IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 4, Issue 2, Feb. 2016, 37-46

POSITION CONTROL OF SINGLE LINK ROBOT MANIPULATOR USING BLDC MOTOR

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ABSTRACT

Position servo control is more important in recent industrial and robotic applications. This paper presents the position control of robot arm using Brush Less DC (BLDC) motor. A single arm vertical rotating robot has been made through 360^o movement with gear arrangement. While vertical movement of robot arm the load is varying with depending upon the position in nature. We need to maintain the speed of arm and desired position at whatever the load is varying in any directions. So it is required a four quadrant operation of drive with robust closed loop control. In this paper position is controlled through closed loop PI controller to get better dynamic performance. The simulated design is tested using various tool boxes in Matlab/Simulink environment. The hardware demonstration of robotic arm coupled with brushless DC motor drive has been obtained using dsPIC 30F2010 digital signal controller.

KEYWORDS: BLDC Servo Drive, Dspic, PI Controller, Position Control, Single Arm Robot

INTRODUCTION

In recent years BLDC motors are used in high performance drive system because of its advantages like high ratio of starting torque to inertia and faster dynamic response. A BLDC servo motor which is usually a BLDC motor of low power rating can be used as an actuator to drive a load. Because of their high reliability, flexibility and low cost, BLDC servo motors are widely used in industrial applications, robot manipulators and home appliances where speed and position control of motor are required [1], [2]. BLDC servo motor is a common actuator in control system. Servo drive systems normally use the full four quadrant operations which allow bidirectional speed control with regenerative braking capabilities [3].

This paper demonstrates the position control based drive by closed loop PI controller. The output of the motor is coupled to a control circuit when the motor turns, its speed and/or positions are relayed to the control circuit. If the rotation of the motor is impeded for whatever reason, then the feedback mechanism senses that the output of the motor is not yet in the desired location. The control circuit continues to correct the error until the motor finally reaches its proper point [4] – [6]. The information regarding the degree of rotation on its axis always sends to the robotic control circuit. Hence it is possible for the control circuit to sense the inappropriate position and actual position to be made [7] – [9]. A 360^o free rotating vertical arm with load torque curve is show in Figure 1.During the horizontal motion of the arm in full rotation, there is no change in the load torque whereas when the arm rotates in vertical motion, the load torque varies with respect to change of position. If the vertical rotating arm position gets changes from 0^o to 180^o, arm will rotate clockwise direction and the load is increasing propositionally with angular displacement. When the arm needs to reach 90^o, it is required maximum torque to oppose the gravitational force. From 90^o to 180^o, torque will gradually decrease and reaches zero load torque at 180^o. During this period motor will work on forward motoring mode and the load curve looks like half sin wave. Whatever the load is varying we need to maintain angular velocity constant, otherwise arm will be delayed in time to reach the desired position. Similarly if the position gets changes from 180^o to 360^o the load torque is negative due to gravitational force, then the arm will be pulled down to downward direction since the speed may go higher than safe limited. During this condition we need to work drive on breaking mode with constant speed and hence it is called as forward braking.

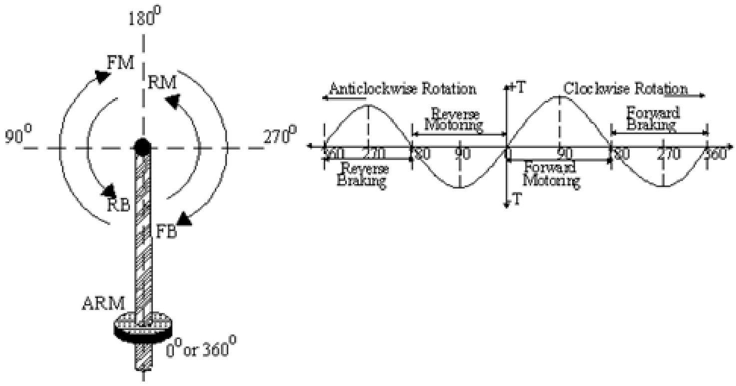

Figure 1: Torque versus Angle of Vertical Arm

Similarly when arm moves from 0^o to 180^o in anticlockwise direction motor runs at reverse motoring mode and the load torque is peak at 90^o. Even though the speed will reduce when increasing torque, it is needed to maintain speed constant at rated value. During reverse rotation of arm from 180^o to 360^o the motor operates at reverse braking mode. The curve between the entire full rotation of vertical rotating arm load and position looks like a sine waveform in both forward and reverse directions. Thus in the proposed technique the motor which can operate in four modes with constant speed. The digital control techniques have predominated over analog counts parts. The advantages of digital controllers are power saving options, less external passive components, less sensitive to temperature variation and high efficiency. The available digital control hardware option presented in this paper is dSPIC processor [10] – [12]. In this proposed method, the Proportional Integral (PI) controller has been used for the servo control of motor drive to maintain a zero steady-state error to a step change in reference.

The first section gives the introduction about the paper. The second section of the paper discusses the proposed position control of BLDC servo drive with design of PI controller. The third section deals the simulation work carried through MATLAB environment. The fourth section is about hardware implementation of proposed scheme. The fifth section is about the results and discussions. The final section presents the conclusion.

POSITION CONTROL OF BLDC SERVO DRIVE

The block diagram of the proposed position servo BLDC motor is shown in Figure 2. When actual position of the arm, obtained through the position sensor positions is compared to a set position, a difference between two generates an error. If the set position is greater than the actual position, then the position error output of the comparator is positive else it is negative if the set position is lower than the actual position. The position error so obtained is processed in position PI controller which generates the pulse to control the decoded gate signals to feed three phase inverter. In many applications, a simple voltage regulation would cause lots of power loss on control circuit thus, a pulse width modulation method (PWM) is used in many motors controlling applications. In the basic PWM method, the operating power to the motors is turned ON and OFF to modulate the current to the motor. The PWM control method uses the width of the pulses in a pulse train to control the speed of the motor.

The duty cycle of the pulses determines the speed of the motor. Therefore, the higher the duty cycles, higher the speed. This would give the motor the ability to safely vary the position from stand still to its maximum position. Sometimes, the rotation direction needs to be changed. The period of current variation and also the number of pulses are proportionally related to the motor speed. In the BLDC motors, the rotation is changed by changing the hall signal decoding sequence.

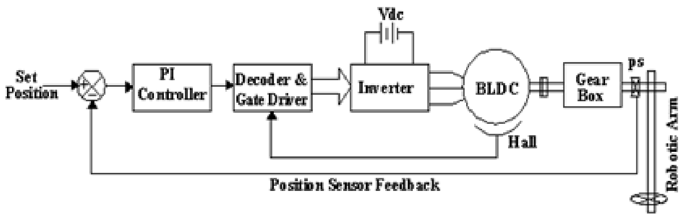

Figure 2: Block Diagram of Drive

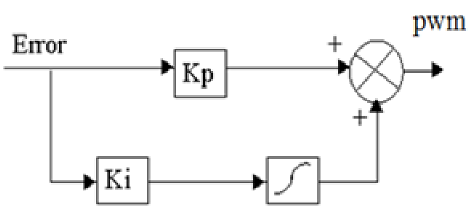

Figure 3: Position PI Controller

The inverter is formed by MOSFET switches, energizing the perticular winding of the motor according to the control signals of the decoder. The motor shaft and robot arm are connected through gear arrangement. Most of the actuators are using self locking gear mechanism arrangment to provide holding torque such as warm and worm wheel gears. The corresponding position of the motor is controlled without any speed change and oscillations. The position PI controller block model is given in Figure 3. It is one of the most common approaches for position control in industrial electrical drives. In general, because of its simplicity and the clear relationship existing between its parameters and the system response specifications, the Ziegler-Nichols method is used for determining the K_p and K_i constants of the PI controller.

Simulation of Single Arm Bldc Drive

Simulink model of the position control of BLDC motor drive with a single arm loaded is depicted in Figure 4. The closed loop four quadrant controller for a BLDC servo motor drive is modeled by using MATLAB/SIMULINK environment. It consists of two feedback signals, one is for actual position and another one is for actual speed.

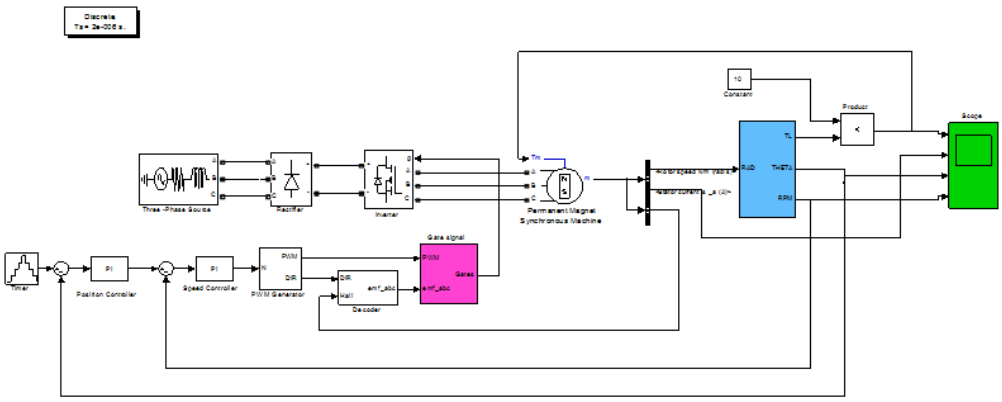

Figure 4: Simulink Model of Position Controlled BLDC Servo Motor Drive

The actual position is compared with the set position using the comparator. The output of the position controller is compared with the inner loop speed controller. In this PWM generator block we can change the direction of the drive whether it will be forward or reverse. The corresponding hall position signal is sensed by using hall sensors and fed to decoder and from decoder it is given to gate signal generation unit. Figure 5 shows the mechanical subsystem unit for receiving the speed in radiance/second signal for manipulation. The speed is reduced as per gear ratio using gain 1 and it is integrated to generate actual position of the robot arm. The sin value of position gives load torque because of vertical rotating arm load torque in nature. Motor speed in RPM and arm position in theta are the outputs of the mechanical subsystem unit.

Figure 6 shows the block models for speed and position PI controller. This Simulink model gives the entire work of position control of BLDC servo drive which is controlled in four quadrant modes. The external pay load torque of 10 N/M is multiplied with load torque and it’s fed to motor.

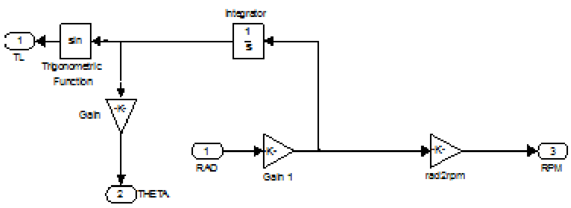

Figure 5: Mechanical Subsystem Unit

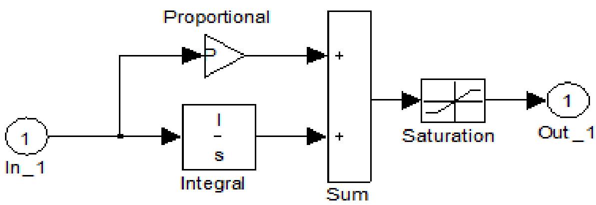

Figure 6: Speed/Position PI Controller

Hardware Implementation of Vertical Rotating Single Arm Robot

The position control of BLDC servo motor drive based vertical rotating single arm robot is experimentally implemented using dsPIC 30F2010 processor and it is programmed through MATLAB/SIMULINK software environment. Figure 7 shows the block diagram of such hardware implementation. It has two potentiometers, one is coupled with the arm shaft to sense the actual position of the arm, and another one is used for set the reference position. From the information of set and actual position, dsPIC controller generates speed and direction signals. These PWM signals are fed to the bi-directional drive. The bidirectional drive contains six MOSFETS devices which are triggered by inbuilt AMB364 driver controller and hall signal decoder to operate the drive in required modes. A 24V BLDC with 5000 RPM rated speed motor is connected with arm through warm and warm wheel gear arrangement. Figure 8 shows photo view of the hardware setup for position control of single arm robot using BLDC servo drive.

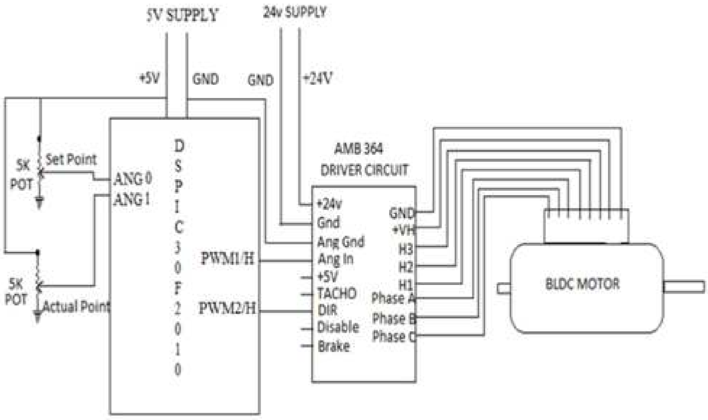

Figure 7: Hardware Functional Block Diagram

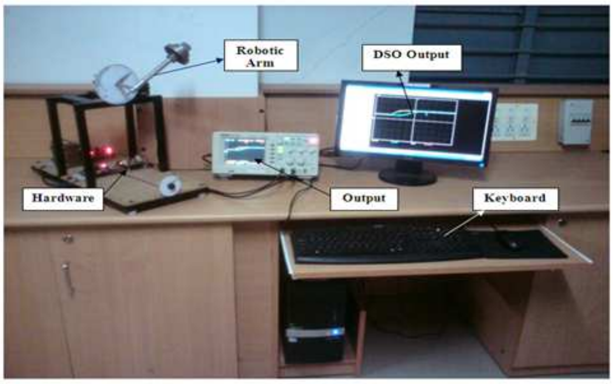

Figure 8: Snap Shot of Entire Hardware Implementation

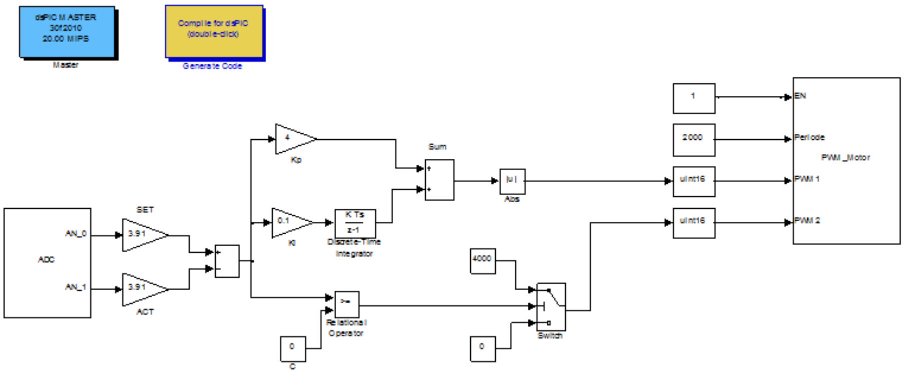

Figure 9: Graphical Embedded Programming

The hardware implementation in graphical way of embedded programming is carried through MATLAB /SIMULINK software environment so the complexity of text based embedded coding was eliminated and it is depicted in Figure 9. The ADC input block consist of 2 analog inputs namely AN_0 for set position value and AN_1 for actual position value. Graphical program have PI controller and control logic units. PWM signal generation block generates two PWM signals one is for analog input for speed control and other one is for direction control. The block sets are downloaded and utilized from Lubin Kerhuel website. Form the Simulink itself we can generate hex file and this can be dumped to processor through MPLAB-IDE with help of PICKIT-3 programmer.

RESULTS AND DISCUSSIONS

Several tests are performed to validate the performance of the position control of single armed vertical rotating robot using BLDC servo motor drive system which is simulated in MATLAB/SIMULINK environment. The simulation results are obtained from MATLAB and validated with the results from the hardware interfacing in MATLAB. For real time implementation, the measurements of set and actual position information are recorded using DSO. The arm can rotate 360 degree, which can operate in four quadrant operation in both the motoring and braking/regenerative modes. It operates in both the direction of forward and reverse.

Case 1: Forward Motoring (FM)

Figure 10 shows the output waveform for forward motoring mode. This plot indicates that time period from 0.5 sec to 1.5 sec the drive will operate in motoring condition because the speed and corresponding torque is in positive direction. At 0.5 sec position it changed to 90^o and maintained up to 1 sec. When the arm at 90^o maximum load torque of +10N/M is attained and this will try to reduce the speed of motor but the closed loop controller will maintain the speed constant. Hence the arm will reach desired position in a uniform speed. When the position is changed from 90^o to 180^o at 1 sec, the motor will rotate in forward direction and the load torque is reducing to zero. Settling time of step change of position from 0^o to 90^o and 90^o to 180^o is equal whatever the load is varying.

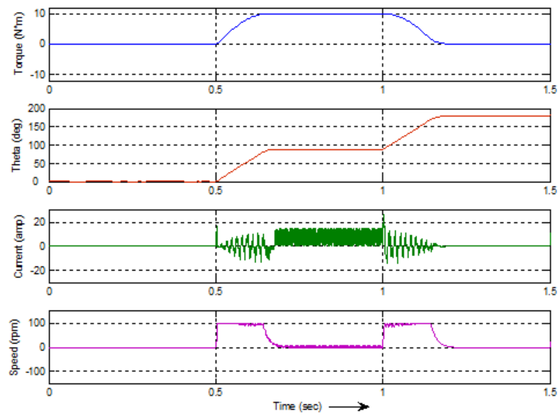

Figure 10: Torque, Theta, Current & Speed for FM

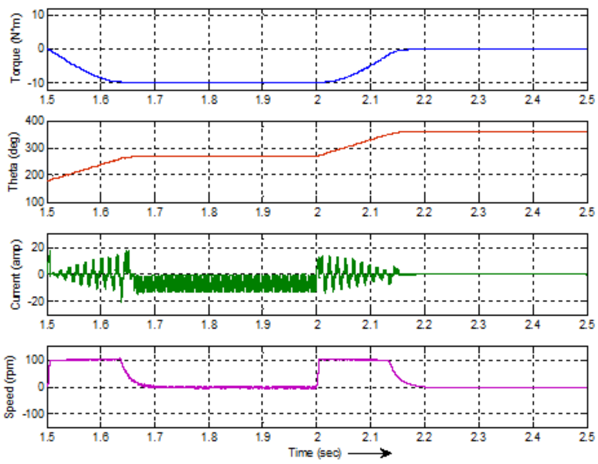

Figure 11: Torque, Theta, Current & Speed for FB

Case 2: Forward Braking (FB)

Figure 11 indicates the output waveforms for forward braking mode. At 1.5 sec the set position is changed from 180^{o} to 270^{o} and the motor will rotate clockwise direction but the direction of torque gets reversed which results in forward braking condition. The torque is at its maximum -10N/M peak when arm reaches 270^{o}. During this period current is in reverse direction so then the drive will operate in regenerating mode. At 2 sec set position is changed to 360^{o} hence motor will continue to rotate forwarded direction and the settling time is same for both motoring and braking mode.

Case 3: Reverse Motoring (RM)

The output waveform for reverse motoring mode is depicted in figure 12. At 2.5 sec the set position is changed from 360^{o} to 270^{o} and the motor will rotate in reverse direction and torque also in negative direction which results in reverse motoring condition. At 3 sec set position changed to 180^{o} and the motor continue to rotate in anti clock wise direction. Still the torque is in reverse direction and a maximum torque of -10N/M is reached 270^{o}. Due to closed loop controller action the arm reaches uniform speed whenever step change of position and load is varying.

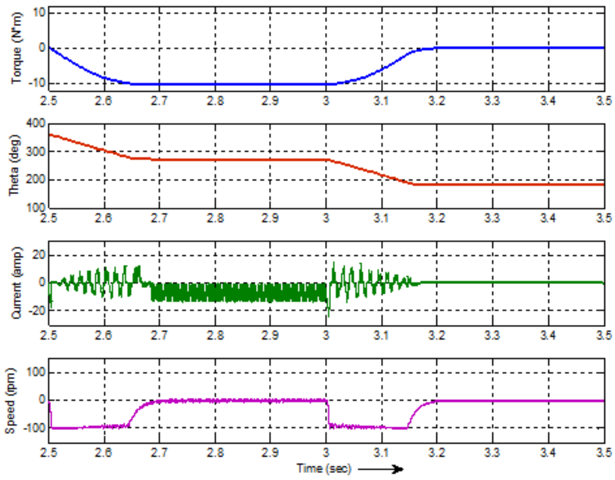

Figure 12: Torque, Theta, Current & Speed for RM

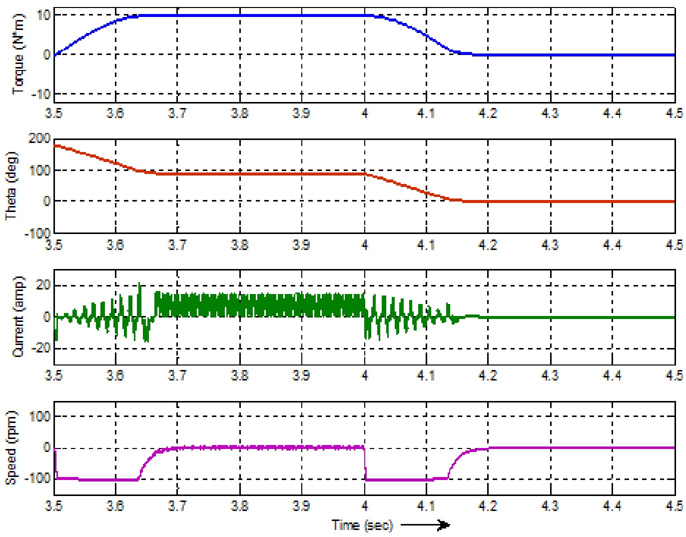

Figure 13: Torque, Theta, Current & Speed for RB

Case 4: Reverse Braking (RB)

The output waveform for reverse braking mode is depicted in Figure 13. At 3.5 sec set position is changed from 180^o to 90^o and the motor will rotates in reverse direction and the torque in positive direction which makes the drive to operate in reverse braking mode. Torque will reach maximum peak of +10N/M when arm reaches 90^o but the speed is maintained constant. At 4.5 sec set position changed from 90^o to 0^o and the arm rotate in reverse direction and the torque is still in positive direction up to arm reaches zero degree. Whatever step change of set position and load varying, the arm will reach desired position in a uniform rate of speed due to closed loop position PI controller.

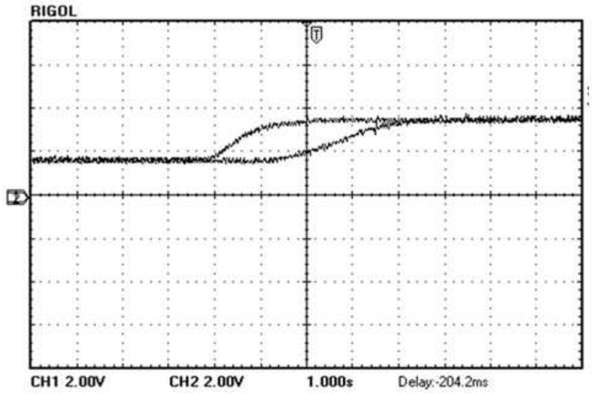

Figure 14: Forward Rotation (115.2^{o} to 259.2^{o})

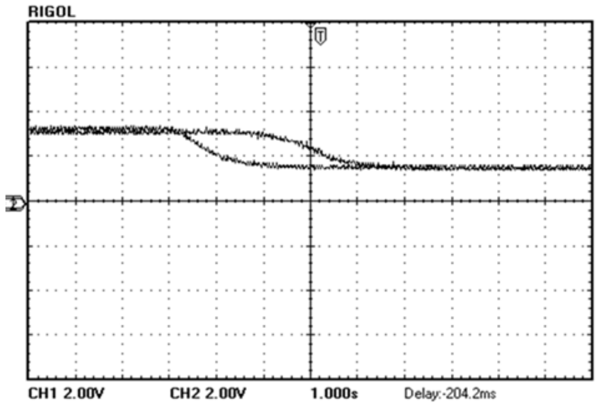

Figure 15: Reverse Rotation (230.4^{o} to 115.2^{o})

The Hardware results are taken by connecting the DSO to measure position equivalent voltage of two potentiometers. The free rotating 360^{o} potentiometers are supplied from constant 5V dc source, while rotating the shaft from 0^{o} to 360^{o} voltage is equality divided so we can get 13.88mV on every 1^{o} rotation. While setting the reference voltage from 1.6V to 3.6V, the arm will rotate forward direction of 115.2^{o} to 259.2^{o}, which includes forward motoring and forward braking. The robotic arm will reach the desired position at time delay of 4 sec. The closed loop position controller maintain the uniform rise time while varying the load and change of mode. Figure 14 shows such phenomenon. Figure 15 shows the arm rotation of 230.4^{o} to 115.2^{o} which includes reverse motoring and reverse braking. Here varying the set position through the potentiometer from 3.2V to 1.6V equivalent position of robotic arm takes place with the set position after the time delay of 3.8 sec. The closed loop position controller maintain the uniform fall time while varying the load and change of mode. Both forwarding and reversing actions of the arm reaches uniform settling time.

CONCLUSIONS

The main goal of this work is to design a vertical rotating single arm robot, made through BLDC motor position control system. While the vertical movement of robot arm changes the load torque is varied, depending upon the position in nature. The closed loop PI controller maintains the speed of arm and desired position at whatever the load is varying in all four quadrants. The model was simulated and shows different performance in MATLAB/SIMULINK environment. The hardware was implemented in dsPIC 30F2010 microcontroller through MATLAB/SIMULINK based graphical programming. In future it is possible to reduce the settling time by replacing conventional PI controller in to fuzzy logic based controllers.

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