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Simulation of DC Link Capacitor Free BLDC Motor Drive using Different Current Controllers

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***Abstract*—A DC link capacitor is an integral component of every BLDC motor drive. It is rated for a lower number of operating hours in comparison to other components used in the circuit. In addition, the lifetime of electrolytic capacitors is severely affected by the ambient operating temperature. As such, the DC link capacitor is considered to be a frequent component of failure. Therefore, the inclusion of the capacitor reduces the durability of the motor drive, particularly in hot or cold environments. Excluding DC link capacitor from the drive yields additional advantages like cost reduction and overall reduction in the area of the printed circuit board. However such a setup gives rise to torque ripples, which causes vibrations and acoustic noise in the drive. This paper focus on a compensation method to reduce the ripples for smooth operation of the drive. Simulations using different controllers are done and their performances are compared.**

***Index Terms*— DC Link Capacitor; Mat lab; Torque Ripple Compensation.**

I. INTRODUCTION

BLDC motors have finer characteristics compared to other motor types such as brushed DC and induction motors. BLDC motors usually tend to be more reliable, long lasting and efficient. BLDC motors utilize electronic commutation either by obtaining rotor position information from the position sensors or by using the motor drive parameters. A three phase BLDC motor requires rotor position information every 60 electrical degrees, which can be procured from either the three Hall sensors or by back EMF sensing method. A typical BLDC motor drive with rotor position feedback is illustrated in Fig 1. The conventional drive consists of a diode bridge rectifier (DBR), a large electrolytic DC link capacitor and an inverter which is controlled by the rotor position information fed back by the sensors.

Capacitors are primarily used for dc links in the power converter circuitry to reduce the voltage fluctuations in the dc link. They also serve the purpose of balancing the instantaneous power difference between the input source and output load. However, in comparison with the other components of the drive, the dc-link capacitor is the most important part to ensure the life time of the motor drive system [1]. Although it smoothens out the dc link voltage, it is highly sensitive to extreme temperature conditions, which reduces its reliability in applications like air conditioning, heating etc.

Various studies highlight that almost 60-70% of the power supply failures occur due to capacitor breakdown [2]. T hese surveys may conclude that DC link capacitor is a frequent component of failure. DC link

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capacitors are also bulky in size and use up a fairly large area of the printed circuit board. Also its cost mainly depends upon the materials used and manufacturing cost, hence the cost more or less remains invariable. As such DC Link capacitor may be considered as the single most expensive component in the circuit. Since optimization of the drive calls for reduction in electronic components, a BLDC motor drive excluding DC link capacitor can be used which reduces the overall size and cost of the drive along with an increase in reliability of the whole system. A DC link capacitor free BLDC motor drive is explained in the next section.

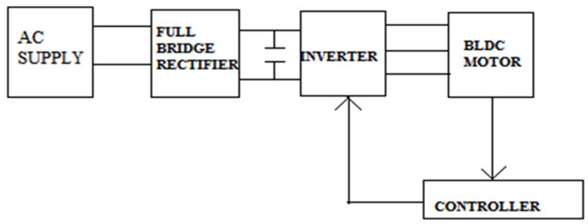

Fig 1.Conventional BLDC Motor Drive

II. A DC LINK CAPACITOR FREE BLDC MOTOR DRIVE

A BLDC motor drive without using a DC link capacitor is shown in Fig.2. In conventional BLDC motor drives, a large DC link capacitor is placed between the diode bridge rectifier and inverter circuit to smoothen the ripples in the rectified supply voltage. But, as explained in the introduction, excluding the DC link capacitor gives rise to some disadvantages, which reduces the reliability of the drive [3]. So a new strategy is developed based on expulsion of the bulky capacitor from the main circuitry. As seen from the Fig.2. , without the DC link capacitor, the BLDC motor drive is operated directly from rectified input mains supply. In the absence of the DC link capacitor, the voltage supplied to the motor can vary from zero to peak value of the input main supply. The rectified voltage, which is now a pulsating DC voltage, is delivered in to the three phase inverter consisting of six power electronic switches which are aligned as three half bridges. Switching signals are generated by the microcontroller from the rotor position and are given to the the inverter switches which accordingly excite the BLDC motor for the drive operation. The rotor position information is obtained from the Hall position sensors which are spatially placed 60 degree electrical from each other. Thus this proposed system can be termed as a conventional BLDC motor drive without a dc link capacitor. Suppose if in a conventional BLDC motor drive, the phase current of the motor is interfered suddenly, the freewheeling diodes in the inverter switches will be forward biased, thereby allowing the phase current to continue through the dc link capacitor. However in the proposed scheme, this is not possible since there is no continuation path for the current due to the absence of the dc link capacitor. This situation gives rise to high voltage spikes resulting in damage of the inverter circuitry. Therefore a precise switching algorithm that provides an obstacle free path for the phase current at any instant of time is essential for the smooth and safe operation of the motor drive. Fig.3. shows the switching algorithm for the BLDC motor drive without the dc link capacitor.

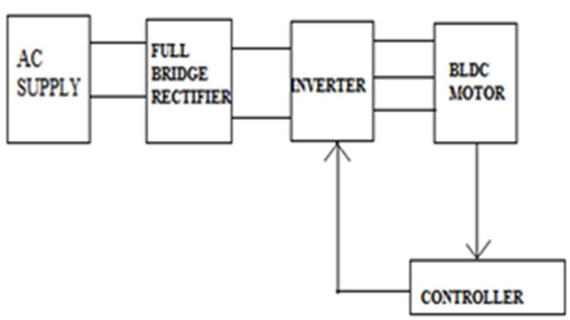

Fig.2.DC Link Capacitor Free BLDC Motor Drive

Constant torque from a BLDC motor drive can be generated by square wave shaped excitation currents that energize only two phase windings at any particular instant in time. Usually, controlled switching signals are applied to a lower and an upper switch of two half bridges of the inverter. The selection of the two half bridges and the switches are based on the required phases that need to be energized and the direction of the current, respectively. However, such a control technique is not appropriate for a BLDC motor drive without a DC link capacitor as there are switching instants where both the controlled switches are in off state.

Switching step	Hall sensors			Controlled switch	On state switch
	H_a	H_b	H_c		
1	1	0	0	C_2	A_1
2	1	1	0	B_1	C_2
3	0	1	0	A_2	B_1
4	0	1	1	C_1	A_2
5	0	0	1	B_2	C_1
6	1	0	1	A_1	B_2

Fig.3.Switching Algorithm

Therefore, a control algorithm is developed specifically for this case [4] such that out of the two switches that are considered at a particular switching interval, only one switch is controlled and the other switch remains ON for the entire interval. The switch that remains in ON state permits the motor phase current to circulate back to the motor during the OFF state of the controlled switch. The two switches considered at any instant are from two different legs of the inverter. The complete switching strategy is given in Fig.3. The outputs of Hall effect sensors are denoted by H_a, H_b and H_c .The switches of the three half bridges A, B, and C of the inverter are represented by A_1, A_2, B_1, B_2, C_1 and C_2 where subscripts 1 and 2 denote the upper and the lower switch of each half bridge, respectively. This arrangement of the switches is illustrated in Fig. 3. Consider the step 1 in the switching algorithm in Fig.3. Here the controlled switching signal is applied to C_2 while A_1 remains in the ON state. The current path when controlled switch C_2 is ON is given in Fig.4.

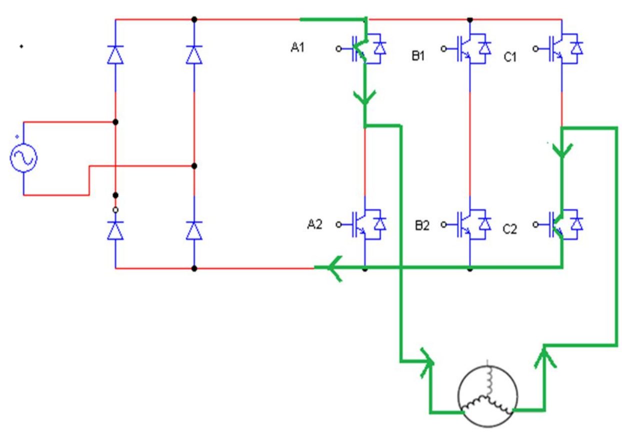

Fig.4.Current path when switches A_1 and C_2 are ON

As seen from Fig.4.the motor phase current flows in a continuous path through switches A_1 and C_2. While C_2 is in the OFF state, the freewheeling path for the phase current is given by the freewheeling diode associated with C_1. The motor phase current is continued and circulated through A_1, as it remains ON for the entire switching interval. The current path for this case is given in Fig.5. Similarly, if the Hall Effect signals from Ha, Hb and Hc are 1, 1 and 0, respectively, as tabulated in step 2 in Figure 3, then the windings B and C should be excited by energizing the devices B1 and C2. During that step the controlled switching signal is applied to B1 while C2 remains in the ON state. The freewheeling path to phase current while B1 is in off state is provided through the freewheeling diode associated with B2. Motor phase current is continued through C2, since it remains in on state for the entire switching interval.

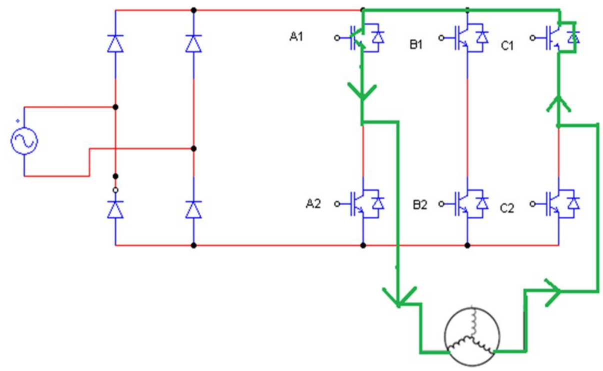

Fig 5.Current path when switches A_1 is ON and C_2 is OFF

Switching signals of the proposed algorithm for one electrical revolution are given in Fig.6.

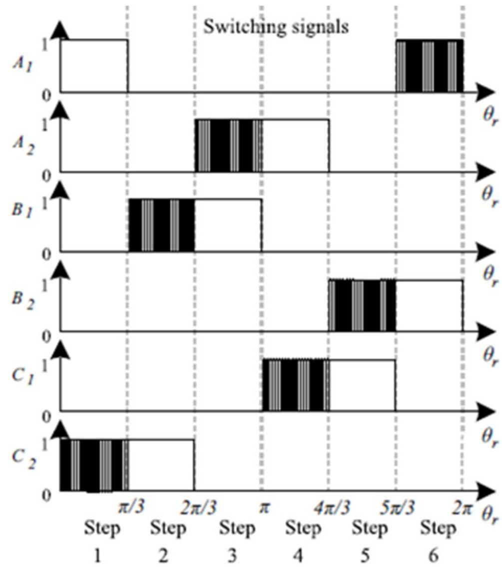

Fig.6. Switching signals

III. Compensation Technique for Torque Ripple Minimization

In a DC link capacitor free BLDC motor drive, ripples in phase current are produced at instants where the generated back emf is greater than the supply voltage input. During these instants the phase current becomes uncontrollable. Simultaneously, during these uncontrollable regions, torque ripples are also formed in proportion to the dips in phase current. It is necessary to reduce these ripples to improve the reliability of the drive or for implementation in applications requiring constant torque operation. Thus apart from commutation torque ripple and cogging ripples an extra source of torque ripples is introduced to the system in the absence of DC link capacitor. The formation of this extra torque ripples can be observed from figure 7.
In order to reduce the torque ripples a compensation technique utilizing a small capacitor which is actively controlled by a power electronic switch was put forward[5] as illustrated in figure 8 .The controlled capacitor and the controlling switch are denoted by CDC and SDC, respectively. During region 1 of figure 7, CDC charges through the anti-parallel freewheeling diode associated with the switch SDC. Since S_{DC} is off during region 1, there is no natural discharging path for the capacitor. Now S_{DC} is made on during region 2, and the capacitor discharges and produces sufficient energy to maintain the phase current at the reference value.

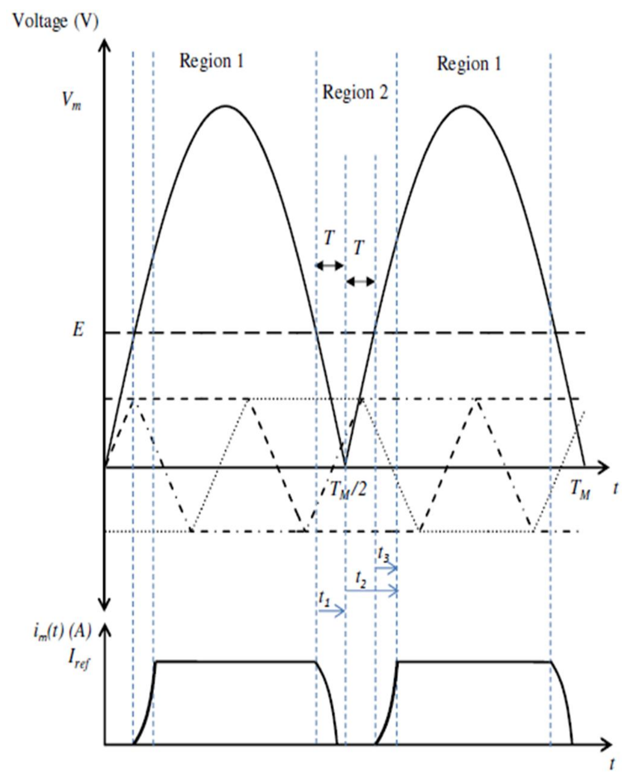

Fig.7. Controllable and Uncontrollable Regions of Phase Current [3]

IV. SIMULATION OF BLDC MOTOR DRIVE WITHOUT DC LINK CAPACITOR

In a DC link capacitor free BLDC motor drive, the input supply varies between zero and peak value of the supply voltage due to the absence of DC link capacitor. Under such a condition, there arise certain instants when the generated back emf of the motor exceeds the input voltage of the motor.

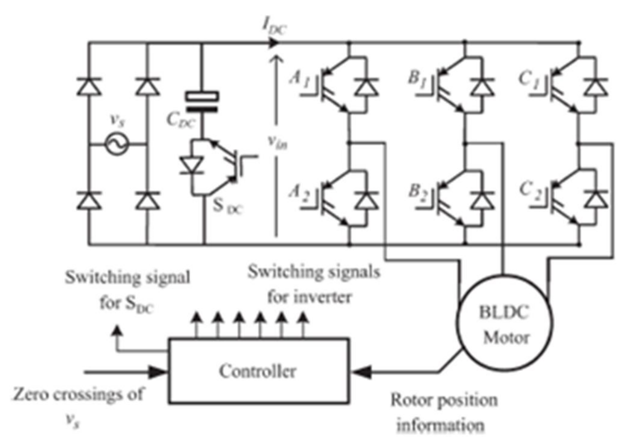

Fig .8. Compensation Technique [5]

During these instants the phase current cannot be maintained at a constant value and decreases to zero. As a result the torque generated by the motor decreases and manifests itself as a ripple. These ripples can cause vibrations and noises in drives, which raises reliability concerns. In order to study the effects of excluding

DC link capacitor from the drive simulations are done in MATLAB/SIMULINK environment. Fig. 9 shows the simulation circuit of a DC link capacitor free BLDC motor drive.

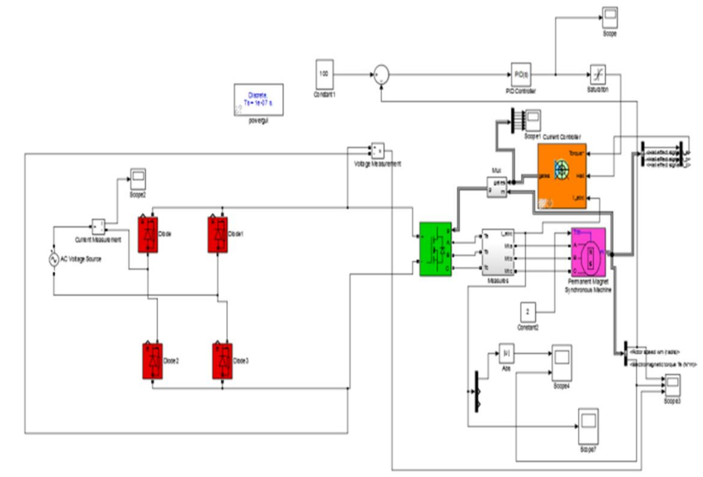

Fig.9. Simulation circuit of BLDC motor drive without a DC Link capacitor

As shown in Fig.9. There is no DC link capacitor after the diode bridge rectifier and the inverter is supposedly fed from a pulsating DC supply. The output of this simulation is shown in fig.10. As observed from Fig.10 such a drive produces a torque which is observed to be falling from a constant value towards zero. Hence such a drive is not suitable for constant torque applications.

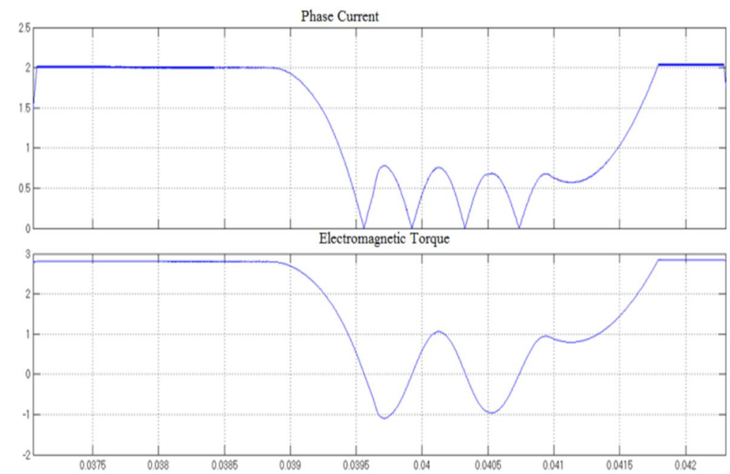

Fig.10. Simulation output of DC Link capacitor free BLDC motor drive

To maintain the phase current or torque at a constant value, a compensation technique is used and is simulated. In order to select a suitable current controller for hardware implementation, the simulation of the compensation was done using Hysteresis current controller and a PI controller. Simulation using Hysteresis controller is given in Fig.11.

The compensation technique employing a very small capacitor which is controlled by a power electronic switch nullifies the torque ripple resulting in a smooth torque curve as shown in Fig.12. From the simulation results shown in Fig.12, the compensation technique helped to reduce torque ripples. The same technique is simulated using a PI controller as shown in Fig.13.

From figure 14 it can be inferred that utilizing PI controller instead of hysteresis controller yields a similar output. The electromagnetic torque is produced without torque ripples even in the absence of DC link capacitor. The speed is also seen to be settling at 1000rpm which is the set speed. Table 1 gives a comparison between the outputs obtained using PI controller and Hysteresis controller.

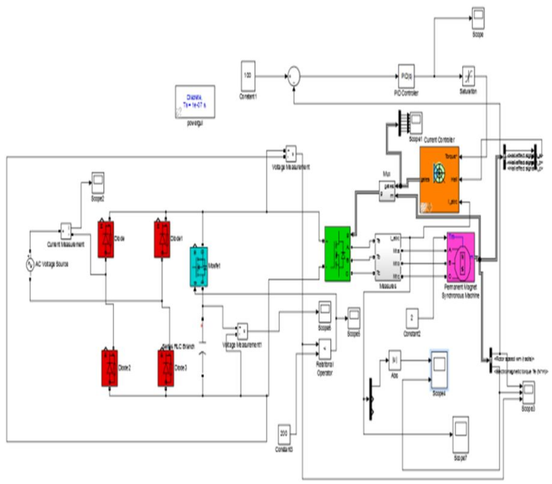

Fig.11. Simulation circuit of BLDC motor drive using compensation employing Hysteresis controller

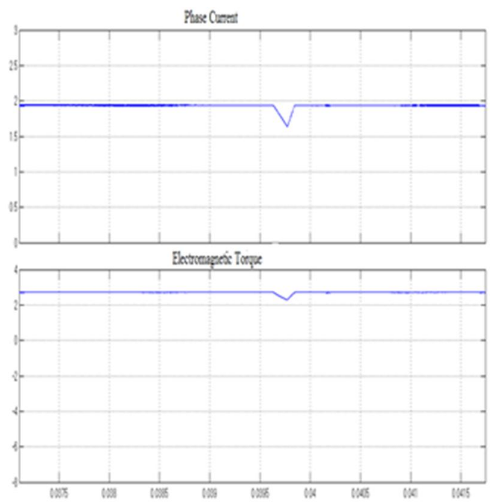

Fig.12. Simulation output of BLDC motor drive using compensation employing Hysteresis controller

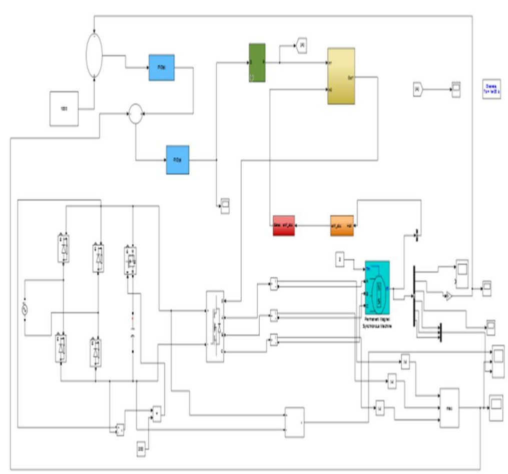

Fig.13. Simulation circuit of BLDC motor drive using compensation employing PI controller

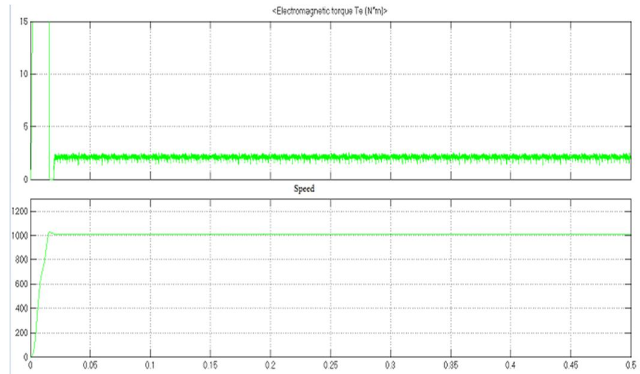

Fig.14.Simulation output of DC link capacitor free BLDC motor drive using PI controller

TABLE I.

	PI Controller	Hysteresis Controller
Electromagnetic Torque	No Torque Ripples	No Torque Ripples
Speed of Motor	Settles at set speed	Settles at set speed

V. CONCLUSION

The absence of a DC link capacitor between the diode bridge rectifier and the inverter in a BLDC motor drive results in a pulsating supply to the inverter. Whenever the supply falls below the emf value, phase current drops to zero along with creation of torque ripples. The torque ripples affect the reliability of the drive as vibrations and noises are increased in the drive. The compensation proposed for the DC link capacitor free BLDC drive effectively nullifies the torque ripples and results in a smooth torque output. The origin of torque ripples in the absence of the DC link capacitor has been validated using simulation of the drive in MATLAB/SIMULINK software. The torque ripples created so are observed to be reduced in the simulation output waveform when using the compensation technique. The effectiveness of this compensation in drive using PI and hysteresis current controllers is also checked in the simulation and the motor is seen to be running at the set speed without any torque ripples.

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