Brushless DC Motor Drive using Modified Converter with Minimum Current Algorithm

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***Abstract*— a brushless DC (BLDC) motor has many application in industrial, medical, aeronautical field. A new and improved configuration of converter for brushless DC (BLDC) motor drive with power quality improvements at AC supply mains is introduced. In order to reduce switching losses associated with VSI a low frequency of switching is used. This is achieved by adjusting the Dc link voltage of voltage source inverter for controlling the speed and commutation of brushless DC motor by electronically. For the voltage control, the converter is operated in discontinuous conduction mode and power factor correction is achieved at AC supply main using single voltage sensor. The circuit is further modified by introducing a new algorithm for which BLDC can be run in bidirectional direction with minimum Current. The control circuit is done in pic16f877a microcontroller. The simulation of the proposed circuit is done in POWERSIM and results are obtained**

Keywords*— BLDC (Brushless DC), Discontinuous Inductor Current Mode (DCM), Voltage Source Inverter (VSI)

I. INTRODUCTION

Brushless DC motors are widely used in the development of mid power household appliances, industrial tools, medical application etc. Household appliances such as fans, refrigerators, air conditioners and water pumps use this BLDC motor. Advantages such as high ruggedness, good energy-density, high torque/inertia ratio, good efficiency and low maintenance cost requirements make this motor a good choice for mid power applications[1]. Brushless DC motor (BLDC motor) is a three phase synchronous motor in which on the rotor side permanent magnets and on stator side three-phase winding . For the commutation of BLDC motor hall effect sensor is used which senses the position of rotor electronically

For driving BLDC motor a combination of bridge rectifier and DC link capacitor is requires[1]. A high total harmonics distortion of supply current at low power is occurs due to a high current distortion from supply current when above combination is used. The poor power quality indices at AC main is not permitted by international power quality standers like IEC 6100-3-2. Hence the designed power factor correction converter should meet the guide lines of IEC 6100-3-2. The design of PFC done either in continuous conduction mode or discontinuous conduction mode. If the voltage across capacitor or current flowing through inductor is continuous then it becomes continuous conduction mode else it become discontinues conduction mode. For the PFC in continues mode with voltage control it requires input current of main (i_{in}), supply voltage of main (vs), DC link capacitor voltage (V_{dc}).. As a result the solid state switching stress of PFC converter is reduced but the increases the number of sensors. The operation of discontinuous inductor conduction mode of PFC converter need only one voltage sensor for the control of voltage and power factor correction. As a result in discontinuous current of operation the PFC converter's stress increases and, hence suitable for medium power applications [2].

For BLDC motor drive a PFC buck converter has been widely used as PFC converter. In such scheme, a constant voltage is regulated at the DC-bus capacitor and a current controller based on pulse width modulation (PWM) which is used for the control of speed of a Brushless DC motor. The system efficiency is reduced due to the high frequency pwm signal which causes the switching losses in VSI. These losses in VSI can be effectively reduced by using low frequency switching pulses for VSI by commutating the BLDC motor, electronically. Moreover for the speed control of BLDC motor the DC bus voltage adjust itself. [3].

A new arrangement of converter is used for DC-DC conversion which shows a good regulation of voltage over a wide range of voltage variation and also acquire high and good light load efficiency. It can also operate as an excellent power factor preregulator. A Brushless DC motor drive fed by a Power Factor Correction converter has been proposed. The bridgeless configurations decreases the front-end converter conduction losses due to complete and partial removal of DBR; but needs higher number of components.

These configurations belong to a non-isolated category Therefore, this paper investigate a new design of a converter for Brushless DC (BLDC) motor drive with reduced number of sensor and power factor correction (PFC). The circuit is further modified by introducing a new algorithm for which BLDC can be run in bidirectional direction with minimum Current.

II. PROPOSED BLDC MOTOR DRIVE USING MODIFIED CONVERTER WITH MINIMUM CURRENT ALGORITHM

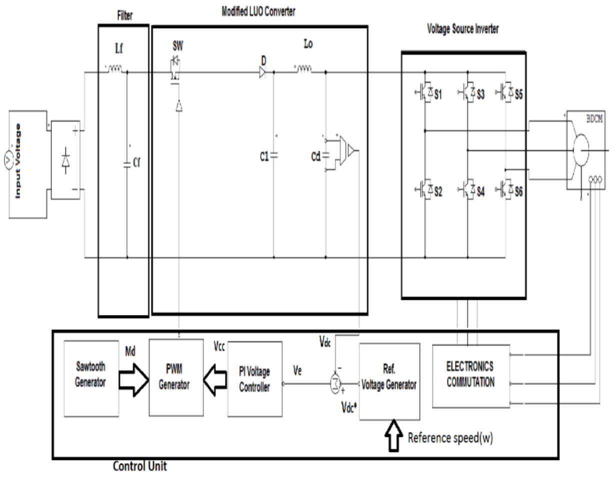

Fig-1: Proposed converter

Fig-1 shows proposed brushless dc motor drive using modified converter with new minimum current algorithm. A diode rectifier followed by a PFC DC to DC converter is used for control of DC bus voltage for improvement of power quality at AC supply mains. Inorder to reduce the switching losses the brushless dc motor (bldc) commutate electronically. Inorder to reduce the overall cost the complete operation of drive accomplish using single voltage sensor. The designed drive is evaluated at different speed and different supply voltage.

III. DESIGN OF CONVERTER

For a Brushless DC motor of 30W, a converter of 25 W (Po) is designed. The DC link voltage is to be regulated from 15V (V_{dcmin}) to 30V (V_{dcmax})
Let the input Voltage V_s is taken as

$$V_s = V_m \sin 2\pi f t = 48\sqrt{2}\sin 314t \ldots\ldots\ldots\ldots (1)$$

Where V_m represent the peak value of the input voltage (67.88V), f is the frequency of line i.e. 50 Hz.

The average rectified voltage is obtained as

$$V_{in} = \frac{2\ V_m}{\pi} = \frac{2*67.88}{\pi} = 43.21\text{V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The input voltage as well as output voltage is related by expression (3), which is given by

$$V_{dc} = d*V_{in} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where the duty ratio is represented by d .Now using equation (3), the duty ratio for which the designed DC link capacitor voltage of 17 V (V_{des}) is results as 0.39 (d_d).

The intermediate capacitor (C_1) is obtained using equation (4) as [6].

$$C_1 = \frac{V_C\, d_d}{2R_L\ f\Delta V_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The permitted capacitor ripple voltage is given by ΔV_C and V_C is intermediate capacitor voltage (i.e.$0.5V_{in}+V_o$). By equation (4), the intermediate capacitor is obtained as 98.8 µF and is chosen as 100 µF for $\Delta V_C = 0.5V_C$.

The equation for L_o the output inductors, can be obtained using equation (6) as [6]

$$L_0 = \frac{d_d\ I_{Lo}}{16f^2\ c_1\ \Delta I_{Lo}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The output side inductors current I_{Lo} which is given by P_o/V_{des}. Hence, using equation (6) L_0 the output side inductors are obtained for a ripple current value of 2%

$$= \frac{0.39*3.176}{16*((4*10^3)^2*(100*10^{-6})*0.063}$$

=7.6mH

Selected as 8 mH.

By using equation (7) the DC link capacitor (C_d) is obtained as [6]

$$C_d = \frac{I_{omin}}{2*\omega_l*\Delta V_{dcmin}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$= \frac{1}{2*2*\pi*4*10^3*0.045}$$

=100µF

Where the I_{omin} is obtained by P_{omin}/V_{dcmin} (where P_{omin} is 54 W, power at DC output voltage of 15 V). $\omega_L = 2\pi f_L$, where line frequency is represented by f_L and ΔV_{dcmin} is permisible DC link capacitor voltage ripple which is given by the 3% of V_{dc}. Using equation (7), the DC link capacitor is obtained as 100 µF and it is chosen as 4.4 mF.

C_f is filter capacitance which is obtained such way that it's value is lower than a maximum filter capacitive value (C_{max}) and is given by the equation (8) [7]

$$C_{max} = \frac{I_{peak}}{\omega_l*V_{peak}} * \tan\theta \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$= \frac{2}{2*\pi*f*48} = 1658\text{nF}$$

The peak value of main supply current is represented by I_{peak}, the peak value of main supply voltage is represented by V_{peak} and the displacement angle is represented by θ.

Using equation (8), C_{max} is obtained as 1658 nF and therefore, the value of C_f is chosen as 1000 nF.

The filter inductance (L_f) is obtained by equation (9) [7]

$$L_f = \frac{1}{4\pi^2*f_c^{\,2}*c_f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$= \frac{1}{4*\pi^2*(4*10^2)^2*1000*10^{-9}}$$

=1.5mH

Where f_c represented the cut-off frequency; $f_c=f_s/10$.

IV. CONTROL OF PROPOSED BLDCMOTOR DRIVE FED BY MODIFIED CONVERTER

This section is divided into two sub-sections as the control of a PFC converter for adjusting the DC bus voltage with PFC operation and the control for BLDC motor to achieve an electronic commutation.

a) Control of a Converter

This section deals with the generation of high frequency PWM pulses for solid-state switch (S_w) of PFC converter. For the control of Power factor correction converter a voltage follower approach using one voltage control loop is used. A reference voltage for DC bus capacitor (V_{dc}*) is as,

$$V_{dc}^* = k_v \omega^*$$

where k_v is motor voltage constant and V_{dc}* is reference speed. Inorder to generate Ve, the voltage error signal the sensed voltage of DC bus capacitor (Vdc) is compared with the reference voltage Vdc*.

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k)$$

kth sampling instant is represented by k

To generated controlled output voltage V_{cc} the error voltage is given to PI controller,

$$V_{cc}(k) = V_{cc}(k-1) + k_p\{V_e(k) - V_e(k-1)\} + k_i V_e(k)$$

The gains of PI controller is given by k_p and k_i. The PWM pulses are generated by comparing the controller output voltage with a saw-tooth signal (m_d) of high frequency as,

$$\{\text{if } m_d < (t)\ V_{cc}(t) \text{ then } S_w = \text{'ON'}\}$$

$$\{\text{if } m_d(t) > V_{cc}(t) \text{ then } S = \text{'OFF'}\}$$

Where Sw1 is the PWM signals given to solid-state switch of the PFC converter.

b) Electronic Commutation of Brushless DC Motor

The Brushless DC motor is commutated electronically which includes perfect switching of Voltage Source Inverter, such that a uniform direct current is drawn from DC bus for a 120° and placed uniformly at centre of back-EMF of each phase. The position of rotor is sensed over a span of 60° by Hall Effect sensors for commutating electronically Brushless DC motor. A new algorithm which consume less current is introduce in this paper. The algorithm is shown in figure 2

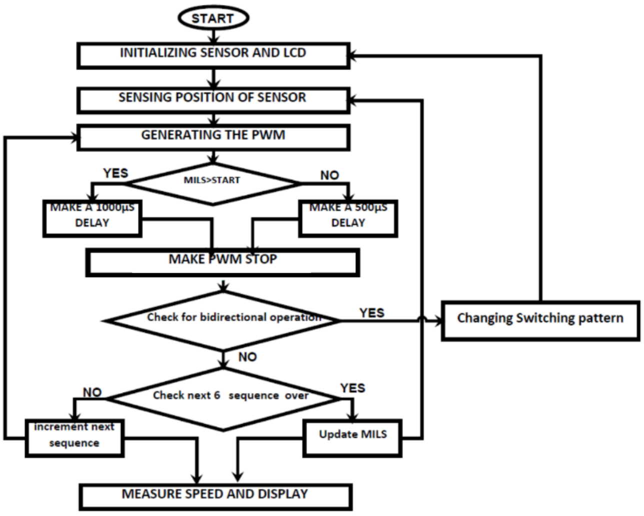

Fig-2: New minimum current algorithm

In this algorithm, the output of Hall Effect sensor is given to microcontroller. A count is stored in variable start. A timer is started at the beginning of first switching and stop at the end of switching. The value of the timer is compared with count. If value of timer is less than count means the speed of motor is not high, hence provide a small delay and hence the coils will energized for more time and results to increase the speed of motor. If value of timer is greater than count means the speed of motor high, hence provide a delay since the motor can run with the property of inertia, so the coils are too energized for only few time. The main advantage of proposed algorithm is that it draws only few currents compare to previous algorithm. It draws only 200mA. Bidirectional operation is done by changing the switching sequence.

V. SIMULATION RESULT

The simulation parameter is shown below

Table-1: Simulation Parameter

PARAMETER	VALUES
Supply voltage	48V
Switch	mosfet
Inductor L_0	8mH
Inductor L_f	1.5mH
Capacitor C_f	1000nF
Capacitor C_d	100µF
Capacitor C_1	100µF

The simulation diagram of proposed Brushless DC motor drive is shown in figure 3

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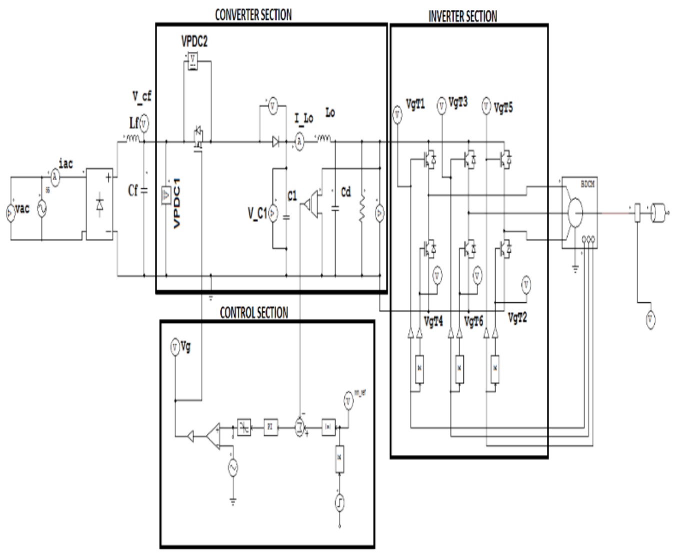

Fig -3: Simulation diagram of proposed Brushless DC motor drive

The simulation is done for a speed of 300rpm. The input current and voltage is shown below

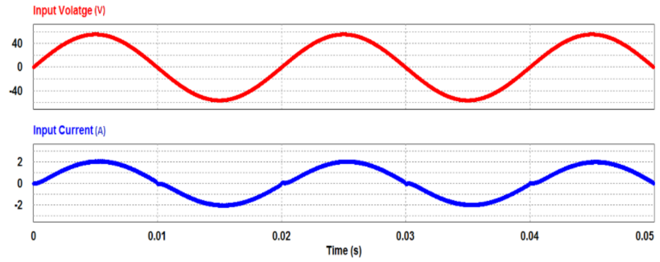

Fig -4: Input voltage and input current

The input voltage is 48V AC and the input current is obtained as 2A. From the graph we can see that the input voltage and input current are in phase so the converter itself act as power factor correction circuit.

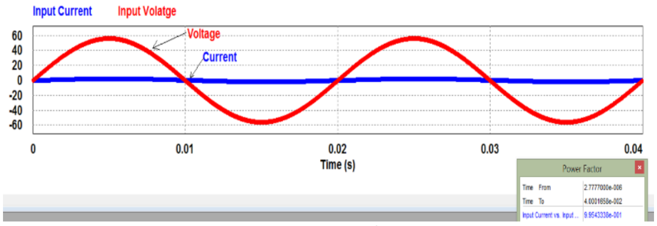

Fig -5: Power factor

The power factor is obtained as 0.98. Figure 6 shows switching pulses of VSI

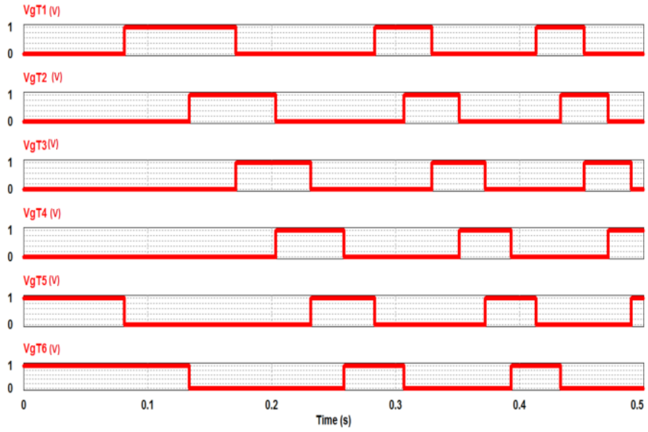

Fig -6: Switching pulses of VSI

Six mosfet switches are used in voltage source inverter. At a time only two switches are ON state, remaining are OFF state.

The voltage waveform of capacitor C_d is shown in figure 7.

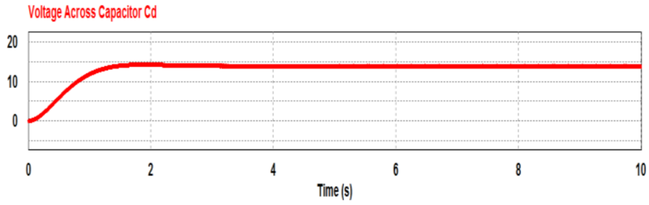

Fig -7: Voltage across capacitor C_d

The voltage across capacitor is about 15V. The capacitor voltage become steady after a time of 1s. From the graph it can be inferred that the V_{dc} voltage i.e the V_{dc}, DC link voltage is almost ripple free.

Figure 8 shows the waveform of speed in RPM

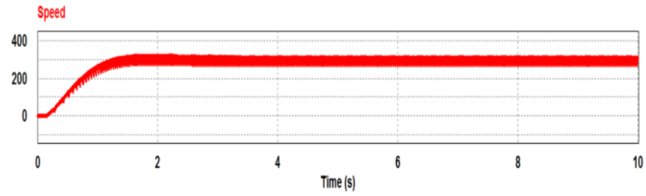

Fig -8: Speed of BLDC motor

The speed of motor is obtained as 300rpm. From the graph it can be inferred that the presence of ripples. The speed ripples obtained as 14rpm. The torque waveform is shown in fig 9.

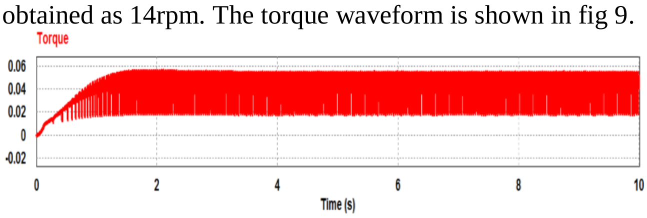

Fig -9: Torque

The torque is obtained as 0.05NM. Torque contain some ripple which is about 0.038NM.

The experimental setup of proposed system is shown in figure figure 10

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VI. EXPERIMENT SETUP AND RESULTS

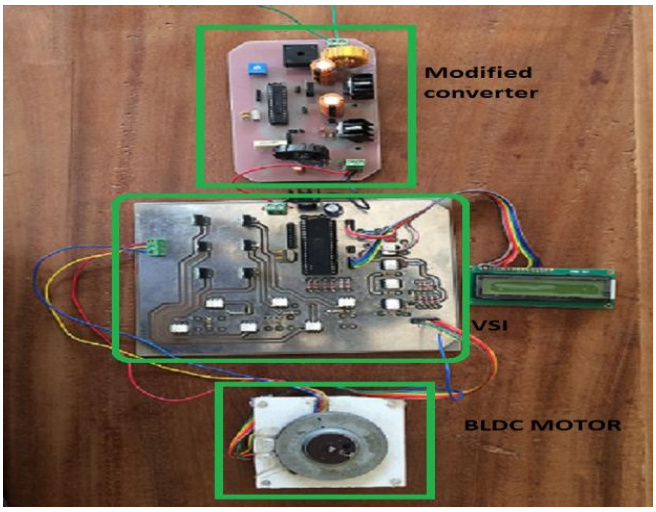


Fig -10: Experiment setup

The experiment setup is shown above, which contain an AC to DC converter, voltage source inverter and BLDC motor. IRF540 is used as switch .4N35 used as mosfet driver. 49e used for sensing the speed. The controller used in the prototype is PIC16f877a.

The hardware result shown below, for a speed of 780 rpm. The DC link voltage V_{dc} is shown in figure 11. From the waveform the DC link voltage (voltage across capacitor C_d) is obtained as 30V.

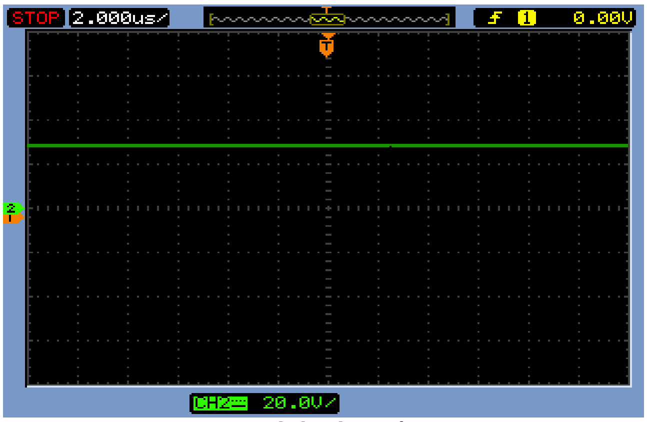
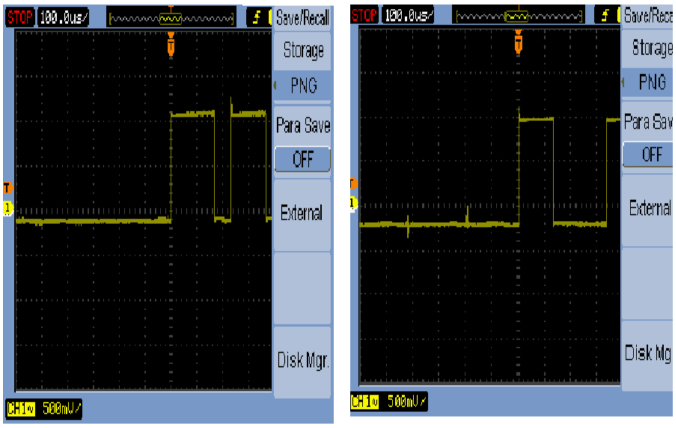


Fig-11: Dc link voltage of converter

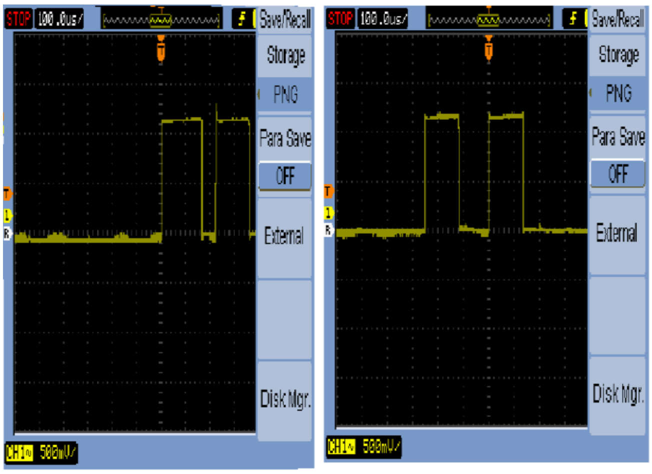
From the above waveform it can be inferred that the Dc link capacitor voltage V_{dc} is almost ripple free. This DC link voltage is given as input to voltage source inverter. The AC to DC converter adjust itself by using controller to provide voltage (DC link voltage) for desire speed. For a speed of 780 rpm the dc link voltage is obtained as 30V.

The switching pulses for the voltage source inverter is shown in figure12-14. The DC voltage from the converter is given to VSI. These VSI drives the motor either in clockwise or anticlockwise. For rotation of motor proper switching sequence is given to VSI using microcontroller. At a time only two switches of VSI are conducting and remains are non-conducting. By providing proper switching the motor can run bidirectional.



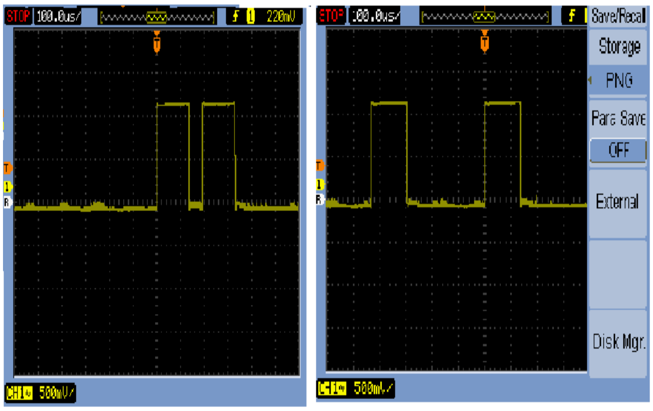
(a) (b)

Fig-12: Switching pulses for switch T1 and T4



(c) (d)

Fig-13: Switching pulses for switch T3 and T2

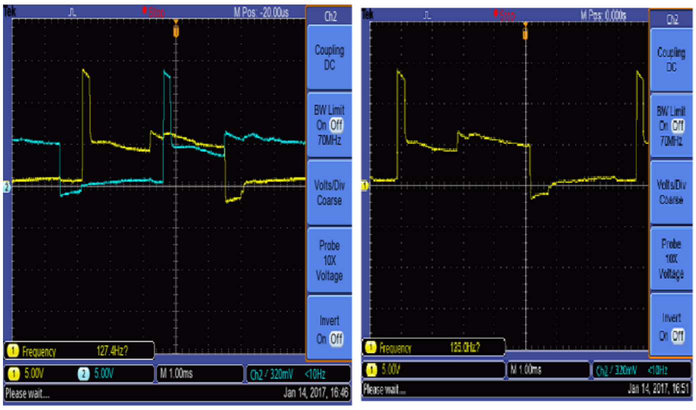


(e) (f)

Fig-14: Switching pulses for switch T3 and T2

4N35 is used as mosfet driver. From the graph it can be seen that at a time only two mosfet are conducting for running BLDC motor.

The waveform of back emf is shown in figure 15. The back emf waveform is almost a trapezoidal shape. The waveform contain some distortion which may due to switching of mosfets.



(a) (b)

Fig-15: Back EMF

VII. CONCLUSION

A new configuration of an AC to DC converter has been proposed in this work for feeding the BLDC motor drive. The operation of proposed drive has been realized using a single voltage sensor. An approach of variable DC link voltage has been used for adjusting the speed of a BLDC motor. Moreover, switching losses in six mosfet switches of VSI has been reduced by electronically commutating Brushless DC motor such that the Voltage Source Inverter operates in low frequency switching. An inherent power factor correction has been achieved due to the design of PFC converter in DICM. The propose converter reduces voltage stress, current ripple comparing to conventional converter. A new algorithm is proposed in which motor works in reduced current. The motor can be run in bidirectional by changing switching sequence.

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