Hardware Implementation of Field Oriented Control of Permanent Magnet Synchronous Motor

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Abstract: Permanent magnet motors have been broadly utilized in light of the fact that they have value of high power thickness, high productivity; straightforward structure, high element reaction, higher velocity extent, and expansive beginning torque quiet operation. Two sorts of permanent magnet ac drives are accessible in the drives business. These are the changeless magnet synchronous-engine (PMSM) drive with a sinusoidal flux distribution, and the brushless dc engine drive with a trapezoidal flux distribution.Field situated control of PMSM is one vital variety of vector control routines. The point of the FOC system is to control the attractive field and torque by controlling the d and q parts of the stator streams or therefore the fluxes. In this, Hardware of Sensored Field oriented Control (FOC) of PMSM is Implemented.

Index Terms **- PMSM, FOC, Inverter, speed.**

I. INTRODUCTION

In synchronous machine vector control strategy is used with a purpose of having an easier control and the algorithm is performed in the rotating d, q rotor reference frame. In this rotor reference frame the currents and voltages both are considered as constant values throughout.

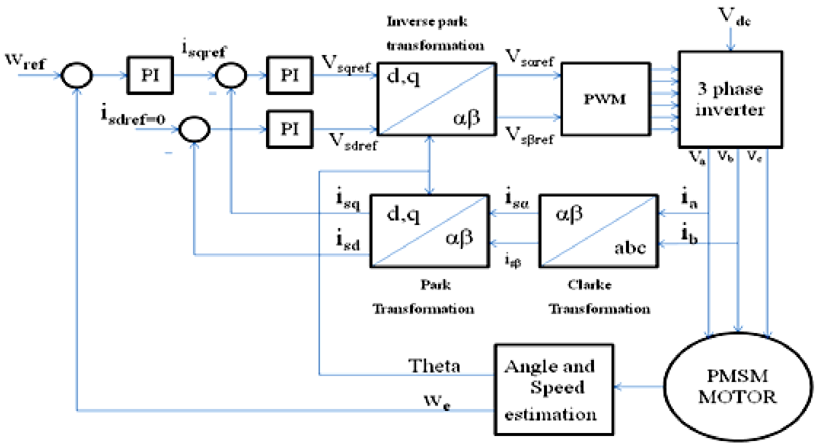


FIGURE 1 Block diagram of Field oriented control of PMSM

Two motor phase currents are measured. These measurements feed the Clarke transformation module. The outputs of this projection are designated $i_{s\alpha}$ and $i_{s\beta}$. These two components of the current are the inputs of the Park transformation that gives the current in the d,q rotating reference frame. The isd and isq components are compared to the references i_{sdref} (the flux reference) and i_{sqref} (the torque reference). At this point, this control structure shows an interesting advantage: it can be used to control either synchronous or HVPM machines by simply changing the flux reference and obtaining rotor flux position. As in synchronous permanent magnet a motor, the rotor flux is fixed determined by the magnets; there is no need to create one. Hence, when controlling a PMSM, i_{sdref} should be set to zero. As HVPM motors need a rotor flux creation in order to operate, the flux reference must not be zero. This conveniently solves one of the major drawbacks of the “classic” control structures: the portability from asynchronous to synchronous drives. The torque command i_{sqref} could be the output of the speed regulator when we use a speed FOC. The outputs of the current regulators are V_{sdref} and V_{sqref}; they are applied to the inverse Park transformation. The outputs of this projection are $V_{s\alpha ref}$ and $V_{s\beta ref}$ which are the components of the stator vector voltage in the (α, β) stationary orthogonal reference frame. These are the inputs of the Space Vector PWM. The outputs of this block are the signals that drive the inverter. Note that both Park and inverse Park transformations need the rotor flux position. Obtaining this rotor flux position depends on the AC machine type (synchronous or asynchronous machine).

II. HARDWARE IMPLEMENTATION OF FOC

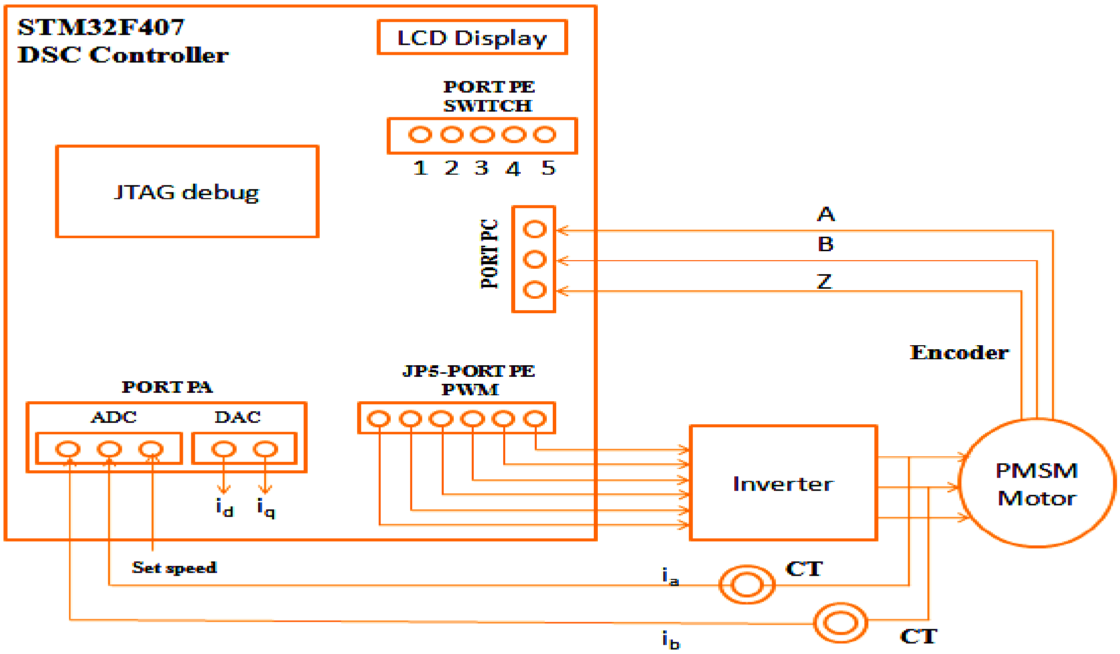


FIGURE 2 Basic Block Diagram of Hardware Implementation

Microcontroller:

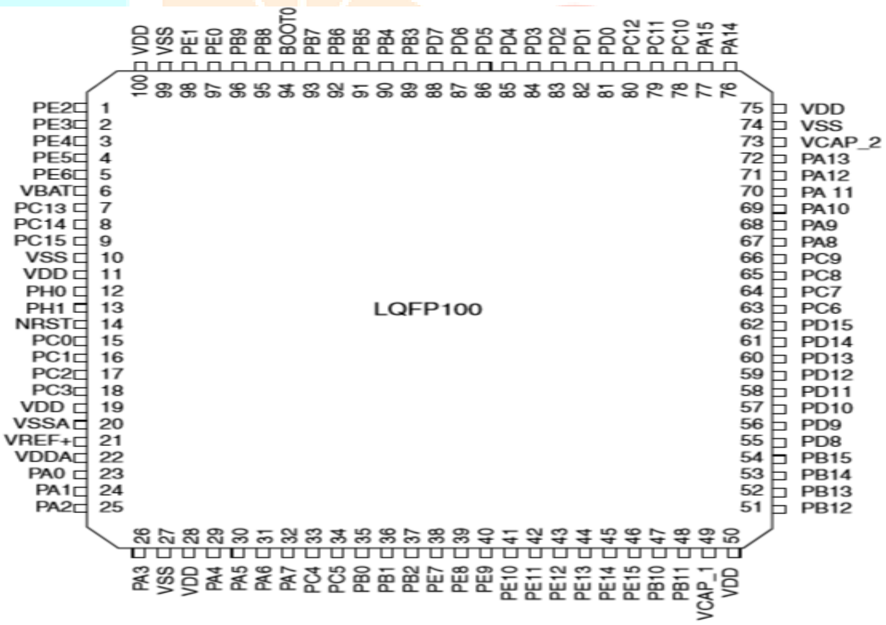


FIGURE 3 Pin diagram of STM32F407 Controller

STMicroelectronics made STM32F407 DSC is used in this experiment. It is based on 32-bit CORTEX M4 core with highest CPU execution speed of 168 MHz, offering 210 MIPS of performance. Controller has on chip floating point unit accompanied by 32x32 single cycle multiply and accumulate (MAC) unit. On chip 1MB of flash memory + 192 KB of SRAM facilitate complex code and wider data handling. Total fourteen timers are available with two advanced control timers with three complimentary PWM channels and programmable dead time. It has three on chip 12-bit ADCs working at 2.4 MSPS, making simultaneous sampling of two line currents possible. Two 12-bit DACs are very handy to monitor intermediate variables or signals. A dedicated QEI module provides easy interface to the incremental encoder.

Inverter Card:

It includes Driver circuit and Power circuit.VSI consists of IGBT based inverter module with isolated gate drive circuits. An over current protection circuit with trip signal is included. High side and low side switching is handled by the driver IC IR2130 of International Rectifier. Six IGBTs 30N120HD are rated with 30A, 1200V with internal reverse recovery diode.

Sensor card:

Current sensing is done by CTs having ratio of 1200:1 and Maximum Capacity of CT`s is 5A. Since Current sensed by the CT is converted in to voltage by a burden resistor. Since the voltage signal produced corresponds to current is of very less magnitude, amplification of the signal is required. ADC of the microcontroller accepts only the uni polar signal, ranging from 0 to 3.3 V; an offset of 1.65 V needs to be added. Hence signal conditioning circuit is split in two stages; amplification and offset addition such that maximum possible current wave is represented as unipolar signal having peak to peak voltage.

Encoder:

It utilizes two yield channels (A and B) to sense position. Utilizing two code tracks with divisions situated 90° degrees out of stage, the two yield channels of the quadrature encoder show both position and bearing of turn as indicated in figure.

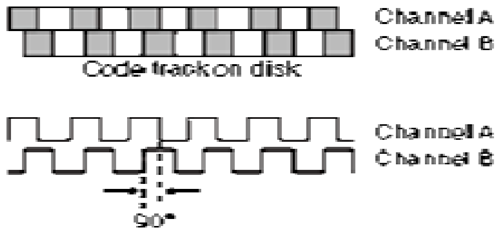


FIGURE 4 Quadrature Encoder Channels [2]

On the off chance that A leads B, the plate is pivoting in a clockwise heading. On the off chance that B drives A, then the plate is turning in a counter-clockwise heading. By observing both, the quantity of heartbeats and the relative period of signs A and B, it's conceivable to track position and heading of revolution. Some quadrature encoders additionally incorporate a third yield channel, called a zero or record or reference signal, Which supplies a single pulse per revolution. This single pulse is used for precise determination of a reference position.[2]

III. PROCEDURE OF HARDWARE IMPLEMENTATION

When motor starts, initially it generates pulses from which current feedback is taken. Only two currents i_a and i_b are sensed using current transformer. Using encoder connected with motor, speed feedback is taken into account. These two currents and speed is given to microcontroller through ADC port .By using code, Clarke and park transformation and PI tuning is done and using DAC port i_d and i_q are observed on DSO. Six PWM pulses are generated using code and which are observed on PWM port of microcontroller. Encoder pulses are also observed using GPIO port. Two timers are used in coding. Timer 1- For Encoder pulses and Timer 8 – For PWM pulse generation. Two switches are used in this controller. Key 1 -To start / to stop motor and Key 2 - Set speed / to change direction of motor. Initially Motor is in off condition. Now by pressing key 1, motor start running and by pressing key 2 we can change set speed up to maximum speed. Now to stop motor press key 1 again. Once motor is stopped, by pressing key 2 we can change direction of motor either in CW (clockwise) or CCW (Counter clockwise). 6 PWM pulses generated using controller given to inverter. From inverter 3 phase supply is given to PMSM and motor runs. This whole process provides close loop control of PMSM. So, if load is applied motor still runs at its reference speed. Setup for Hardware implementation is shown in figure 5.

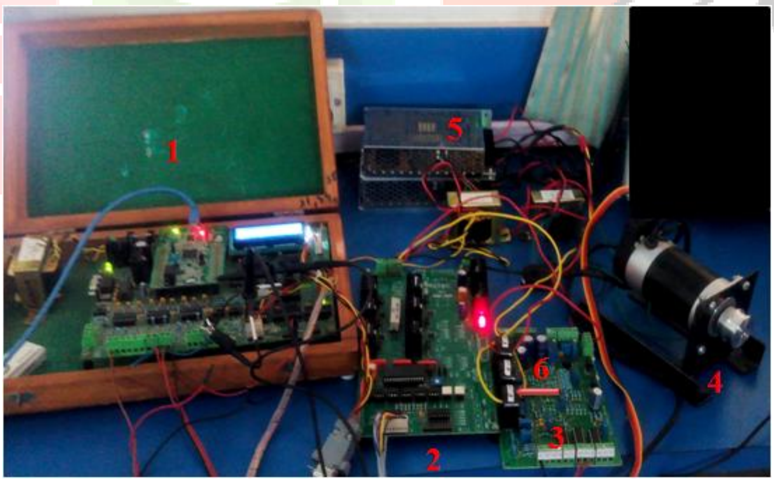


FIGURE 5 Setup for Hardware implementation of Sensored FOC

1. STM32F407 DSC – Arm cortex Controller kit

2. Inverter 3. Sensor card 4. PMSM Motor 5. SMPS 6. CT

IV. RESULTS

4.1 Inverter Gate pulse Waveform

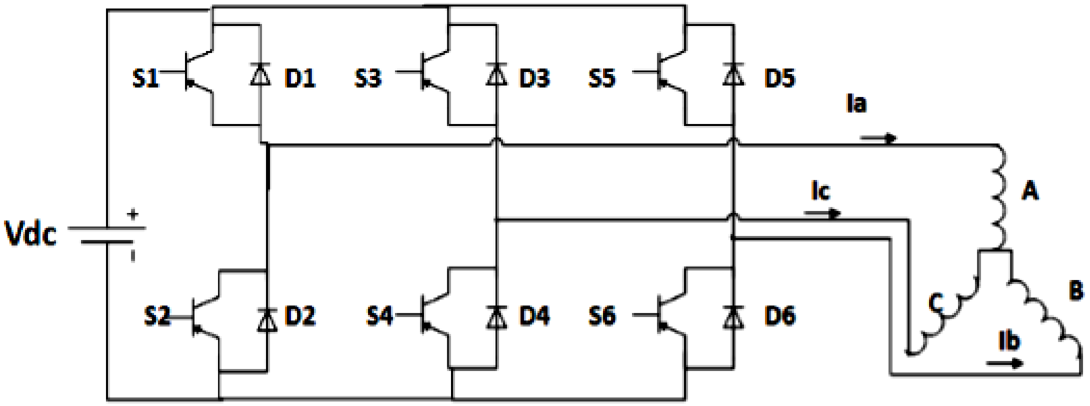
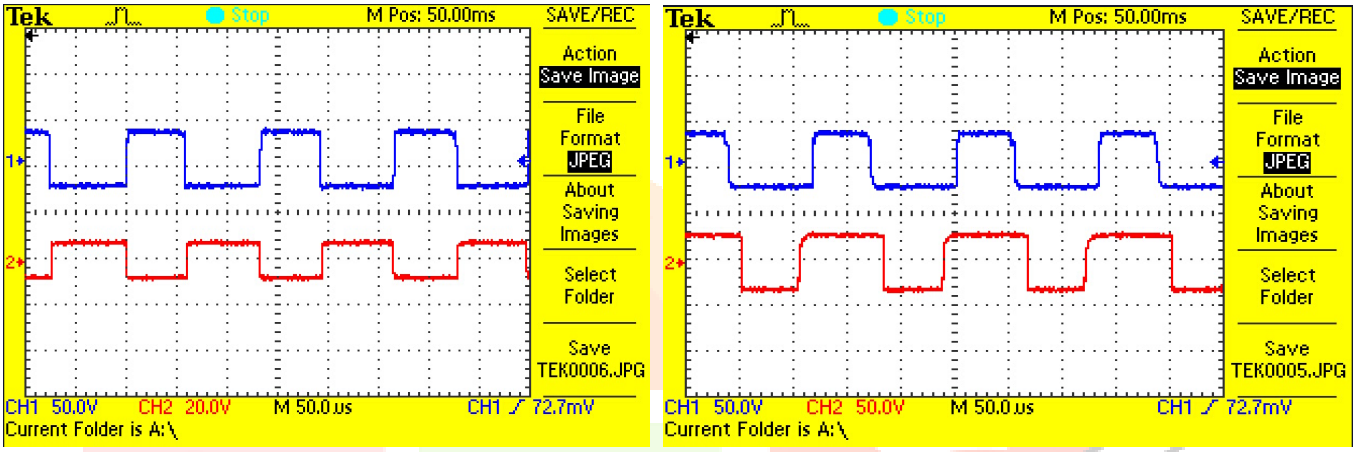


FIGURE 6 Three Phase Inverter



(a) (b)

FIGURE 7 (a) G1, G2 Waveform (b) G1, G3 Waveform

Three phase inverter is shown in Figure 6.Here gate pulse of S1, S2, S3 are shown. G1 and G2 are 180 degree with respect to each other. Here switching frequency is 7.5 KHz

4.2 Experiment Results with No Load Torque.

CASE 1 : Set Reference Speed = 1003 RPM.

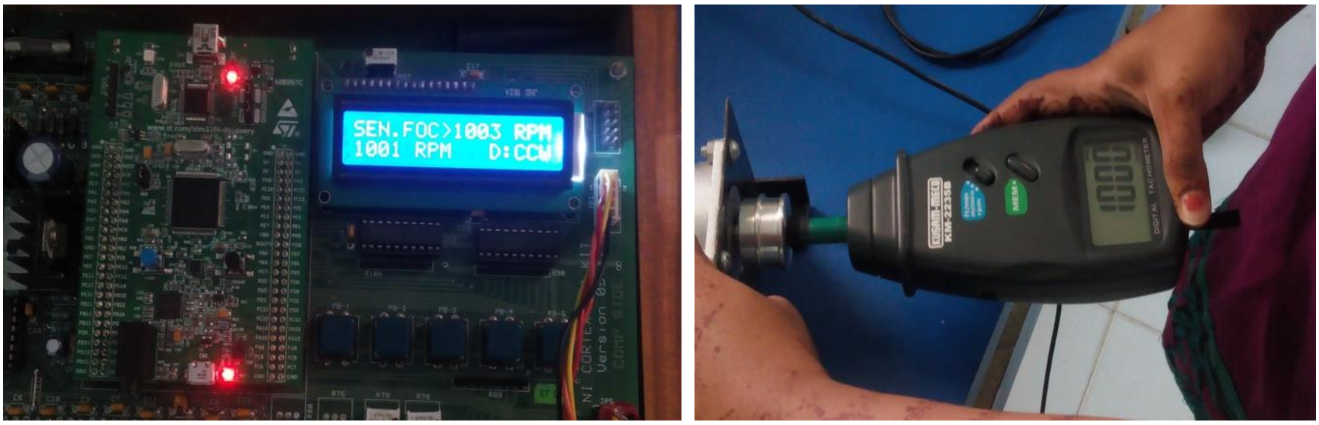
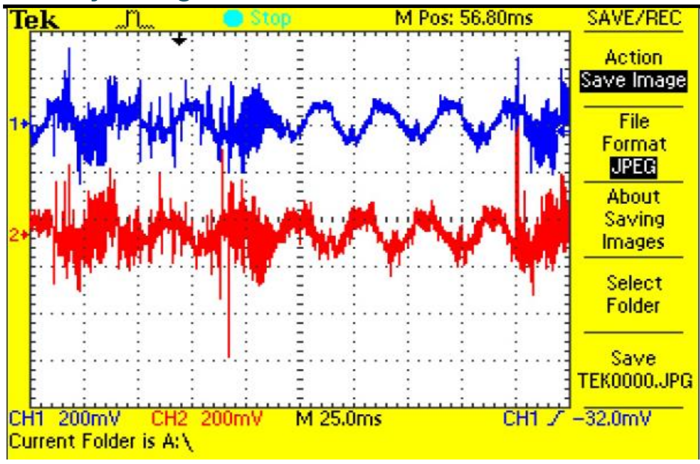
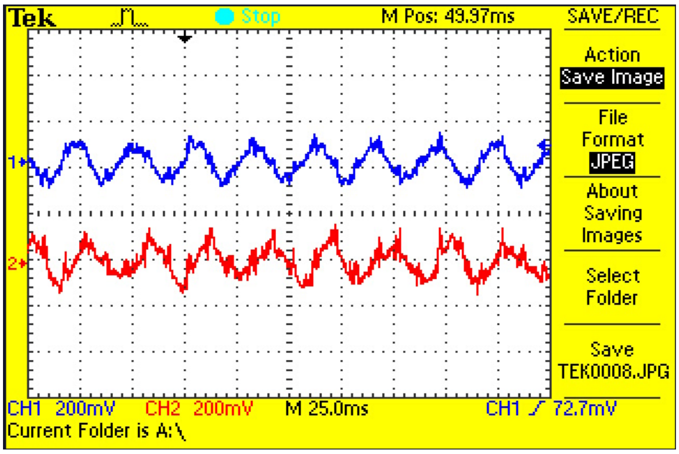


FIGURE 8 Set speed and Actual speed

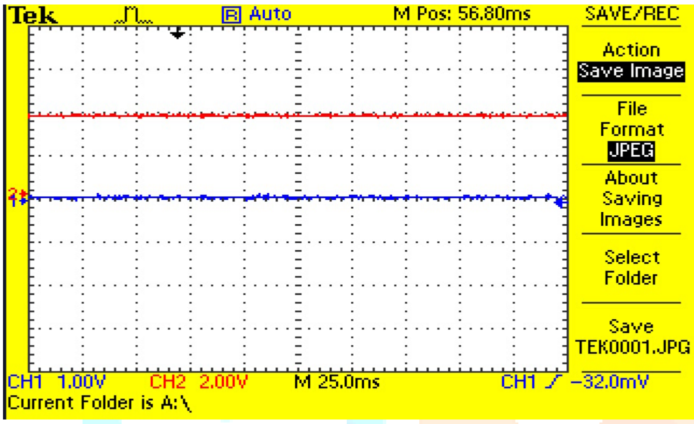
Here, Reference speed is set at 1003 RPM. According to it, Actual speed of motor is measured using tachometer. Above figure shows that both speeds are nearly equal to each other.



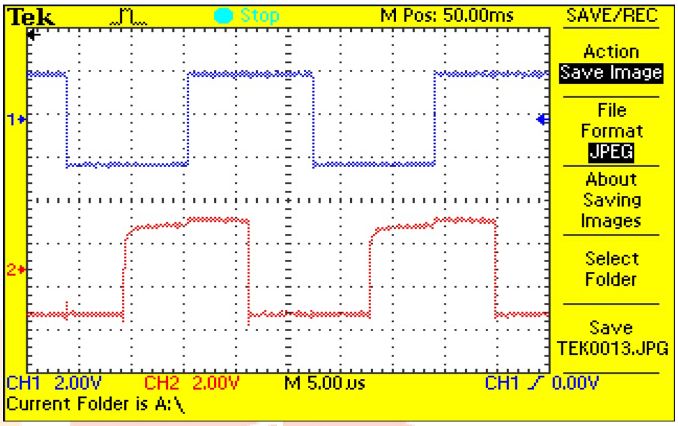
(a)



(b)



(c)



(d)

FIGURE 9

(a) i_a and i_b Waveform (b) i_{alfa} and i_{beta} Waveform (c) i_d and i_q Waveform (d) Encoder pulses waveform

In figure (a) These two currents are sensed using two CTs. These are 120 degree phase shifted and sinusoidal. But, Here due to lower speed,, noise is higher and waveform are not pure sinusoidal. In figure (c), blue line represents i_d current waveform which is zero after performing Clarke and park transformation in controller. Red line represents i_q current waveform which is positive. Here I_d=0, so motor runs in constant torque region. In figure (d) Encoder pulses A and B are shown which 90 degree phase shifted to each other.Frequency of encoder pulse is 42 KHZ.

CASE 2: Set Reference Speed = 2007 RPM.

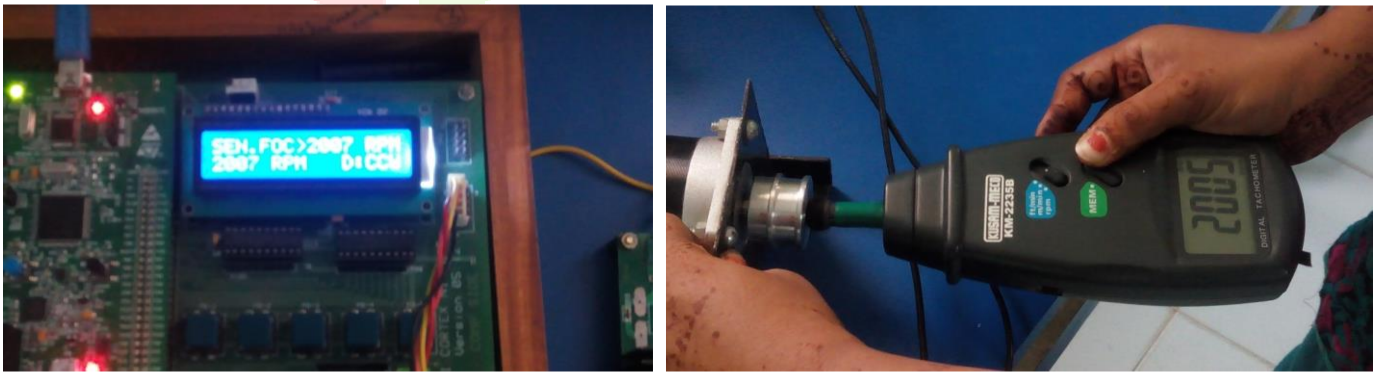
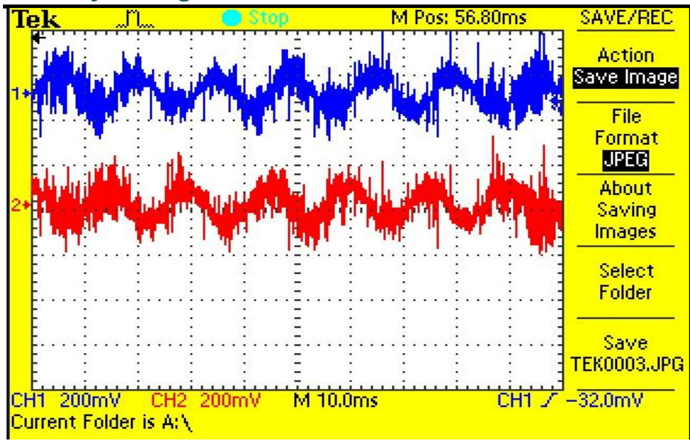
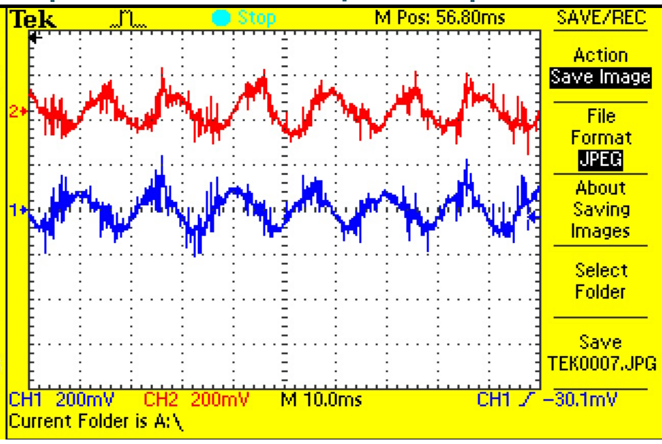


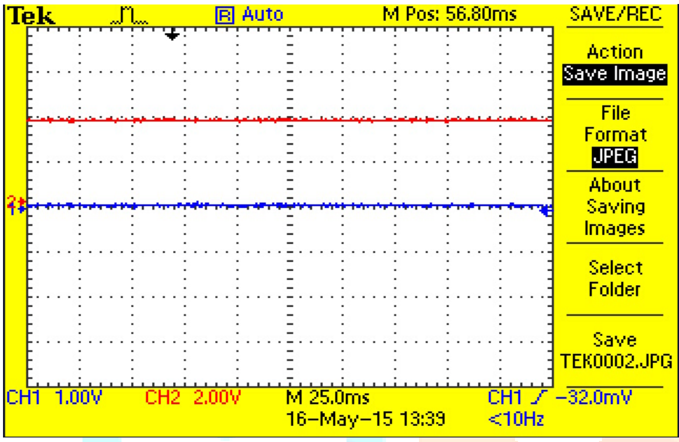
FIGURE 10 Set speed and Actual Speed



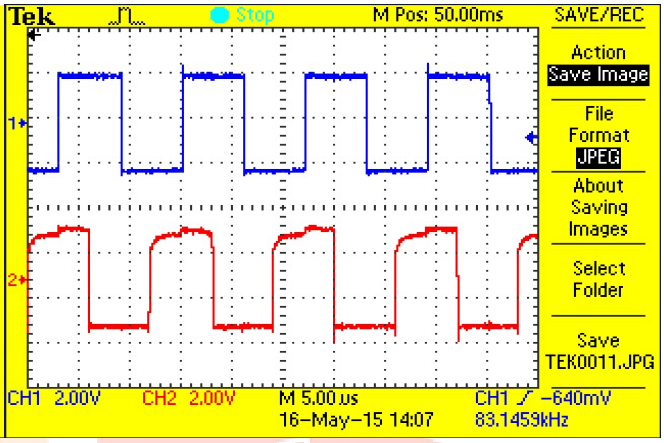
(a)



(b)



(c)



(d)

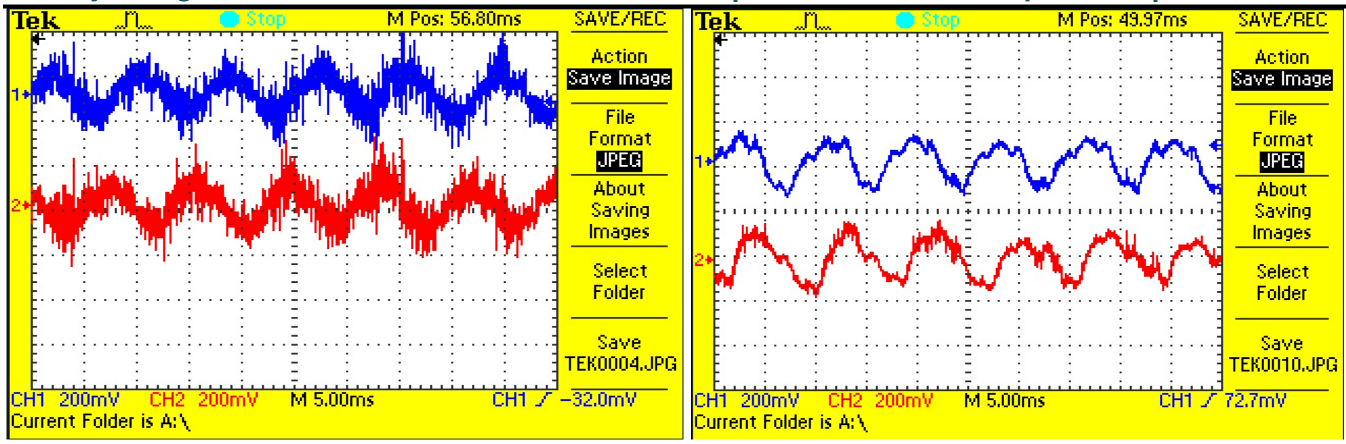
FIGURE 11

(a) i_a and i_b Waveform (b) i_{alfa} and i_{beta} Waveform (c) i_d and i_q Waveform (d) Encoder pulses waveform

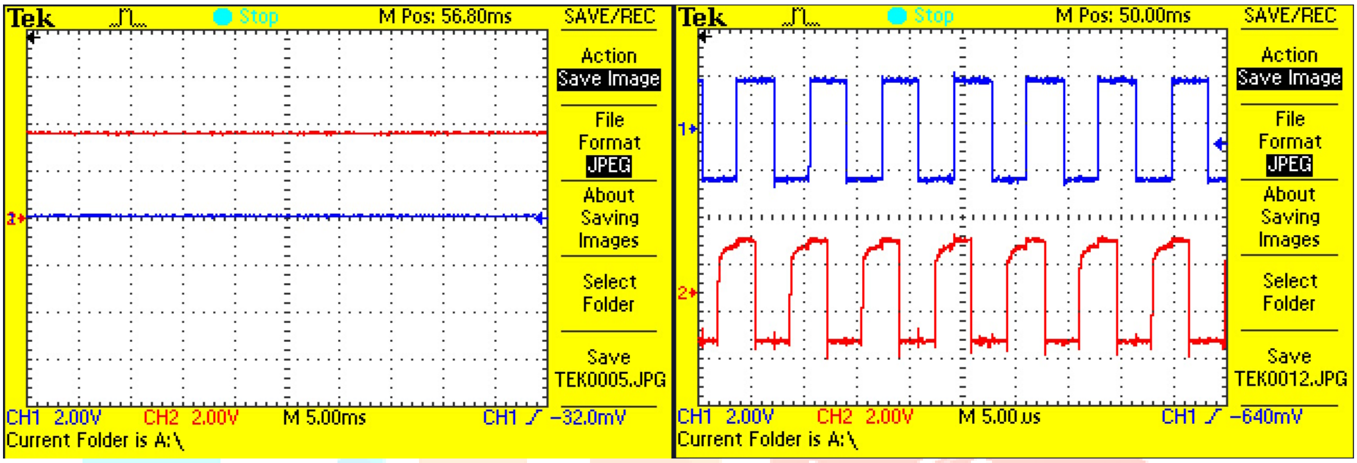
Here, Encoder pulses A and B are shown which 90 degree phase shifted to each other. Frequency of encoder pulse is 83 KHZ.

CASE 3 : Set Reference Speed = 3500 RPM.

FIGURE 12 Set speed and Actual Speed



(a) **(b)**



(c) **(d)**

FIGURE 13

(a) i_a and i_b Waveform (b) i_{alfa} and i_{beta} Waveform (c) i_d and i_q Waveform (d) Encoder pulses waveform

we can see that as speed is increased, current competes more number of cycles in same interval. Here, Encoder pulses A and B are shown which 90 degree phase shifted to each other. Frequency of encoder pulse is 145 KHZ.

V. CONCULSION

In Hardware portion, Implementation of FOC of PMSM drive for speed 1003, 2007, 3000 rpm is achieved on no load torque condition. Clarke and Park transformations, discrete PI controllers and PWM technique are implemented as software in microcontroller.

Set speed (rpm)	Actual Speed(rpm)	Encoder pulse frequency (Hz)
1003	1000	42 KHz
2007	2005	83 KHz
3500	3500	145 KHz

This table shows that actual speed of motor nearly match to reference set speed during no load condition Encoder pulse frequency increases as speed is increased. Noise in current waveform is higher at lower speed. So, Close loop control of FOC is achieved.

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