DIGITAL CONTROL STRATEGY FOR FOUR QUADRANT OPERATION OF BLDC MOTOR USING HALL EFFECT SENSORS

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Abstract: *A brushless DC electric motor also known as electronically commutated motor powered by DC electricity via an inverter or switching power supply which produces the electricity in the form of AC to drive each phase of a motor via a closed loop controller. Brushless DC motor consists of permanent magnets on the rotor and windings on the stator. It uses one or more Hall Effect sensors to sense the position of the rotor. These drives are becoming more popular in industrial and traction applications. This paper deals with the digital control of BLDC motor drives which is very low cost and simple to implement. The motor is controlled in all the four quadrants without any loss of power and in fact energy is conserved during the regenerative period. The paper is concerned about determining the performance of the permanent magnet motor while operating as a brushless DC motor and to study the four-quadrant operation of brushless DC motor with Digital Control. The digital controller is advantageous over other controllers as it combines the calculation capability of Digital Signal Processor and controlling capability of microcontroller, to achieve precise control. A control scheme is proposed for BLDC motor to change the direction from clockwise to anticlockwise but the transition is too quick and the speed control is achieved for both servo response and the regulator response. The modular design of the inverter and the BLDC motor is very advantageous and economical as the power rating of the drive can be changed by removing and adding the inverter and motor modules. The effect of PWM strategies and the results can be achieved by the variation of proportional and the integral constants of the PI controller.*

Keywords: **BLDC, four quadrant control, hall sensors, motor drive.**

1. INTRODUCTION

The Brushless DC motor (BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system instead of a mechanically commutation system. BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils. The brushes and commutator have been eliminated and the windings are connected to the control electronics. The control electronics replace the function of the commutator and energize the proper winding. Due to the absence of brushes BLDC motors are capable to run at high speeds. The efficiency of BLDC motors is typically 85 to 90 percent. BLDC motors have high power-to-weight ratio, high speed, electronic control, and low maintenance. They are potentially cleaner, faster, more efficient, less noisy and more reliable. The Brushless DC motor is driven by rectangular or trapezoidal voltage strokes coupled with the given rotor position. The voltage strokes must be properly aligned between the phases, so that the angle between the stator flux and the rotor flux is kept close to 90 to get the maximum developed torque. BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position or its position can also be detected without sensors. BLDC motors are very popular in a wide variety of applications compared to DC motor such as in Automotive, Aerospace, Consumer, Medical, Industrial Automation equipment and instrumentation. This paper describes the four-quadrant operation of the three phase BLDC motor, its features, the controller, the complete drive system, simulation of four quadrant control operation of the BLDC Motor with the results.

2. Proposed System

The closed loop controller for a three-phase brushless DC motor is modeled using MATLAB/Simulink is shown in Figure 1. Permanent Magnet Synchronous motor with trapezoidal back EMF is modeled as a Brushless DC Motor. The model of the controller receives the Hall signals as its input, converts it in to appropriate voltage signals. The gate signals are generated by comparing the actual speed with the reference speed. Thus, a closed loop speed control is achieved with the help of PI control, present in the controller block.

The permanent magnet synchronous machine is used here instead of BLDC motor as the function of both are same and there is no availability of the BLDC motor in the MATLAB. The three-phase bridge inverter with IGBT's is connected to the permanent magnet synchronous machine in order to convert DC to AC. The converter circuit which is present at bottom in the Simulink model is to collect the wasted energy and rectify it and stored in the battery. The model of the converter circuit is shown in the Figure 2. The sub circuits i.e. the decoder and the pulse width modulation circuits are shown in the Figures 3 and 4.

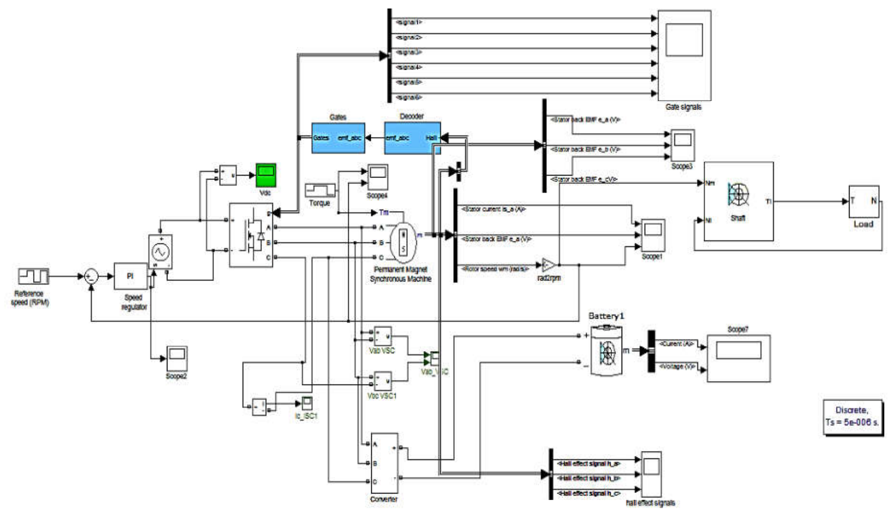


Figure 1. Simulink Model of Proposed System

A converter is that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction or vice-versa. The process of conversion from alternating current (AC) to direct current (DC) is known as rectification. Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter to produce a steady current.

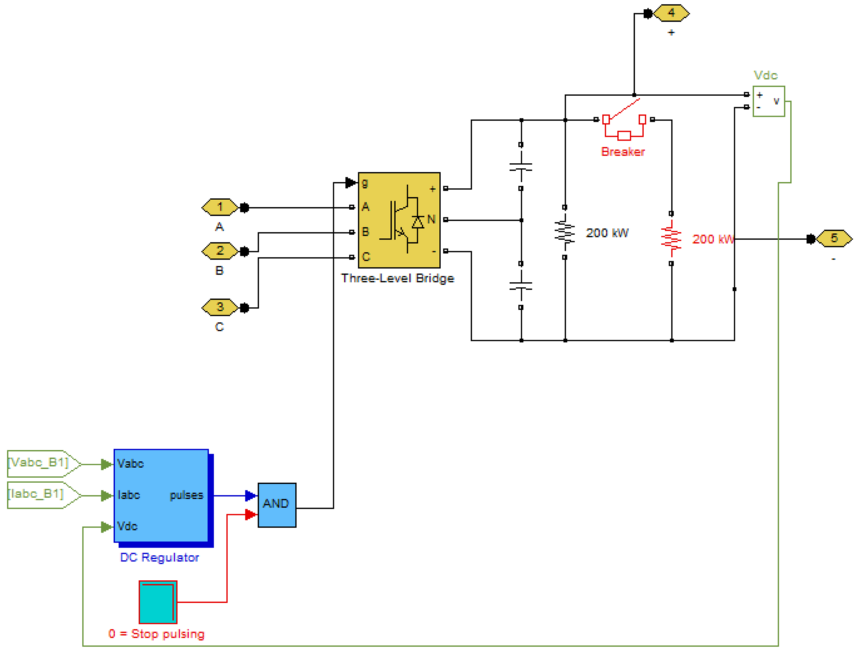


Figure 2. Simulink Model of Converter Circuit

A decoder is a device which does the reverse operation of an encoder, undoing the encoding so that the original information can be retrieved. The same method used to encode is usually just reversed in order to decode. It is a combinational circuit that converts binary information from n input lines to a maximum of 2^n unique output lines. In digital electronics, a decoder can take the form of a multiple-input, multiple-output logic circuit that converts coded inputs into coded outputs, where the input and output codes are different. e.g. n-to-2^n, binary-coded decimal decoders. Enable inputs must be on for the decoder to function, otherwise its outputs assume a single "disabled" output code word. Decoding is necessary in applications such as data multiplexing, 7 segment display and memory address decoding.

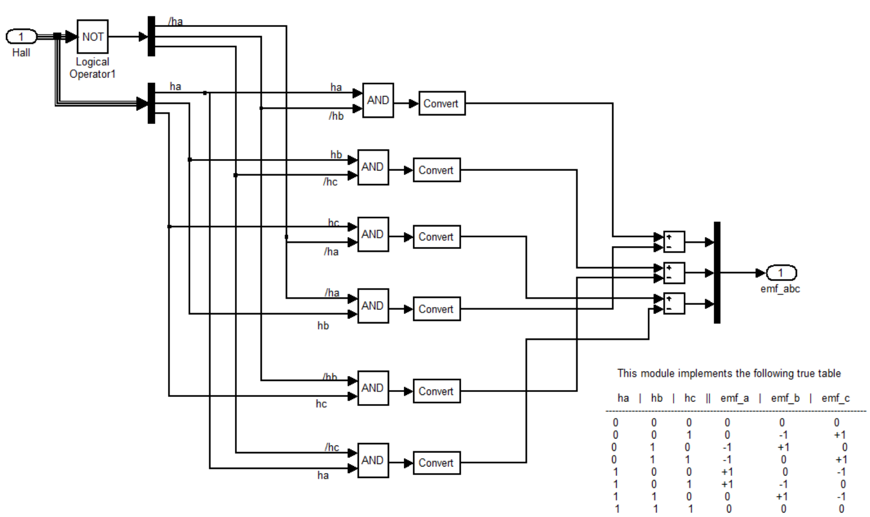
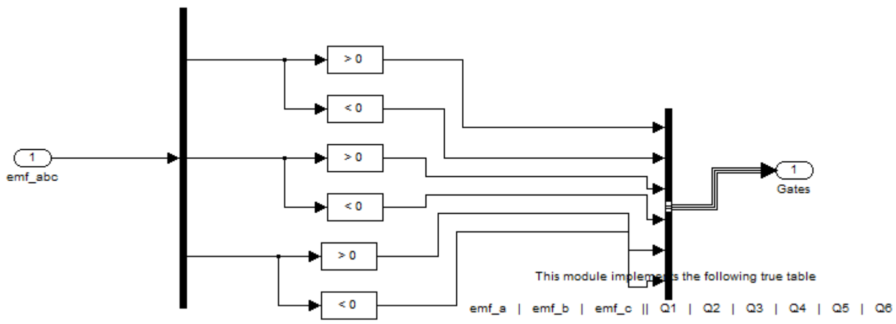


Figure 3. Simulink Model of Decoder circuit

Pulse-width modulation (PWM), or pulse-duration modulation (PDM), is a modulation technique that controls the width of the pulse, formally the pulse duration, based on modulator signal information. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.



This module implements the following true table

emf_a	emf_b	emf_c	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

Figure 4. Simulink Model of Pulse Generator

Single phase inverter covers low range power applications. Meanwhile, 3-phase inverters are usually used for a high-power application. The 3-phase inverters generally are used for supplying 3-phase load especially in AC motor drives and uninterruptible AC power supplies. In order to avoid undefined states in the VSI, and undefined AC output line voltages, switches between upper leg and lower leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon respective line current polarity. In addition, it is also would result in short circuit across the DC link voltage supply which will damage the inverter system if the switches is switching on simultaneously. There are six modes of operating the switches, where in a cycle the phase shift of each mode is 60º. In order to generate a desired voltage waveform, the transistor condition moves from one states to another. The load can be connected in wye or delta connection. The line current is determined when the phase current are known.

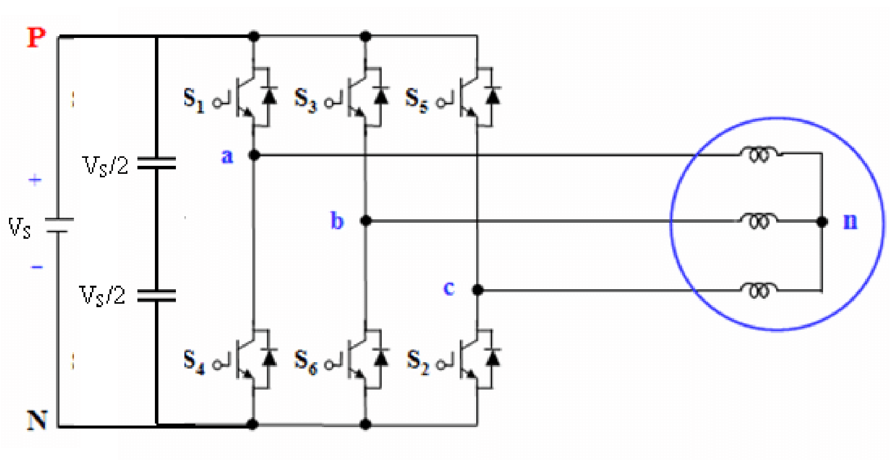


Figure 5. Power Circuit of 3-phase Bridge Inverter

3. Results and Discussion

The simulation results are shown in Figures 6 to Figure 13. Figure 10, indicates that when a negative torque is applied at time 0.6s, there is a peak overshoot in the actual speed, which means it aids the motor to run. At other times the speed is stabilized with the reference speed.

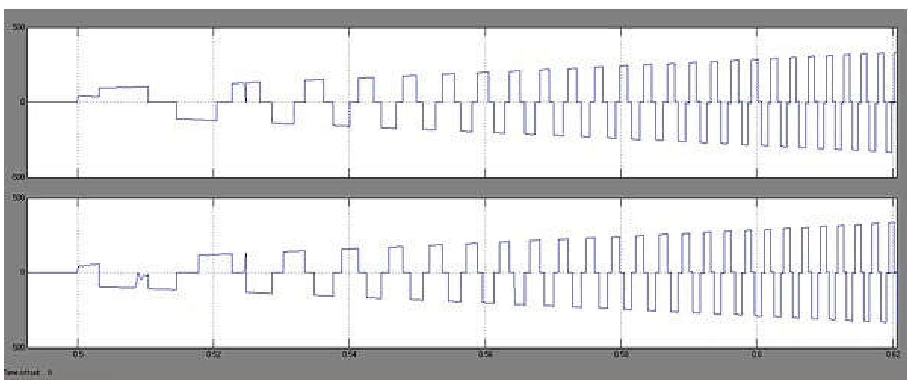


Figure 6. Trapezoidal voltages V_{ab} and V_{bc}

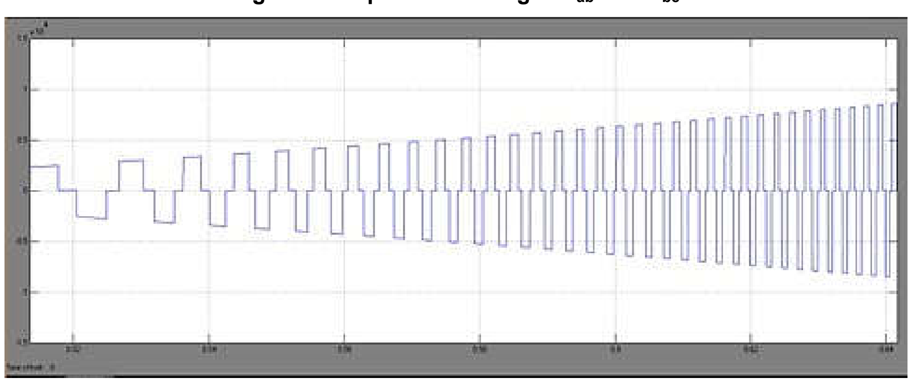


Figure 7. Phase current I_c

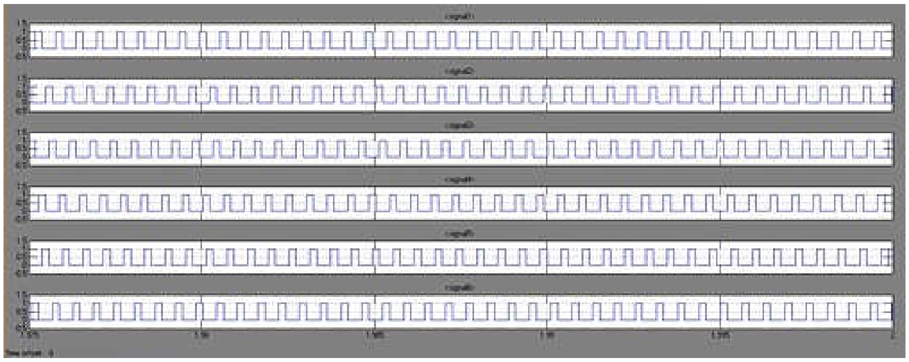


Figure 8. Gate signals

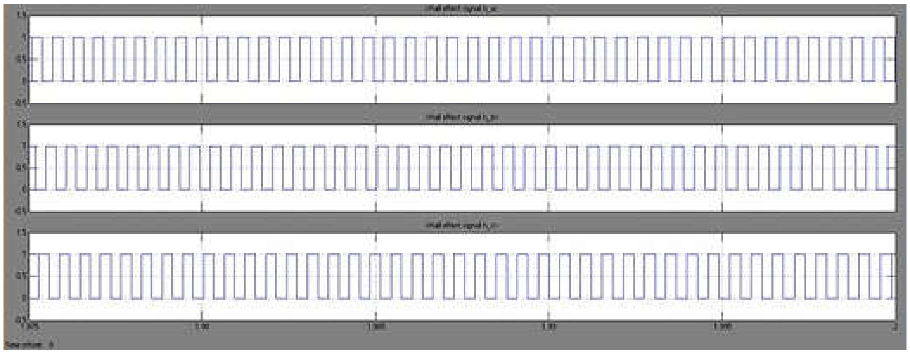


Figure 9. Hall Effect signals

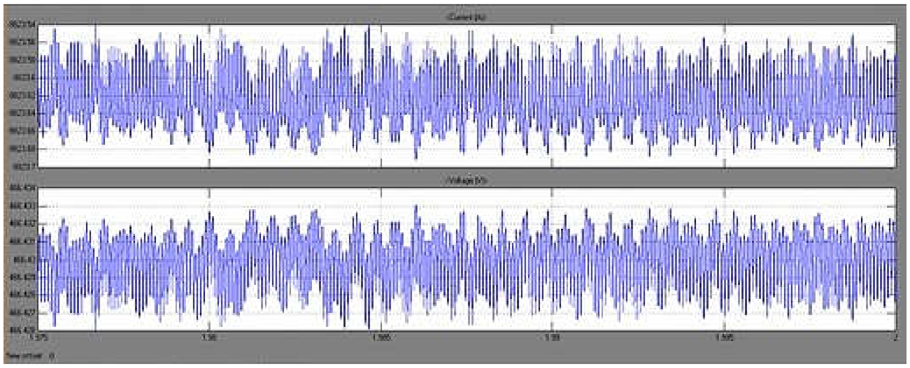


Figure 10. Battery Current and Voltages

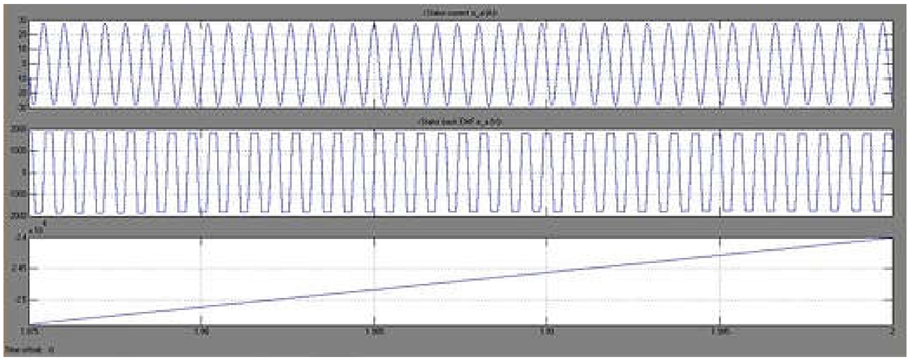


Figure 11. Stator Current, Stator Back Emf and Rotor Speed (rpm)

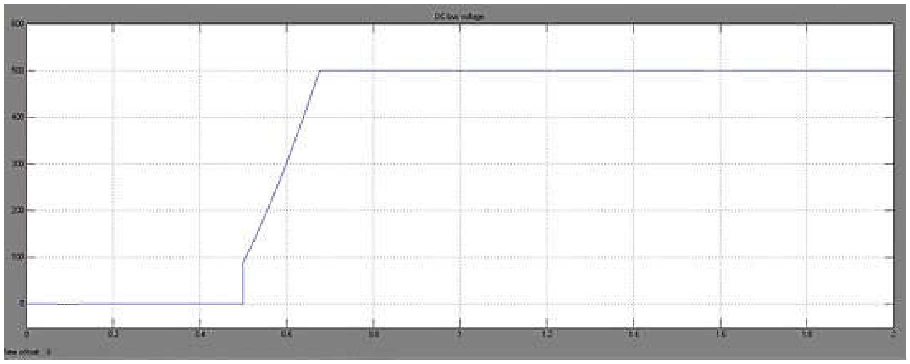


Figure 12. DC Bus voltage

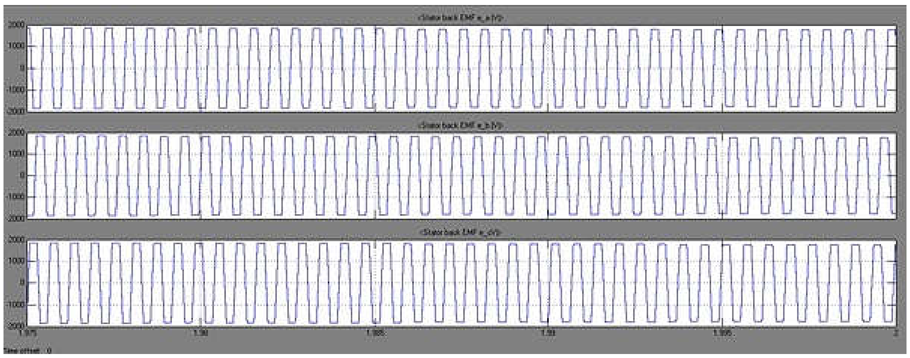


Figure 13. Stator back EMFs

8. Conclusions

In this paper, a control scheme is proposed for BLDC motor to change the direction from CW to CCW and make the BLDC motor operate in all the four quadrants and the speed control is achieved both for servo response and regulator response. The motor reverses its direction almost instantaneously, it will pass through zero, but the transition is too quick. The time taken to achieve this braking is comparatively less. The generated voltage during the regenerative mode can be returned back to the supply mains which will result in considerable saving of power. The speed control is achieved through PI controller and has a simple operation and cost effective. It is observed that the speed remains constant at a desired speed in closed loop control method. The significant advantages of the proposed work are: simple hardware circuit, reliability of the control algorithm, excellent speed control, smooth transition between the quadrants and efficient conservation of energy is achieved with and without load conditions.

For the future development, Hardware development can be implemented. As well as different triggering techniques like spwm and nspwm can be implemented for the three-phase bridge inverter. Sinusoidal Pulse width modulation (spwm) generated by comparing amplitude of triangular wave (carrier) and sinusoidal reference wave (modulating) signal. By using spwm technique it can control the inverter output voltage as well as reduce harmonics. The nspwm is the advanced technique after spwm technique. This concept may well be utilized in the rotation of spindles, embroidery machines and electric vehicles where there is frequent reversal of direction of rotation of the motor. The designed model may be implemented even for higher rated motors. Arcing might occur during the switching on and off of the relay contacts, when implemented in higher rating motors. But if the proposed method is implemented in low power motors, like motor used in sewing/embroidery machines, arcing will be very less which is not even visible.

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