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A Comparative Study Between Sensorless Control of 6 Switch Inverter and 4 Switch Inverter fed BLDC Motor Drive for Bore-well Pumping Applications

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ABSTRACT

The sensorless controlled brushless direct current (BLDC) motor drives are becoming very popular in bore-well water pumping applications because of their less maintenance, higher efficiency, reliability, low cost etc. For bore-wells, the motor drive and the controller parts are submerged inside it and there will be a large increase in the temperature. So the Sensorless control of BLDC motor is preferred as the hall sensors used for rotor position sensing are more temperature sensitive. In order to minimize the entire size of the system we can remove the 2 switches of the inverter. In this paper, a comparative study between sensorless control of 6 switch inverter and 4 switch inverter for bore-well pumping application is considered. Both the inverter fed BLDC motors are simulated in MATLAB simulink and the outputs are analysed.

Keywords: *6 switch inverter, 4 switch inverter , Sensorless control, Back emf.*

1. INTRODUCTION

The DC motors are widely used in rural areas for bore-well water pumping applications. But they require frequent maintenance because of the wear and tear of the brushes in it and therefore they are less efficient for this application. Induction motor needs only less maintenance and they are reliable when it is used in the submersible water pumping systems. As compared with the Permanent magnet BLDC motors, induction motors are not efficient. Hence, permanent magnet BLDC motors are suitable for this system. The brushless DC (BLDC) motor is becoming very attractive in industrial and commercial products [1]-[6]. The BLDC motor is also called as electronically commutated motor and they are synchronous motors that are powered by direct current (DC). An inverter converts the DC into AC to drive each phase of the BLDC motor. The major advantages of the brushless motor over the other motors are electronic commutation, reduced noise, less maintenance and high speed. Due to these advantages they are highly preferable in bore-well pumping applications [7]. For electronic commutation of the motor normally they uses hall effect based position sensors.

The sensorless control of the BLDC motor using back emf eliminates the use of hall effect sensors. The hall effect sensors are highly sensitive to the temperature. Also it should be mounted such a way that it does not affect the other components of the system. The sensorless control of BLDC motor using back emf method is chosen here [8]-[13]. There is an inverter before the BLDC motor to convert the input DC voltage to output AC. Normally in this application 6 switch inverter is used . To reduce the entire size of the system we can remove one leg of the inverter replacing the 2 switches by 2 capacitors and there by reducing the no. of components [14]. So in this paper, the comparison between the sensorless control of a 6 switch inverter fed BLDC motor and a 4 switch inverter fed BLDC motor is shown.

This paper is organized as follows. Section-II deals with the description of six switch inverter fed BLDC motor, Section-III deals with the description of four switch inverter fed BLDC motor. The sensorless control method is presented in Section-IV. Section-V describes the simulation results. Section-VI deals with the conclusions of this comparison.

2. 6 SWITCH INVERTER FED BLDC MOTOR DRIVE

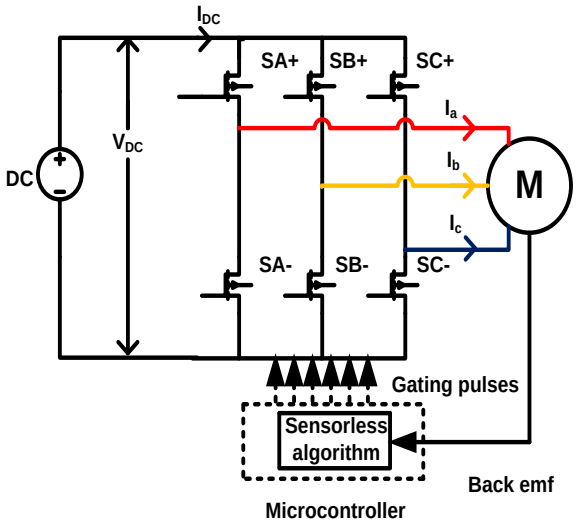

Fig. 1. Sensorless Control of 6 Switch BLDC Motor Drive.

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The system mainly includes a DC source, dc-ac converter having 6 switches, a circuit for sensing the three back emf signals and a submersible BLDC motor. The 6 switch inverter is working in the 120 degree conduction mode. Therefore at any given point of time, only two phases will be conducting.

The logical equations that are used for the 6 switch inverter fed BLDC motor commutation strategy can be given as:

$$S_1 = h_a * \overline{h_b} \quad (1)$$

$$S_2 = h_b * \overline{h_c} \quad (2)$$

$$S_3 = h_c * \overline{h_a} \quad (3)$$

$$S_4 = \overline{h_a} * h_b \quad (4)$$

$$S_5 = \overline{h_b} * h_c \quad (5)$$

$$S_6 = \overline{h_c} * h_a \quad (6)$$

where S_1, S_2, S_3, S_4, S_5, S_6 are six switches of the inverter, and h_a, h_b, h_c are the three hall signals.

3. 4 SWITCH INVERTER FED BLDC MOTOR DRIVE

The schematic diagram of the sensorless control of a 4 switch BLDC motor drive for bore-well pumping application is shown in Fig. 2. The system mainly includes a DC source, dc-ac converter having 4 switches, a circuit for sensing the three back emf signals and a submersible BLDC motor.

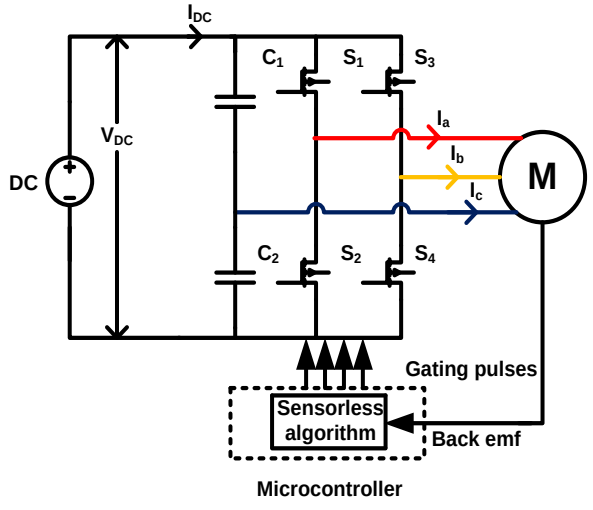

Fig. 2. Sensorless Control of 4 Swich BLDC Motor Drive.

The four switch inverter topology includes 4 switches having 3 legs. The last two legs have 2 switches each and the other leg contains 2 capacitors that replaces the 2 switches. At the midpoint of the two split capacitors, the third phase of the motor is connected. The input DC voltage is divided as half and is given across each capacitors.

Table-I: Switching Sequences of 4 Switch Bldc Motor

Modes	Active switches	Phases- Active
1st Mode	S_4	B, C
2nd Mode	S_1, S_4	A, B
3rd Mode	S_1	A, C
4th Mode	S_3	B, C
5th Mode	S_2, S_3	A, B
6th Mode	S_2	A, C

The logical equations that are used for the 4 switch inverter fed BLDC motor commutation strategy can be given as [10]:

$$S_1 = h_a * \overline{h_b} \quad (7)$$

$$S_2 = \overline{h_a} * h_b \quad (8)$$

$$S_3 = \overline{h_c} * h_b \quad (9)$$

$$S_4 = h_c * \overline{h_b} \quad (10)$$

By reducing the no. of components it is possible to reduce the entire size of the system. So in 4 switch inverter fed BLDC motor drive the no. of components of the circuit is reduced and thereby reduces the size of the system. A sensorless control approach that generates the hall signals from the back- emf is used here.

A. Modelling of split capacitors c_1 and c_2

At minimum speed operation of the motor the designed value of the split capacitance is,

$$C_1, C_2 = \frac{I_{dc}}{4 * f * V_{dc} * \Delta V_{dc}} \quad (11)$$

where, I_{dc} is the DC- link current, 4 is the no of switches, f is the frequency of operation, V_{dc} is the DC- link voltage , and ΔV_{dc} is the DC- link voltage ripple.

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4. SENSORLESS CONTROL METHOD

Normally, in BLDC motor drives for the purpose of position sensing hall-effect sensors are used. In the BLDC motor drive system that are using hall sensors, the circuit of the hall sensor and it's control are very easy but these will increase the entire size and cost of the system.

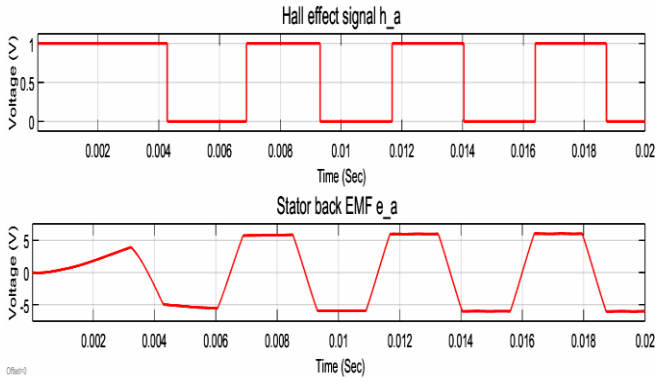

Fig. 3. Hall signal ha and Back emf ea.

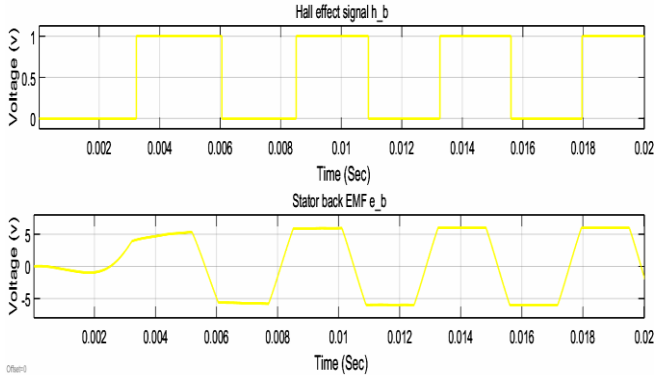

Fig. 4. Hall signal hb and Back emf eb.

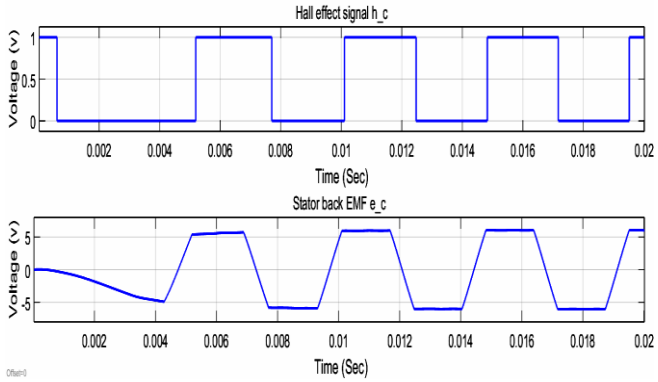

Fig. 5. Hall signal hc and Back emf ec.

On considering some particular applications like air conditioner, submersible bore-well motor pumping etc it may be very difficult to mount the hall sensors on the stator of the motor. Also in the case of bore-wells there will be a higher increase in temperature and the ambience inside it will be very poor. Therefore, BLDC sensorless control approach is having a good interest in the industry. So in this paper a sensorless control of the BLDC motor drive is preferred.

Here the hall signals are generated from the back emfs. That is by comparing the back emfs with zero we can generate the hall signals without using hall-effect sensors. It is shown in the Fig. 3, Fig. 4, and Fig. 5.

During the starting time of the BLDC motor we can see that there is no back emf generated. So, the sensorless control of BLDC motor using back emf cannot be adopted and here the hall signals are generated from a predetermined angle or position of the rotor. From the Fig. 6. it can be seen that by using a ramp signal a virtual speed is created and the angle corresponding to that particular speed for the different sectors will produce the hall signals.

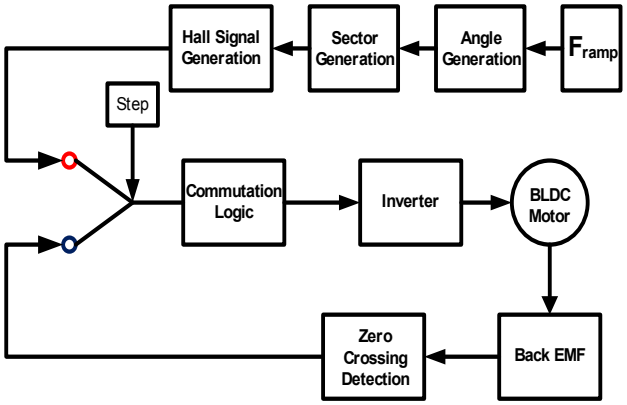

Fig. 6. Control Block Diagram for Sensorless control.

For a small time of 0.3 seconds the motor will run in starting mode as said above and after the 0.3 seconds it will step into the sensorless control using back emf method. Table-II gives the specifications if the major parameters.

Table-I: Specifications Of The Major Parameters

Design Parameters	Value
Rated Torque T_d	0,125 Nm
Rated Power P_d	52 W
Rated Speed Nr	4000 rpm
Poles Nm	8
Phase Inductance L_{ph}	1,2 mH
Phase Resistance R_{ph}	0.72 Ω
Torque Constant Kt	0.036 Nm/A
Moment of Inertia J	^{48} kg/cm^2

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Fig. 9. Torque characteristics of Sensorless control of 6 switch BLDC motor pump.

5. SIMULATION RESULTS

The simulation diagram for 6 switch inverter fed BLDC motor using sensorless control is shown in the fig. 7. In this an inverter is supplied by a dc source having a voltage of 30 V. The inverter converts the DC into corresponding AC to excite the 3 windings of the motor. By using back emfs the sensorless control of BLDC motor is used here and that generates the hall signals by eliminating the hall-effect sensors. For the starting of the motor a predetermined position of the rotor is used to generate the hall signals. After 0.3 seconds the motor will work with the sensorless control method using back emf.

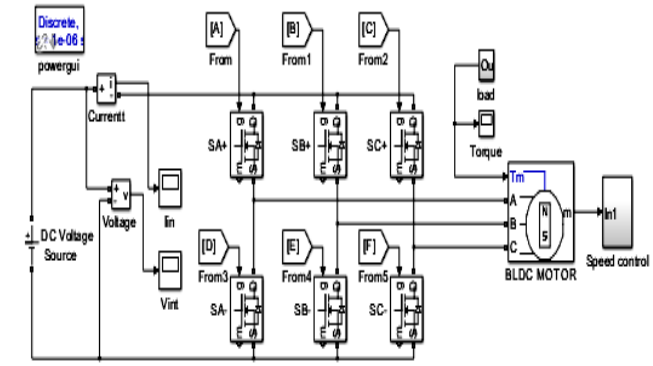


Fig. 7. Sensorless control of 6 switch BLDC motor pump.

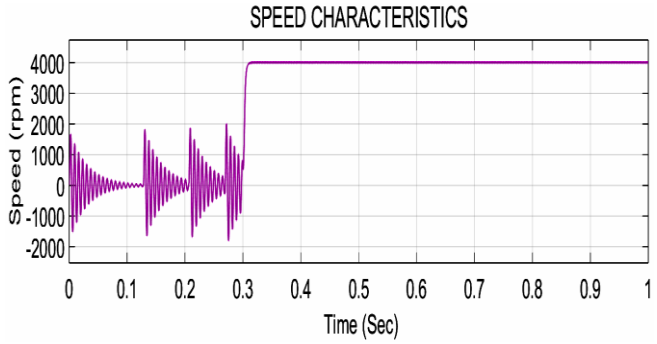
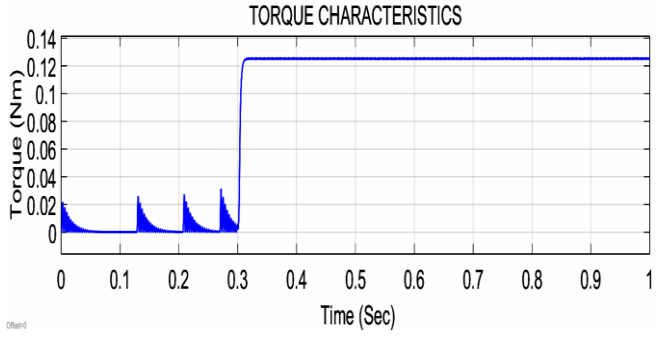


Fig. 8. Speed characteristics of Sensorless control of 6 switch BLDC motor pump.



The simulation diagram for 4 switch inverter fed BLDC motor using sensorless control is shown in the fig. 10. In this also the inverter is supplied by a dc source having a voltage of 30V. The 4 switch inverter converts the DC into corresponding AC to excite the 3 windings of the BLDC motor. As in 6 switch inverter fed BLDC motor , here also a sensorless control of BLDC motor using back emf is used and that generates the hall signals by eliminating the hall-effect sensors. For the starting of the motor a predetermined angle or position of the rotor is used to produce the hall signals.

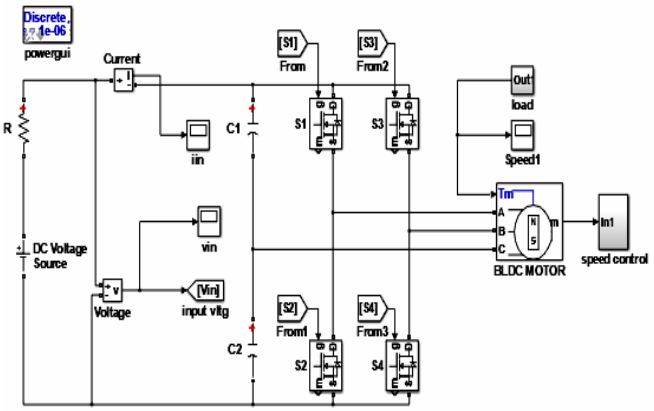


Fig. 10. Sensorless control of 4 switch BLDC motor pump.

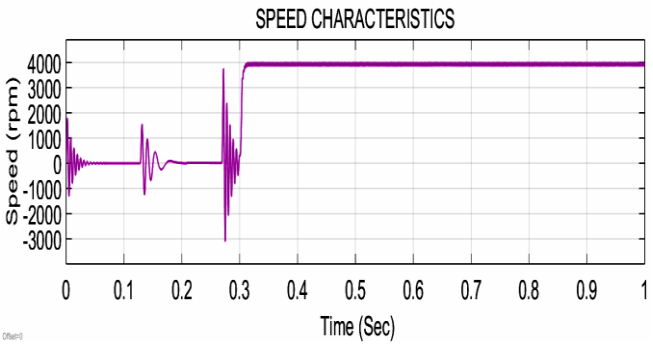


Fig. 11. Speed characteristics of Sensorless control of 4 switch BLDC motor pump.

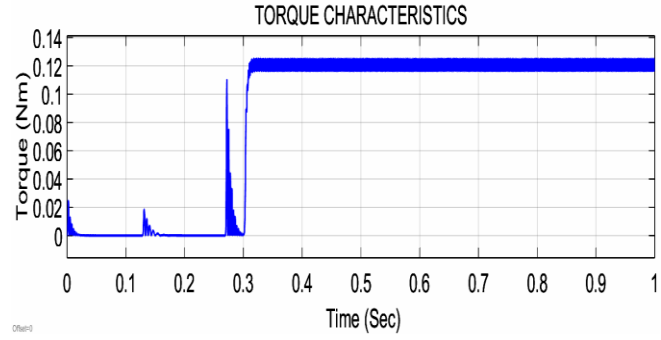


Fig. 12. Torque characteristics of Sensorless control of 4 switch BLDC motor pump.

On comparing Fig. 8. with Fig. 11., and Fig. 9. with Fig.12. we will get the performance of the two systems in bore- well pumping applications. That is, from the speed and torque characteristics it can be seen that large ripples are there in the four switch inverter fed BLDC motor than the six switch inverter fed BLDC motor. So the efficiency of the six switch inverter will be more than the four switch inverter. But on considering the switching losses, due to the reduced no. of switches four switch inverter is better and it reduces the cost of the system. From the speed characteristics of both the systems, upto 0.3 seconds the motor is working in starting method and after that the motor steps into the running mode which uses the back emf method of sensorless control. Table-II shows the comparison between these two.

Table-I: Comparison Between Sensorless Control Of 6 Switch And 4 Switch Inverter Fed BLDC Motor Drive.

6 Switch inverter fed BLDC Motor	**4 Switch inverter fed BLDC Motor**
6 No. of Switches	4 switches No. of switches
Higher Switching Losses	Lesser Switching Losses
High cost	Low cost
Complexity in control Algorithms	Simplicity in control Algorithms
Reduced ripples in speed and torque	Increased ripples in speed and torque

6. CONCLUSION

An efficient 6 switch inverter fed BLDC motor drive and a low cost 4 switch inverter fed BLDC motor for bore- well pumping application are designed and analysed in this paper. In both the systems a back emf based sensorless control method is used. The four switch inverter fed BLDC motor drive system reduces the cost of the inverter by eliminating some components, the switching losses can be decreased by avoiding the 2 switches, and the complexity in controlling algorithms can be minimized. The 6 switch inverter fed BLDC motor drive system increases the efficiency of the system by reducing the ripples that comes in speed and torque. The sensorless control method incorporated in the drive system achieves high performance by eliminating the hall-effect sensors. So this paper gives the comparison of performances for 4 switch inverter fed BLDC motor drive with a conventional six switch inverter fed BLDC motor drive using sensorless control method. The 4 switch inverter fed BLDC drive has been found attractive in low-cost applications.

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