A Novel Approach of Position Estimation, PFC based Buck Boost Converter and Energy generation in BLDC Motor Drive

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Abstract— Brushless DC (BLDC) motor drives are becoming more popular in industrial and traction application. This proposed approach makes the control of BLDC motor with sensorless motion control of BLDC motor, Bridgeless Buck-Boost Rectifier based power factor correction and regeneration of electric power from the motor at time of running condition as well as in braking condition.

Keywords: BLDC motor, Power Factor Correction, Fly wheel generator, Regenerative Braking.

I. OBJECTIVE

The main objective of this paper is efficient way of estimation, control of industrial based BLDC drives and also electrical energy conservation from the motor at running time as well as braking time.

II. INTRODUCTION

Now a day’s BLDC motor drives becomes more popular in industries, traction, and electrical vehicles. Normally BLDC motor has a rotor with permanent magnet and stator with windings. Brushless motors are not self-commutating, and hence are more complicated to control. BLDC motor control requires knowledge of the rotor position and mechanism to commutate the motor. For closed-loop speed control it requires two additional requirements, measurement of the motor speed and/or motor current and PWM signal to control the motor speed and power. BLDC motors can use edge-aligned or centre-aligned PWM signals depending on the application requirements. Most applications, that only require variable speed operation, will use six independent edge-aligned PWM signals. This provides the highest resolution. If the application requires servo-positioning, dynamic braking, or dynamic reversal, it is recommended that complementary centre-aligned PWM signals be used. To sense the rotor position BLDC motors use Hall Effect sensors to provide absolute position sensing, which results in more wires and higher cost. Sensorless BLDC control eliminates the need for Hall Effect sensors, using the back-EMF (electromotive force) of the motor instead to estimate the rotor position. Sensorless control is essential for low-cost variable speed applications such as fans and pumps.

Refrigerator and air conditioning compressors also require sensorless control when using BLDC motors.

III. BLOCK DIAGRAM OF THE PROPOSED SYSTEM

Fig. 1 shows the block diagram of proposed system. The proposed system consists of bridge less power factor Converter, Three Phase Inverter, BLDC Motor Fly Wheel Generator, Battery and Zero Crossing Detector.

IV. NEED OF POWER FACTOR CORRECTION IN INDUSTRY

A power factor of one or "unity power factor" is the goal of any electric utility company since if the power factor is less than one, they have to supply more current to the user for a given amount of power use. In so doing, they incur more line losses. They also must have larger capacity equipment in place than would be otherwise necessary. As a result, an industrial facility will be charged a penalty if its power factor is much different from 1. Industrial facilities tend to have a "lagging power factor", where the current lags the voltage (like an inductor). This is primarily the result of having a lot of electric induction motors - the windings of motors act as inductors as seen by the power supply. Capacitors have the opposite effect and can compensate for the inductive motor windings.
Some industrial sites will have large banks of capacitors strictly for the purpose of correcting the power factor back toward one to save on utility company charges.

V. POWER FACTOR CORRECTION CONVERTER

![Diagram of PFC based bridgeless Buck-Boost Converter](image)

In the proposed configuration of bridgeless buck-boost converter has the minimum number of components and least number of conduction devices during each half cycle of supply voltage which governs the choice of BL buck-boost converter for this application. The operation of the PFC bridgeless buck-boost converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage and during the complete switching cycle.

A. Operation During Positive and Negative Half Cycle of Supply Voltage

In this mode converter switches Sw1 and Sw2 are operate in positive and negative half cycle of supply voltage respectively. During positive half cycle switch SW1, inductor Li1 and diodes D1 and Dp are operated to transfer energy to DC link capacitor Cd. Similarly in negative half cycle of supply voltage switches Sw2, inductor Li2 and diode D2 and D2 conducts. In Discontinuous Inductor Current Mode(DICM) operation of converter the current in the inductor Li becomes discontinuous for certain duration in a switching period.

B. Operation During Complete Switching Cycle

In this switching cycle there are three modes of operation.

- **Mode I:** In this mode, switch Sw1 conducts for charging the inductor Li1, hence the inductor current iLi1 increases in this mode. Diode Dp completes the input side and the DC link capacitor Cd is discharged by VSI fed BLDC motor.

- **Mode II:** In this mode of operation switch Sw1 is turned off and the stored energy from the inductor Li1 is transferred to DC link capacitor Cd till the inductor is fully discharged and current in the inductor is fully reduced to zero.

- **Mode III:** In this mode of operation inductor Li1 operate in discontinuous conduction mode and diodes and switch are in off condition. At this time DC link capacitor Cd starts discharging. This operation can be continue up to switch Sw1 is turned on again.

VI. INVERTER

The word ‘inverter’ in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The ‘inverter’ does reverse of what ac-to-dc ‘converter’ does (refer to ac to dc converters). Even though input to an inverter circuit is a dc source, it is not uncommon to have this dc derived from an ac source such as utility ac supply. Thus, for example, the primary source of input power may be utility ac voltage supply that is ‘converted’ to dc by an ac to dc converter and then ‘inverted’ back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives (ASDs), which are the most popular application of inverters. Similarly, these topologies can be found as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required. Static power converters, specifically inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones. Here we have use Voltage Source Inverter. The simplest dc voltage source for a VSI may be a battery bank, which may consist of several cells in series-parallel combination. Solar photovoltaic cells can be another dc voltage source. An ac voltage supply, after rectification into dc will also qualify as a dc voltage source. A voltage source is called stiff, if the source voltage magnitude does not depend on load connected to it.
All voltage source inverters assume stiff voltage supply at the input. Some examples where voltage source inverters are used are: uninterruptible power supply (UPS) units, adjustable speed drives (ASD) for ac motors, electronic frequency changer circuits etc. Most of us are also familiar with commercially available inverter units used in homes and offices to power some essential ac loads in case the utility ac supply gets interrupted. In such inverter units, battery supply is used as the input dc voltage source and the inverter circuit converts the dc into ac voltage of desired frequency. The achievable magnitude of ac voltage is limited by the magnitude of input (dc bus) voltage. In ordinary household inverters the battery voltage may be just 12 volts and the inverter circuit may be capable of supplying ac voltage of around 10 volts (rms) only. In such cases the inverter output voltage is stepped up using a transformer to meet the load requirement of, say, 230 volts.

**VII. BRUSHLESS DC MOTOR**

BLDC motors are very popular in a wide variety of applications. Compared with a DC motor, BLDC motor uses an electric commutator rather than a mechanical commutator, so it is more reliable then the DC motor. In a BLDC motor, rotor magnets generate the rotor’s magnetic flux, so VLDc motor achieve higher efficiency. Therefore, BLDC motors may be used in high-end white goods (refrigerators, washing machines, dishwashers, etc.), high end pumps, and fan and in other appliances which require high reliability and efficiency.

BLDC motor has a stator with an three phase stator like that an induction motor, and the rotor has surface is a classic 3-phase stator like that of an induction motor, and the rotor has surface-mounted permanent magnets are shown in Fig. 3.

In the DC commutator motor, the current polarity is altered by the commutator and brushes. However, in the DC motor, polarity reversal is performed by power transistors switching in synchronization with the rotor position. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual position, or the position can be detected without sensors.

**VIII. POSITION AND SPEED CONTROL OF BLDC MOTORS USING SENSORS**

PM motor drives require a rotor position sensor to properly perform phase commutation or current control. For BLDC motor six phase-commutation per electrical cycle is needed, therefore Hall-effect sensors are usually used.

**A. Hall-effect sensors:**

These kinds of devices are based on Hall-effect theory, which states that an electric current carrying conductor is kept in magnetic field exerts a transverse force on the moving charge carrier that tends to push them to one side of the conductor. A build-up of charge at the sides of the conductor will balance this magnetic influence producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall-effect. Most BLDC motors have three Hall sensors inside the stator on non-driving end of the motor. Whenever the rotor magnetic poles pass near the hall sensors they give a high or low signal indicating the N or S pole is passing near the sensors. Based on the combination of these three hall sensor signals, the exact sequence of commutation can be determined.

**B. Accelerometers:**

Accelerometers is a electromechanical devices that measures acceleration forces, which are related to the freefall effect. Several types are available to detect magnitude of the acceleration as a vector quantity, and can be used to sense the position, vibration and shock. The most common design is based on a combination of Newton’s law of the mass acceleration and Hook’s law of spring, which is depicted in Figure 4. When the accelerometer experiences acceleration, the mass is displaced to the point that the spring is able to accelerate the mass at the same rate as casing. The displacement is then measured to give the acceleration.

![BLDC Motor Construction](image-url)
IX. TECHNIQUES USED FOR SENSORLESS CONTROL

The position sensors can be completely eliminated, thus reducing further cost and size of motor assembly, in those applications in which only variable speed control is required and system dynamics is not particularly demanding. In fact, some control methods, such as back-EMF and current sensing, provide, in most cases, enough information to estimate with the sufficient precession rotor position and therefore to operate the motor with synchronous phase currents. The BLDC motor provides an attractive application for sensorless operation because the nature of its excitation inherently offers a low-cost way to extract rotor position information from the motor-terminal voltages. In the excitation of a three-phase BLDC motor, except for the phase-commutation periods, only two of the three phase windings are conducting at a time and the no conducting phases carries the back-EMF. There are many categories of sensorless control strategies that are given below.

A. Back-EMF Zero Crossing Detection methods

The zero-crossing approach is one of the simplest methods of back-EMF sensing techniques, and is based on detecting the instant at which the back-EMF in the unexcited phase cross zero. This zero crossing triggers a timer, which may be as simple as an RC time constant, so that the next sequential inverter commutation occurs at the end of this timing interval.

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 5 can be estimated by the zero crossing point (ZCP) of back-EMF and a 30° phase shift [1,4], using a six-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.

B. Third Harmonic Voltage Integration method

This method utilizes the third harmonic of the back-EMF to determine the commutation instants 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 elimination 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 constant phase displacement with the fundamental air gap voltage for any load and speed. An appropriate processing of the third harmonic signal allows the estimation of the rotor flux position and a proper inverter current control. In contrast with indirect sensing methods based on the back-EMF signal, the third harmonic requires only a small amount of filtering. As a result, this method is not sensitive to filtering delays, achieving a high performance for a wide speed range. A superior motor starting performance is also achieved because the third harmonic can be detected at low speeds.

Figure 6 depicts the motor internal voltage corresponding to phase A, eA, the third harmonic signal, VSUM, obtained from the summation of the stator phase voltages, the rotor flux third harmonic component \( \lambda_3r \), the rotor flux \( \lambda r \), and the stator phase currents. In order to obtain maximum torque per ampere, the stator current is kept at 90 electrical degrees with respect to the rotor flux.
In addition, the zero crossings of the rotor flux third harmonic component occur at 60 electrical degrees, exactly at every desired current commutation instant.

To produce the maximum torque, the inverter commutation should be performed every 60° so that the rectangular-shaped motor line current is in phase with the back-EMF signal. A starting circuit is needed to give a commutation signal for starting. This approach makes it possible to detect the rotor position over a wide speed range, especially at a lower speed, and to simplify the starting procedure.

D. Back-EMF Integration Method:

In this technique, the commutation instant is determined by integration of the silent phase’s back-EMF (that is the unexcited phase’s back-EMF). The main characteristic is that the integrated area of the back-EMFs shown in Figure 7 is approximately the same at all speeds. The integration starts when the silent phase’s back-EMF crosses zero. When the integrated value reaches a pre-defined threshold value, which corresponds to a commutation point, the phase current is commutated. If flux weakening operation is required, current advance can be achieved by changing the threshold voltage. The 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. As the back-EMF is assumed to vary linearly from positive to negative (trapezoidal back-EMF assumed), and this linear slope is assumed speed-insensitive, the threshold voltage is kept constant throughout the speed range.

E. Methods based on PWM strategies:

There are many methods based on PWM control schemes, but the most relevant are conventional 120°, elimination of virtual neutral point, techniques for low speed, high speed and small power applications, and direct current controlled, which are explained below.
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 sequence of commutations is retained in proper order such that the inverter performs the functions of brush and commutator in a conventional DC motor, to generate a rotational stator flux. Figure 8 shows the PWM waveforms for this conventional approach, which has low switching losses in the inverter side at the cost of significantly high harmonic contents. This results in increase of loss in the motor side.

X. FLY WHEEL GENERATOR

Fly wheel generator is a special type of generator. Working of fly wheel generator is as like an normal generator. Here we have use the permanent magnet generator. Mechanical power input is taken from the BLDC motor and generator output is connected with the battery storage.

XI. SIMULATION

Here we have use MATLAB simulink for simulation platform. Figure 9 shows the existing method used for BLDC motor control.

![Fig. 9 Existing BLDC motor Control](image)

There is no PFC and Regeneration is not used in the existing BLDC motor. Input power factor variation in the existing system is shown in figure 10.

![Fig. 9 Input Power Factor of Existing System](image)

Figure 11 shows the proposed system used for BLDC motor control. proposed system consist of BLPFC Boost Converter, Speed Regulator, and then flywheel generator.
Input power factor in proposed system is shown in figure 12.

Power Factor Correction Converter is used to maintain input power factor in unity. So the system can maintain the input power factor.

Speed controller is used to maintain the BLDC motor in constant speed. Figure 13 shows the scope output of the motor speed.

Mechanical output from the BLDC motor is connected to the flywheel generator. Flywheel generator has been used to generate the electrical output at time of BLDC motor running. Figure 14 shows the flywheel generator speed with respect to time.

Figure 15 shows the output three phase voltage from the flywheel generator.

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