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A Review of Different Postion Sensorless Drive Techniques for BLDC Motor

Kanaiya.L.Nishad[1], Prof.Mahesh.A.Patel[2]

[1] *Student, M.E, Electrical Department, Atmiya Institute of Technology & Science, Rajkot, India*
[2] *Professor, Electrical Department, Atmiya Institute of Technology & Science, Rajkot, India*

Abstract — this paper presents a technical review on different position Sensorless drive technique for bldc motor are presented. It includes the background analysis using sensors, limitations and advances. The main purpose of this paper is to provide an insight of Sensorless operation, need for Sensorless operation, classification of existing Sensorless methods together with their merits and demerits were presented.

Keywords- Brushless DC motor, back-EMF detection, surface permanent magnet, Zero Crossing Detection, Sensorless

I. INTRODUCTION

The permanent magnet (PM) brushless DC (BLDC) is one of the motor types that is rapid gaining popularity, mainly because of their superior speed versus torque characteristics, high dynamic response, high efficiency and reliability, higher speed ranges, and reduction of electromagnetic interference. These motors are used in a great amount of industrial sectors because their architecture is suitable for any safety critical applications. The brushless DC motor is an electronically commutated motor that, having a linear relationship between torque and current, speed and voltage.

BLDC motor is a synchronous electric motor, whose design perspective, looks exactly like a DC motor, But BLDC motor design is just inside-out of DC motor i.e., motor armature is at stator, field magnets at rotor and instead of having a mechanical commutation, it is an electronically controlled commutation system.

In BLDC motor, rotor position sensing is an essential part to produce torque or generate power. These BLDC machine is inherently electronically controlled and requires rotor position information. However, due to problems with the cost, mounting of rotor position sensors (Hall Effect sensor) and sensitive to high temperature have motivated research in the area of position Sensorless BLDC motor drives[2]. With these Sensorless approach, position sensors will be eliminated and cost of the system also tend to be reduce.

Typically a BLDC motor (trapezoidal type) is driven by a 3 phase inverter with 6-step commutation. In the conventional approach, 120° PWM method is used where the conducting interval of each phase is 120° electrical angle as shown in Figure 1. In order to produce maximum torque, inverter should be commutated every 60°, so that the current is in phase with the back emf.

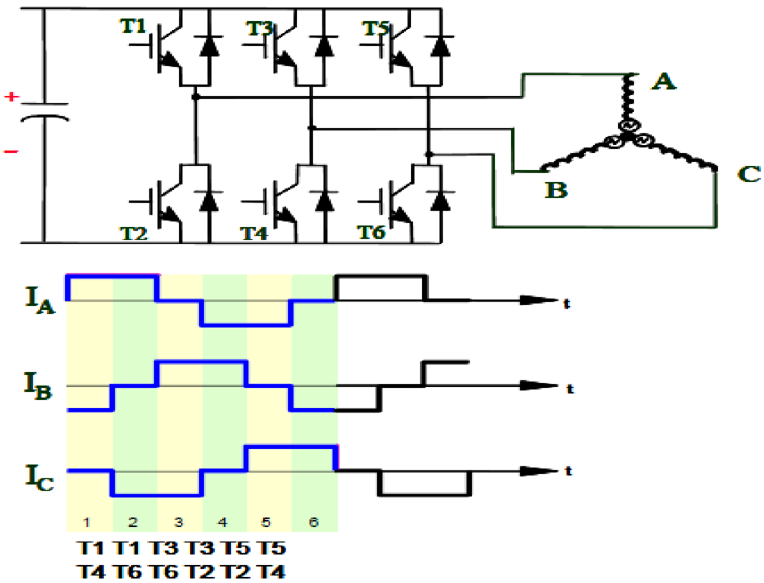


Figure 1: Inverter configuration and current commutation sequence for BLDC motor

II. Review of Sensorless Control Methods

For the surface permanent magnet (SPM) type of BLDC motors, usually Hall Effect position sensors are used to identify which phase is to be commutated to maintain the electrical synchronism. For high performance drives, high-resolution optical encoders or resolvers are typically used. However, the mechanical position sensors lead to several problems in practice such as cost, bulkiness & mounting of the mechanical position sensors and also such sensors are temperature sensitive as they lose sensing capability at the temperature beyond 120 ºC. So it lead to generate incorrect switching signal to motor phases [3]. To overcome this, Sensorless drive of BLDC motor is introduced, in this Sensorless commutation technique, both the hardware complexity due to position sensors as well as energy and space consumption of associated circuitry are reduced.

Various Sensorless control methods for BLDC motor drives have been given from literature [1-16] with different detection principles.so Sensorless techniques can be grouped into four categories:

- Back-EMF based methods.
- Flux calculation based methods.
- Inductance-based method
- Artificial-intelligence-based method
- Observer based methods.

The back-EMF based methods for the BLDC motors are divided in two categories, such as;

- Direct back-EMF detection.
- Indirect back-EMF detection.

Direct back-EMF detection methods

The back-EMF of floating phase is sensed and its zero crossing is detected by comparing it with neutral point voltage. This scheme suffers from high common mode voltage and high frequency noise due to the PWM drive, so it requires low pass filters, and voltage dividers. The methods can be classified as:

- Back-EMF Zero Crossing Detection (ZCD) or Terminal Voltage Sensing.
- PWM Strategies.

Indirect back-EMF detection methods

In direct back emf detection scheme because filtering introduces commutation delay at high speeds and attenuation causes reduction in signal sensitivity at low speeds, the speed range is narrowed in direct back-EMF detection methods. In order to reduce switching noise, the indirect back-EMF detection methods are used. These methods are the following:

- Back-EMF Integration.
- Third Harmonic Voltage Integration.
- Free-wheeling Diode Conduction or Terminal Current Sensing.

A. *Back-EMF Zero Crossing Detection method (Terminal Voltage Sensing)*

The zero-crossing detection based is one of the simplest methods of back-EMF sensing technique, and is based on detecting the instant at which the back-EMF in the unexcited phase crosses zero].

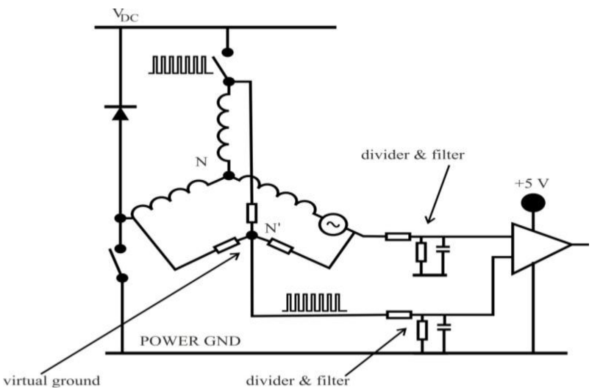


Figure 2: Back EMF sensing based on virtual neutral point.

For typical operation of a BLDC motor, the phase current and back-EMF should be aligned to generate constant torque. The current commutation point shown in Figure.1 can be estimated by the zero crossing point (ZCP) of back-EMFs and a 30° phase shift, using a 6-step commutation scheme through a three-phase inverter for driving the BLDC motor. The conducting interval for each phase is 120 electrical degrees. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60° by detecting zero crossing of back-EMF on the floating coil of the motor , so that current is in phase with the back-EMF.

In these back EMF of unused phase to obtain the commutation sequence for motors. Here the emf of the floating phase is sensed and the zero crossing of this emf detected by comparing with neutral point voltage. Since the neutral point of the motor is not stable during to PWM operation so these scheme suffers from problem of high common mode voltage and high frequency noise, so to eliminate higher harmonics in the phase terminal voltages caused by the inverter switching. Low pass filter (LPF) and voltage divider is used, but these filter introduce the time delay which limit the high speed operation capability of the BLDC machine. Consequently speed range is remain narrowed [2, 3, 4, 5, 6].

B. *Methods based on PWM strategies*

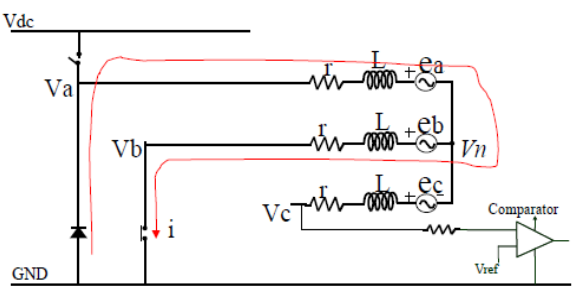
In this method PWM strategies are used for back EMF sensing which does not require a virtual neutral point and large amount of filtering. So eliminates the requirement motor neutral terminal and also in most cases, the motor neutral point is not available. Hence instead of motor neutral point, inverter DC link ground terminal is referred [4, 6, 7, 8, 9]. .Here the zero crossing of back-emf of floating phase is obtained by properly selecting the PWM and sensing strategy.

In BLDC motor only two out of three phases are excited at any instant of time.so in these scheme, PWM driving signal can be arranged in three ways:

a. On the high side: the PWM is applied only on the high side switch, the low side is on during the step.
b. On the low side: the PWM is applied on the low side switch, the high side is on during the step.
c. On both sides: the high side and low side are switched on/off together.

1. PWM Technique Which Eliminates Virtual Neutral Point

In these scheme, PWM signal is applied on high side switches only, low side switches are remain ON only switched to provide commutation, so here the back EMF signal is detected during the PWM off time as shown in Figure.3



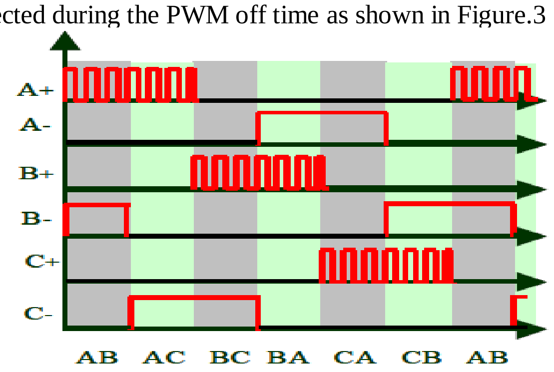


Figure 3: Back EMF detection during the PWM OFF time

As shown in Figure 3 when phase A and B are conducting and phase C floating. Upper switch A is pulse width modulated and lower switch of phase B is ON during the entire step, switched only at commutation, while the measurement is done from terminal voltage V_c. so when upper switch of phase A is turned off current freewheels through the diode. During this freewheeling period, there is no current in phase C, at this moment the terminal voltage Vc is detected as Phase C back EMF [4, 7].

From the above circuit, we have, $V_c = e_c + V_n$ where Vc is the terminal voltage of the floating phase C, e_c is the phase back EMF and Vn is the neutral voltage of the motor. From phase A, if we ignore the forward voltage drop of the diode, we get

$$V_n = 0 - ri - L\frac{di}{dt} - e_a \tag{2.1}$$

From phase B, if we ignore the voltage drop on the switch, we get

$$V_n = ri + L\frac{di}{dt} - e_b \tag{2.2}$$

Adding (2.1) and (2.2), we get

$$V_n = \frac{e_a + e_b}{2} \tag{2.3}$$

Assuming it to be balance three-phase system, we have

$$e_a + e_b + e_c = 0 \tag{2.4}$$

From (2.3) and (2.4),

$$V_n = \frac{e_c}{2} \tag{2.5}$$

So, the terminal voltage Vc,

$$V_c = e_c + V_n = \frac{3}{2}e_c \tag{2.6}$$

Since, the terminal voltage is referred to the ground instead of the neutral point, hence, eliminates the requirement of neutral point to detect then back EMF zero crossing, and the problem of common mode voltage and high frequency noise will be resolved. Since the true back EMF is extracted from the motor terminal voltage, the zero crossing of the phase back EMF can be detected very precisely.so, these scheme provides a much wider speed range.

2. PWM Technique at Low Speed Application

For low voltage application, the voltage drop across the antiparallel diode of the MOSFET's switch's will affect the performance. When the motor speed goes low, zero crossing is not evenly distributed. If the speed goes further low, the back emf amplitude becomes too low to detect.

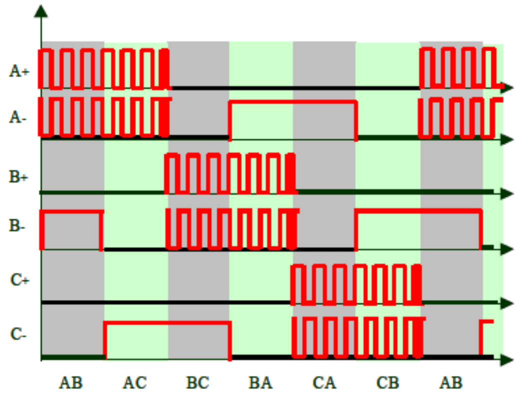


Figure 4: Complementary PWM algorithm

In order to overcome, i.e. to correct the offset voltage of back EMF signal .Two method are proposed such as First method is to use complementary PWM with this it reduces the conduction loss as shown Figure 4. Another method to eliminate the effect of diode voltage drop is to add a constant voltage to compensate the effect of diode and threshold voltage for zero crossing detection.in this paper [4, 7] pre-conditioning circuits for low speed applications is presented. Which not only compensates the offset voltage caused by diodes but also amplifies the signal of back EMF near zero crossing.

3. Improved Direct Back EMF Detection Scheme

In second scheme, PWM signal is applied on low side switches only, high side switches are remain ON only switched to provide commutation, so here the back EMF signal is detected during the PWM ON time as shown in Figure 4.This scheme eliminates the drawback of back EMF detection during PWM off time. That is in paper [7] it cannot go up to 100% duty cycle since we need minimum off time window to detect the back EMF. Here back EMF is detected during PWM ON time for some applications where 100% duty ratio is necessary [4, 8]. In some applications, when high inductance motors are used, it is found that the long settling time of a parasitic resonant between the motor inductance and the parasitic capacitance of power devices can cause false zero crossing detection of back EMF.

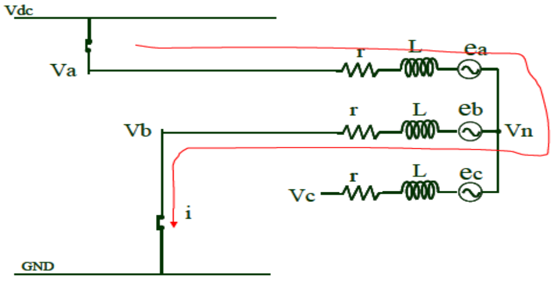


Figure 5: Back EMF detection during the PWM ON time

Figure 4 shows the winding terminal voltage during PWM ON time when phase A and B are conducting current and phase C is floating. Under this condition terminal voltage of floating phase C is

$$V_c = e_c \frac{3}{2} + \frac{V_{dc}}{2} \quad (2.7)$$

Comparing V_c with $V_{dc}/2$ gives zero crossing of back emf e_c .Thus duty cycle limitation can be overcome by synchronously detecting the back EMF during the PWM on time.

4. Further Improved Direct Back EMF Detection Scheme

Previously in [7] direct back EMF sensing scheme required minimum PWM off time to do the detection. But suffer from the limitation of duty cycle which is cannot be utilized up to 100% because of resonant transient caused by motor inductance and power devices parasitic capacitance will further limit the duty cycle.so In [8] paper, an improved direct back EMF detection scheme which samples the motor back EMF synchronously during PWM "on" time is proposed to overcome the problems. In [9] paper an further improved direct back EMF detection scheme the motor back EMF can be detected during PWM "off' time at start-up and low speed and while PWM "on" time at high speed. With the combination of two detection schemes in one system, the motor can run very well over wide speed range and the impact of the parasitic resonant between motor inductance and the power device capacitance can be minimized.

C. *Back-EMF Integration*

In this technique, the position information is extracted by integrating unexcited phase's back-EMF. The integration starts when unexcited phases back-EMF crosses zero crossing points (ZCP). When the integrated value reaches a pre-defined threshold value, the integration stops, which gives the corresponding commutation point and the phase current gets commutated.

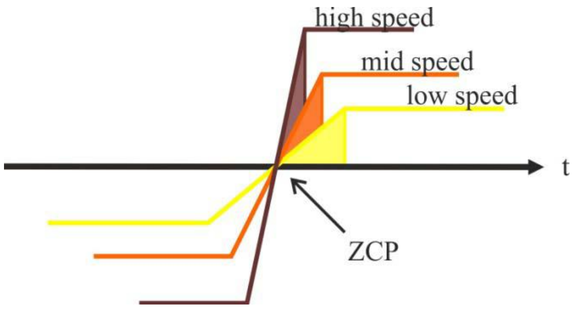


Figure 6: Integrated areas of the back-EMF

The integrated area of the back-EMFs shown in Figure 5 is approximately the same at all speeds. Once the integrated value reaches the threshold voltage, a reset signal is set to zero the integrator output. To prevent the integrator from starting to integrate again, the reset signal is kept on long enough to insure that the integrator does not start until the residual current in the open phase has passed a zero-crossing. For position detection use of discrete current sensors for each motor phase will provide complete current feedback, but the cost associated with individual current sensors is often prohibitive.

An alternative will be use of current sensors which are integrated into the power switches, such as power MOSFET'S and IGBT's, which are available from several device manufacturers with ratings up to several hundreds of volts and several tens of amps. However, embedded current sensors have their own constraints; for example, the current sensing terminal is not electrically isolated from the associated power device. Also, the availability of new power integrated circuits makes it possible to take more complete advantage of these sensors for the combined purposes of current regulation and overcurrent protection [2, 6].

Finally, the back-EMF integration approach provides significantly improved performance compared to the zero-crossing algorithm. Instead of using the zero-crossing point of the back-EMF waveform to trigger a timer, the rectified back-EMF waveform is fed to an integrator, whose output is compared to pre-set threshold. This integration approach is less sensitive to switching noise and automatically adjusts for speed changes, but low speed operation is poor due to the error accumulation and offset voltage problems from the integration.

D. *Third Harmonic Voltage Integration*

In this technique Commutation instants of BLDC motors can be estimated from the third harmonic of the back EMF waveform. Consider a symmetrical three phase Y-connected motor with trapezoidal air gap flux distribution, the summation of the three stator phase voltages results in the elimination of all polyphase , i.e. fundamental and all the harmonics components like 5th, 7th, etc. The resulting summation of the terminal voltages will provide the third harmonic component that keeps a constant phase displacement with the fundamental air gap voltage for any load and speed. Then the third harmonic voltage component is then integrated to find the zero crossing, which gives the corresponding commutation points [2, 6].

For a full pitch magnet and full pitch stator phase winding, the internal voltages can be represented using the Fourier expansion:

$$e_a = E_1\sin\theta + E_3\sin3\theta + E_5\sin5\theta + E_7\sin7\theta + ... \quad (2.8)$$

$$e_b = E_1\sin(\theta - \frac{2\pi}{3}) + E_3\sin3(\theta - \frac{2\pi}{3}) + E_5\sin5(\theta - \frac{2\pi}{3}) + E_7\sin7(\theta - \frac{2\pi}{3}) + ... \quad (2.9)$$

$$e_b = E_1\sin(\theta + \frac{2\pi}{3}) + E_3\sin3(\theta + \frac{2\pi}{3}) + E_5\sin5(\theta + \frac{2\pi}{3}) + E_7\sin7(\theta + \frac{2\pi}{3}) + ... \quad (2.10)$$

Summing the three phase back-EMFs:

$$e_a + e_b + e_c = 3E_3\sin3\theta + 3E_9\sin9\theta + 3E_{15}\sin15\theta + ... = 3E_3\sin3\theta \quad (2.11)$$

The summed terminal voltage contains only the third multiple harmonics due to the fact that the summation of three phase currents is zero. From the summation of three terminal voltages, the third harmonic of the back-EMF can be measured as:

$$V_{sum} = V_{an} + V_{bn} + V_{cn} \approx (e_a + e_b + e_c) \quad (2.12)$$

$$V_{an} + V_{bn} + V_{cn} = (R + L\frac{d}{dt})(i_a + i_b + i_c) + (e_a + e_b + e_c) = e_a + e_b + e_c = 3E_3\sin3\theta \quad (2.13)$$

Now, to obtain commutation instants, the summed voltage is integrated as (2.14).

$$\lambda_{3rd} = \int V_{sum}dt \quad (2.14)$$

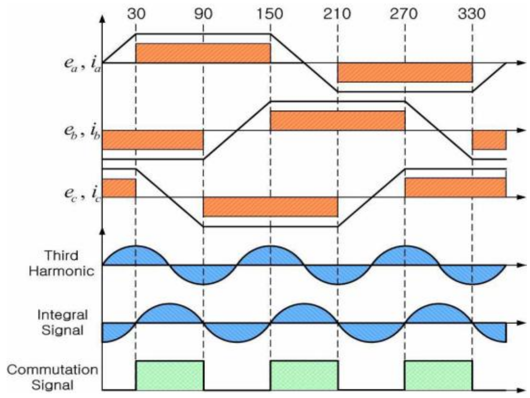


Figure 7: Commutation signal using third harmonic signals

Since the third harmonic signal has a frequency three times higher than the fundamental signal, there is a reduced filtering requirement and signal detection at low speeds is possible, allowing wide speed range of operation. Also, the phase delay is smaller than the terminal voltage sensing method. However, at low speed, the integration process can cause a serious position error, as noise from sensing can be accumulated for a relatively long period of time.

E. *Free-wheeling Diodes Conduction method*

In this technique, the rotor position information is determined based on the conducting state of antiparallel connected freewheeling diodes in the unexcited phase. Detecting the free-wheeling diode conducting status in the unexcited phase gives the zero-crossing point of the back EMF waveform, this method is also called Terminal Current Sensing.

This method utilizes current flowing through a freewheeling diode in unexcited phase. For a short period after reaching zero crossing of the back-EMF in unexcited phase, a tiny current is flowing through the freewheeling diode during the active phase switches are turned off under alternate chopper control. As shown in Figure 8, if the third phase back-EMF, e_c, is smaller than $-V_D$ (voltage drop of the diode), the bottom diode of the phase C is turned on and small current flows through it [2, 6]. This silent phase current starts to flow in the middle of the commutation interval, which corresponds to the point at which the back-EMF of the open phase crosses zero. This methodology makes it possible to find the rotor position over a wide speed range, especially at a lower speed. But like other back-EMF based methods; this method has a position error of commutation points in the transient state.

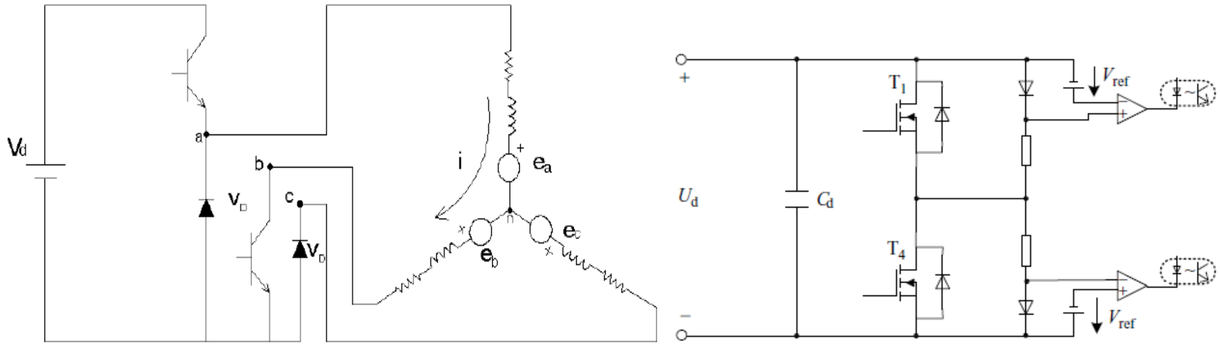


Figure 8: Current path in silent phase.

But the most serious drawbacks of this method is the use of six isolated power supplies for the comparator circuitry to detect current flowing in each freewheeling diode and requires complicated sensing circuits, which prohibits this method for use in practical applications.

F. *Flux calculation based methods*

This method is different from the back-EMF-based ones, can obtain the rotor position information by estimating the flux. The fundamental idea is to take the voltage equation of the machine,

$$V = ri + \frac{d\psi}{dt}$$

Where, *V* is the input voltage, *i* is the current, *R* is the resistance, and ψ is the flux linkage, respectively. Then, the flux linkage can be calculated as:

$$\psi = \int_0^t (V - ri)dt$$

Based on the initial position, machine parameters, and relationship between the flux linkage and rotor position, the rotor position can be estimated. At the very beginning of the integration the initial flux linkage has to be known precisely to estimate the next step flux linkages. This means that the rotor has to be at a known position at the start [2, 5].

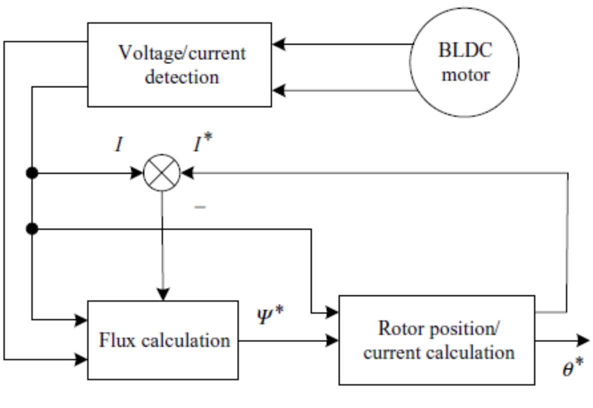


Figure 9: Principle of flux-linkage-based method.

Due to the large integral calculation of this method, an accumulative error may be produced when the motor is running at low speed. Moreover, this method is easily affected by the motor parameters

G. *Inductance-Based Method*

Both the back-EMF-based method and the flux-linkage-based method determine the rotor position depending on the movement of the rotor magnetic field As a result, neither of the two methods can provide the initial rotor position for the self-starting of the motor at standstill. In order to resolve this problem, an inductance-based method is adopted to determine the rotor position at standstill [5, 10].

The basic principle of the inductance-based method is that the amplitude of the current, which is generated by injecting specific square-wave voltage pulse into the winding, is measured. Then, the difference between the inductances is obtained by comparing the amplitude of the currents. Thus, we can determine the rotor position. The system determines the actual rotor position of the motor at standstill and provides appropriate starting pulses to inverter switches to turn on. Once the motor starts to rotate, it then directly extracts the back EMF from the motor terminals between the floating phase and the midpoint of DC link or dc link ground terminal. The most advantage of this method is that it requires only three voltage pulse injections of small duration for the estimation of rotor position. Additionally one sensing resistor is added to a typical Sensorless drive. Moreover no machine parameters are required. Hence this method proves to be very effective for the rotor position estimation in position Sensorless BLDC.

H. *Artificial-intelligence-based method*

This Artificial-intelligence-based method is well for it strong adaptability and good self-learning ability. Basically there two types of Artificial-intelligence- based estimators such as; artificial neural network (ANN) or a fuzzy-neural network. The basic principle of rotor-position detection based on an artificial intelligence algorithm require the relationship is established between voltage, current and rotor position of the BLDC motor with the help of such theories as artificial neural networks, fuzzy strategy, genetic algorithms, adaptive artificial immune algorithms, etc. Then, the rotor position or commutation signals for Sensorless control are acquired through the measured motor voltage and current signals. In this condition, an accurate mathematic model of BLDC motor is not necessary [5, 6, 15]. Thus, the artificial-intelligence-based method is suitable for a nonlinear electrical machine control system. Such an ANN contains an input layer, an output layer and the hidden layers. However, the number of hidden layers to be used is not known in advance; this has to be determined by trial and error. In ANN-based approach it is difficult to relate the structure of the network to the physical process and there are no guidelines for the selection of the number of hidden layers and nodes. It is possible to overcome some of the difficulties of the ANN-based approach by using a fuzzy-neural estimator. A fuzzy neural system combines the advantages of fuzzy-logic and neural networks. Number of layers and also the number of nodes are known is the main advantage of a fuzzy-neural network.

I. *Observer based methods*

In this method, various types of observers are used to estimate rotor position and speed. The main idea is that a mathematical model of the machine is utilized and it takes measured inputs of the actual system and produces estimated outputs. The error between the estimated outputs and measured quantities is then fed back into the system model to correct the estimated values. Such various Sensorless control based methods based on Disturbance Observer (DOB), Extended Kalman Filter (EKF), Sliding-Mode Observer (SMO), and Wavelet Neural Network (WNN). Many papers have presented several Sensorless drive schemes for BLDC motors.

In paper [6, 11] a Sensorless drive system had presented three different Disturbance Observer (DOB) such as voltage observer, speed observer, and torque observer. In which disturbance voltage observer which can estimate the back emf from BLDC motor and this back emf is utilized for estimation of rotor speed and rotor position. This position estimation is robust for parameter variation in the e.m.f. constant. The rotor speed can be estimated by the speed observer which only requires the information of the equivalent BLDC motor. This speed observer improves the speed estimation, and is robust for the parameter variation on the e.m.f. constant. The equivalent disturbance torque observer is also constructed together with the speed observer. This equivalent disturbance torque observer makes the speed performance of Sensorless drive system to be robust for parameter variations and disturbance load torque.

Extended Kalman Filter (EKF)

Extended Kalman filter algorithm is an optimal recursive estimation algorithm for nonlinear systems. That is it uses the previous estimate and the latest input data to get new estimate data by using the recursive algorithm. So the filter only needs to store the previous estimate, and can meet the real-time requirement of the system [6, 12].Now in order to provide a quick and accurate estimation of the parameter and also to achieve a rapid convergence, it require following factor such as knowledge of the system dynamics, statistical description of the system errors such as; noises, disturbances, etc., and information about the initial conditions of the parameter which is required to be measured. Each recursive cycle includes two processes, in the very first stage at the time of calculations, by using a mathematical model the states are predicted and in the second stage; the predicted states are continuously corrected by using a feedback correction scheme. This scheme uses actual measured states by adding a term to the predicted states which is obtained in the very first stage. The additional term contains the weighted difference of the measured and estimated output signals.

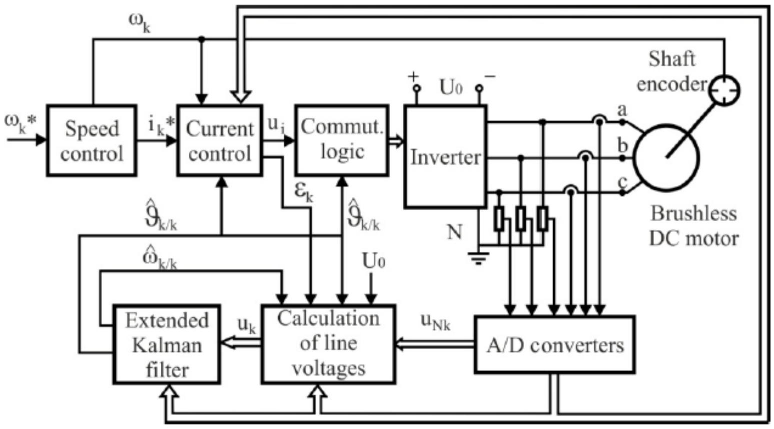


Figure 10: System configuration for speed and rotor position estimation of a BLDC motor

Based on the deviation obtained from the estimated value, the Extended Kalman filter (EKF) provides an optimum output value at the next input instant. The EKF estimation is very sensitive to the PM flux linkage error. However, at least one major drawback of the EKF application to Sensorless drives which is not yet solved, is the poor performance in low speed (<5Hz). In addition to the influence of estimation algorithm, the precision of system error estimation is mainly determined by the system observability. The observations of EKF filter are voltage and current. There is not any impact on current data in low speed. But there is one problem that is the harmonic component has a high ratio in voltage data. This estimation fluctuates severely because of the slowly changed system error information disturbed by quickly changed random error. That is why the higher ratio of signal-to-noise (SNR) of voltage [12], there would be a better performance in low speed. A simple method for high Signal-to-noise ratio is to reduce the voltage level of DC bus. This method can be used to estimate the rotor position and speed. Motor state variables are estimated by means of measurements of stator line voltages and currents.

Sliding-Mode Observer (SMO)

Sliding mode observer is a non-linear high gain observer has the ability to bring co-ordinates of the estimator error dynamics to zero in finite time and it is used for the accurately estimation phase-to-phase back-EMF. Sliding mode control (SMC), is a nonlinear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behaviour. The principle of sliding mode control is to forcibly constrain the system, by suitable control strategy, to stay on the sliding surface on which the system will exhibit desirable features. When the system is constrained by the sliding control to stay on the sliding surface [6, 13, 14].

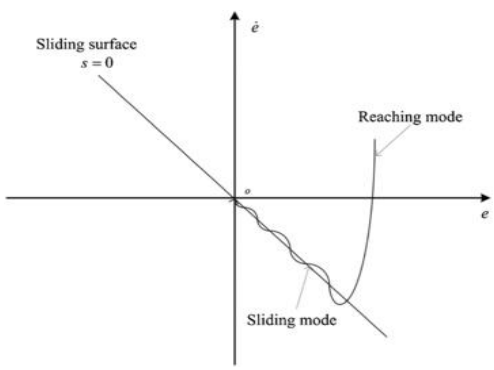


Figure 11: Sliding motion

A trajectory starting from a non-zero initial condition, evolves in two phases:

i. Reaching mode, in which it reaches the sliding surface.
ii. Sliding mode, in which the trajectory on reaching the sliding surface, remains there for all times and thus evolves according to the dynamics specified by the sliding surface.

As shown in Figure 11 represents the phase trajectory of a sliding mode representing two modes of the system. In the first part, the trajectory starting from a non-zero initial condition on the phase plane moves towards the sliding surface and reaches the surface in finite time. This is known as reaching, hitting, or non-sliding phase and the system is sensitive to parameter variations and disturbance rejection in this part of the phase trajectory. The second part is the sliding phase in which the state trajectory moves to the origin along the sliding surface and the state never leave the sliding surface. During this period, the system is defined by the equation of the sliding surface and thus it is independent of the system parameters and external disturbances.The special feature of Sliding Mode Observer (SMO) is that it have much better disturbance rejection capabilities against parameter variations and external load torque. But sliding mode control suffer from issue of chattering in case of first order sliding mode control (SMC) because of high-frequency control switching, following chattering issue can be minimized by selecting suitable control law and it will also be reduced by higher order SMC .

Wavelet Neural Network (WNN)

WNN is a feedforward artificial neural network (ANN) based on wavelet decomposition. It combines a wavelet transform with ANN together by replacing a neuron nonlinear excitation function with nonlinear wavelet basis WNN has many of the merits of a wavelet transform and ANN[2,16].

As shown in Figure 12, the hidden nodes of the network are all wavelet functions, w_i is the weight from the i^{th} hidden node to the output, a_i and t_i are the scale factor and translation factor of the wavelet function for the i^{th} hidden node, respectively. The optimum values of w_i, a_i and t_i are obtained by training so that the network can approximate f(x) well.

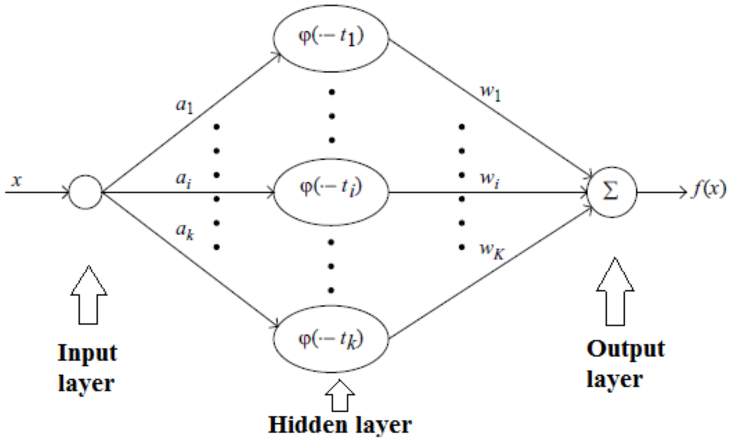


Figure 12: Structure diagram of a SISO wavelet neural network

During the beginning there is no hidden layer unit, during the learning process, hidden layer units are increased according the rule, and the hidden layer units, which have not affected network output, will be cancelled. After training, a simple, compact and with least hidden layer units network will be formed.

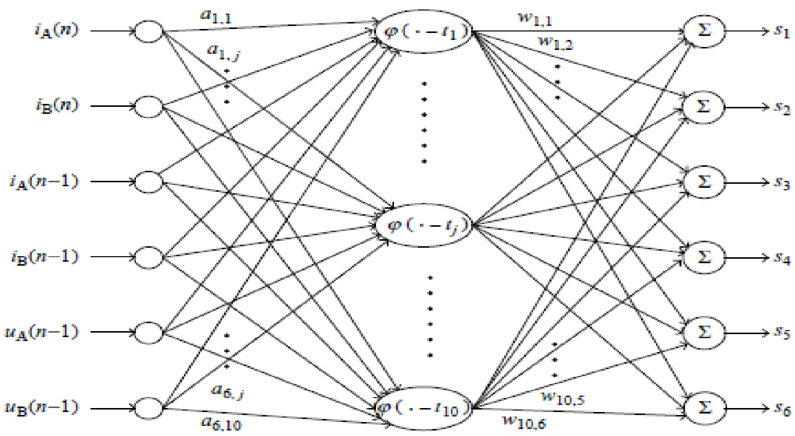


Figure 13 : Topology of WNN for rotor-position detection.

The important part in WNN is to train the network such as; offline training and online training. As shown in Figure 13 the topology of a WNN that is used to detect the rotor position. This WNN topology includes six input signals for the input layer, ten nodes in the hidden layer and six switch signals of the output layer. Here gradient descent error algorithm is used to train the parameters of the network.

During offline network training process it is important to get learning samples. Although training samples can be obtained from simulation data, a further training must be done based on the experimental data. This will make the WNN more suitable for the Sensorless control of BLDC motors. After getting learning samples, offline training method is developed in a PC by using MATLAB. After being trained by 4000 samples [2], WNN can meet the predetermined precision. Then, the scale factor (a_i), the translation factor (t_i) and the connection weight of the output layer are all determined.

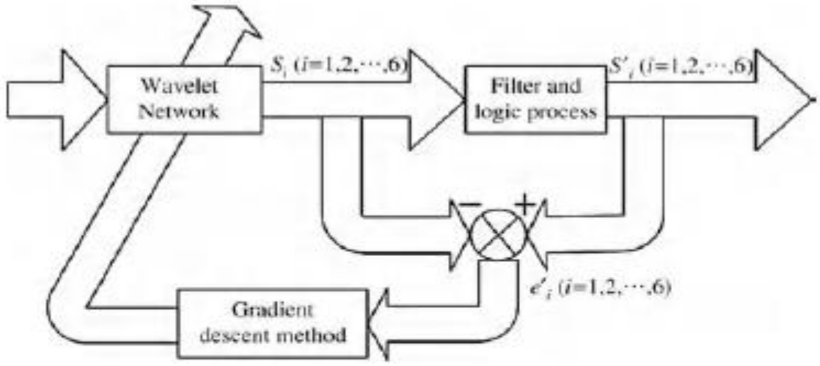


Figure 14: Online training scheme of WNN.

As shown in Figure 13, In order to adapt the change of environment well, and enhance the robust online training is adopted into the WNN. Hence, the connection weights of the output layer can be adjusted by supervised learning. The gradient descent error algorithm is employed, and the external teachers for supervised learning are the output signals coming from the logic process.

III. CONCLUSION

In this paper, a review of previous research in position Sensorless drive technique for BLDC motors has been presented. The principle fundamentals of various methods have been introduced as a useful reference for preliminary investigation of conventional and advance methods. It will provide the insight of Sensorless operation, the need for Sensorless operation, classification of existing Sensorless methods, with their merits and demerits were presented.

REFERENCES

[1] Krishnan R , “Motor Drives Modeling Analysis And Control”, prentice hall of India 2002.

[2] Chang-Liang Xia, “Permanent Magnet Brushless DC Motor Drives and Controls”,Wiley publication, June 2012, ISBN: 978-1-118-18833-0, pp. no.167-207.

[3] Tae-Hyung Kim, Hyung-Woo Lee, and Mehrdad Ehsani, “State of the Art and Future Trends in Position Sensorless Brushless DC Motor/Generator Drives”, 0-7803-9252-3/05/2005 IEEE.

[4] Vinatha U, Swetha Pola, Dr.K.P.Vittal, MIEEE, “Recent Developments in Control Schemes of BLDG Motors”,1-4244-0726-5/06/'2006 IEEE.

[5] Jyoti Agrawal, Sanjay Bodkhe “Sensorless Permanent Magnet Synchronous Motor Drive: A Review”, National Conference on Innovative Paradigms in Engineering & Technology (NCIPET), IJCA,2013.

[6] Jose Carlos Gamazo-Real , Ernesto Vazquez-Sánchez and Jaime Gómez-Gil, “Position and Speed Control of Brushless DC Motors Using Sensorless Techniques and Application Trends”, ISSN 1424-8220, Sensors 2010, 10, 6901-6947; doi:10.3390/s100706901.

[7] Jianwen Shao, Dennis Nolan, and Thomas Hopkins “A Novel Direct Back EMF Detection for Sensorless Brushless DC (BLDC) Motor Drives”,, 0-7803-7404-5/02/2002 IEEE.

[8] Jianwen Shao, Dennis Nolan, and Thomas Hopkins “Improved Direct Back EMF Detection for Sensorless Brushless DC (BLDC) Motor Drives”, 0-7803-7768-0/03/2003 IEEE.

[9] Jianwen Shao, Dennis Nolan“Further Improved Direct Back EMF Detection for Sensorless Brushless DC (BLDC) Motor Drives”, 0-7803-8975-1/05/2005 IEEE.

[10] Neethi S.Pillai, Vipin A.M, Remna Radhakrishnan “Analysis And Simulation Studies For Position Sensorless BLDC Motor Drive With Initial Rotor Position Estimation” International Conference on Nascent Technologies in the Engineering Field (ICNTE-2015), 978-1-4799-7263-0/15,2015 IEEE.

[11] Tomonobu Senjyu, Mutuwo Tomita, Shinji Doki, Shigeru Okuma “Sensorless Vector Control of Brushless DC Motorsn Using Disturbance Observer” 0-7803-2730-6195,1995 IEEE.

[12] Gu Shan-Mao, He Feng-You ,Zhang Hui, “Study on Extend Kalman Filter at low speed in Sensorless PMSM Drives” International Confe"rence on Electronic Computer Technology,978-0-7695-3559-3/09,2009 IEEE

[13] SHI Tingna, LU Na, LI Wenshan “Sensorless Control for Brushless DC Motors Using Adaptive Sliding Mode Observer” 29th Chinese Control Conference Beijing, China, July 29-31, 2010.

[14] Namita P. Galphade and Subhash S. Sankeshwari "Simulation Of Bldc Motor Control Using Sliding Mode Control Technique" International Journal of Advances in Engineering & Technology(IJAET-2015) , ISSN: 22311963, Vol. 7, Issue 6, pp. 1857-1865.

[15] R. A. Gupta · Rajesh Kumar · Ajay Kumar Bansal "Artificial intelligence applications in Permanent Magnet Brushless DC motor drives",DOI 10.1007/s10462-009-9152-3, Springer Science+Business Media B.V. 2009.

[16] Yang Tian, Ting-na Shi, Chang-liang Xia, Dan Liu, Qian Zhang "Sensorless Position Control using Adaptive Wavelet Neural Network for PM BLDCM" 1-4244-0755-9/07,2007 IEEE.