Simulation of Sensorless Digital Control of BLDC Motor Based on Zero Cross Detection

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Abstract: **This paper presents the simulation of sensorless digital control of BLDC motor based on zero cross detection. From the terminal voltage difference, zero crossing is detected. The difference in line voltage provides an appropriate back EMF at its zero crossing. A special control of digital control is used for smooth and reliable sensorless operation.BLDC motor is controlled in all four quadrants, even the energy is conserved during regenerative braking.**

***Keywords*: BLDC motor, Sensorless, zero crossing, digital control, regenerative braking.**

I. INTRODUCTION

In BLDC motor the rotor is connected to the permanent magnet and the stator to the windings.They are of star connection. Here the windings are connected to the control electronics rather than brushes and commutators. BLDC motor has less inertia, such that the start and stop of the motor is easier. They either have rectangular or trapezoidal voltage stroke with rotor position. When the motor is of 90° they provide maximum torque. BLDC motor is powered by voltage source or current source inverter, which is controlled by rotor position detected by hall sensor.

Many techniques have been presented based on position sensing using zero detection crossing, sensing third harmonic of motional emf, terminal voltage sensing, integration of back emf, inductance variation, flux linkage variation, Kalman's filter [4, 5]. Only two phases are excited out of three, where the third winding is left floating at any instance. From floating winding, back emf can be measured for switching sequence in three phase inverters. The terminal voltage of the floating winding with respect to the neutral point of the motor is in need for the zero-crossing time of the back emf. They are widely used for low cost application. ZCP cannot be obtained when BLDC motor is in standstill or operating nearly at zero speed. Therefore, digital control is obtained for smooth and reliable sensorless operation. The simulation is obtained by MATLAB/SIMULINK. The effectiveness of the sensorless control has been studied with digital control. BLDC motor are of fast operation, less noise, more efficient and reliable. BLDC motors are used in Aerospace, Industrial automation, Medical analyser, Industrial engineering, Model engineering.

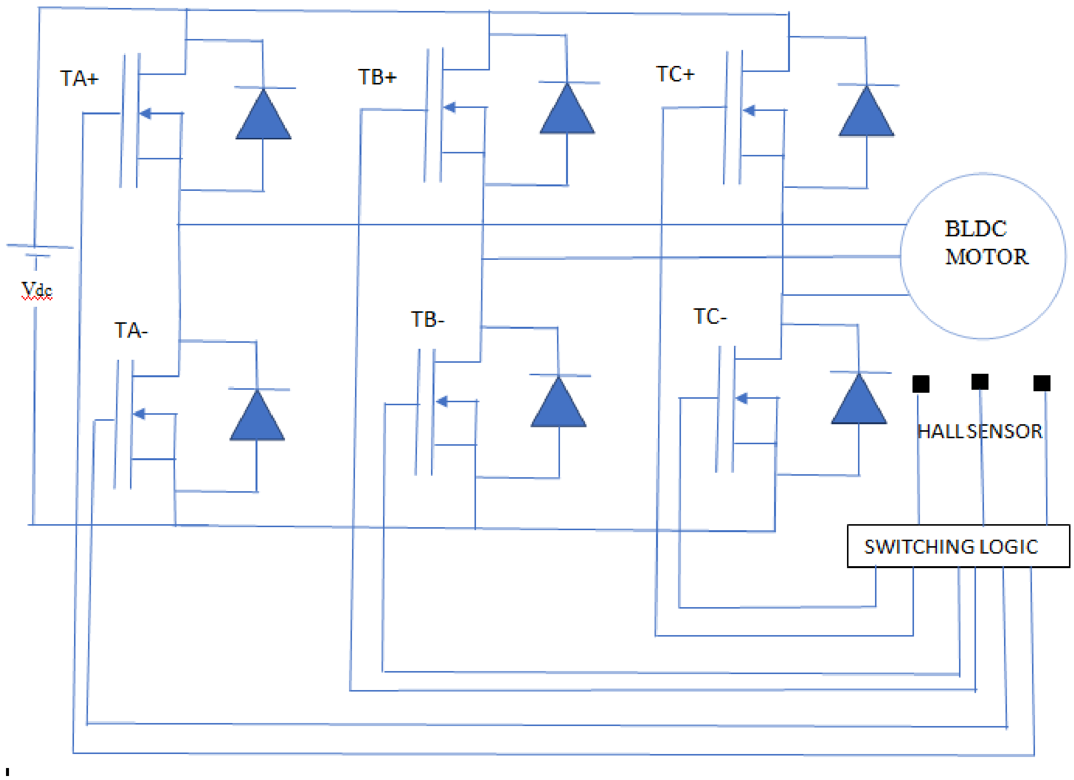
II. BRUSLESS DC MOTOR

Conventional Dc motors are highly efficient. Their characteristics make them suitable for the use of servomotors. The main drawback is that they are in need of commutators and brusheswhere the requirement of maintenance is must. These commutators and brushes are replaced by solid state switches, where BLDC motor is emerged. The function of both the brushless and DC commutator motor is same. The only difference is that the brushes and their maintenance, also the problems associated with brush is eliminated.

BLDC motors are driven by DC voltage but the current commutation is controlled by solid state switches. The commutation instants are determined by rotor position sensor but here the sensors are eliminated. Instead of sensors zero crossing detection method is used to determine the position. In BLDC motor only two windings are excited, leaving the third winding floating. To determine the zero-crossing time of the back emf, the floating winding of the terminal voltage to the neutral point has to be determined. They are widely used for low cost applications. ZCP method is not applicable when the motor is in standstill or near zero speed [7].

III. EQUIVALET CIRCUIT OF BLDC MOTOR

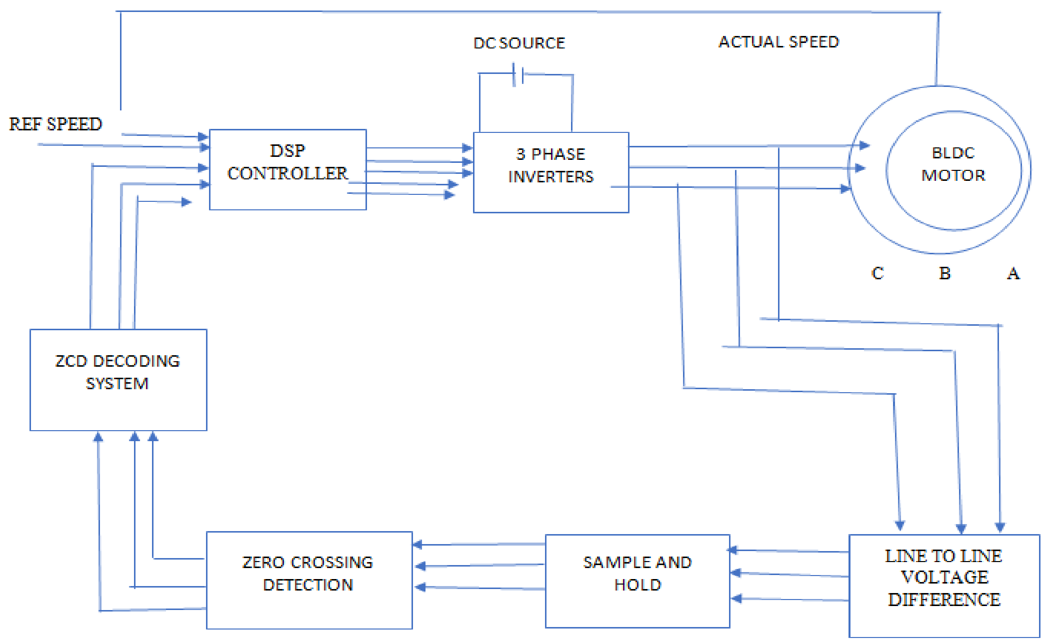
They consist of six switches where two of them are connected in series and four switches are connected in parallel as shown in fig (1). These switches are supplied with dc voltage. From the BLDC motor using ZCD method the position is sensed and they are decoded and send to the hall signal in the controller. The PWM signals are generated and those signals are sent to the inverters, where the BLDC motor starts to run.



EQUIVALENT CIRCUIT OF BLDC MOTOR. FIG (1)

IV. METHODOLOGY

BLDC motor runs when the pwm signals are obtained from the inverter. The full system is controlled by the digital controller, which combines the digital signal processor features and PIC microcontroller features. Instead of sensor here sensorless ZCP method is used to detect the position.



BLOCK DIAGRAM FIG (2)

The input signals to BLDC motor is given from the inverter. Using zero crossing detection from the line to line voltage difference the pwm signals are detected. The values from the zero-crossing detection is decoded and send to dsp controller. In the controller the actual speed and the reference speed is compared and also the required signals to the inverter is sent through the controller.

V. ZERO CROSSING METHOD

Consider three phase stators winding of BLDC motor connected in star. The motor is driven by three phase inverters which are triggered by the rotor position. The phase to neutral point of the three phases are given as

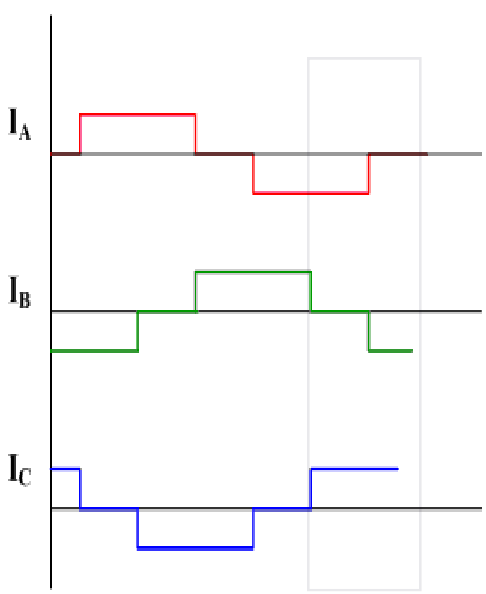
$$V_{an}=R_a i_a+L_a di_a/dt+e_{an}$$

$$V_{bn}=R_b i_b+L_b di_b/dt+e_{bn}$$

$$V_{ac}=R_c i_c+L_c di_c/dt+e_{cn}$$

Where R_{is} the stator resistance, L is the phase inductance, e is the back emf and i is the phase current.

VI. PHASE CURRENT OF BLDC MOTOR



PHASE CURRENT AND BACK EMF. FIG (3)

From the above equation, line voltage is determined as

$$V_{ab}=V_{an}-V_{bn}$$

$$V_{ab}=R(i_a-i_b) + Ld(i_a-i_b)/dt+e_{an}-e_{bn}$$

$$V_{bc}=V_{bn}-V_{cn}$$

$$V_{bc}=R(i_b-i_c) + Ld(i_b-i_c)/dt+e_{bn}-e_{cn}$$

$$V_{ca}=V_{cn}-V_{an}$$

$$V_{ca}=R(i_c-i_a) + Ld(i_c-i_a)/dt+e_{cn}-e_{an}$$

These line voltages can be estimated without the use of star point, by taking the terminal voltage differences with respect to the negative DC bus.

Since only two terminal phases are in conduction and leaving the other phase floating, we will subtract V_{bc} from V_{ab}, it gives

$$V_{abbc}=V_{ab}-V_{bc}$$

$$V_{abbc}= R(i_a-2i_b+i_c) + Ld(i_a-2i_b+i_c)/dt+e_{an}-2e_{bn}+e_{cn}$$

Let us consider the, the phase A and C are in conduction and leaving out the phase B open as shown by the shaded region in the fig (3). Here phase A is connected to the positive terminal and the phase C to the negative terminal, where phase B is left open. Such that back emf in the phase A and C are equal and opposite respectively.

Therefore,

$$i_a=-i_c, \text{ and}$$

$$i_b=0$$

The voltage of V_{abbc} can be re-written as

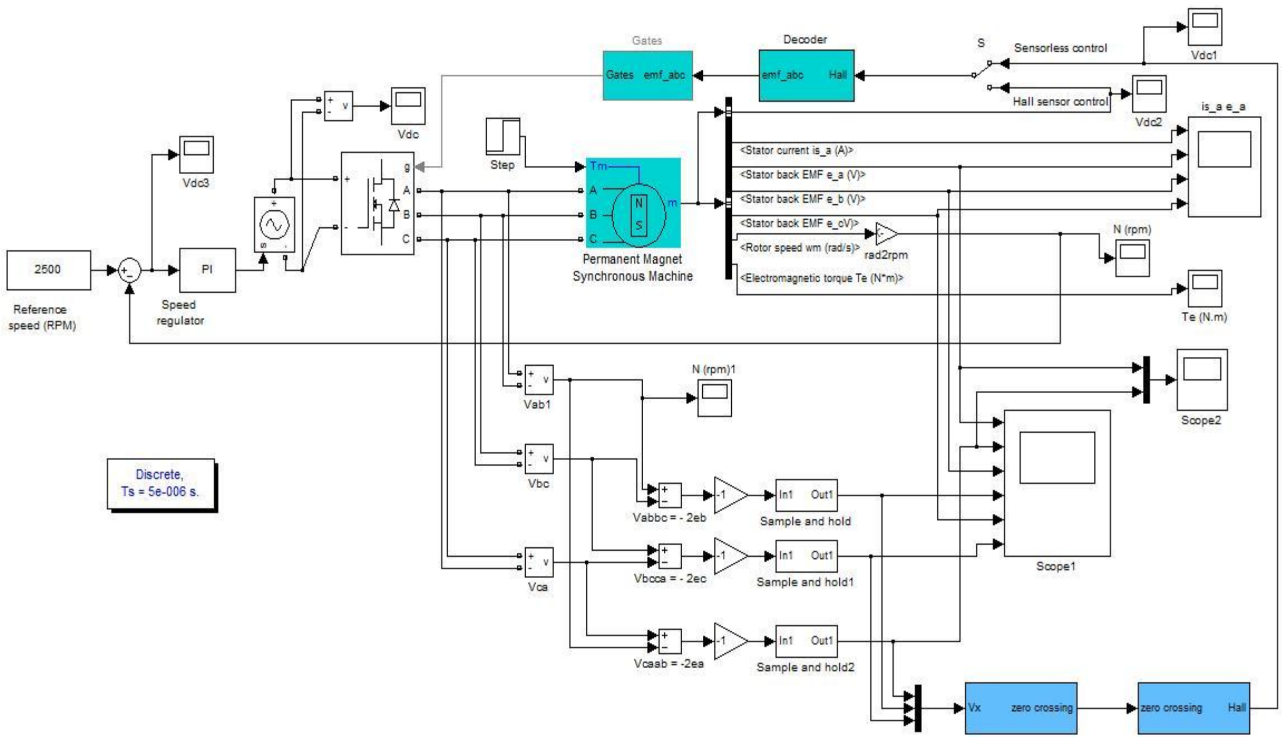
$$V_{abbc}=e_{an}-2e_{bn}+e_{cn}=-2e_{bn}$$

From the graph, it is shown that the back emf of phase B moves from one polarity to the other. This polarity change enables the zero-crossing detection. Similarly, for Vbcca and Vcaab the phases of phase C and A changes the polarity respectively, which enables the zero-crossing detection. Therefore, the zero-crossing instant can be measured indirectly from the three terminal voltages of the motor, where the commutation instants are estimated.

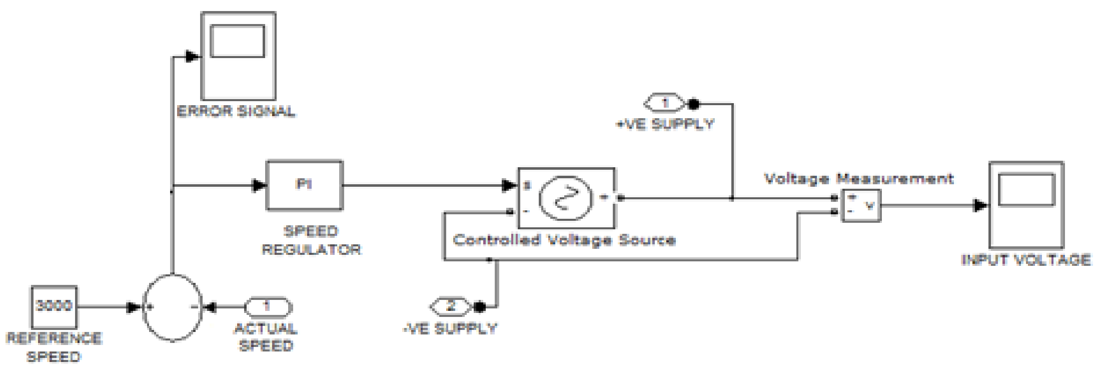
The zero-crossing instants are decoded to corresponding signals using ZCD decoding system. Then the decoded signals are sent to the hall sensor, where gate signals are generated and fed to inverter. These all the signals are controlled by the controller.

VII. DIGITAL CONTROLLER

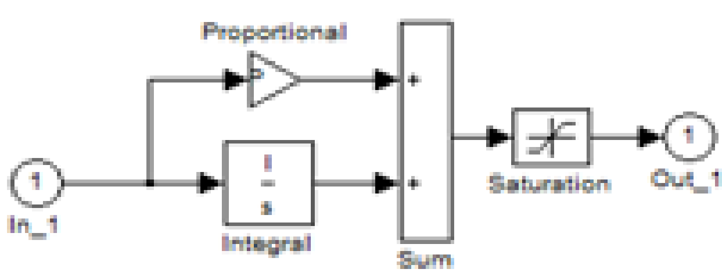
The digital controller will be cost effective and efficient. Here the instructions are performed in a single cycle. This controller carries out the direction from clockwise to anticlockwise and the speed control is also achieved with PI controller. The controller carries out the reference speed and the actual speed, where they are compared. In the controller the decoded signals are received and the hall sensor provides pwm signals to the inverter.



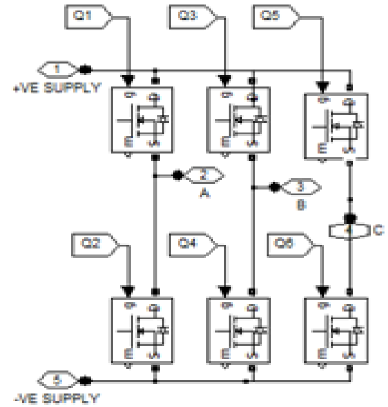
Simulation of sensorless BLDC motor with ZCD fig(4)



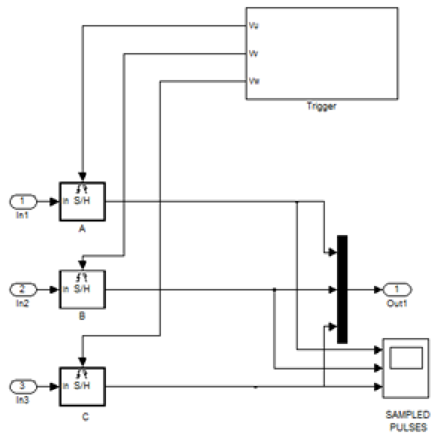
Speed Controller Sub System fig(6)



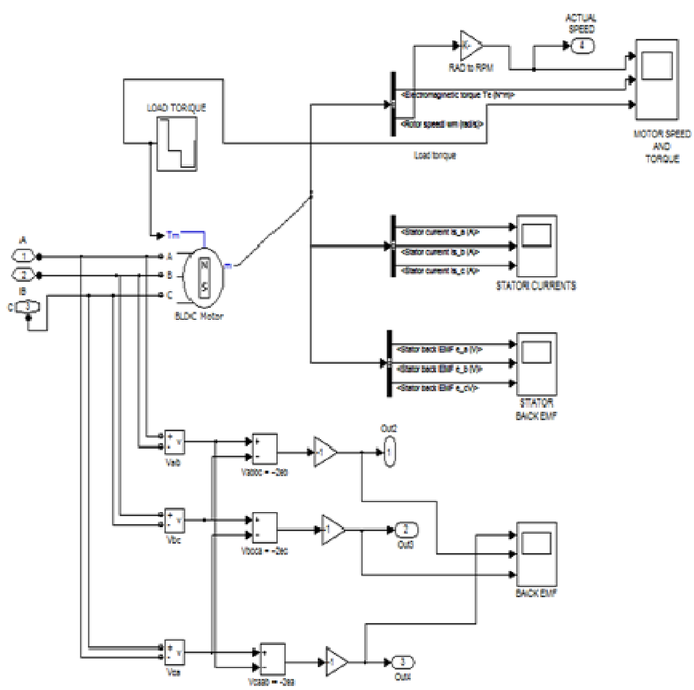
PI Controller fig (7)



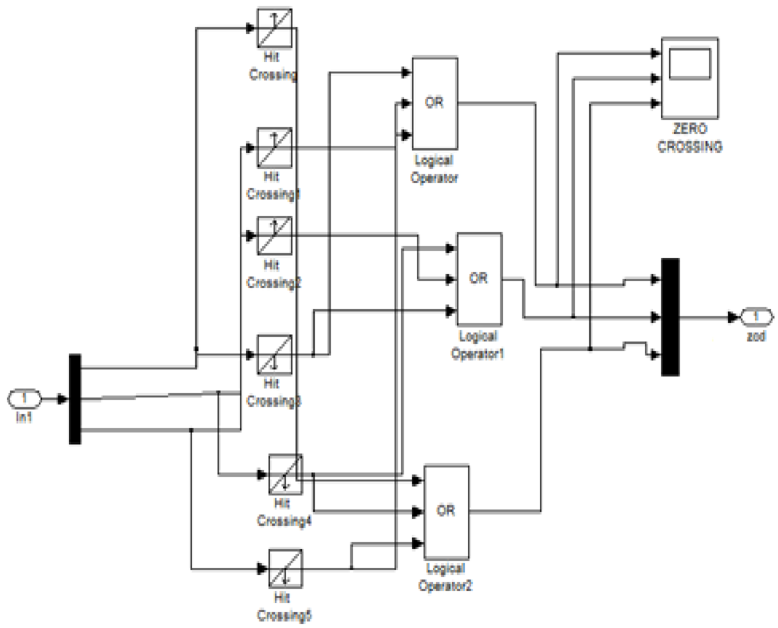
Inverter Sub System fig (8)



Sample and Hold fig (10)



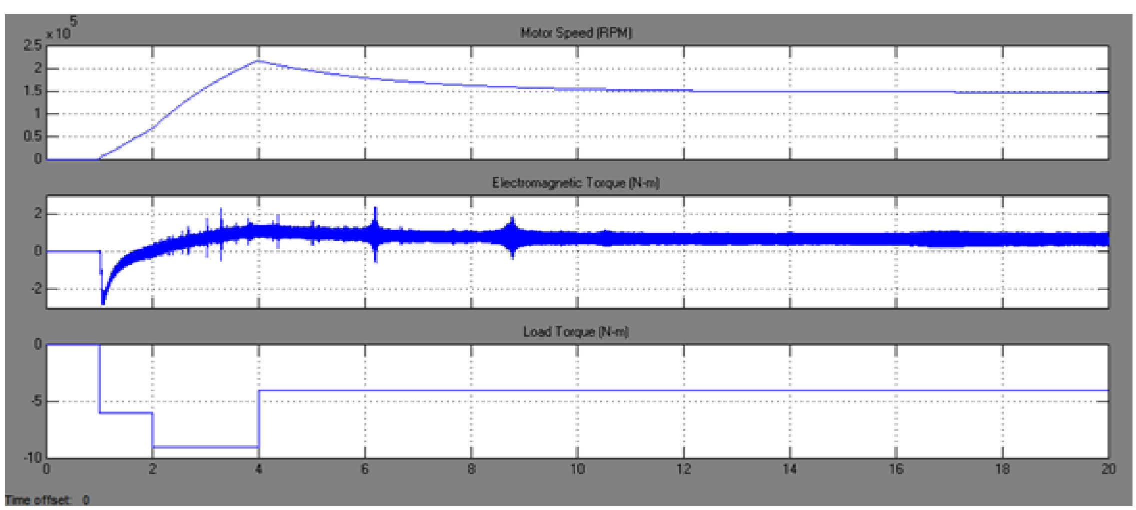
BLDC Motor Sub System fig (9)



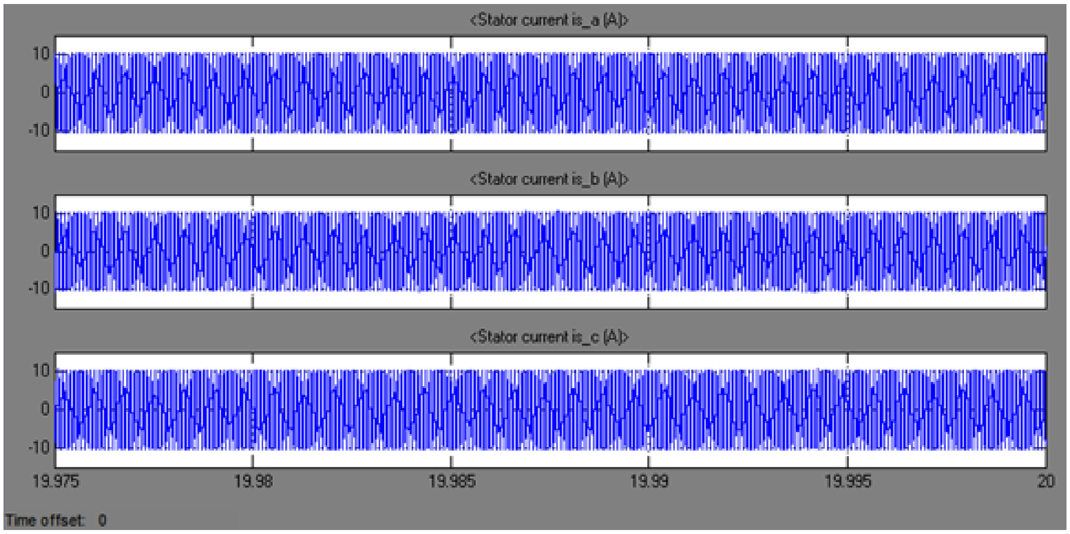
Zero Crossing Detector Sub System fig (11)

Load Variations

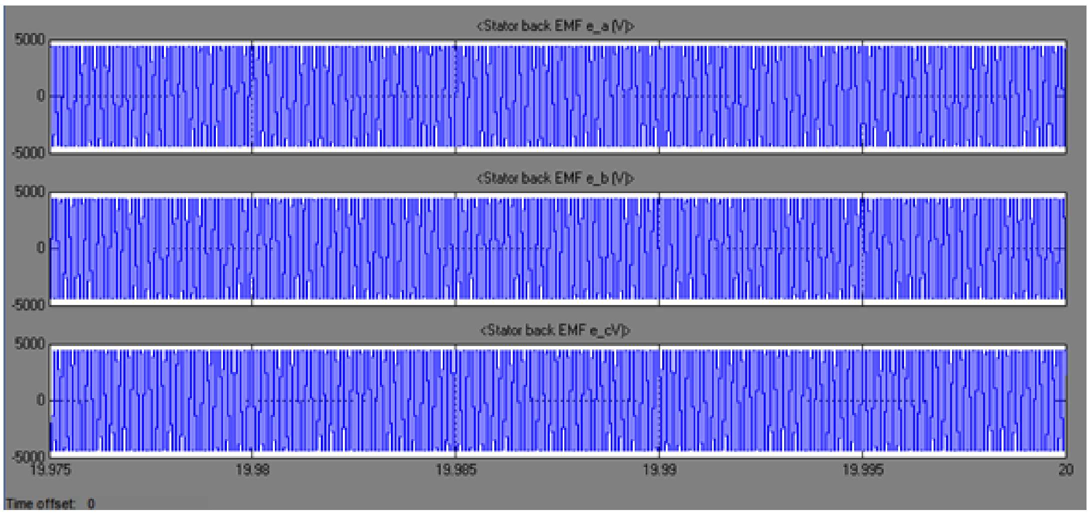
TIME IN SECONDS	LOAD TORQUE	ELECTROMAGNETIC TORQUE
0	0	0
1	-6	-2.7225
2	-9	0.2768
4	-4	1.1112



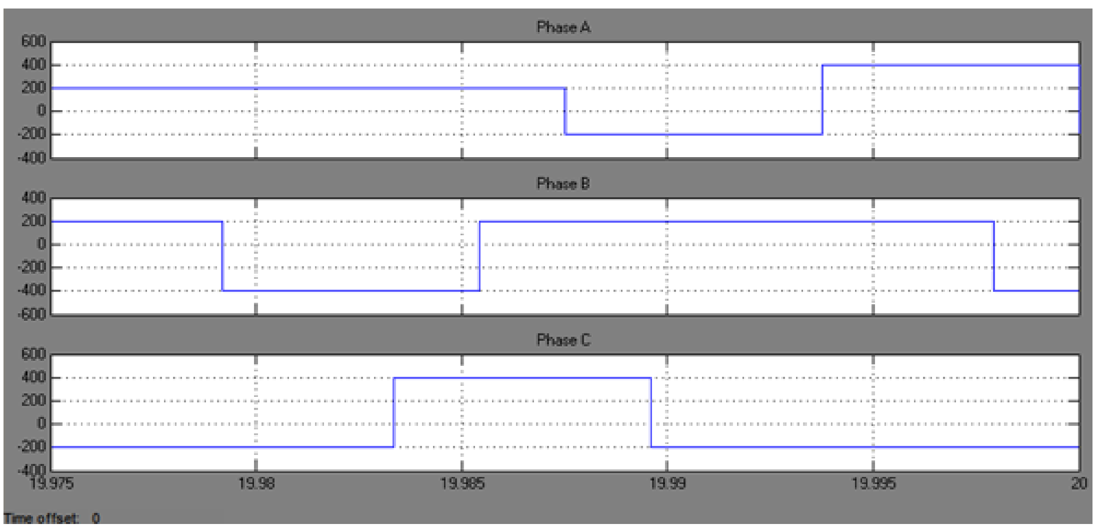
Mechanical output of motor fig (12)



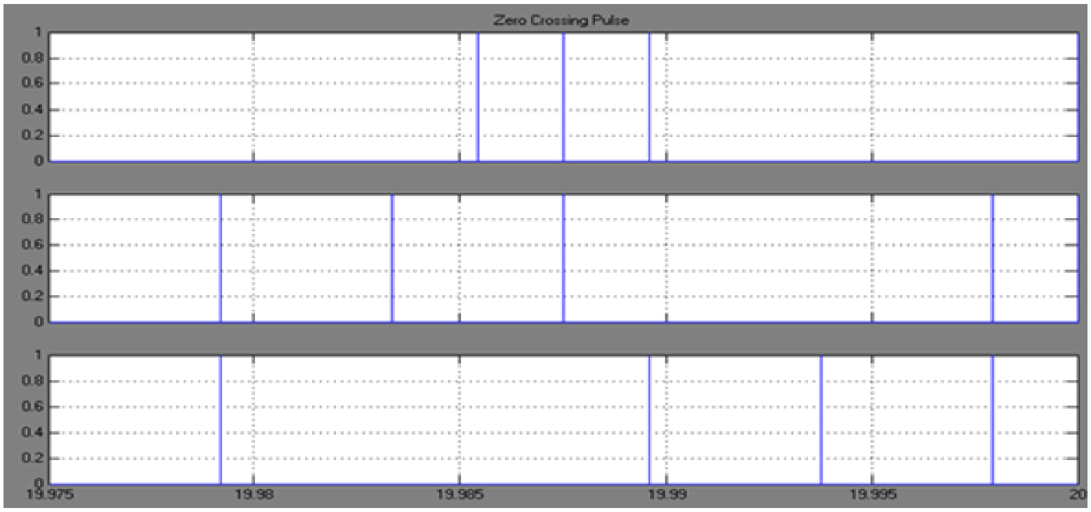
Stator Output of Motor fig (13)



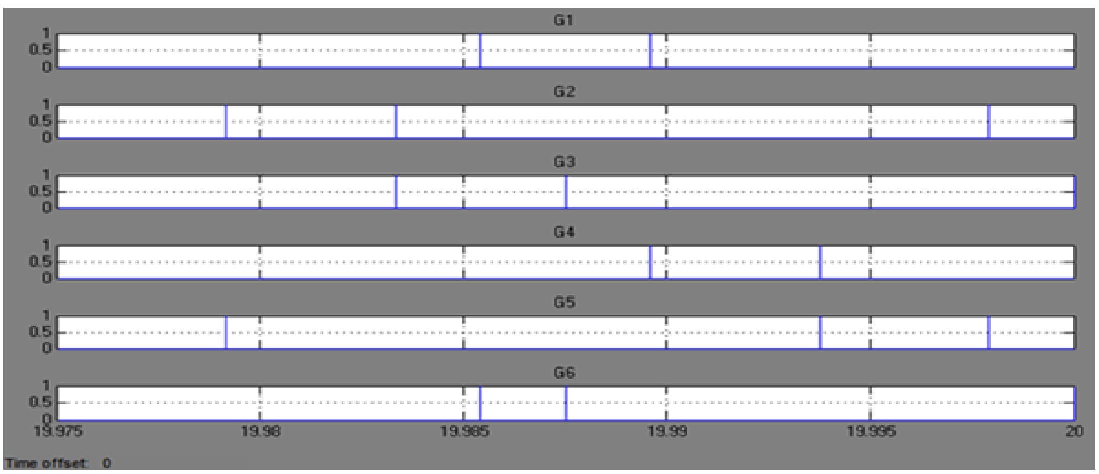
Back EMF of Motor fig (14)



Sampled pulse fig (15)



Zero Crossing Pulse fig (16)



PWM Signals fig (17)

VIII. PI CONTROLLER

For a closed loop system PI controller is used. If the speed controller of P is increased sensitivity of the controller is increased. Such that small error in the speed is rectified in a faster manner. By rectifying the error faster, the operation of the system gets faster and the output obtained will be soon. Increase in P also reduces the speed overshooting. When the desired speed is achieved the armature, current gets reduced.

Similarly, when I is increased the motor speed takes up the ramp to catch the reference speed a lot faster during sample period. This will diminish the speed error. But the increase level of P and I should be within the limit if it exceeds a limit they cause instability and the controller become insensitive.

IX. DRIVE SYSYTEM

When the motor is in running mode or in clockwise direction, they are of accelerating mode. But when a brake is applied there will be a reversal current known as regenerative mode. This reversal current is rectified and stored in a rechargeable battery. Here relays are used in order to protect the motor from the over current. When the reversal current is received, the relay contacts are closed. Such that the reversal current is rectified and stored. When the motor is in motoring mode the relay is kept open. Both the motoring and the regenerative mode can take place here.

X. CONCLUSION

In this paper, the function of sensorless motor and they are controlled by dsp controller where the regenerative braking is done. The simulation output for both the sensorless operation and regenerative braking is shown. The sensorless operation by zero crossing detection has been established in this paper using MATLAB/SIMULINK. The neutral voltage terminal can be eliminated. The reversal operation of the motor is faster. The voltage stored during reverse motoring can be reused for the main supply, which reduces the consumption of power in large amount. This system can be extended in industrial model, electric vehicle by monitoring inverter input voltage and current.

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