors from near-zero to high speeds, IEEE Trans. Power Electron, vol. 19, no. 6, pp. 1635–1645, Nov. 2004.

[23]. S. Ogasawara and H. Akagi, ,An approach to position sensorless drive for Brushless DCmotors, IEEE Trans. Ind. Appl, vol. 27, no. 5, pp. 928–933, Sep./Oct. 1991.

[24]. P. Damodharan and Krishna Vasudevan, MembeSensorless Brushless DC Motor Drive Based on the Zero-Crossing Detection of Back Electromotive Force (EMF) From the Line Voltage Difference IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 25, NO. 3, SEPTEMBER 2010

[25]. P. Suganthi; S. Nagapavithra; S. Umamaheswari, ,Modeling and simulation of closed loop speed control for BLDC motor, 2017 Conference on Emerging Devices and Smart Systems (ICEDSS) .

[26]. D. Nandini; Juna John Daniel,Modelling of BLDC motor driven solar water pump with INC-MPPT in MATLAB, 2017 International Conference on Circuit ,Power and Computing Technologies (ICCPCT)

[27]. Gang Liu; Shaohua Chen; ShiqiangZheng; Xinda Song,Sensorless Low-Current Start-Up Strategy of 100-kW BLDC Motor With Small Inductance, IEEE Transactions on Industrial Informatics Year: 2017, Volume: 13, Issue: 3 Pages: 1131 – 1140. [49]

[28]. D. Kamalakannan; N Jeyapaul Singh; M. Karthi; V. Narayanan; N S Ramanathan,Design and development of DC powered BLDC motor for Mixer-Grinder application, 2016 First International Conference on Sustainable Green Buildings and Communities (SGBC) Pages: 1 – 6.

[29]. Amir Dadashnialehi; Alireza Bab-Hadiashar; Zhenwei Cao; Reza Hoseinnezhad, ,Reliable EMF-Sensor-Fusion-Based Antilock Braking System for BLDCMotor In-Wheel Electric Vehicles, IEEE Sensors Letters Year: 2017, Volume: 1, Issue: 3.

[30]. Hyun-Young Lee; Byeong-Chan Jeon; Won-ki Park; Sung-Chul Lee, ,Design and verification of sensorless BLDC motor start-up logic with FPGA, 2016 International SoC Design Conference (ISOCC) . Pages: 341 – 342

[31]. O. C. Kivanc; O. Ustun; G. Tosun; R. N. Tuncay, ,On regenerative braking capability of BLDC motor, IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society Pages: 1710 – 1715.

[32]. BattuPrakash Reddy; AshwinMurali, ,SoC FPGA-based field oriented control of BLDC motor using low resolution Hall sensor, IECON 2016 42nd Annual Conference of the IEEE Industrial Electronics Society Pages: 2941 – 2945.

[33]. A. Sathish Kumar; S. Sudha , ,Design of wireless sensor network based fuzzy logic controller for a cold storage system, ,2016 IEEE 7th Power India International Conference (PIICON) Pages: 1 – 6.

[34]. S. Durgadevi; M. G. Umamaheswari , ,Adaptive neuro fuzzy logic controller based current mode control for single phase power factor correction using DC-DC SEPIC converter, ,2017 International Conference on Power and Embedded Drive Control (ICPEDC) Pages: 490 – 495.

[35]. Prerna Gaur; DiwakerPathak; Bhavnesh Kumar; Yogesh K. Chauhan,PI and fuzzy logic controller based tip speed ratio control for smoothening of output power fluctuation in a wind energy conversion system, 2016 7th India International Conference on Power Electronics (IICPE) Pages: 1 – 6

[36]. XianchengZheng; HaiderZaman; Xiaohua Wu; Husan Ali; Shahbaz Khan , ,Direct fuzzy logic controller for voltage control of standalone three phase inverter, 2017 International Electrical Motorering Congress (iEECON) Pages: 1 – 4.

[37]. B. V. Ravi Kumar; K. Siva Kumar, ,Design of a new Dual Rotor Radial Flux BLDC motor with Halbach array magnets for an electric vehicle, 2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) Pages: 1 – 5

[38]. Ogasawara, S.; Akagi, H. An Approach to Position Sensorless Drive for Brushless DC Motors. IEEE Trans. Ind. Appl. 1991, 27, 928-933.

[39]. Van Hout, H.M. ,Brushless D.C. Motor and Switching Device for use in such a D.C. Motor, U.S. Patent 4,748,385, May 31, 1988.

[40]. Lai, Y.S.; Shyu, F.S.; Chang, Y.H. Novel Pulse-Width Modulation Technique with Loss Reduction for Small Power Brushless DC Motor Drives. In Proceedings of the Industry Applications Conference (37th IAS Annual Meeting), Pittsburgh, PA, USA, October 2002; pp. 2057-2064; Volume 3.

[41]. Shao, J.; Nolan, D.; Hopkins, T. ,A Novel Direct Back EMF Detection for Sensorless Brushless DC (BLDC) Motor Drives,. In Proceedings of the Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition (APEC 2002), Dallas, TX, USA, March 2002; pp. 33-37; Volume 1

[42]. Shao, J.; Nolan, D.; Teissier, M.; Swanson, D. A ,Novel Microcontroller-Based Sensorless Brushless DC (BLDC) Motor Drive for Automotive Fuel Pumps,. IEEE Trans. Ind. Appl. 2003, 39, 1734-1740.

[43]. Vinatha, U.; Pola, S.; Vittal, K.P. ,Recent Developments in Control Schemes of BLDC Motors,. In Proceedings of the IEEE International Conference on Industrial Technology (ICIT 2006), Mumbai, India, December 2006; pp. 477-482.

[44]. Luenberger, D. An Introduction to Observers. IEEE Trans. Autom. Control 1971, 16, 596-602

[45]. Kim, T.; Lee, H.W.; Ehsani, M. Position Sensorless Brushless DC Motor/Generator Drives: Review and Future Trends. IET Electr. Power Appl. 2007, 1, 557-564

[46]. Johnson, J.P.; Ehsani, M.; Guzelgunler, Y. ,Review of Sensorless Methods for Brushless DC,. In Proceedings of the 1999 IEEE Industry Applications Conference (Thirty-Fourth IAS Annual Meeting), Phoenix, AZ, USA, October 1999; pp. 143-150; Volume 1.

[47]. Peixoto, Z.M.A.; Freitas Sa, F.M.; Seixas, P.F.; Menezes, B.R.; Cortizo, P.C.; Lacerda, W.S. ,Application of Sliding Mode Observer for Induced E.M.F, Position and Speed Estimation of Permanent Magnet Motors,. In Proceedings of the 1995 International Confererence on Power Electronics and Drive Systems (PEDS 95), Singapore, February 1995; pp. 599-604; Volume 2.

[48]. Markadeh, G.R.A.; Mousavi, S.I.; Daryabeigi, E, Position Sensorless Direct Torque Control of BLDC Motor by using Modifier, In Proceedings of the 11th International Conference on Optimization of Electrical and Electronic Equipment, 2008 (OPTIM 2008), Brasov, Romania, May 2008; pp. 93-99.

[49]. Markadeh, G.R.A.; Hajian, M.; Soltani, J.; Hosseinia, S, Maximum Torque Per Ampere Control of Sensorless Induction Motor Drives with DC Offset and Parameter Compensation. ,Energy Convers. Manage. 2010, 51, 1354-1362.

[50]. Dhaouadi, R.; Mohan, N.; Norum, L, Design and Implementation of an Extended Kalman Filter for the State Estimation of a Permanent Magnet Synchronous Motor, IEEE Trans. Power Electron. 1991, 6, 491-497.

[51]. Barut, M. ,Bi Input-Extended Kalman Filter Based Estimation Technique for Speed-Sensorless Control of Induction Motors,. Energy Convers. Manage. 2010, 51, 2032-2040

[52]. Terzic, B.; Jadric, M. Design and Implementation of the Extended Kalman Filter for the Speed and Rotor Position Estimation of Brushless DC Motor. IEEE Trans. Ind. Electron. 2001, 48, 1065-1073.

[53]. Becerra, R.C.; Jahns, T.M.; Ehsani, M. Four-Quadrant Sensorless Brushless ECM Drive. In Proceedings of the Sixth Annual Applied Power Electronics Conference and Exposition (APEC 1991), Palm Springs, CA, USA, March 1991; pp. 202-209.

[54]. Moreira, J.C. ,Indirect Sensing for Rotor Flux Position of Permanent Magnet AC Motors Operating Over a Wide Speed Range,. IEEE Trans. Ind. Appl. 1996, 32, 1394-1401.

[55]. Ogasawara, S.; Akagi, H. An Approach to Position Sensorless Drive for Brushless DC Motors. IEEE Trans. Ind. Appl. 1991, 27, 928-933

[56]. Kim, T.H.; Ehsani, M, Sensorless Control of the BLDC Motors from Near-Zero to High Speed,s. IEEE Trans. Power Electron. 2004, 19, 1635-1645.
[57]. Brushless DC Motor Control using the LPC2141 Application Note; AN10661, NXP Semiconductors: Eindhoven, the Netherlands, October 2007.
[58]. Brushless DC (BLDC) Motor Fundamentals Application Note; AN885, Microchip: AZ, USA. 2003.
[59]. Burger, F.; Besse, P.A.; Popovic, R.S,. New Single Chip Hall Sensor for Three Phases Brushless Motor Contro,l. Sens. Actuat. A-Phys. 2000, 81, 320-323
[60]. Bucak, I.Ö. Position Error Compensation Via a Variable Reluctance Sensor Applied to a Hybrid Vehicle Electric Machine. Sensors 2010, 10, 1918-1934
[61]. Hernandez, W. Robust Multivariable ,Estimation of the Relevant Information Coming from a Wheel Speed Sensor and an Accelerometer Embedded in a Car Under Performance Tests,. Sensors 2005, 5, 488-508.
[62]. Lee, D. ,Wireless and Powerless Sensing Node System Developed for Monitoring Motors, Sensors 2008, 8, 5005-5022.
[63]. Rajagopalan, S. Detection of Rotor and Load Faults in Brushless DC Motors Operating Under Stationary and Non-Stationary Conditions. Ph.D. Dissertation, Georgia Institute of Technology: Atlanta, GA, USA, August 2006. 17. Shen, J.X.; Iwasaki, S. Sensorless Control.
[64]. 3-Phase BLDC Motor Control with Hall Sensors using 56000/E Digital Signal Controllers Application Note; AN1916, Freescale Semiconductor: TX, USA, 2005.
[65]. Damodharan, P.; Vasudevan, K, Indirect Back-EMF Zero Crossing Detection for Sensorless BLDC Motor Operation, In Proceedings of the International Conference on Power Electronics and Drives Systems (PEDS 2005), Kuala Lumpur, Malaysia, November 2008; pp. 1107-1111.