Simulation of Back EMF Based Sensorless BLDC Drive Using Filtered Line Voltage Difference

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Abstract: **With the rapid and increasing advancements in field of semiconductor technology the brushless DC motors are extensively used in the computer peripherals, videos recorders, spindle drives, aerospace industry, military equipments, automated industry, and other household equipments, since practically they need no maintenance, have long life, low inertia and friction. Because of low inertia and friction they can be used in very high speed applications. This paper deals with, a position sensorless brushless direct current (BLDC) drive operation is described. Detection of back EMF zero crossing from line voltage difference is employed here for the sensorless drive operation. The line voltage difference gives an amplified version of back EMF which makes the sensorless operation possible. Low pass filters are used for eliminating the spikes in the wave form and to provide the necessary delay required for the proper commutation of switches. Neutral potential is not needed for obtaining the commutation pulses. Sample and hold circuit is also not needed since the use of filter eliminates the spikes. Proposed sensorless drive is simulated using MATLAB/ SIMULINK. The PMBLDC motors are controlled electronically and for the proper commutation of current, rotor position information is required, on the other hand the problems of the cost temperature sensitivity and reliability of position sensors have motivated the research in the area of sensor less PMBLDC motor drives.**

Keywords: **Back electromotive force (EMF) detection, Brushless DC motor, Filtered line voltage difference, Low pass Butterworth filter, and sensorless control.**

1. INTRODUCTION

Brushless DC (BLDC) are replacing DC motors in a wide range of applications now-a-days such as household goods, automotive and aviation industry. Such applications require a very robust, compactness, reliable, high power density and efficient motors for the operation. These appliances have relied on traditional electric motors such as single phase AC motors including capacitor- start, capacitor- run motors, and universal motors. However, consumers now demand better performance, reduced acoustic noise and higher efficient motor for their appliances. Hence, BLDC have been introduced in order to fulfill these requirements.

Close loop control of PMBLDC motor by sensorless method is presented in this thesis work. The basic concept of this topic is observed from [1]. Now-a-days conventional DC motors are being replaced by BLDCs due to their high efficiency and low noise quality which is more desirable for consumer's point of view. Current hysteresis controller block which is described in [1] in which input signals are three phase reference currents and practical currents, and output signals will act as the controlling signals for the voltage source inverter. The speed control applies a PI controller, which has been extensively used in several fields. And its integral term has the effect of accumulation, memorization and time delay, which enables The PI controller is to remove the static error. The various controlling methods for BLDC are described in [2].

Controlling strategies are characterized by two ways:

•Sensor Control: such as Hall sensor, Priority resolver etc.

•Sensorless Control: direct back EMF, indirect back EMF, FOC schemes comes in this category.

Brief introduction of PMBLDC Motor, its advantages, applications, and world-wide acceptance is presented in [3] G K DUBEY. The brushless DC (BLDC) motors are becoming fashionable because, as their name suggests, it does away with the wear prone brushes used in the traditional motors, replacing them with an electronic controller which improves the reliability of the system. Besides this a BLDC motor can be made smaller and lighter in weight than a brushed type with the same power output, making it appropriate for the applications where space is a concerning parameter.

The non-linear dynamics of Current Controlled D.C. Drive with a PID controller is presented in [4] in which closed loop model for a current controlled PMDC motor drive with PID Controller is given. The speed as output of PMDC motor is compared to preset value of reference speed. The difference between the two signals is fed as error to PID controller. Output of the speed controller is the actuating signal which controls the duty cycle of converter and therefore controls the output of converter. The basic theory which is adopted for controlling the speed of this modeled DC drive is the variation in armature voltage. There are two control loops, one for controlling current and another for speed.

Modeling simulation of sensor less brush less DC motor by the back emf difference method is studied from [5]. In this scheme zero crossing point (ZCP) of the back EMF of motor is determined and thus the commutation point is obtained. The back EMF of motor can be determined when the motor just starts running at high speeds. Directly the back EMF of motor can't be detected. A famous method is detection of terminal voltage. The difference of terminal voltage in open phase and virtual neutral point voltage which is created by connecting three phases to a common point through a resistor is sensed.

The speed control of brush less DC motor using Fuzzy logic PI controller is studied from   [6] in which it is shown that the main controller have utilized a combination of three fuzzy logic and three PI controllers. Output of PI controllers is sum up and is fed as input to the current controller. The current controller uses P controller. The speed from BLDC motor is given as a input to the fuzzy logic PI controller.

Inverse park transformation is explained in [7], in inverse Park transformation DQ is converted to ABC i.e. two phase to three phase conversion is done. Since there is no mechanical or electrical contact between the stator and rotor in the BLDC motor, alternate arrangements are required to point out the relative positions of the component parts in order to facilitate motor control. BLDC motor uses one of two methods to attain this, either employing Hall sensors or measuring back EMF. Controllers and their types such as Derivative P, I, PI and PID are studied from B. S Manke [8]. Inverter their types and modes of operation are studied from [9] Power electronics by P.S. Bhimra. This thesis presents the simulation of sensorless operation of permanent magnet brushless direct current (BLDC) motor is described in [2]. Torque ripple which is the main drawback of the brushless DC motor.

Miller T.J.E [10] introduced the permanent magnet materials and their characteristics, B-H loop and demagnetization characteristic, applications of permanent magnet in motors. He also discussed the square wave permanent brushless motor, sine wave permanent magnet brush less motor and their torque, E.M.F equation and torque-speed characteristics. A. Kusko and S.M. Peeran [11] presented definitions of a brush less DC motor are inadequate to differentiate it from other types of brushless motors. A formal definition of a brushless DC motor is given. The definition includes the components of the motor and the types of circuits to energize the stator windings.

M.A.Jabbar, M.A. Rahman [12] presented designing consideration for permanent-magnet motors projected for brushless operation. Two-rotor configurations are described - the imprecated rotor and the segmented rotor. The segmented rotor is designed especially for high speed operation. A brushless DC drive system is also described.

A new model of simulation for BLDC motor with back EMF waveform is proposed by Jeon Y.S.Mok,[13]. The torque characteristic of a BLDC motor is an important parameter in the designing, so it's essential to predict the accurate value of torque, which is estimated from the back EMF waveform. Back EMF waveform is some degree deviated from the ideal trapezoidal waveform. As a result, when ideal trapezoidal waveform is used, an error occurs. As a consequence, in order to minimize such error, the model of the BLDC motor with a real back EMF waveform is needed instead of its approximation model.

The power converter is a three phase power semiconductor bridge shown in Figure 3.3. The main function of the power converter is to transform power from the DC source to AC so the motor can convert electrical energy to mechanical energy. The sensor is used to determine the rotor position, and it sends this information to the controller.
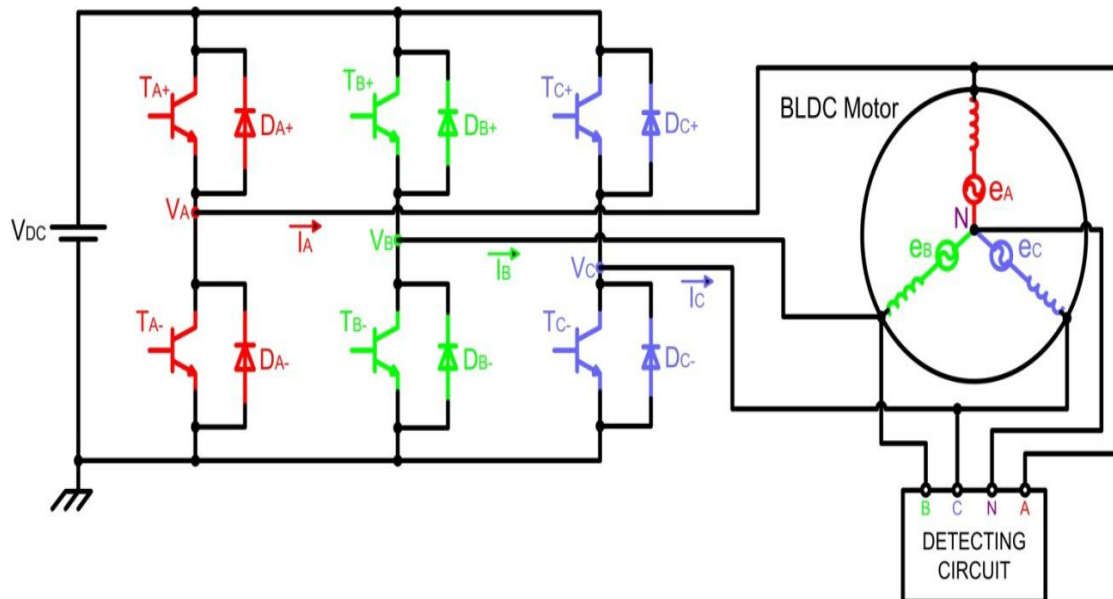

Fig 3.4: Typical sensorless BLDC motor drive

Above figure shows a typical sensor less PMBLDC drive. Generally permanent magnet brushless DC motors comes in fixed voltage type, such as 5V, 6V, 12V, 24V, 48Vetc, in which 12V type being common and used widely. When rated voltage is applied to the motor it will rotate with maximum speed, but by varying the applied voltage the speed of motor can be controlled. of course, if the voltage is higher than speed is higher and vice versa.

1.2 BLDC v/s Conventional DC motors:

In a conventional i.e. in a brushed type DC motor, the brushes are responsible for creating the mechanical contacts with a set of electrical contacts on the rotor referred to as the commutator. This forms a electrical circuit between the DC electrical source and the armature winding. As the armature rotates, the stationary brush comes in contact with the different sections of the commutator. The rotating commutator and the brush- system forms a set of electrical switches, which operates in a proper sequence to allow electric current to flow through the armature coils closest to the field which can be either electromagnet or a permanent magnet. In a typical BLDC motor, armature coils do not move, and in its place, the permanent magnets rotate. Therefore the armature remains stationary which avoids the problem of how to transmit current to a moving armature. In a BLDC the commutator assembly is replaced by electronic controller which is programmed to perform switching of coil.
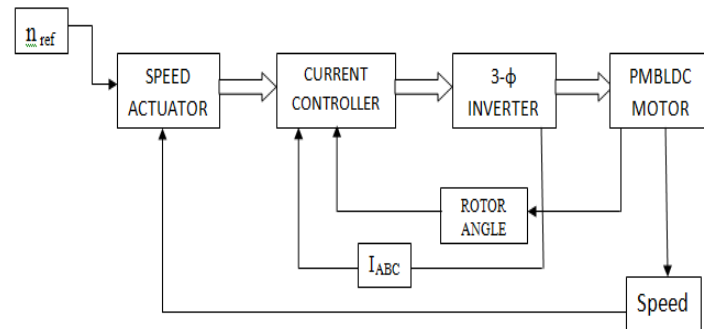
Some major advantages of BLDCs are pointed here:

- Highly efficient.

- Better speed-torque characteristics.

- High dynamic response.

- Low moment of inertia.

- High torque to volume ratio.

- Long operational life

- Low Noise level

- Variable High speed range

The main disadvantage of PMBLDCs is its high cost.

2. PROPOSED METHOD

With the rapid and increasing advancements in field of semiconductor technology the brushless DC motors are extensively used in the computer peripherals, videos recorders, spindle drives, aerospace industry, military equipments, automated industry, and other household equipments, since practically they need no maintenance, have long life, low inertia and friction. Because of low inertia and friction they can be used in very high speed applications. The PMBLDC motors are controlled electronically and for the proper commutation of current, rotor position information is required, on the other hand the problems of the cost temperature sensitivity and reliability of position sensors have motivated the research in the area of sensor less PMBLDC motor drives.

**Fig:2.1 Block Diagram of closed loop BLDC Control**

In this close loop control of sensorless PMBLDC motor rotor angle of motor and the output current of three phase inverter is fed to the Current controller. Measured speed from the motor is applied to the speed actuator which compares the actual speed with reference speed and the resultant output is given to the current controller. Current controller produces required gate pulses for three phase inverter for the desired operation of the motor.
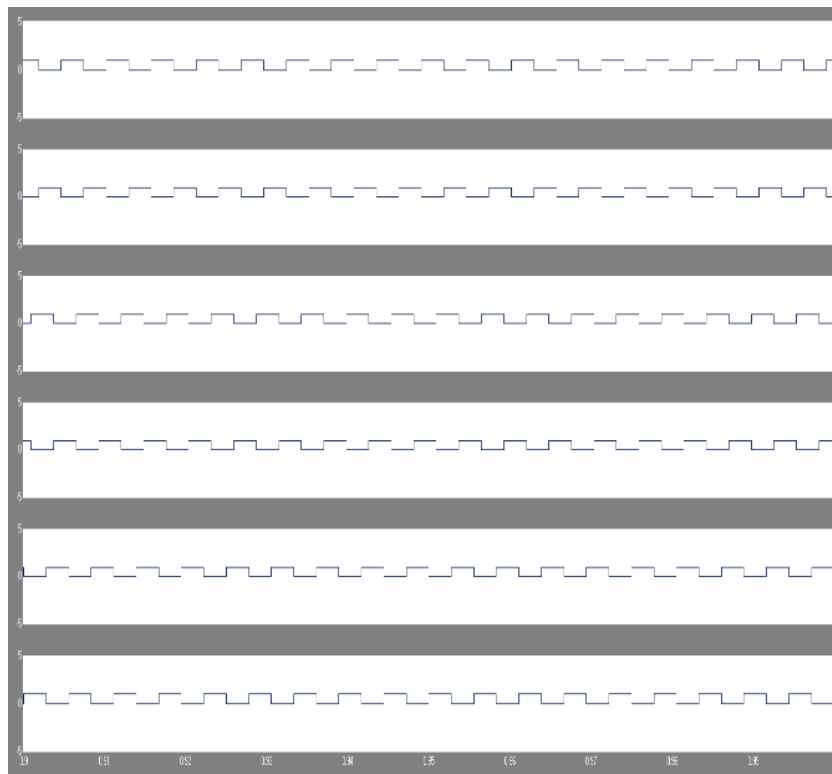
**Fig 2.2. Gate pulses fed in Inverter**

3. SIMULATION RESULT

### 3.1 Speed waveform:
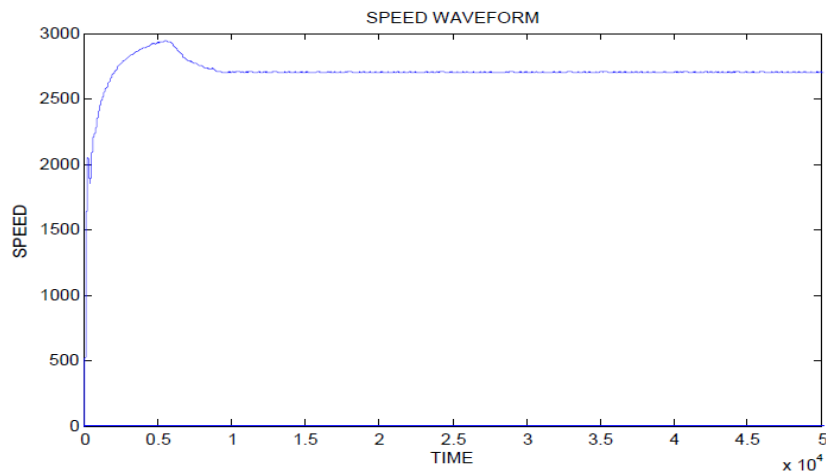
Fig 3.1: Rotor Speed Waveform

This above fig depicts that the speed waveform of the rotor of a PMBLDC motor, on the X- axis time and on the Y-axis speed is taken, as the motor just starts speed goes on increasing and continuously rises up to a maximum value of 2900 RPM and then from there it slightly decreases and becomes constant near to a value of 2600 RPM.

3.2 Torque waveform:
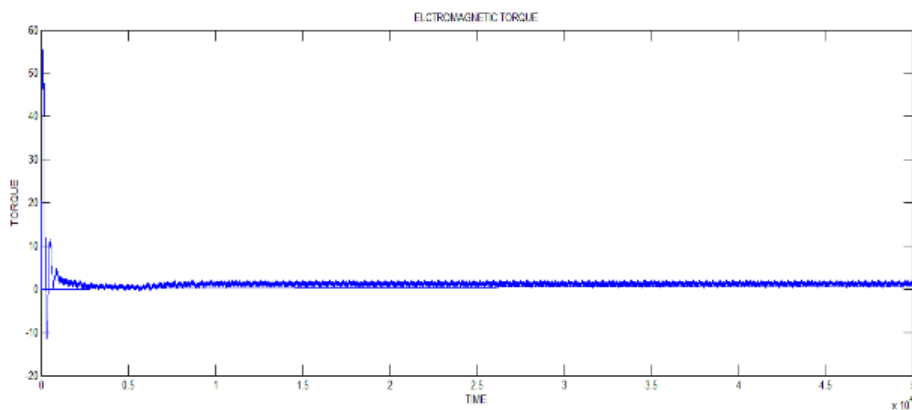
Fig 3.2: Electromagnetic Torque (in Nm)

3.3 Back EMF waveform:
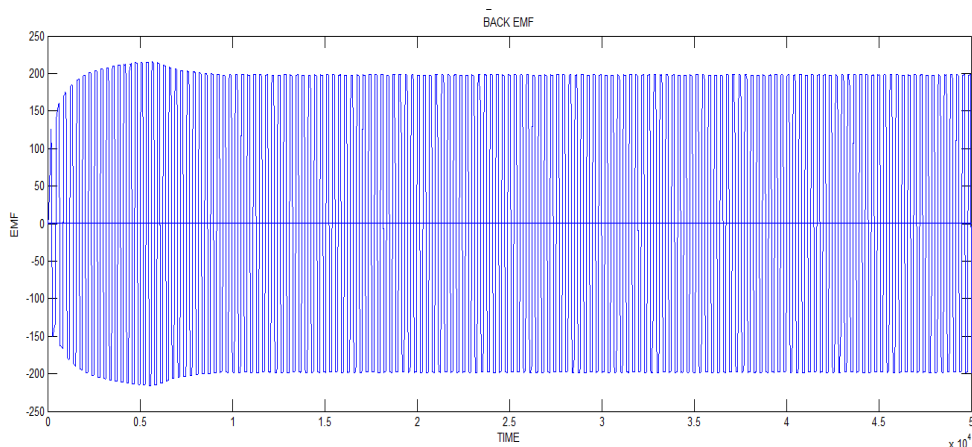
Fig 3.3: Back EMF (V/sec) Waveform

3.4 Stator Current:

The below figure clearly shows the stator current waveform for phase A, in which on the X axis we have taken time (in sec) and on the Y axis we have taken current in (A). This figure clearly shows that at first when motor is initially started the stator current rises suddenly to some 40A and then from there it falls down and after 1 sec it becomes almost constant on 8A.
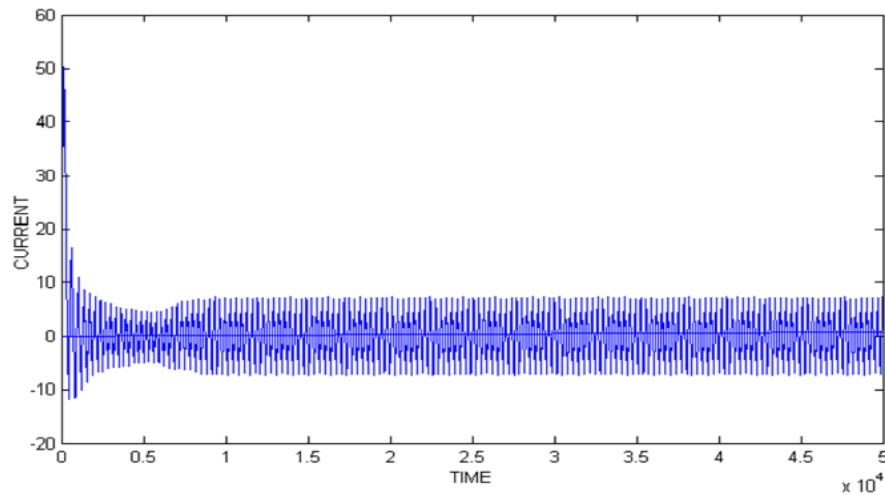
- Stator current phase A-

Fig 3.4: Stator Current Waveform for Phase A
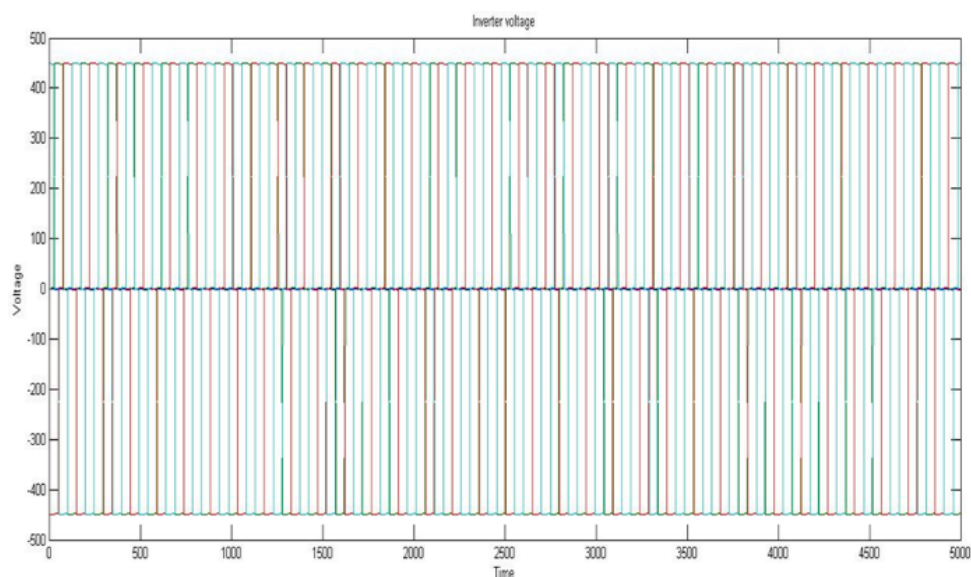
3.5 Inverter voltage:

Fig 3.5: inverter voltage

4. CONCLUSION

The speed control of sensorless Permanent Magnet Brushless DC motor by MATLAB simulation is presented in this work. Here we have employed a PI controller for the generation of reference torque by the help of reference speed and actual speed generated by the motor, and this torque is applied to the current hysteresis controller block which generates the required six gate pulses for turning ON the three phase six pulse voltage source inverter. This three phase six pulse voltage source inverter further feds to the permanent magnet synchronous motor. The rotor speed of the permanent magnet brushless DC (PMBLDC) motor is observed 2590 RPM approximately. The back EMF is of Trapezoidal in nature and the voltage of the VSI is stepped type which is fed to the motor. All the simulation work done here is on the MATLAB 2013.

5. APPENDIX

The Parameters used in MATLAB /Simulation is:

Ls	8.5e-3
R_S	2.8750 ohms
P	No. of poles = 4
Flux linkage	0.175
K_P	3
K_i	6.2
V_S	450V

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