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Sensorless Control of PMBLDC Motor Drivebased on Back EMF Detection Technique

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Abstract

This paper presents a position Sensorless control scheme for Permanent magnet Brushless dc (PMBLDC) motor drive which proposes an improved methodology based on a potential start-up method with a high starting torque. By eliminating the drive components such as sensors the manufacturing cost had reduced which is essential for some applications. There is no need of any additional sensors and information of motor parameters, the rotor position is aligned at stand still for maximum starting torque. The open loop control scheme is applied to accelerate the motor from standstill with known information of rotor position and given commutation logic. The feasible operation of the sensorless control is demonstrated by MATLAB/Simulink results.

Key words: BLDC motor, Sensorless control, maximum starting torque, start-up technique.

Introduction

The stator of PMBLDC motor has three phase winding and rotor with permanent magnet, in which brushes and commutators have been completely eradicated. The winding of stator have energized and de-energized with the necessity of the power electronics switching devices by known information of the rotor position. It is easy to start and stop the PMBLDC motor due to low inertia. The communication of the stator current is an important with the help of rotor position information which is attained by providing mechanical arrangement of the hall sensor with rotor an accurate and ripple free instantaneous torque of the PMBLDC motor is achieved. This leads to become high cost and poor reliability.to overcome the above mention restrictions a potential solution of many position sensorless algorithms has been considered. By integrating the back EMF of the floating phase, the rotor position of the rotor can be extracted easily.

However this method has a drawback in finding the rotor position at lower speeds. Due to the access of the motor neutral point will complicate the motor construction and also cost of the motor neutral point will complicate the motor construction and also cost of the motor increased to same extent. To coincide with the six communication point an approach use the zero crossing point of the three phase line to line voltage. Hence the sensorless drive scheme needed a specific start up process. In general it is difficult to implement this procedure it is necessary to excite two implement the open loop start up system termed as align and go. To implement this procedure it is necessary to excite two phases of the three phase windings for a predetermined time. At that instant, the permanent magnet rotor rotates to align to an exact position. The open loop control system is applied to accelerate the motor from standstill with known information of rotor position and specified commutation logic.

The zero crossing point of back emf induced in the stator winding is detected by the sensorless rotor position systems. However one of the three phase winding is not energized. To control the phase voltage and to commutate the energized pair it is essential to process the information attained using pulse width modulation. For modeling, torque calculation and control concept of the offer drive, this application notes provides a fundamental mathematical method. The establishment of this drive was to implement in simple applications (e.g. pumps, compressors, fans…) within a speed range in addition to load. The drive performance at different operation condition has to be monitor with the simulation outcome.

Back EMF Sensing

In PMBLDC machine the instantaneous rotor position and trapezoidal variation with 120º flat span will result in magnitude of back emf. However, in practice, it is difficult to measure the back EMF, due to the quickly changing currents in machine windings and induced voltages due to phase switching. At the time of starting the back EMF is not enough until the rotor reaches some speed. In general, the preliminary acceleration under open-loop control by using a ramped frequency signal so that the back-EMF is computable for the controller to lock in.

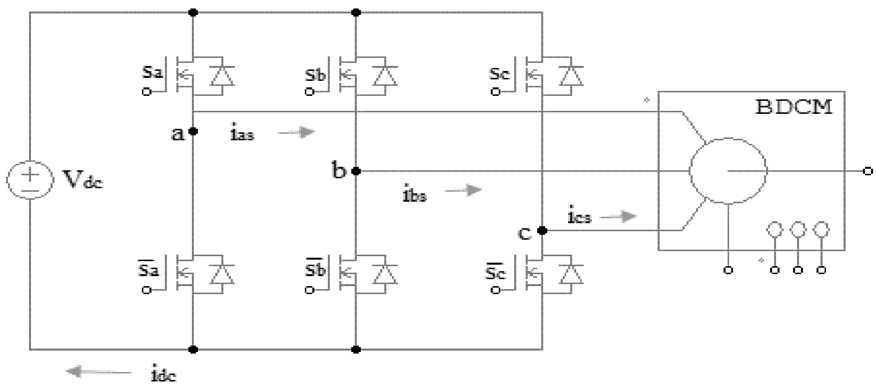

Figure 1: Circuit diagram of a BLDC motor drive

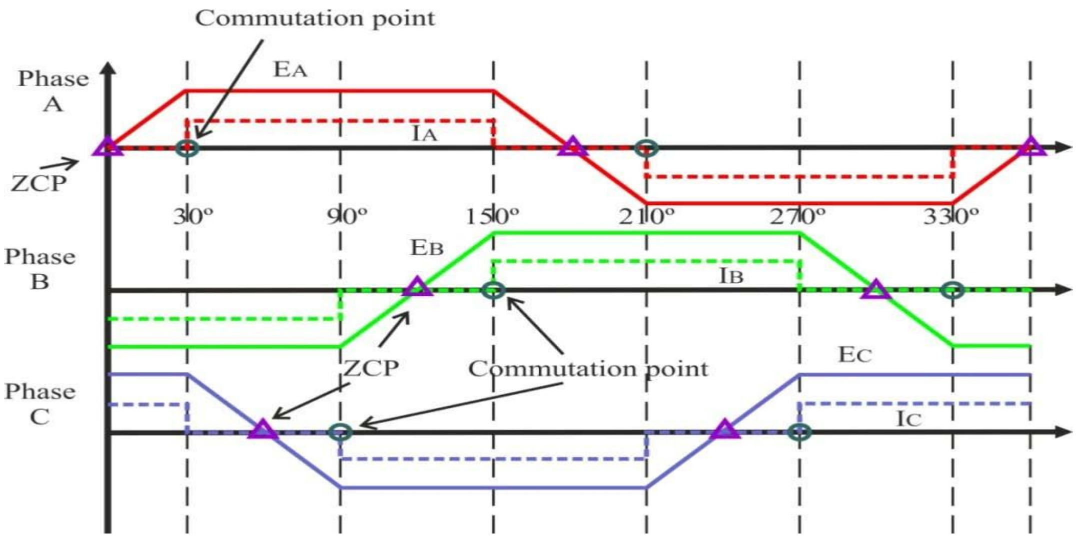

Figure 2: Zero crossing points of the back-EMF and phase current commutation points

One of the favorable widespread starting methods is "align and go", in which the rotor is line up to the definite position by energizing any two phases of the stator and by giving the appropriate commutation sequences then the rotor is accelerated to the desired speed. Due to large instantaneous peak currents at initial the demagnetization of permanent magnets has main drawback of the "align and go" method. The detection of zero crossing points of the back EMF in each phase is an elegant feature and these points occur at rotor position where the phase winding is not energized moreover these points do not related to the commutation moments. For proper commutation the signals need to be phase shifted by 90° electrical. To overcome the phase-shifting difficulties direct control procedure and phase locked loops have been suggested. A special start up procedure is necessary in sensorless drive system the rotor position of the motor at standstill or very low speed the back EMF is too small.

Alignment of Rotor Position

In the BLDC motor, by utilizing alternative six excited voltage vectors V1~V_6, which are sketched in Fig. 4. Only two phases of the three-phase stator windings are excited at any instant. The commutation is done at every 60° electrical and the flow of current is only in two of the three winding. At standstill, the determination of the rotor position which is aligned into one of six positions by the six excited voltage vectors to energize two phases of the PMBLDC motor. As it is clearly known, the deviation of these voltage vectors is of every 60° of electrical angle.

The main drawback of the conventional start-up method has reduced the performance of the PMBLDC motor. To overcome this limitation, a simple start-up method is proposed to achieve the maximum starting torque and to control the stator current. A remarkable technique is shown in Fig. 3.by implementing this principle. The path of the current and position of the initial voltage vector V_i are shown in Fig. 3 and 4, respectively. The two stator windings are excited, in the conventional method whereas all the three stator windings are energized in the proposed start-up scheme by using a specific initial voltage vector V_i (1,0,0). If the rotor is located between voltage vector V_1 and V_2, the voltage vector V_3 is orthogonal to V_i. It is chosen as the next applied voltage vector in order to achieve maximum starting motor torque at start-up.

Start-Up Procedure

The acceleration of the BLDC motor from standstill to a specific speed is consider by startup procedure after align the rotor position, where the Sensorless scheme is not self-starting. To detect the zero crossing point of the back EMF, the motor is started and brought to certain speed. The rotor speed increases by gradually increasing the frequency. The reference voltage magnitude is adjusted which is proportional to the rotor speed. The integration of the rotor speed, the modulation of the pulse width with respect to the reference voltage magnitude, the phase angle can be obtained. However without any rotor position information, the six PWM signals with 60 degree phase displacement are generated with respect to the phase angle. To switch the system to Sensorless control where the rotor speed reaches to 2500 rpm, the back EMF is sensed to provide the rotor position information.

The phase ‘A’ terminal voltage with respect to the star point of the stator V_{an}, is given in (1)

$$V_{an} = R_a i_a + L_a \frac{di_a}{dt} + e_{an} \tag{1}$$

$$V_{bn} = R_b i_b + L_b \frac{di_b}{dt} + e_{bn} \tag{2}$$

$$V_{cn} = R_c i_c + L_c \frac{di_c}{dt} + e_{cn} \tag{3}$$

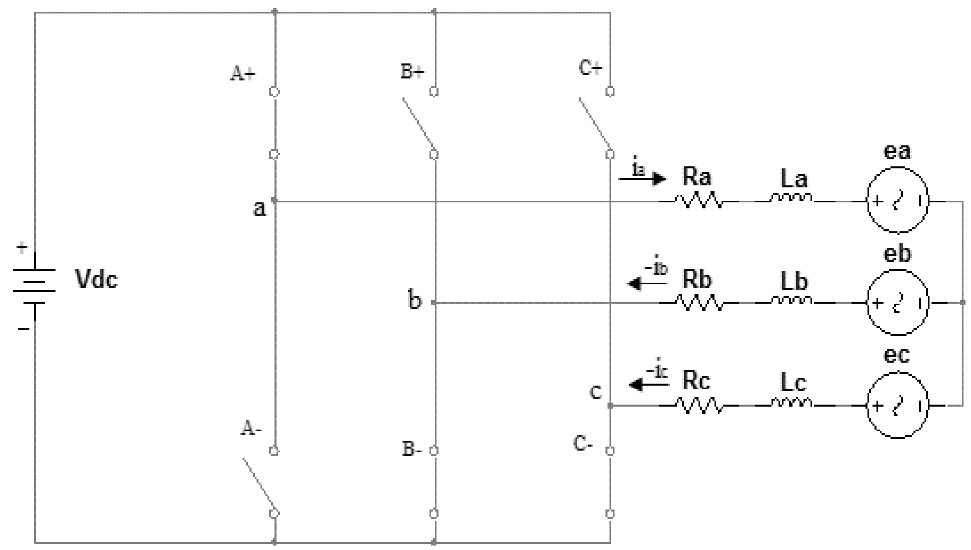

Figure 3: Switching states of the inverter

Where R_a is the stator resistance, L_a is the phase inductance, e_{an} is the back EMF, and $i_a$is the phase current of the "A" phase. Similar equations can be written for the other two phases, as in (2) and (3)

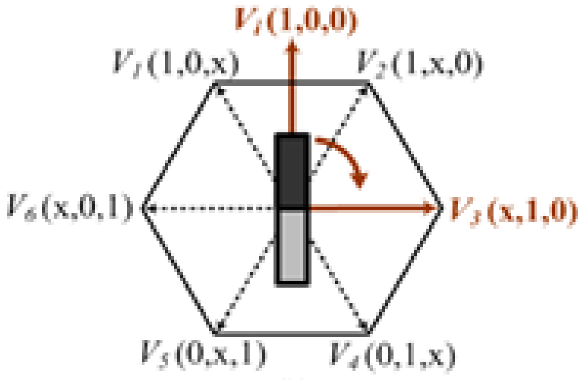

Figure 4: Initial rotor position

Controller

The speed regulation is accomplished with PI controller. For small speed regulation faults, the regulators sensitivity has to improve for faster reaction by increasing the proportional gain of the speed regulator. Moreover this reduces the speed overshooting. The desired speed is achieved by fast decrement of armature current.

An increase of the integral gain will allow the motor speed to catchup with the speed reference to a faster ramp during sampling periods. When a signal is regulated by a subsequent ramp, a faster reaction to small speed error integral terms will occur. By following an accelerating ramp, the speed error integral is reduced by a lot and faster by producing a slightly higher acceleration torque with respect to the regulator. Instability can occur due to the high increase of the proportional, integral gains and the controller becomes insensitive. Too high gains also lead to result in saturation. Tuning process is done by trial and error method where the proportional constant (k_p) and integral constant (k_i) are 0.1 and 0.03 respectively.

Table 1: Block Parameters Of Proposed Bldc Motor System

PARAMETERS	VALUES
Configuration	Trapezoidal
Mechanical input	Torque (Tm) in Nm
Stator Phase Resistance	2.8750 Ω
Stator Phase Inductance	$8.5 * e^{-3}$H
Flux linkage established by magnets	0.175(v.s)
Torque Constant	1.4 (Nm/A)
Back emf flat area	120°

Inertia (J)	0.8e-3 (kgm^2)
Friction factor (F)	1e-3 (N.m.S)
Pole pairs (P)	4

Simulink Model of Proposed System

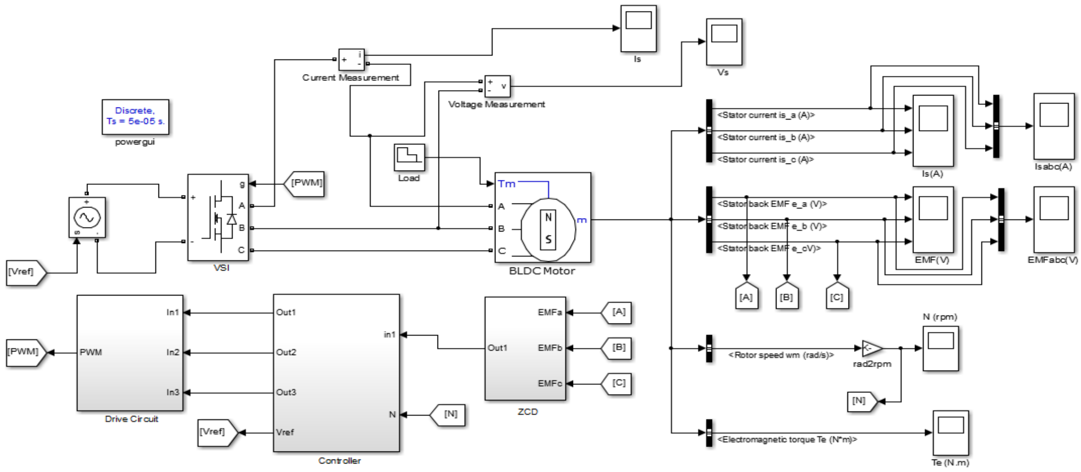

Figure 5: Simulink Model of proposed Sensorless BLDC Drive

The Fig 5 shows the Simulink model of the proposed BLDC motor[17]. A three phase brushless dc motor is modeled using closed loop controller in MATLAB/SIMULINK as shown in the Fig 4. A brushless dc motor is modeled as permanent magnet synchronous motor with trapezoidal back emf. The actual speed signals are the input to the controller which is converted to the appropriate voltage signals. By comparing the actual speed with the reference speed, the gate signals are generated. Thus with the help of PI controller present in the controller block, a closed loop speed control is achieved.

The input to the zero crossing detector are the signals of three phase stator back emf. The PI controller have the inputs from the zero crossing detector and the actual speed of the BLDC motor. The controlled output signals produced by the controller based on the input signals are given to the drive circuit. The simulation model of the drive control circuit is shown in Fig 6. To control the performance of a BLDC motor the output of the drive circuit is given to the inverter circuit which is controlled by the input signals of the drive circuit.

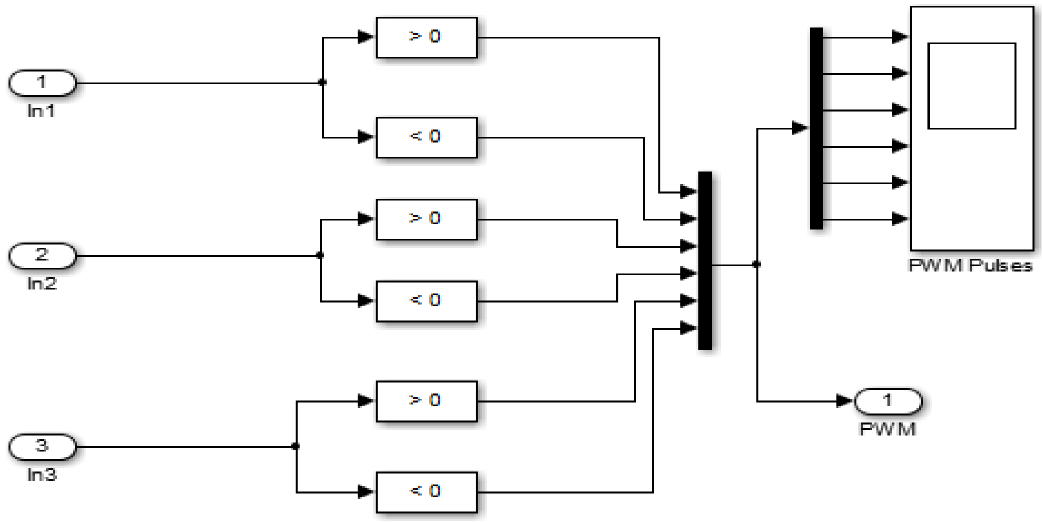

Figure 6: Circuit Diagram of a Drive Control Unit

Results and Discussion

The presented results are arranged based on the parameters shown in Table I. The simulation model of the proposed system is shown in Fig 5. Fig. 7 to 15 shows the experimental results with responses to the reference and rotor speeds, reference voltage and phase-A current to verify the start-up technique.

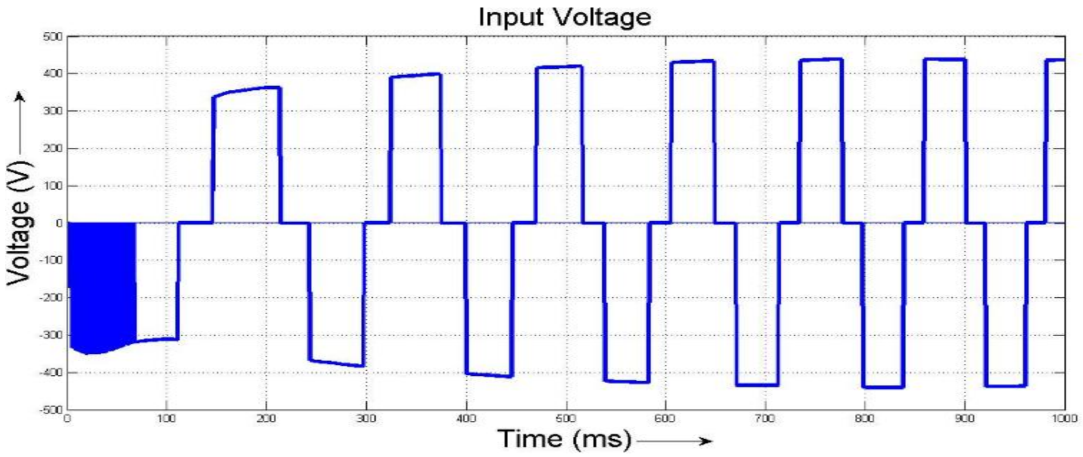

Figure 7: Input Voltage Signal

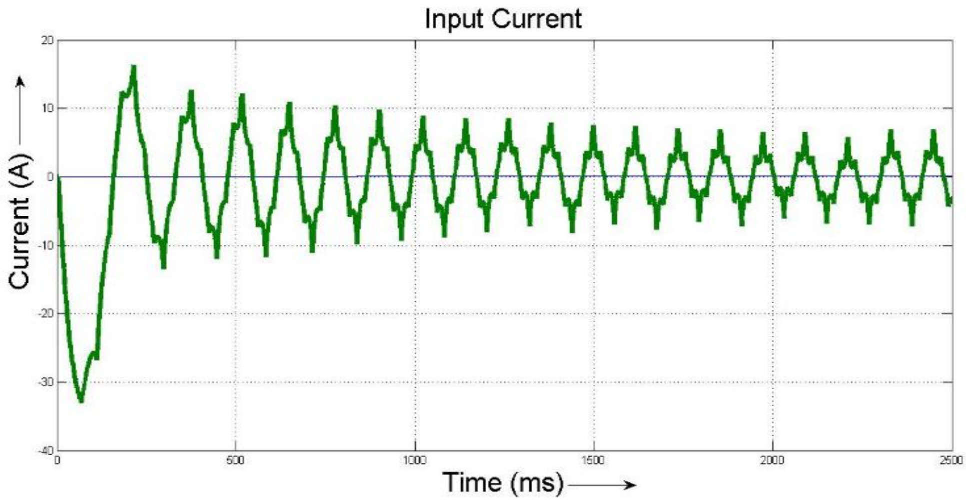

Figure 8: Input Current Signals

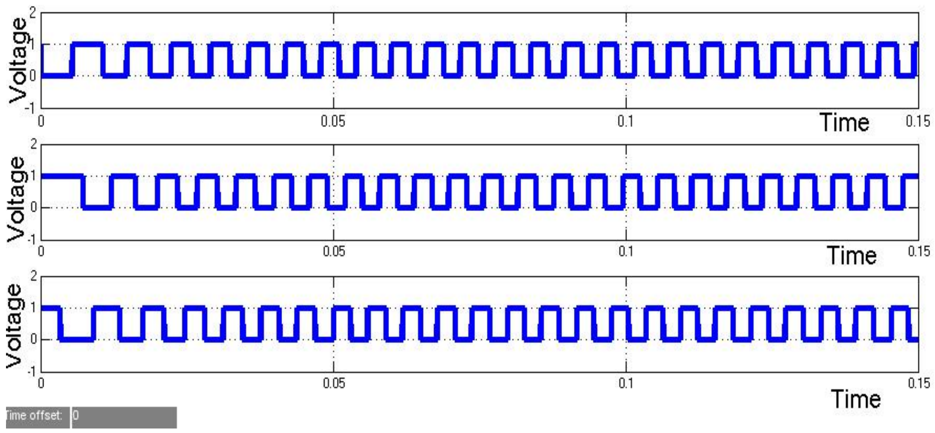

Figure 9: ZCD Signals

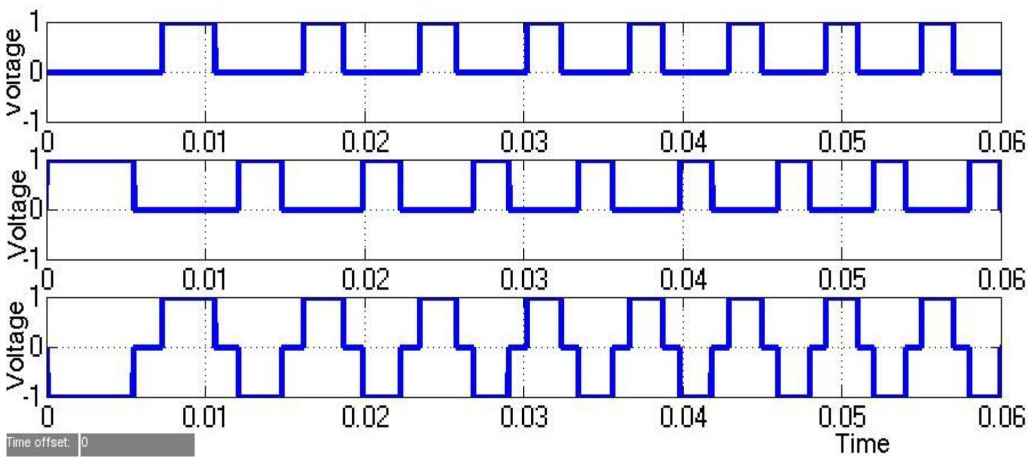

Figure 10: Decoder outputSignals.

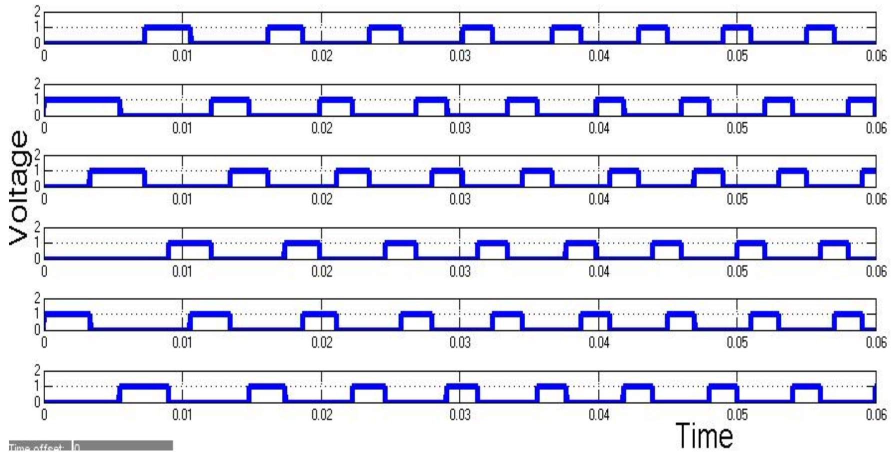

Figure 11: PWM Signals

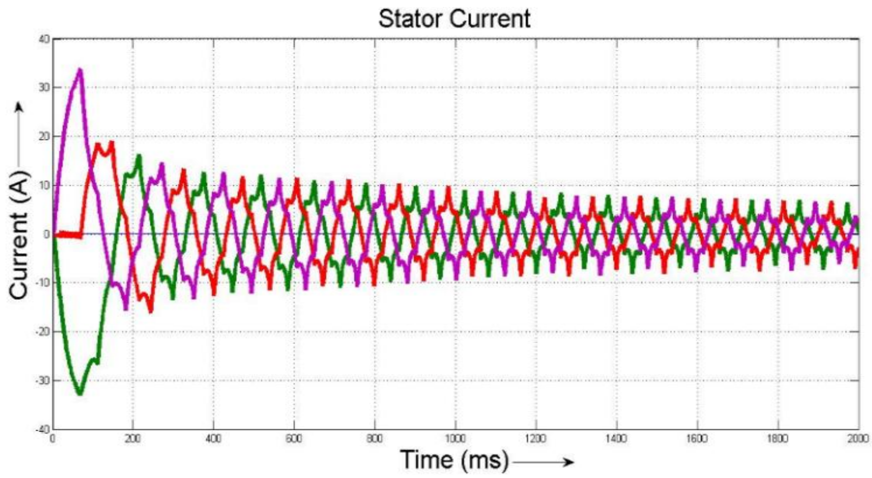

Figure 12: Three Phase Stator Currents

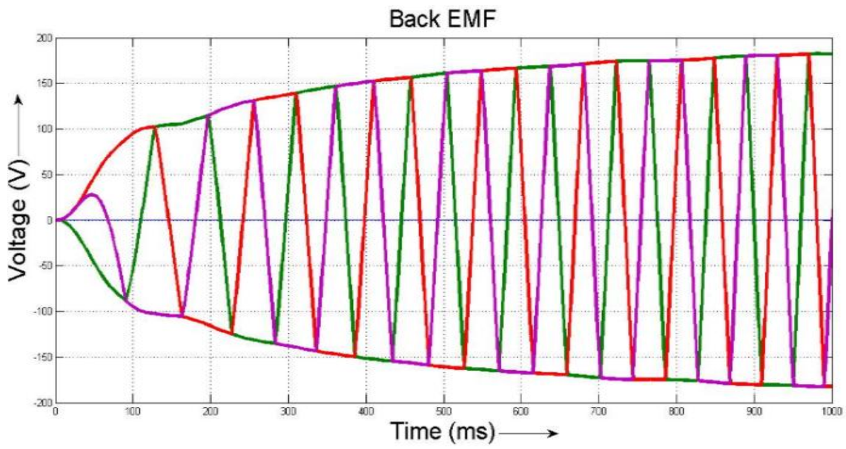

Figure 13: Three Phase Stator EMF

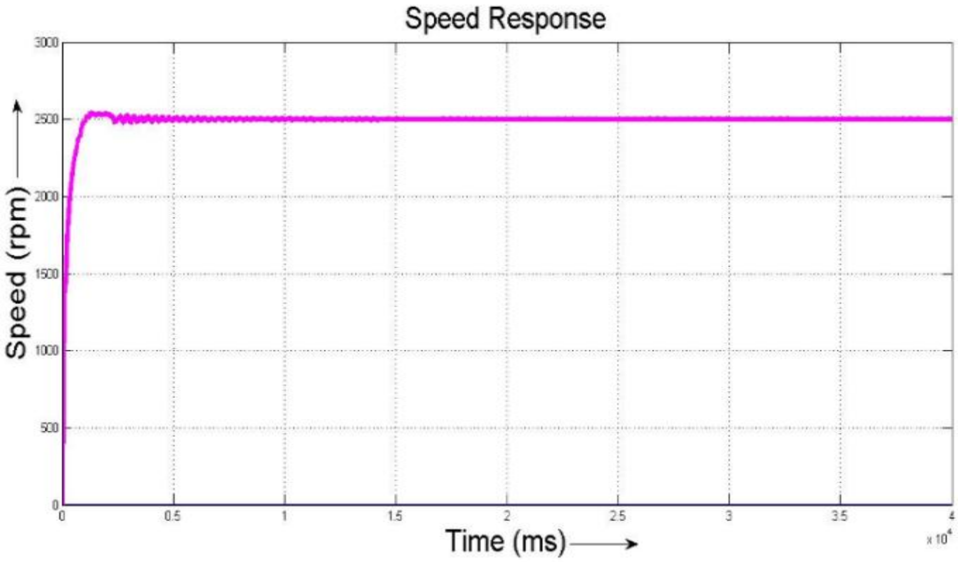

Figure 14: Speed Response Curve

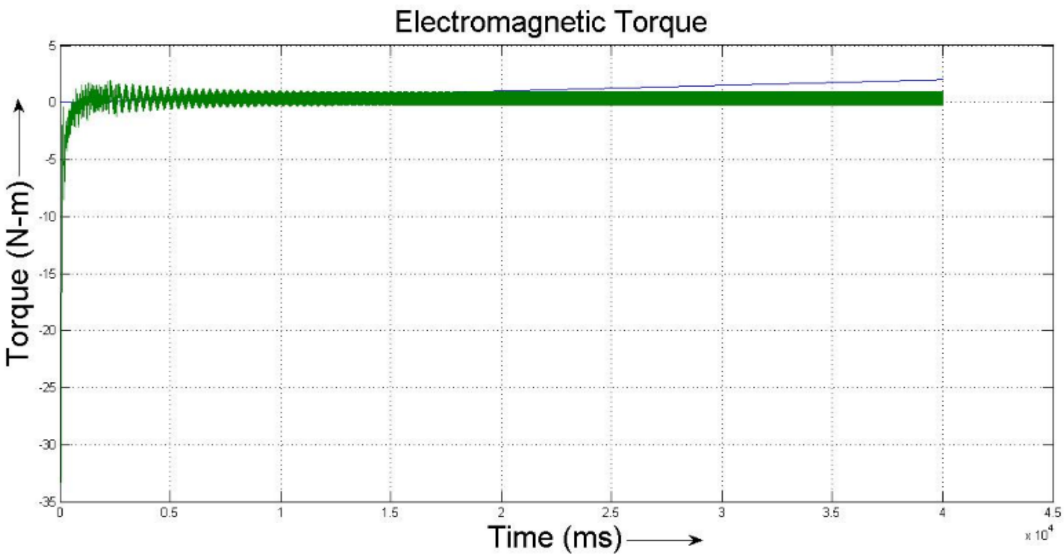

Figure 15: Electromagnetic Torque Curve.

By adjusting the duty cycle to 15%, the rotor is aligned to the initial position for a time interval of 80ms and with the proposed startup method the motor is accelerated to 2500 rpm. The output results of the drive circuit (PWM signals) that are used to drive the inverter circuit with sensorless mode of operation. The waveforms of the three phase stator current are shown in Fig 12 and we consider phase A,B and C respectively which is having 120 degree phase displacement. Similar to the waveforms of the three phase stator current, the waveform of three phase stator emf are shown in Fig 13 and here also we consider phase A,B and C currents respectively which is having 120 degree phase displacement. The speed ranges for 2500 rpm with the help of PI controller are shown in Fig 14 which intimates the speed response curve. Based on the loading nature of the drive, the electromagnetic torque curve is shown in Fig 15. Finally the speed is stabilized with the reference speed of 2500 rpm.

Conclusion

In this paper, a line back emf is proposed to control the BLDC motor based on sensorless scheme. The elaborate version of the back emf is exposed in this method. The motor neutral voltage is eradicated by only measuring the three motor terminal voltages. By using the innovative zero crossing detection algorithm, a sensorless mode provided to run the machine is projected in this paper.Based on the proposed method there is possible to implement in industrial application with low cost.Only three motor terminal voltages want to be measured thus eradicating the need for motor neutral voltage. To accomplish the maximum initial torque, the BLDC motor tracks fast from a standstill up to a nominal speed by aligning the rotor position. By modifying the pulse width of specific switching devices, an effortless control is made to obtain the magnitude of the stator current by aligning the rotor position. Even with normal load and load transients the motor starts with smooth and run in sensorless mode. The suitability of the proposed method is exposed by the simulation results.

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