International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 6 (2018) pp. 4403-4408

The Implementation of Field Oriented Control for PMSM Drive Based on TMS320F28035 DSP Controller

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Abstract

This paper presents the implementation of the Permanent magnet synchronous motor (PMSM) controller by using Field Oriented Control (FOC) method. The digital signal processor (DSP) was used as a controller to interface between the FOC and the PMSM. In this project, a floating 32 bit DSP controller TMS320F28035 is used to realize the drive system. TMDSHVMTRPFCKIT board by Texas Instrument is used to run the motor. The results show that the speed of PMSM was successfully follows the reference speed.

Keywords: Digital Signal Processor, Field Oriented Control, Permanent Magnet Synchronous Motor and Drive system

INTRODUCTION

Permanent magnet synchronous motor (PMSM) become popular in industry because of their advantageous such as light weight, compactness and cost performances [1]-[3]. This type of motor is most applicable where the high speed performance is needed. With elimination of a commutator, PMSM is become more reliable than a DC motor and become more efficient than an AC induction motor because the production of the rotor flux is from a permanent magnet. In order to achieve high performance control characteristics, vector control is used to control the PMSM [4],[5].

The FOC is one of the vector based method that aims to control the torque and rotor flux of the PMSM effectively. The FOC is carry out to control the space vector of magnetic flux, current and voltage of the machines in order to achieve the precise speed target. The stator currents is set as a control variable and this three phase static reference frame of the stator current is transformed and is performed in the d-q coordinate reference frame of the motor. The magnetic flux produced from the rotor of PMSM is locked to the vector of the rotor flux and will rotate at the stator frequency. The voltage supplied to the motor is transformed from d-q coordinate reference frame of the rotor to the three phase static reference frame of the stator before it can be fed to Space Vector Pulse Width Modulation (SVPWM) to get PWM output. The implementation of vector based FOC which is build upon stator-flux oriented method gives a better steady state operation. In order to yield a high performance system, the selection of the microprocessor is important. Many controllers available in market have high capability to achieve high performance application in electrical motor drive. The use of DSP controllers now becomes beneficial because it can incorporate with a multiple advanced power electronics peripherals and simplify the design process, it also have the capability to incorporate with various extra features in the drive [6], [7], [8].

This paper describes the implementation of the PMSM controller by using FOC method and application of the DSP to interface between the FOC and PMSM. All the architecture of the FOC as shown in Figure1 was implemented in a TMS320F28035 DSP controller.

FIELD ORIENTED CONTROL

Mathematical model of PMSM used is according to the d-q Synchronous reference frame. The stator voltages and magnetic flux equation in the d-q synchronous reference frame are given as follows:

$$V_{ds} = R_s\, i_{ds} + L_{ds}\frac{di_{ds}}{dt} - \omega_r\, \Psi_{qs} \text{ ---------------------------(1)}$$

$$V_{qs} = R_s\, i_{qs} + Lqs\,\frac{di_{qs}}{dt} - \omega_r\, \Psi_{ds} \text{ --------------------------(2)}$$

$$\Psi_{ds} = L_{ds}\, i_{ds} + \Psi_m \text{ --(3)}$$

$$\Psi_{qs} = L_{qs} i_{qs} \text{ --(4)}$$

Vds and Vqs are the stator's d-q axis voltage respectively, ids and iqs are the stator's d-q axis currents, Rs is the stator resistance, Lds and Lqs are the d-q axis stator inductances, Ψds and Ψqs are the d-q axis stator magnetic flux, ωr is the electrical rotor speed and Ψm is the rotor's permanent magnetic flux. The current model can be represented by combining equation (1) and (3) for d-axis current and equations (2) and (4) for q-axis current and can be described by equations (5) and (6) as follows.

$$\frac{di_{ds}}{dt} = -\frac{R_s}{L_{ds}} i_{ds} + \frac{\omega_r L_{qs}}{L_{ds}} i_{qs} + \frac{1}{L_{ds}} V_{ds} \text{ ----------------------(5)}$$

$$\frac{di_{qs}}{dt} = -\frac{R_s}{L_{qs}} i_{qs} - \frac{\omega_r L_{ds}}{L_{qs}} i_{qs} + \frac{1}{L_{qs}} V_{qs} - \omega_r \frac{\Psi m}{L_{qs}} \text{ -----------(6)}$$

The developed torque motor is given by;

$$\tau_e = \frac{3}{2}\left(\frac{p}{2}\right)(\Psi_{ds}\, i_{qs} - \Psi_{qs}\, i_{ds}) \text{ -------------------------------(7)}$$

The mechanical torque motor is given by;

$\tau_e = \tau_L + B\omega_m + J\frac{d\omega_m}{dt}$----------------------(8)

The rotor mechanical speed equation is obtained by rearranging equation (8);

$\omega_m = \int \frac{\tau_e - \tau_L + B\omega_m}{J}$ --------------------------(9)

And;

$\omega_m = \omega_r \frac{2}{p}$ ----------------------------------(10)

τe is developed torque, τL is load torque, P is number of pole, ωm is rotor mechanical speed and ωr is rotor electrical speed. Based on the FOC scheme diagram shown in figure 1, the closed loop control is applied to the PMSM. Due to the use of permanent magnet type of therotor, the flux linkage remains constant. For this project, the torque of PMSM is controlled by the q-axis and the d-axis of the stator current is set to zero.The implementation of SVPWM has been adapted to the inverter circuit as illustrated in Figure 1.

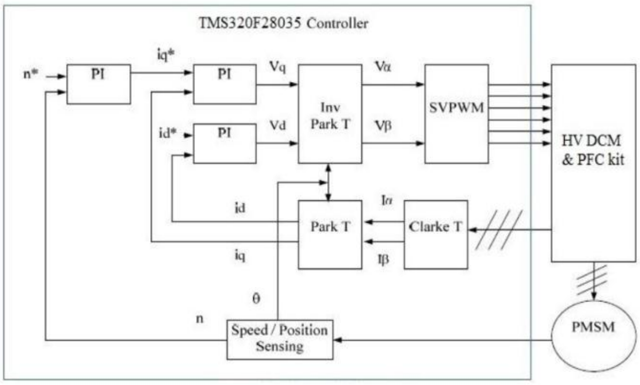

Figure 1: Block Diagram of the Drive system

Park transformation is applied to change the phase current to the d-q components to obtain a complete decoupling of torque and flux. By taking equation (3), the d-axis flux linkage remain unchanged when id is set to zero such that

$\Psi_{ds} = \Psi_{ms}$ ------------------------(11)

The electromagnetic torque is given by following equation.

τe = 3/2 [i_{qs}] ------------------(12)

The torque control of PMSM is done when stator currents interact with rotor flux linkage. The transformation of the voltage and current is done by the following transformation:

- Clarke transformation: stationary a-b-c frame to stationary $\alpha - \beta$ frame.

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \text{-----------------(13)}$$

- Inverse Clarke transformation: stationary α- β frame to stationary a-b-c frame

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \text{--------------------------(14)}$$

- Park transformation: stationary α- β frame to synchronously rotating d-q frame.

$$\begin{bmatrix} f_{ds} \\ f_{qs} \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} \text{--------------------(15)}$$

- Inverse park transformation: synchronously rotating d-q frame to stationary α- β frame

$$\begin{bmatrix} f_\alpha \\ f_\beta \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} f_{ds} \\ f_{qs} \end{bmatrix} \text{--------------------(16)}$$

DSP CONTROLLER

The TMS320F28035 Digital Signal Processor (DSP) is used in this project. The selected DSP controller, TMS320F28035 has High-Performance Static CMOS Technology operating at 60MHz (16.67-ns Cycle Time), low-power supply 1.8V for DSP Core and 3.3V for the I/O buffers [9]. The DSP controllers offer 60 MIPS of 32-bit DSP performance possible to position the edge of a PWM signal with 150 ps precision or 16 bits accuracy in a 100 KHz control loop [10],[11],[12]. Figure 2 shows a block diagram of TMS320F28035 controller. The controllers combine a number of peripherals, such as 64 KB of flash memory, Boot ROM

(8K x16), 45-GPIO pins,16-channel (2 x 8 Channel Input Multiplexer) 12 bit analog to digital converter (ADC), 3 32-bit CPU timers, 14 independent PWM channels, 1 quadrature encoder pulse (QEP), and 1 CAP input for position sensing [9]. A 32-bit wide data path enough to give awful system performance while mixed 16-bit/32-bit instruction achieves code density. Key communication interfaces include multiple serial ports peripheral such as SCI, CAN, I2C, UART, SPI ports and Watch Dog timer module.

For this process the reference speed is set at pre- specified values in DSP controller. The High Voltage Digital Motor control (DMC) and Power Factor Correction (PFC) kit (TMDSHVMTRPFCKIT), provides a great way to control the high voltage motors digitally. In this project 3 phase PMS motor is connected with a incremental encoder, the output of the encoder is fed to QEP module at TMS320F28035 to read the actual speed and resulting angle. The voltage and current sensors sense the voltage across the motor and current through the motor respectively.[13],[14].

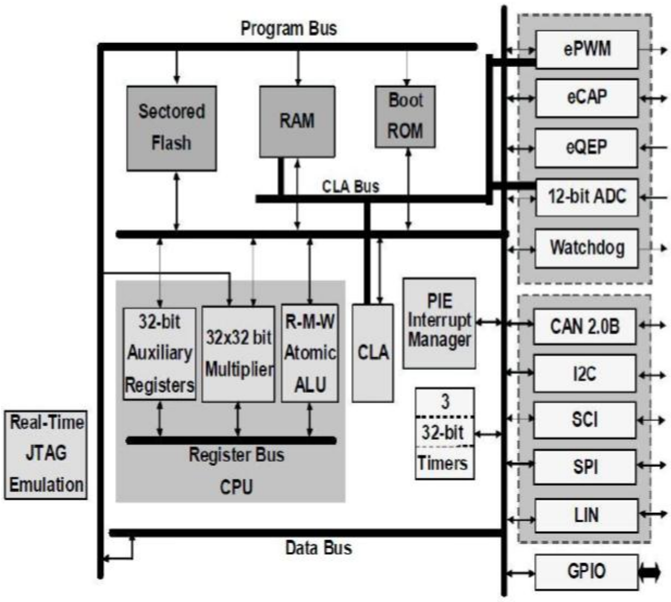

Figure 2: Block diagram of DSP(TMS320F28035) [18]

This voltage and current values are in analog form, using ADC in TMS320F28035 DSP which is converted to digital. On the basis of the obtained values from encoder, voltage sensor and current sensor the DSP will configure and generate 6 PWM signals. This PWM signals drives the driver circuit block to operate the 3 phase Voltage Source Inverter (VSI) as shown in Figure 3. VSI 3-phase output is given to motor[15],[16].

The voltage and current obtained by sensors is monitored continuously [17],[18],[19]. This analog signal will be converted to digital signal to be processed by the DSP. The FOC operation of Park, Inverse Park, Clark, Inverse Clark, SVPWM and PI controller are executed in this DSP.

HARDWARE EXPERIMENTAL SETUP

Figure 4 shows the experimental setup for this project. It consists of TMS320F28035 DSP controller, PMSM and TMDSHVMTRPFCKIT. The 3-phase, 8 poles and a incremental encoder mounted along with shaft of the PMSM used is manufactured by ESTUN (EMJ- 04APB22). The main controller which is DSP development board is interfaced with three phase voltage source inverter.

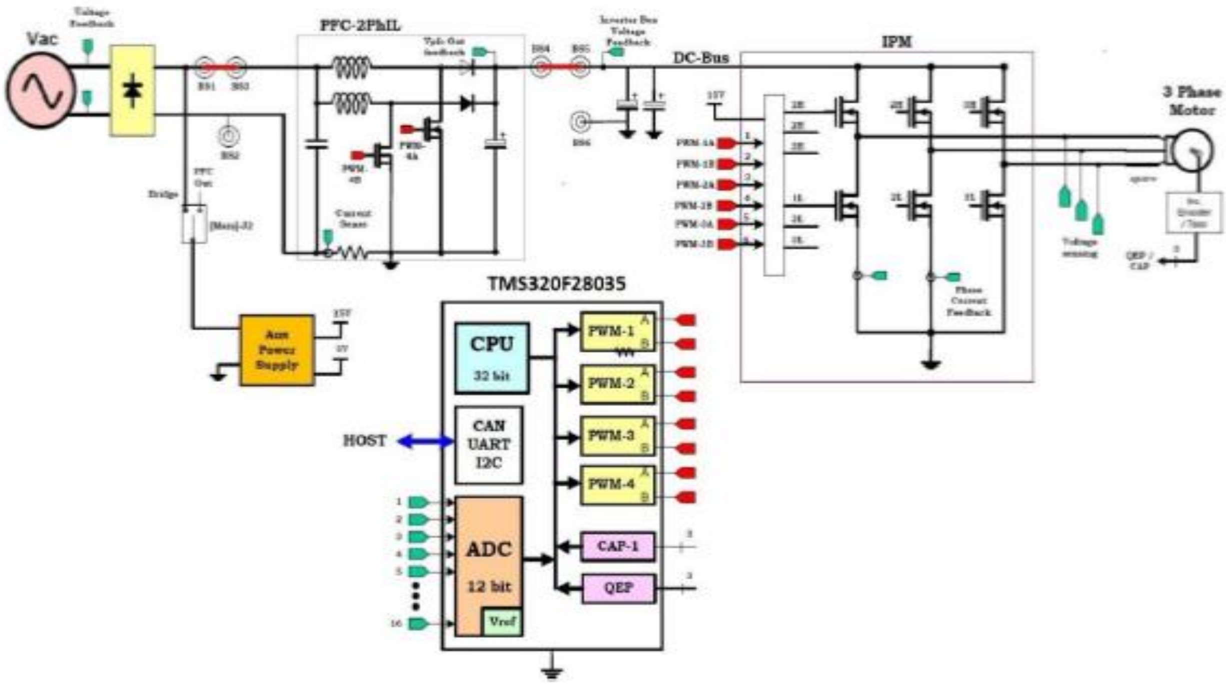

Figure 3: TMDSHVMTRPFCKIT with F28035 DSP Controller [19]

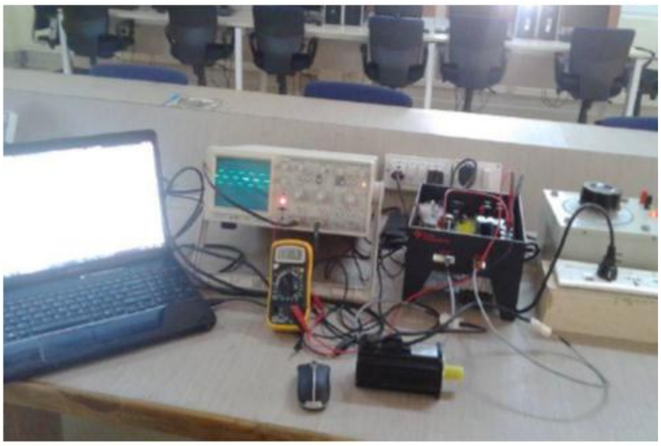

Figure 4: Hardware experimental setup

This TMDSHVMTRPFCKIT board has the following specification,Kit contents

TMS320F28035 DSP Control card

- High Voltage DCM board
- 400V to 15V and 5V power supply
- USB-B to A cable
- Onboard isolated JTAG emulation
- Heat sink attached with DC fan

3-phase inverter stage

- 350V DC max input voltage
- 1.5KW max load
- QEP and CAP inputs available for speed and position measurement

Power factor correction stage

- 750W max power rating
- 400V DC max output voltage
- 200KHz switching frequency for power stage
- 85-132VAC/ 170-250VAC rectified input
- Up to 100KHz PFC control loop frequency

AC rectifier stage

- 750W max power rating
- 85-132VAC/ 170-250VAC input.

In this project, the response of the system is evaluated by using difference pre defined speeds. The parameters of the motor is shown in Table 1.0

Table 1: Motor parameters

Parameters	**Values**
Voltage (V)	220
Output Power (kw)	0.4
Rated speed (rpm)	3000
Rated torque (Nm)	1.27
No of Poles	8
Stator resistance (ohm)	0.79
Stator inductance (mH)	1.17
Flux (volt.sec/rad)	0.017666

EXPERIMENTAL RESULTS

Figure 5 until figure 8 shows the obtained response of the motor. The system is tested under no-load and load conditon at Deadband = 0.83usec, dlog.trig_value=100, Vdcbus=300V, dlog.prescalar =3 at room temperature.

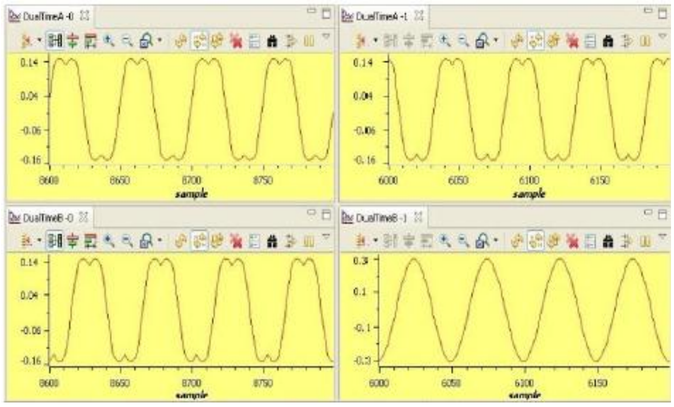

Figure 5: Output of $\boldsymbol{Ta}$, $\boldsymbol{Tb}$, $\boldsymbol{c}$ and $\boldsymbol{Tb}$-$\boldsymbol{Tc}$ waveform

Figure 5 shows the output wave form of Ta, Tb and Tc are 1200 apart from each other.

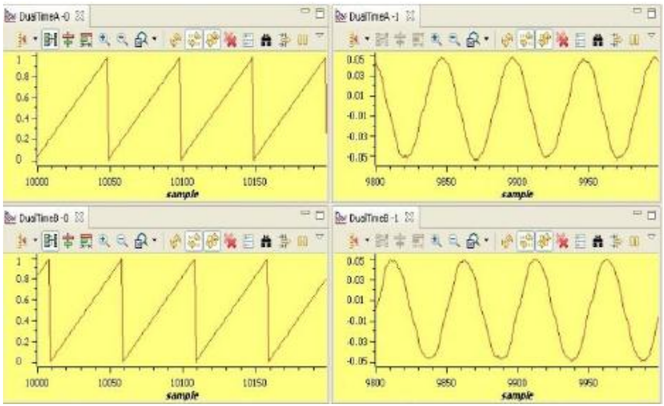

Figure 6 : The waveform to measure theta and phase A & B current waveform

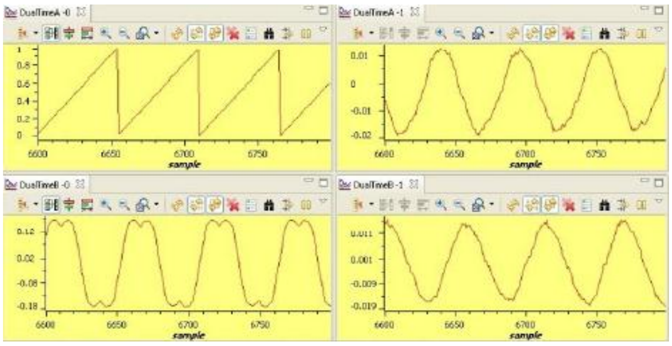

Figure 7: Measured theta, svgen dutycycle and phase A&B current under no-load and 0.3 pu speed

As shown in figure 7 at no load condition noice is pressent in current waveform at low speed. After enploying 0.33pu load on motor at same low speed the noise is reduced as shown in figure 8. At the low speed range , the performance of speed response relies heavily on the good rotor position angle provided by QEP encoder. Figure 9 shows the speed response when the motor is observed through GUI. At starting, the motor is under forward mode of operation which was the speed set at 750 rpm. Then, after some time, the motor speed is changed to 450 rpm and estimated speed is recorded as 456rpm. It clearly shows in Figure 9 that the actual speed follows the reference speed.

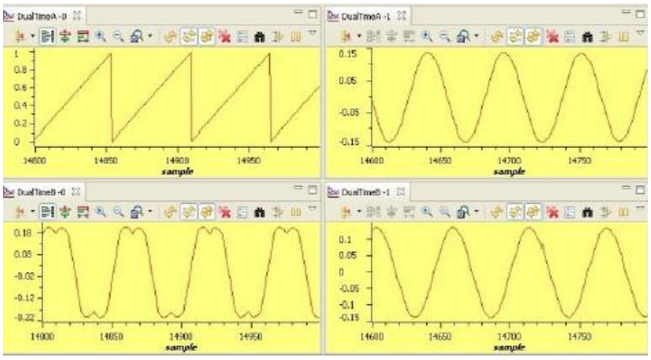

Figure 8: Measured theta, svgen dutycycle and phase A&B current under 0.33pu load and 0.3 pu speed

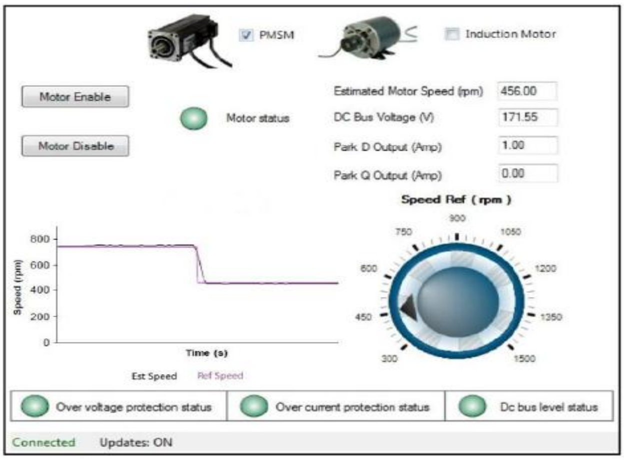

Figure 9: Speed Response

CONCLUSION

From the result obtain, it shows that the speeds follow the reference speed under various mode of operation. Therefore, FOC method can be used to control the PMSM and DSP controller can be implemented to give the high performance drives system.

ACKNOLOWLEDGEMENT

Thank full for the Texas Instrumentation and cranes software limited for allowing doing project in their laboratories.

REFERENCES

[1]. Sujitha S. and Venkatesh, C. " Design and Analysis of Standalone Solar Assisted Switched Reluctance Motor Drives", International Journal of Soft Computing and Engineering, ISSN: 2231-2307, Vol.02, No. 02 pp. 309 – 312, 2012.

[2]. Roopa C, Latha L R and Kartika Analysis of variable speed control and PFC CS converter for switched reluctance motor drive applications, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH, Volume 3, issue 6, December 2015

[3]. Bose B.K., Power electronics and variable frequency drives –technology and application, IEEE Press, 1997.

[4]. Sujitha S. and Venkatesh, C. " Analysis of Regulated PV Switched Reluctance Motor Drives Using Repression Resistor Converter", International Journal of Engineering and Technology, ISSN: 0975-4024, Vol.06, No. 03 pp. 1309 – 1313, 2014.

[5]. Rahman M.A, Hoque M.A, "Online Adaptive Artificial Neural Network Based Vector Control of Permanent Magnet Synchronous Motors", IEEE Trans on Energy Conversion, Vol. 13, no 4, December 1998.

[6]. Sujitha S. and Venkatesh, C. " Design and Comparison of PV Switched Reluctance Motor drives Using Asymmetric Bridge Converter and Buck Boost Converter", Australian Journal of Basic Applied Sciences, ISSN: 1991-8178, Vol.08, No. 06 , 2014.

[7]. Pillay P, Krishnan R, "modeling, Simulation and Analysis of Permanent Magnet Synchronous Motor Drives, Part 1: The Permanent magnet Synchronous Motor Drive", IEEE Trans, Ind. App, Vol. 25, March, April 1989.

[8]. S.Sujitha, Vivek, C.Venkatesh, "Fuzzy Logic Based Speed Control of DC Motor drive", International Conference on Emerging Trends in Engineering and Technology, 2015.

[9]. Narayanan G., Zhao Di, Krishnamurthy Harish K, Ayyanar Rajapandian, Ranganathan V.T, "Space Vector Based Hybrid PWM Techniques for Reduced Current Ripple", IEEE Transactionon India Electronics, Vol. 55, No 4, April 2008.

[10]. S.Sujitha, Sivaranjani, C.Venkatesh: "Photo Voltaic FED Switched Reluctance Motor Drives", International Conference on Emerging Trends in Engineering and Technology, 2015.

[11]. Radwan T.S., Rahman M.A., Osheiba A.M. and Lashine A.e., "Dynamic Analysis of A High Performance Permanent Magnet Motor Drive," Electrical and Computer Engineering, 1996, Canadian Conference on vol. 2.

[12]. S.Sujitha, "Investigation of Standalone PV Fed Switched Reluctance Motor Drives Using C Dump Converter", Global Journal of Pure and Applied Mathematics, Volume 13, Number 9, pp. 6317-6326, ISSN 0973-1768, 2017

[13]. Trzynadlowski A.M, "Field Orientation Principle in Control of Induction Motors," Kluwer Academic Publishers, 1994.

[14]. S.Sujitha, "Exploration of Hybrid Switched Reluctance Motor Drives Using H Bridge Converter", Middle-East Journal of Scientific Research 25 (6): 1298-1302, ISSN 1990-9233, 2017

[15]. Shireen W, Arefeen M S and Figoli D, "Multiple Motor Control Using a Single DSP Controller," IEEE Applied Power Electronic Conference (IEEE-ApEC) 1999.

[16]. Mohammed Arefeen, Godbole Kedar and Konghirun Mongkol "Dual field oerinted permanent magnet synchronous motor drive using a sinlge DSP controller."

[17]. S.Vinod Kumar, Dr.S.Sujitha, "High Frequency Switching of Multi Segment Pseudo Resonant Boost Converter for Electric Drives", International Journal of Advance Research in Science and Engineering, Volume 06, Issue 08, 2017.

[18]. TMS320F28035 Digital Signal Processors Datasheet, Texas Instruments.

[19]. The High Voltage Digital Motor control (DMC) and Power Factor Correction (PFC) kit (TMDSHVMTRPFCKIT) Technical References.