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Digital Control Strategy for Four Quadrant Operation of Three Phase BLDC Motor with Load Variations

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Abstract: The Microcontroller based adjustable closed-loop DC motor speed controller systems has already become an important drive configuration for many applications across a wide range of power and speed . This is due to their simple control, high reliability, low cost and fast response and ability to work in all the four quadrants. Control System Design and Analysis technologies are widely suppress and very useful to be applied in real-time development. Some can be solved by hardware technology and by the advance use of software, control system are analyzed easily. This paper deals with the digital control of DC motor. The motor is controlled in all the four quadrants; in fact energy is conserved during the regenerative period. The digital controller dsPIC30F4011 is used, as it is very advantageous over other controllers, as it combines the calculation capability of Digital Signal Processor and controlling capability of PIC microcontroller, to achieve precise control. In this paper, control techniques of dsPIC30F4011 microcontroller and MOSFET are analyzed by mainly focusing with the Modeling and Simulation of DC Motor using MATLAB. The simulation model is developed using MATLAB/SIMULINK environment. The reason for choice of MATLAB/SIMULINK as development tool is, it is the most important and widely used simulation software. The prototype hardware set is tested in the power electronics laboratory for motor rating of 1HP. The setup is tested for open & closed loop control of motor.

Keywords: BLDC Motor, Digital Control, DSPIC, Four Quadrants, Regenerative Braking.

I. INTRODUCTION

Traditionally, the DC Motors and the associate close loop control systems used to drive them have been modeled using classic control theory techniques, based on transfer functions. Control system design and analysis technologies are widely suppress and very useful to be applied in real-time development. Some can be solved by hardware technology and by the advance used of software, control system are analyzed easily and detail. DC Motors can be used in various applications and can be used as various sizes and rates. The microprocessor computes the actual speed of the motor by sensing the terminal voltage. It then compares the actual speed of the motor with the reference speed and generates a suitable control signal which is fed into the triggering unit. This unit drives a Power MOSFET amplifier, which in turn supplies a PWM voltage to the dc motor. The objective of this paper is to explore the approach of designing a microcontroller based closed loop controller. The interface circuit and the software are all designed to achieve a better performance. The microcontroller system is equipped with an LCD display and a keypad and software was written to monitor the registers on the LCD and read commands from the keypad. Thus, by using the User Interface Module (UIM) the operator can view and/or change all the control and monitoring variables of the controller program.

II. FOUR QUADRANT OPERATION OF DC MOTOR

A scheme that address on building up such a system as mention above is presented here. As the system is based on speed control of DC motor, the desired goal is to achieve a system with control speed and direction of rotation at constant load condition. That means motor will run at variable speed at constant load condition. In implementing this work frequency independent PWM output with variable duty cycle from 0% to 100% is generated. Furthermore a direction change logic circuit is fabricated for the changing the direction of motor (forward and reverse). Also there is use of soft start circuit, to protect the motor from inrush current.

A. DC Motor

The DC motor to be controlled is fed by DC source through a 4 quadrant chopper circuit shown in Fig.1. The output voltage of chopper is fed to the DC motor which rotates in forward and reverse direction according to the conduction of chopper pair. With the help of proximity sensor we measure the speed of motor in RMP along with direction of rotation.

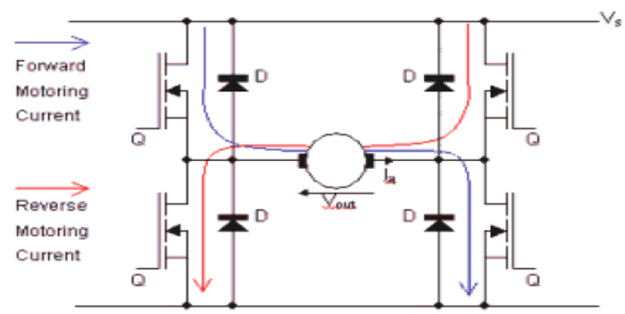

Fig.1. Equivalent Circuit of Power Stage of DC Motor.

B. Four Quadrant Operation

There are four possible modes or quadrants of operation using a DC Motor which is depicted in Fig.2 When DC motor is operating in the first and third quadrant, the supplied voltage is greater than the back EMF which is forward motoring and reverse motoring modes respectively, but the direction of current flow differs. When the motor operates in the second and fourth quadrant the value of the back EMF generated by the motor should be greater than the supplied voltage which are the forward braking and reverse braking modes of operation respectively, here again the direction of current flow is reversed. The BLDC motor is initially made to rotate in clockwise direction, but when the speed reversal command is obtained, the control goes into the clockwise regeneration mode, which brings the rotor to the standstill position. Instead of waiting for the absolute standstill position, continuous energization of the main phase is attempted. This rapidly slows down the rotor to a standstill position. Therefore, there is the necessity for determining the instant when the rotor of the machine is ideally positioned for reversal as shown in Fig.3.

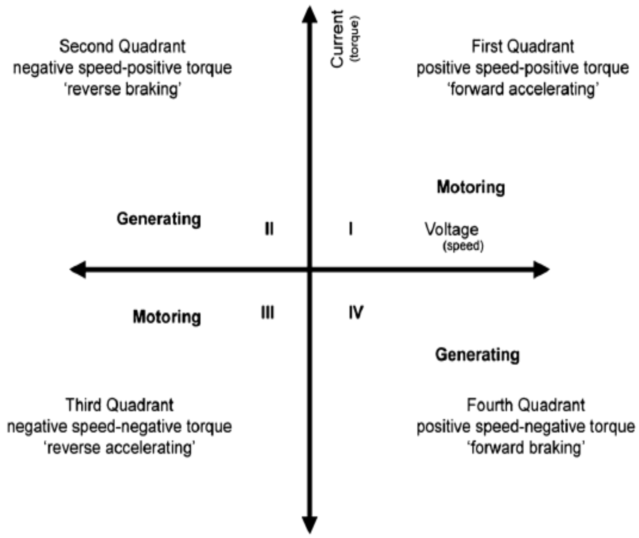

Fig.2. Four Quadrants of Operation.

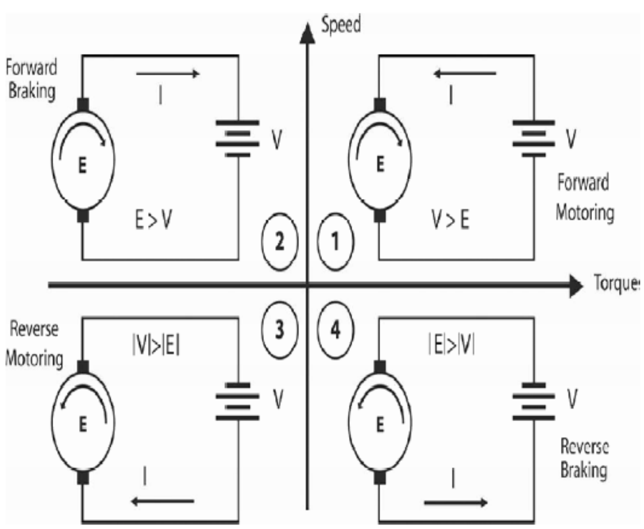

Fig.3. Operating Modes.

III. DIGITAL CONTROLLER

The digital control of the four quadrant operation of the three phase BLDC motor is achieved with dsPIC30F4011. This digital controller combines the Digital Signal Processor features and PIC microcontroller features, making it versatile. The controller has a modified Harvard architecture, with a16 *16 bit working register array. It has two 40 bit wide accumulators. All the DSP instructions are performed in a single cycle. The external interrupt sources, with eight user selectable priority levels for each interrupt source helps to get the proximity sensor inputs from the motor the reference speed and the required duty cycle can be fed into the controller. The closed loop control is achieved with the PI controller.

A. PI Controller

The regulation of speed is accomplished with PI Controller. By increasing the proportional gain of the speed controller, the controller's sensitivity is increased to have faster reaction for small speed regulation errors. This allows a better initial tracking of the speed reference by a faster reaction of the current reference issued by the speed controller. This increased sensitivity also reduces the speed overshooting. The armature current reduces faster, once the desired speed is achieved. An increase of the integral gain will allow the motor speed to catch up with the speed reference ramp a lot faster during sampling periods. This will indeed allow a faster reaction to small speed error integral terms that occur when a signal is regulated following a ramp. The controller will react in order to diminish the speed error integral a lot faster by producing a slightly higher accelerating torque when following an accelerating ramp. On the other hand, too high increase of the proportional and integral gains can cause instability, and the controller becoming insensitive. Too high gains may also result in saturation. Tuning process is by trial and error method and the Proportional Constant (Kp) and Integral Constant (Kd) are 0.1 and 0.03 respectively.

B. PWM Module

The PWM module simplifies the task of generating multiple synchronized Pulse Width Modulated (PWM) outputs. It has six PWMI/O pins with three duty cycle generators. The three PWM duty cycle registers are double buffered to allow glitch less updates of the PWM outputs. For each duty cycle, there is a duty cycle register that will be accessible by the user while the second duty cycle registers holds the actual compared value used in the present PWM period.

C. ADC Module

The 10 bit high speed analog to digital converter (A/D) allows conversion of an analog input signal to a 10 bit digital number. This module is based on Successive Approximation Register (SAR) architecture, and provides a maximum sampling rate of 500 kbps. The A/D converter has a unique feature of being able to operate while the device is in sleep mode. The timer module, input capture and output compare modules are used. The timer registers are used to store the duty cycle of the PWM pulses that are generated. The input capture module captures every falling and rising edge of the sensor signals.

IV. RESULTS

The Hall sensor signals and the phase current (of one phase) of three phase Brushless DC motor are shown in Fig. 4. The digital storage oscilloscope images shown in Fig. 5 indicate the trapezoidal voltage of phases RY and YB. The PWM pulses which are given as input to the inverter are shown in Fig.6.

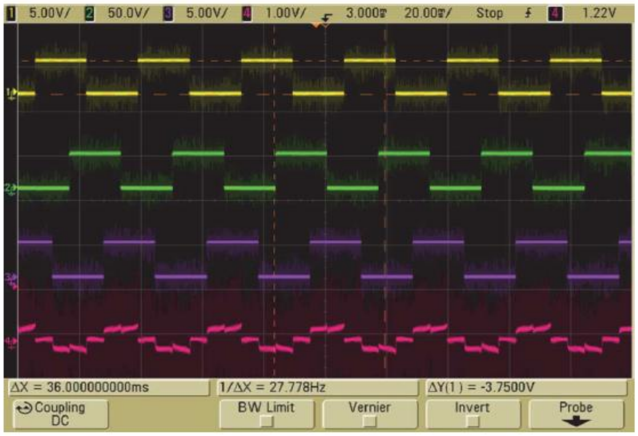

Fig.4. Hall Sensor signals and Phase Current.

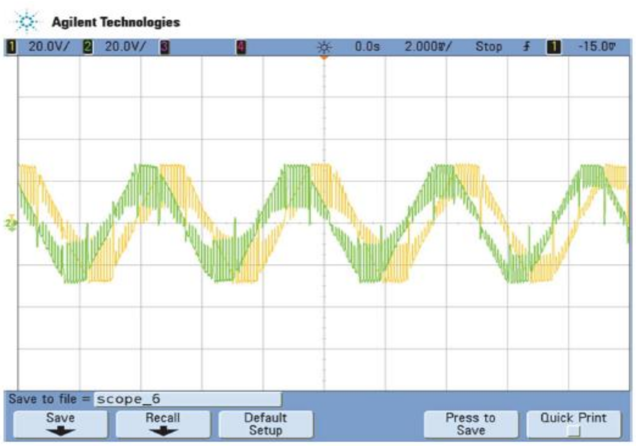

Fig.5. Trapezoidal Voltages of RY and YB.

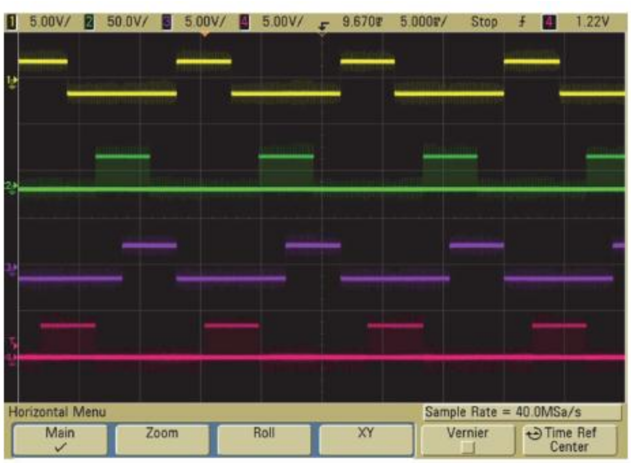

Fig.6. PWM Pulses—Control signals to the Inverter.

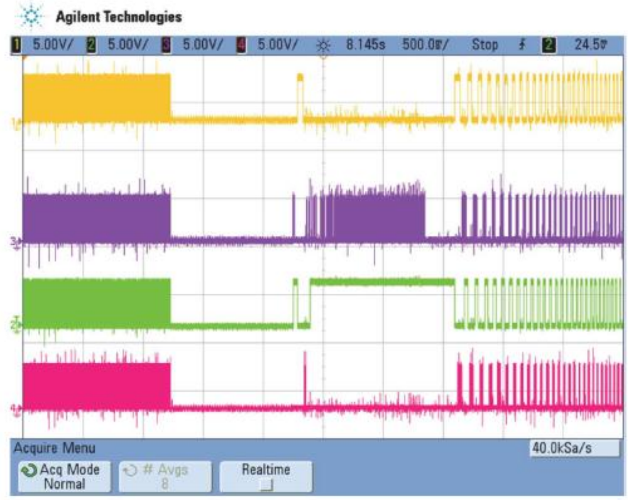

Fig.7. Quadrant transition.

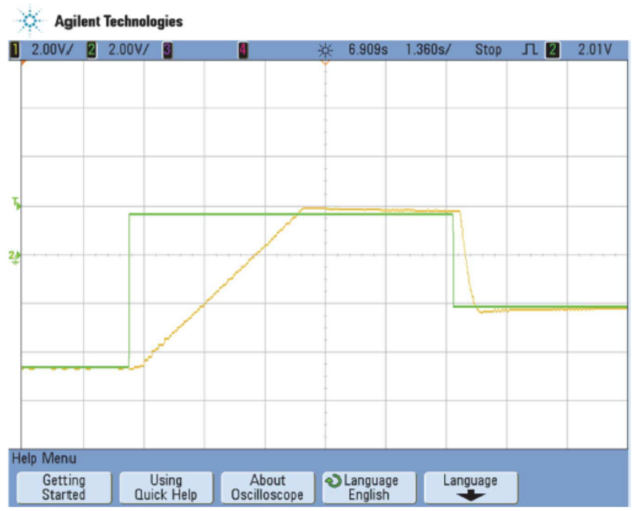

Fig.8. Speed Control with load of 0.5 kg.

The Pulse Width Modulation (PWM) pulses applied to the inverter circuit at the appropriate time to trigger the appropriate switches are the control signals to the circuit, which is shown in the Fig.7. It depicts that the motor is running in the forward direction, after a time interval brake is applied, the motor stops decelerating at this point the battery starts charging. Once the brake is released the motor starts to run. Only four of six PWM pulses are shown in the scope. The speed control plot shown in Fig. 8 depicts that the actual speed catches up with the reference speed. The time taken to attain the reference speed from 500 rpm to 3000 rpm is larger than when compared with 3000 rpm to 1000 rpm, with applied load of 0.5 kg. The energization of the batteries with no load and with loads of 0.5 kg and 1 kg are depicted in the plots of Figs.9, 10 and 11 respectively. They clearly show that the energization decreases as the load increases. In Fig. 12, the waveform shows that the battery starts energizing from the instant the speed reversal command is received. The oscillations die out gradually as the motor changes its direction of rotation.

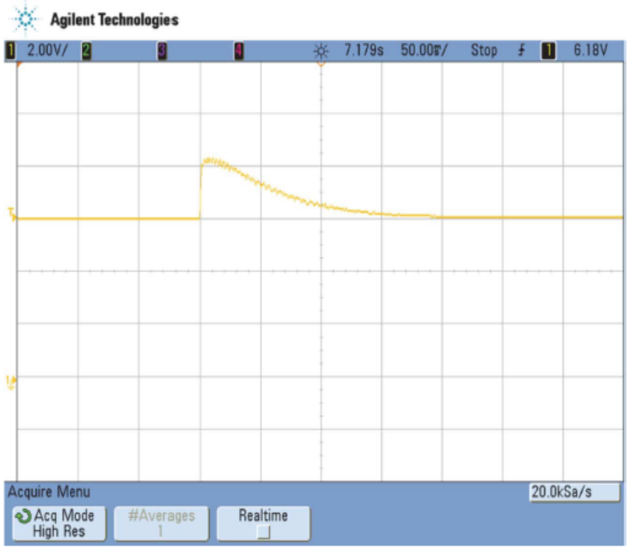

Fig.9. Energization with no load.

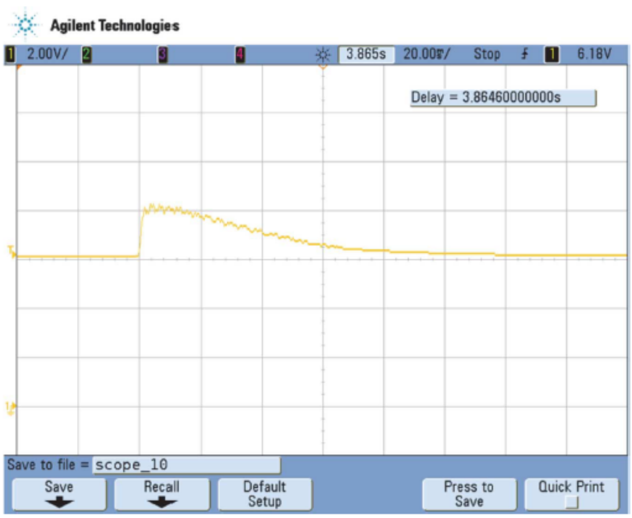

Fig.10. Energization with a load of 0.5 kg.

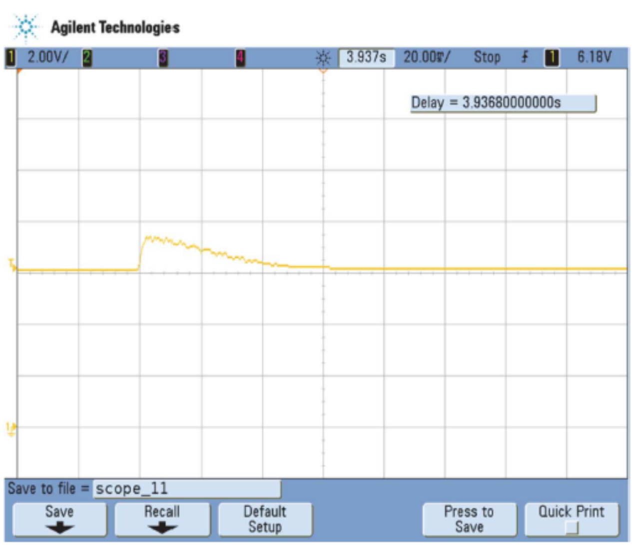

Fig.11. Energization with a load of 1 kg.

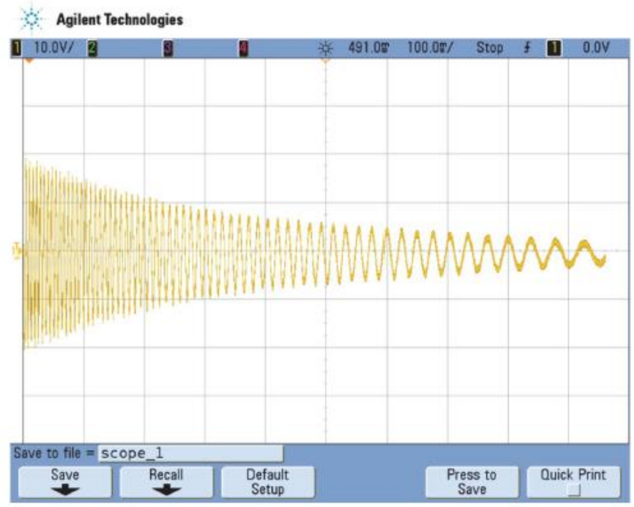

Fig.12. Energization of the Battery.

V. CONCLUSION

The proposed algorithm has been implemented for four quadrant DC motor, and it generates the firing pulses required to drive the MOSFETS. The generated PWM signals for driving the BLDC motor have been successfully tested using a dsPIC30F4011 Digital Signal Controller. The output from the converter is fed to the armature of 1HP, 1500 rpm DC motor and the motor is found to run at constant speed which is set by the key connected to the microcontroller circuit. The program is found to be efficient and the results with the designed hardware are promising. The developed control and power circuit functions properly and satisfies the application requirements. The motor is able to operate in all the four quadrants successfully. Regenerative braking is also achieved. Simulation and experimental results tally with each other & justify effectively the developed drive designs.

VI. REFERENCES

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