PID CONTROLLER BASED FULL BRIDGE DC-DC CONVERTER FOR CLOSED LOOP DC MOTOR WITH UNIPOLAR VOLTAGE SWITCHING

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This paper deals with a method to improve the performance characteristics of the closed loop DC motor drive by using proportional integral derivative controller(PID) with Pulse width modulation(PWM) full bridge DC-DC converter. The PID parameters are found by PID tuning Zeigler- Nichols method and uniploar voltage switching technique is implemented. In the proposed method, RMS ripple output voltage is reduced and also high power factor is achieved in the AC input line current. The over all system is modeled in MATLAB / SIMULINK software, where different modes of operation were presented and discussed. The design of the speed controller for closed loop four quadrant operation of the DC Motor has proved successfully runs at close to the reference speed.

Keywords: DC Motor, DC-DC converter, PWM, PID controller, Ziegler- Nichols method**,** four quadrant operation, unipolar voltage switching

1. Introduction

Many industrial types of equipment driving a load need prime mover. There are various types of prime movers such as steam, hydraulic and other types of engines but most commonly used prime mover is an electric motor. The main advantage of an electric motor is, its various characteristics like speed current, speed-torque etc, which can be adjusted by a control equipment and also a good starting torque which can be started on load. Some industrial equipment need precise speed control. With the help of an electric motor such as a speed, up to accuracy of 1% also can be achieved, using suitable control equipment.

The implementation of DC Motor drive system with phase control is simple. As a result, it has gained high popularity. The disadvantage of this system is that the value of phase delay angle is large, which causes reduced input power factor and high harmonic content in the input AC line current in the discontinuous period [1].

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In general the current through phase controlled converter is unidirectional, while the output voltage is reversible. The two quadrant operation is not suitable for DC motor braking with reversible voltage, which requires the voltage to be unidirectional but the current to be reversible. Four quadrant operation is possible with two back to back connected thyristor converter. Therefore for regenerative braking two back to back connected thyristor converter is suitable. For the same armature inductance, reduced zone of discontinuous conduction operation and reduced load current ripple are achieved when compared to phase controlled converters [2]. Uniform pulse width modulation techniques are extensively used in converter circuits due to the simple implementation of their control circuit and advantages gained from increasing switching frequency [3]. However, this will lead to the increased switching losses. The more availability of high frequency high power switching devices, such as MCT, IGBT and MOSFET are expected to reinforce self- commutated AC to DC converters with PID -PWM control techniques to replace the conventional phase-controlled converters within the available power ratings [4].

In the simulation result the performance of the single phase variable DC drives controlled by PID controller has been improved obviously. [5]-[9]. The performance characteristics of a new four quadrant single phase DC drive closed loop system controlled by PID-PWM full bridge DC-DC converter with bipolar Voltage switching was found to be more efficient in improving the step response characteristics such as , reducing the steady state error, rise time, settling time and maximum overshoot in closed loop speed response of a DC motor with PID controller when compared to the open loop system [10]. The PID controller parameter values have been obtained using the Ziegler-Nichols method. This paper presents PID-PWM full bridge DC-DC converter with unipolar voltage switching and describe the power factor correction and RMS ripple voltage.

2. DC Motor Equivalent Circuit

A separately excited DC Motor equivalent circuit is shown in Fig. 1.

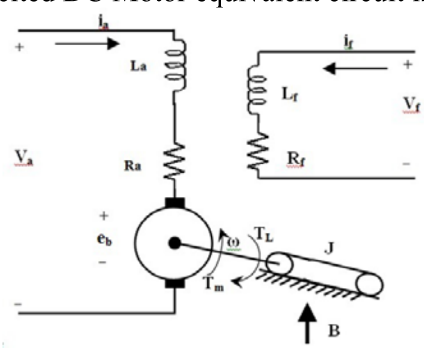

Fig. 1. Equivalent circuit of Separately excited DC Motor

The current in the field coil and the armature is independent of each other. As a result, these motors have excellent speed control. Hence DC motors are typically used in applications that require five or more horse power. The equations describing the dynamic behavior of the separately excited DC Motor are as follows.

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + e_b \tag{1}$$

$$T_m = K_t i_a(t) \tag{2}$$

$$T_m = J\frac{d^2\omega(t)}{dt^2} + B\frac{d\omega(t)}{dt} \tag{3}$$

$$e_b = e_b(t) = K_b\frac{d\omega(t)}{dt} \tag{4}$$

Torque constant (K_t)=Back emf constant(K_b)

Simplification and taking the ratio of $\frac{\omega(s)}{V_a(s)}$ we will get the transfer function as below:

$$\frac{\omega(s)}{v_a(s)} = \frac{K_b}{\left[JL_a S^2 + (R_a J + BL_a)S + (K_b{}^2 + R_a B)\right]} \tag{5}$$

Where, R_a=Armature resistance in ohm, L_a=Armature inductance in henry, I_a=Armature in ampere,V_a=Armature voltage in volts ,e_b=e_b(t)=back emf in voltage in volts, K_b=back emf constant in volt/(rad/sec),Kt=torque constant in N-m/Ampere, T_m=Torque developed by the motor in N-m,w(t)=angular speed of shaft in radians/seconds ,J=moment of inertia of motor and load,B=frictional constant of motor and load in N-m/(rad/sec).

3. Numerical Values

The DC motor under study has the following specification and parameters

a) Specifications
   5hp,240volts,16 amps,1500rpm
b) Parameters
   Ra=0.5 ohm, La=0.01H K_b=1.48 volts/(rad/sec) J=0.05 kg-m^2/rad, B=0.02N-m/rad/sec).
   The overall transfer function of the DC motor

$$\frac{\omega(s)}{V_a(s)} = \frac{1.48}{0.0005s^2 + 0.0252s + 2.2002} \tag{6}$$

4. Proposed Full bridge DC-DC Converter with PID-PWM

The proposed single phase DC motor controlled by PID-PWM full bridge DC-DC Converter with unipolar voltage switching technique is shown in Fig. 2. The single phase AC supply is applied to diode bridge rectifier and a LC filter with braking resistor and LC filter is placed in between DBR and braking resistance, such that a constant amplitude dc link voltage is established. DC motor load is powered through PID-PWM full bridge DC –DC converter which consists of four MOSFET switches (M_1,M_2 M_3 and M_4) and their respective anti-parallel diodes (D_1,D_2,$D_3$and D_4) , these switches are controlled by PWM technique with PID controller. The diagonally opposite switches M_1,M_4, and M_2, M_3 are treated as two switch pairs where pair of switches is turn on and off simultaneously such that the motor voltage is of a bipolar nature. Independent control of the switch in each leg such that the motor voltage of uniplar nature its adopted in the proposed method.

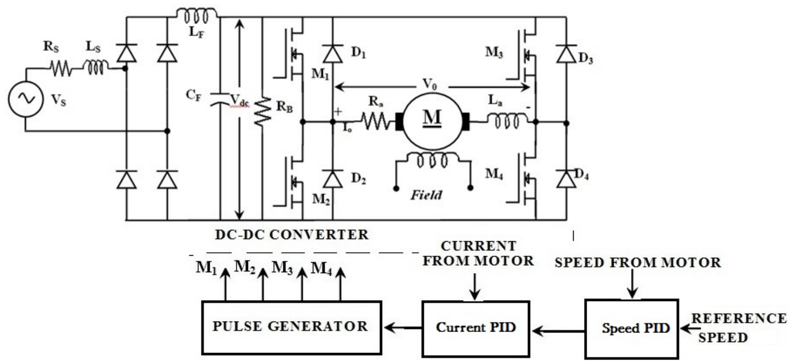

Fig. 2. Circuit diagram of PID-PWM full bridge DC-DC converter

Conventional PID controller is used as a speed controller for recovering the actual motor speed to the reference speed. The reference and measured speed are the input signals to the PID controller. The K_P, K_I, and K_D values of controller are determined by Ziegler-Nichols turning method. The controller output is limited to give the reference signals for one input of current PID controller and other one as measured current from motor .The current error amplified through this controller which is emerged as a control voltage (V_c). This control voltage (V_c) is limited and compared with a triangular signal(V_{tri}) and generate PWM pulses to MOSFET switches.

5. Closed Loop Control of DC Motor with Unipolar Voltage Switching

In practical DC motor drive system, it is required to operate the drive at a constant power or constant torque with controlled acceleration and deceleration.

Most of the industrial drives operates in closed loop control system has advantages like fast dynamic response, reduced effect of load disturbances and improved accuracy.

In this control technique, the switches in each leg are controlled independently of the other leg. The switching patterns are such that when $V_c>V_{tri}$. M_1 is on, and when $-V_c>V_{tri}$.M_3 is on and switching in the same leg have compliment switching patterns. The switching patterns are illustrated in Fig. 3. The duty ratio of the switches M_1 and M_2 are same as the bipolar voltage switching scheme which is given below and the average voltage is also same and varies linearly with control voltage. The converter output voltage is in the motoring mode 0 to V_{dc} and in the reverse motoring mode 0 to $-V_{dc.}$

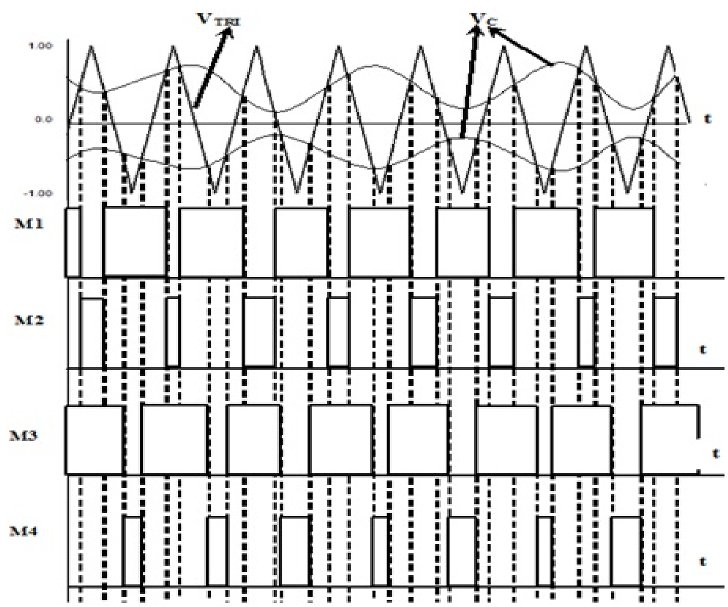

Fig. 3 Switching patterns of Unipolar voltage switching .

The duty cycle (α_1 and α_2) of the switch pairs are given by

$$\alpha_1 = 0.5(1+\frac{v_c}{v_{tri}}) \quad (7)$$

$$\alpha_2 = 1-\alpha_1 \quad (8)$$

Therefore, the converter output voltage (V_o) is given by

$$V_0 = \alpha_1 v_{dc} - \alpha_2 v_{dc} \quad (9)$$

Now α_2 replace by equation 8:

$$V_0 = (2\alpha_1 - 1)v_{dc} \quad (10)$$

Substituting by α_1 from equation 7 yields

$$V_0 = \frac{v_c}{v_{tri}} v_{dc} \tag{11}$$

$$V_0 = k v_{dc} \tag{12}$$

Where k= $\frac{v_c}{v_{tri}}$

The following modes of operation can be defined. The motor current is carried by switch pair M_1 and M_4 in the powering mode. For free Wheeling mode, the motor current continues to flow in an anti-parallel diode when the conducting switch is turned off as in M_1, D_3 andM_4, D_2. A regenerative mode may arise during light loading.

6. PID Controller –Ziegler-Nichols Method

The control system performs poor characteristics and even it becomes unstable, if improper values of the controller tuning constants are used. So it becomes necessary to tune the controller parameters to achieve good control performance with the proper choice of tuning constants. Controller tuning involves the selection of the best values of K_c, T_I and T_D . This is often a subjective procedure and is certainly process dependent. It is widely accepted and straightforward method for tuning the PID controller. First, the controller is set to P mode only. The gain of the controller (K_c) is set to a small value. A small set point change is made and the response of the controlled variable is observed. If K_c is low the response will be sluggish. Increasing K_c by a factor of two and making another small change in the set point or the load is preceded until the response becomes oscillatory. Finally, K_c is adjusted until a response is obtained that produces continuous oscillations. This is known as the ultimate gain (K_u). The period of the sustained oscillations (T_u) is shown in Fig. 4. The procedure of the method includes to set the integral and derivative coefficients to zero and increasing the proportional coefficient gradually from 0 till the system just begins to oscillate continuously. The proportional coefficient at this point is called the ultimate gain K_u and the period of oscillation at this point is called ultimate period T_u. The controller settings are then obtained from the following table 1.

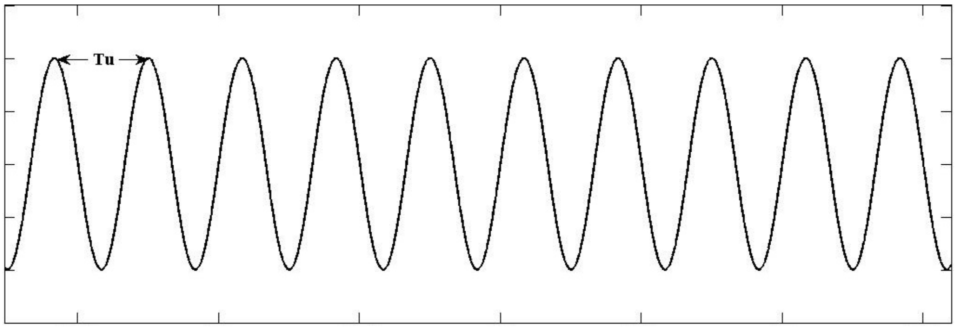

Fig. 4: Steady oscillation illustrating the ultimate period

Table 1

Tuning parameters for Ziegler-Nichols closed loop ultimate gain method

Controller	K_P	T_I	T_D
P	$0.5*K_u$		
PI	$0.45*K_u$	$T_u/1.2$	
PID	$0.6*K_u$	$T_u/2$	$T_u/8$

Advantage

It is an easy experiment; only need to change the P controller, Includes dynamics of whole process, which gives a more accurate picture of how the system is behaving.

Disadvantage

Experiment can be time consuming, it can venture into unstable regions while testing the P controller, which could the system to become out of control, for some cases it might result in aggressive gain and overshoot.

Comparison of the two methods

Ziegler –Nichols can be used for any order of the system, especially for the higher ones, while Cohen –coon can only be used for first order systems Cohen-coon is more flexible since as Ziegler-Nichols is only applicable. When the dead time is less than ½ of the time constant, Cohen-coon is tolerable until ¼ of this value and it can be extended. Therefore, for systems having time delay this tuning method is more convenient. All in all, tuning method satisfies all system requirements. Using the logic of arranging the control parameters described above, some PID tuning software methods are developed, which are easier to apply and save time to get an optimum solution.

7. Simulation result of PID controller design for DC motor using Ziegler-Nichols turning Method

By using only proportional controller, the Simulink / MATLAB diagram of the overall system would be as follows:

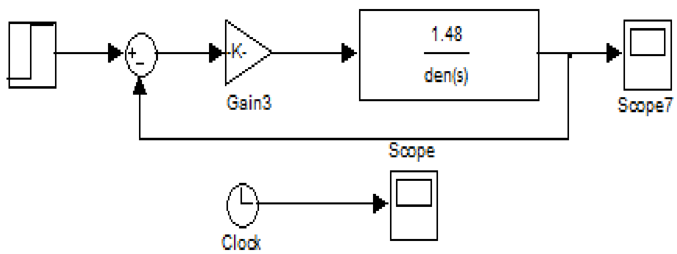

Fig 5. MATLAB/ Simulink diagram to show effect of P controller on the second order plant

According to Ziegler-Nichols turning method

- ❖ Run the controller by only P
- ❖ Increase K_p from 0 to some critical value K_p=K_u at which sustained oscillations occur
- ❖ Note the value K_c and the corresponding period of sustained oscillations, T_u

So, at K_p=74.94step response of DC motor have constant amplitude Which is shown in fig 6.

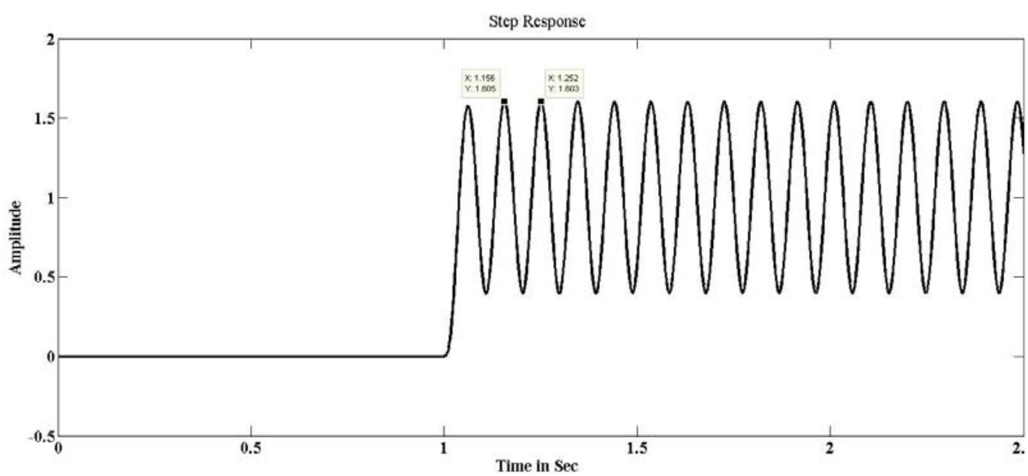

Fig 6 Step response of DC motor (Sustained oscillation)

From Fig. 6, ultimate time (T_u) is calculated as 0.097. The PID gains calculated using table no.:1 and the calculated gains of PID controller are provided in table 2.

Table 2

PID parameters

PID Gains	K_P	T_I	T_D
Values	44	0.0485	0.012

8. Simulation Results and Discussion

The simulation of the proposed four quadrant operation of single phase DC motor drive controlled by PID-PWM full bridge DC-DC converter with unipolar voltage switching was done using the software package MATLAB/Simulink. The simulink model of proposed PID-PWM full bridge DC-DC converter is illustrated in Fig.7, The performance characteristics of DC motor were recorded and analyzed, which are illustrated from Fig. 8 to 17.

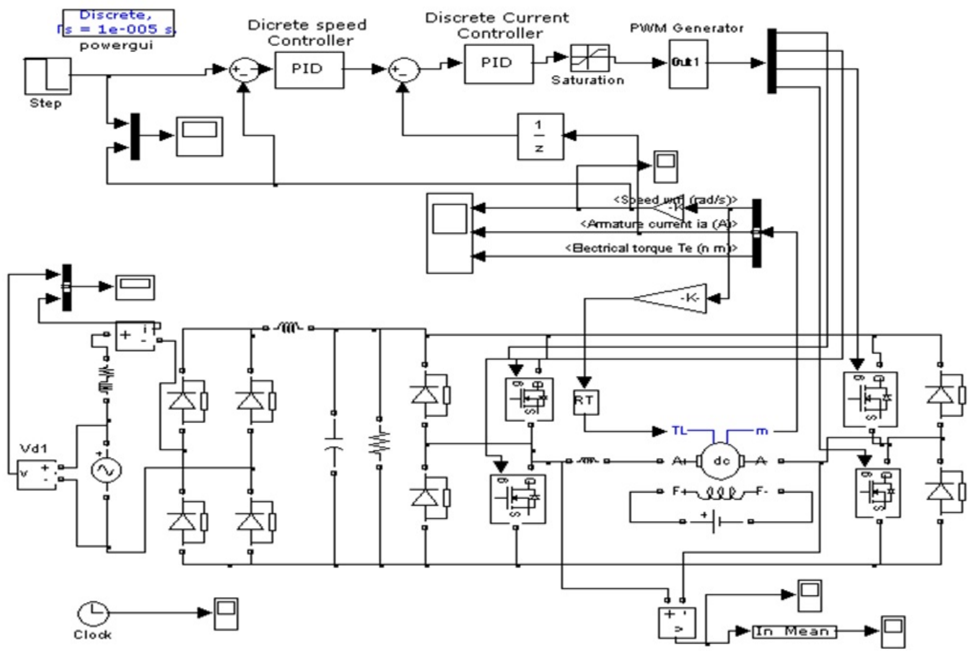

Fig. 7. Simulink model of proposed PID-PWM full bridge DC-DC converter fed DC Motor

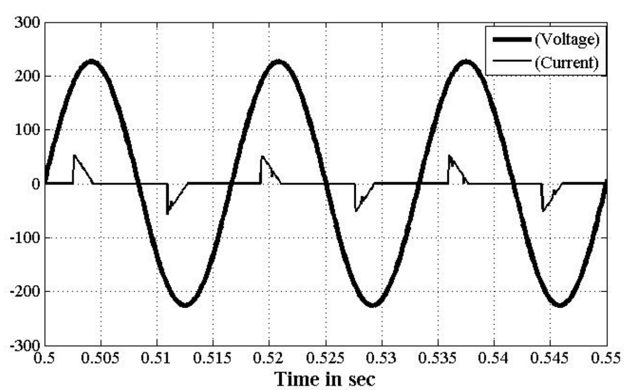

Fig.8. Input Voltage and Input current waveform (Conventional Method)

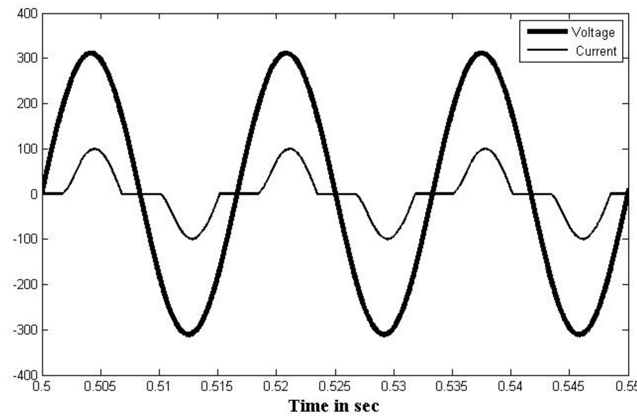

Fig. 9. Input Voltage and Input current waveform (Proposed converter.)

Figs. 8 and 9 show the combined waveform of input AC line current and input voltage, from this figure it is obtained that the input line current wave form circuit is improved and the total harmonic distortion of the current is reduced to a great extend. Thus, the power factor is improved by employing the LC filter circuit across the diode bridge rectifier.

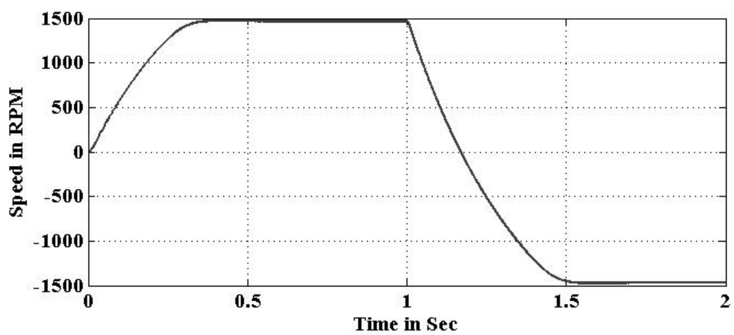

Fig. 10. Motor Speed response –Four Quadrant (Bipolar)

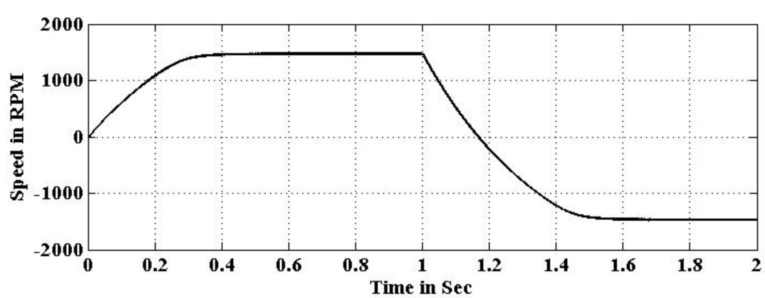

Fig. 11. Motor Speed response –Four Quadrant (Unipolar)

From Figs. 10 and 11, it was concluded that smooth speed response is obtained with PID controller.

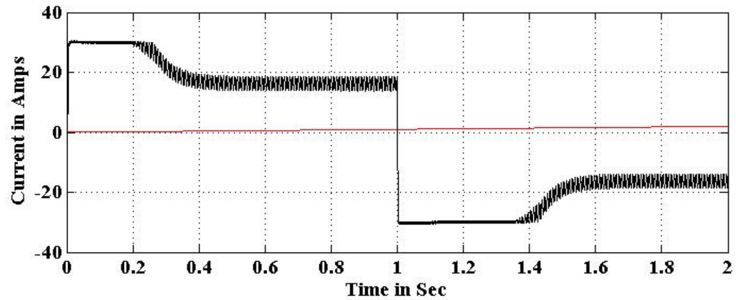

Fig. 12. Load Current -Four Quadrant (Bipolar)

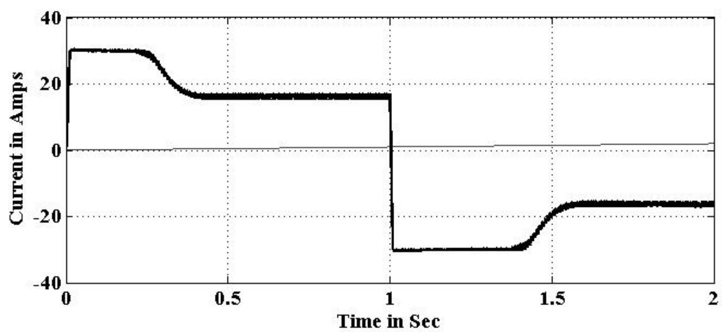

Fig. 13. Load Current -Four Quadrant (Unipolar)

From Figs. 12 and 13, the current ripples are reduced in the proposed method, compared to bipolar voltage switching technique.

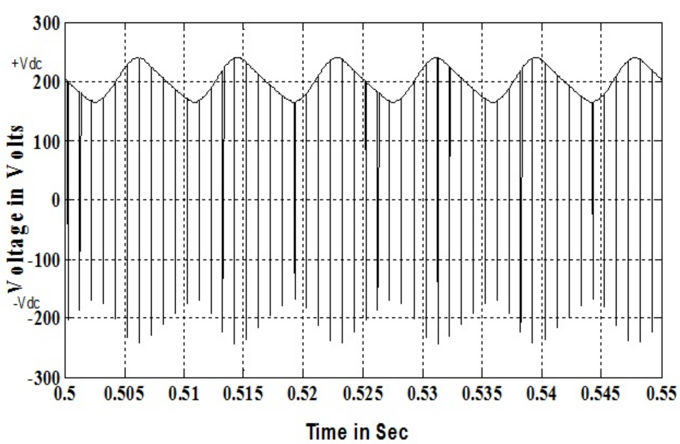

Fig. 14. Load voltage - Forward motoring mode(Bipolar)

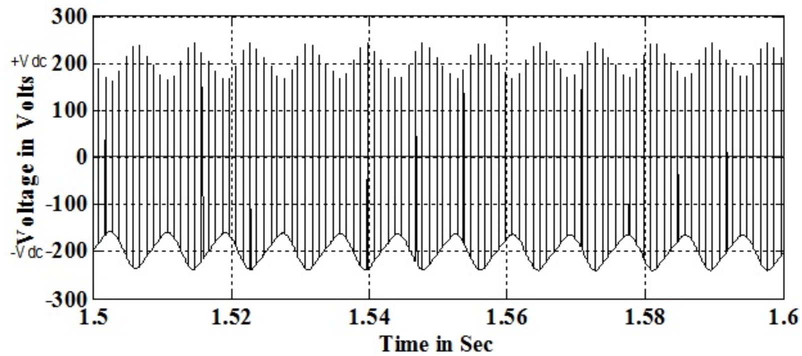

Fig. 15. Load voltage - Reverse motoring mode (Biploar)

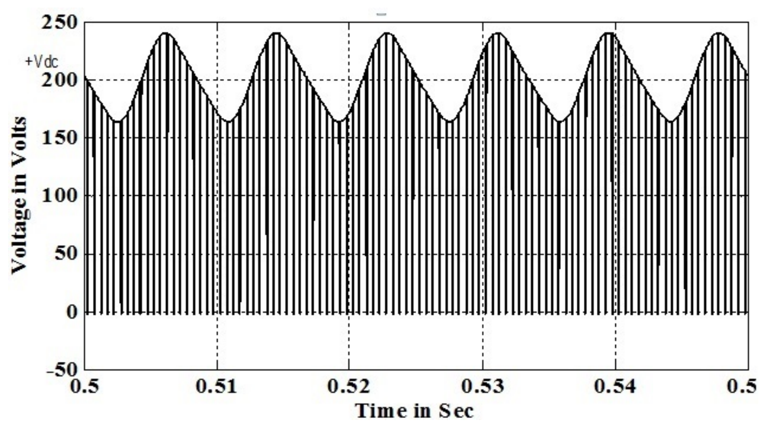

Fig. 16. Load Voltage -Forward motor (unipolar)

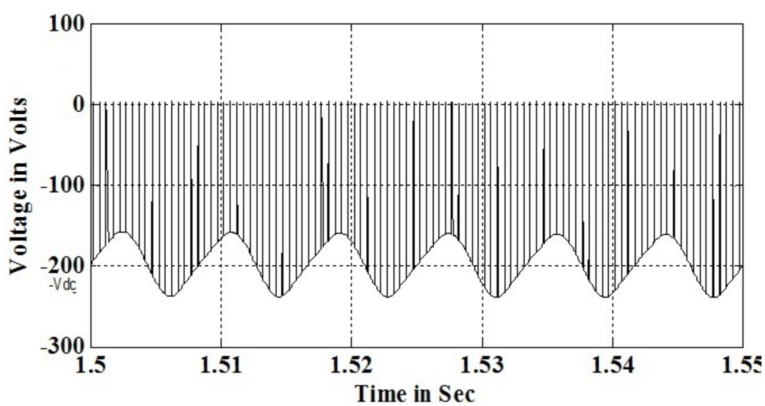

Fig. 17. Load voltage - reverse motoring mode (Uniploar)

Figs. 16 and 17 show that for unipolar voltage switching, the output voltage changes in the forward motoring mode 0 to + $V_{dc}$and 0 to-V_{dc}in the reverse motoring mode while motor current can be either positive or negative such that the motor can be operated in the four quadrants of the V_o-I_o plane.The switching frequency of two PID-PWM techniques is the same, but unipolar voltage switching has proved better output voltage waveform, output current wave form and better frequency response. Hence output voltage is doubled, RMS ripple voltages are reduced and power factor is improved.

10. Conclusion

A single phase DC motor drive system controlled by PID-PWM full bridge DC –DC Converter with unipolar voltage switching technique has been presented. The simulation of the DC motor Closed loop four quadrant operation was done using the software package MATLAB / Simulink. The parameters of PID controller are found by Ziegler-Nichols turning method used in the speed control for four quadrant operation of DC motor with unipolar voltage switching improves the performance in terms of speed , torque, less RMS ripple content in current and output voltage and power factor has been improved to 0.93 from 0.65 by using LC filter.

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