International Journal of the Physical Sciences Vol. 6 (20), pp. 4790-4797, 23 September, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.491
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Implementation of proportional integral (PI) controlled DSP based cost effective inverter fed speed control of induction motor drive with VisSim/ embedded controls and developer (ECD)

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Accepted 6 July, 2011

Real-time implementation of PI controller based cost effective inverter fed speed control of induction motor drive using high performance TMS320F2812 DSP with VisSim/ embedded controls and developer (ECD) is presented in this paper. The four switch three-phase inverter (FSTPI) fed drive system consists of a power circuit having an insulated gate bipolar junction transistor (IGBT) based bridge inverter module feeding a 5 hp three-phase squirrel cage induction motor and control circuits that comprises of digital signal processor (DSP), processor board, driver circuit, sensor (for sensing speed signals), interfacing circuits and PC with VisSim/ECD software. The PI controller block and PWM generation block of this drive system are designed using VisSim/ECD to control the speed of induction motor in closed loop. Observations are made by changing speed of motor at different loads. Results obtained from this experimental work are satisfactory and shown using GUI of VisSim /ECD software and digital storage oscilloscope.

Key words: Four switch three-phase inverter (FSTPI), digital signal processor (DSP), proportional integral (PI), Sinusoidal pulse width modulation (SPWM) and VisSim/ embedded controls and developer (ECD).

INTRODUCTION

Most of the industrial drive applications use AC induction motors because of their robustness, reliability, and efficiency and low price. However, the induction motor has its own disadvantages, namely it is difficult to control due to its complex mathematical model, non-linearity and electrical parameter variations due to the presence of frequency.

Induction motors have been widely used mainly for constant-speed applications. Due to progress in power electronic devices such as insulated gate bipolar junction transistor (IGBT) and microelectronics such as fast digital signal processor (DSP), the induction motor drive system becomes suitable and efficient for variable-speed motor drives presented by Bose (2006, 1980). PWM controlled voltage source inverters (VSI) are used in a wide variety of industrial applications, such as uninterruptible power supplies (UPS), static frequency changers, and variable-speed motor drives. Most of the industrial applications need variable speed motor drives.

The six-switch three-phase voltage source inverter (SSTPI), widely used in variable AC drives, has three legs, with a pair of complementary power switches per phase. A reduced switch voltage source inverter, that is, four-switch three-phase inverter (FSTPI) uses only two legs, with four switches and a split capacitor. Several articles report on FSTPI structure regarding inverter performance and switch control namely, Broeck and Van Wyk (1984), Jacobina et al. (1995), Blaabjerg et al. (1997, 1999), Correa et al. (2005), Uddin et al. (2006) and Kim et al. (2009). The advantages of FSTPI is the reduced cost of the inverter, lesser switching losses, lower electromagnetic interference (EMI), and less complexity of the control algorithms and interface circuits

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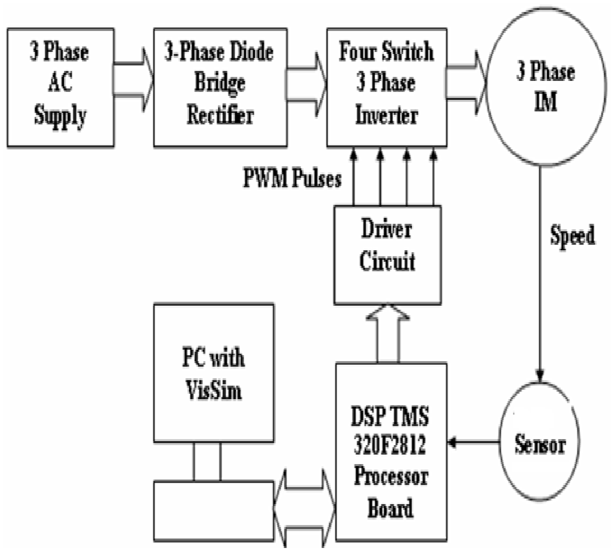

Figure 1. Block diagram of FSTPI fed close loop induction motor drive.

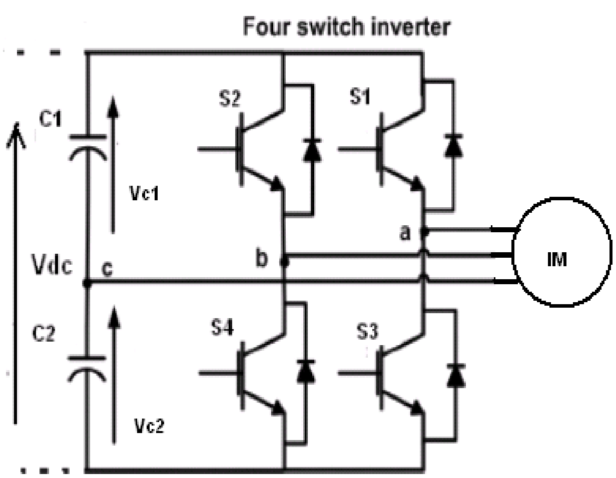

Figure 2. Circuit diagram of FSTPI with induction motor.

to generate PWM logic signals. Due to less number of switches, this inverter is a cost effective one.

The proportional integral (PI) controller is the most widely used conventional controller for speed control of motor drives. A major feature of the PI controller is its ability to maintain a zero steady state error to a change in reference and load disturbances.

DSP provides high speed, high resolution and sensor-less algorithms to reduce system costs. Providing a more precise control to achieve better performance often means performing more calculations.

In this paper, the use of PI controller in FSTPI induction motor drive using DSP processor and Vissim/ECD software is presented. The performance of the drive system in terms of speed control is investigated at different load conditions.

PROPOSED TOPOLOGY

The block diagram of the proposed FSTPI fed induction motor drive system is shown in Figure 1. The drive system consists of a three-phase AC supply, three-phase diode bridge rectifier, three-phase four switch Inverter and 3-phase induction motor. The controlled equipments are PC with VisSim/ECD software, DSP processor board and driver circuit. The standard AC supply is converted to a DC voltage by a three-phase diode bridge rectifier. A voltage source FSTPI is used to convert the DC voltage to a variable AC voltage. The output of the FSTPI is fed to the three-phase induction motor. PC is loaded with VisSim/ECD software and Texas code composer software. The VisSim software consists of several external modules used for different engineering applications. The requirement is built into the VisSim blocks using drag and draw method. The values of each block are adjusted according to the need of drive system. After compiling, “C” codes are automatically generated and these codes are targeted (loaded) to the DSP processor through Joint Test Action Group (JTAG). The DSP processor generates the required SPWM pulses according to the user’s setting in VisSim/ECD blocks in PC. The sensor is connected at the shaft of the motor to sense the actual speed of the induction motor. The sensor output is fed to the processor through the ADC of DSP processor. The DSP processor compares the reference speed (set speed) with actual speed through VisSim/ECD software. The generated error signal is fed to the PI controller in the DSP processor. Based on the output of PI controller, the processor generates the required controlled SPWM pulses for FSTPI to control the speed of the induction motor.

FSTPI AND ITS OPERATION

The power circuit of the FSTPI fed induction motor drive is shown in Figure 2. The power inverter has 4 switches, S1, S2, S3 and S4 and a split capacitor. The switches are controlled in order to generate AC output from the DC input. The two phases ‘a’ and ‘b’ are connected through two legs of the inverter, while the third phase ‘c’ is connected to the center point of the DC link capacitors, C1 and C2, whose value of capacitances are equal. Vc1 and Vc2 are the voltages across the two DC link capacitors C1 and C2 and V_{dc} is the voltage across them (V_{dc} = Vc1 + Vc2).

The four power switches S1 to S4 can be assumed to be denoted by binary variables. Binary ‘1’ corresponds to an ON state while binary ‘0’ corresponds to an OFF state of the switches. The states of the upper (S1, S2) and lower (S3, S4) switches are complementary, that is S3 = 1 - S1 and S4 = 1 - S2. Considering an ideal case 3-phase Y-connected induction motor, the terminal voltages V_{as}, V_{bs} and V_{cs} can be expressed as the function of the states of the upper switches as in Equations 1 to 3.

$$V_{as}=\frac{V_c}{3}\left(4S_1-2S_2-1\right) \quad (1)$$

$$V_{bs}=\frac{V_c}{3}\left(-2S_1+4S_2-1\right) \quad (2)$$

$$V_{cs}=\frac{V_c}{3}\left(-2S_1-2S_2+2\right) \quad (3)$$

Table 1. Modes of operation of FSTPI and output voltages.

Switching state		Output voltage		
S_1	S_2	V_{as}	V_{bs}	V_{cs}
0	0	$-\frac{V_c}{3}$	$-\frac{V_c}{3}$	$\frac{2V_c}{3}$
0	1	$-V_c$	V_c	0
1	0	V_c	$-V_c$	0
1	1	$\frac{V_c}{3}$	$\frac{V_c}{3}$	$-\frac{2V_c}{3}$

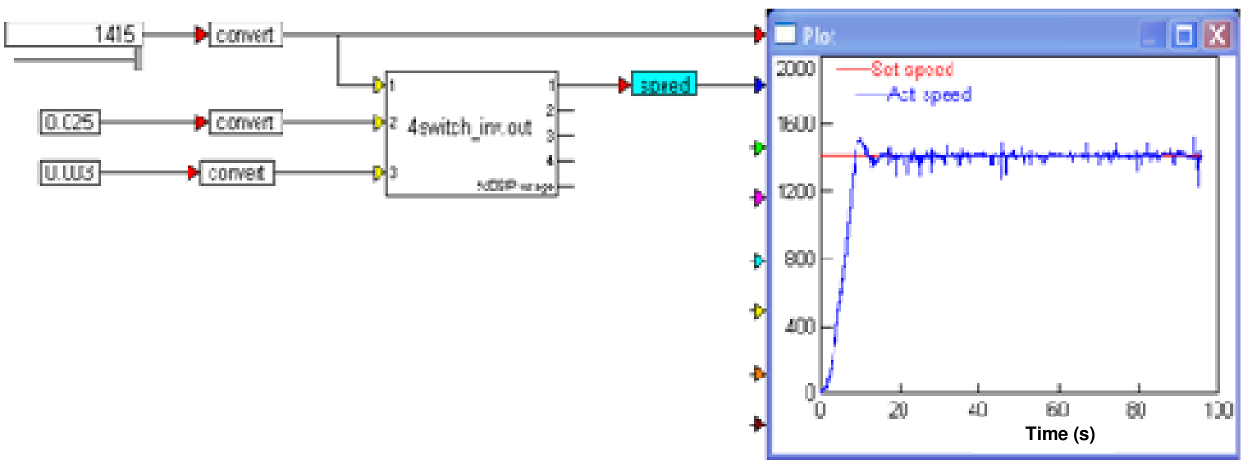

Figure 3. The main block diagram of PI controlled based FSTPI drive with VisSim/ECD.

where V_{as}, V_{bs}, V_{cs} are the inverter output phase voltages. Equations 1 to 3 can be represented in matrix form in Equation 4.

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \frac{V_c}{3}\begin{pmatrix} 4 & -2 \\ -2 & 4 \\ -2 & -2 \end{pmatrix}\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} + \frac{V_c}{3}\begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix} \quad (4)$$

Table 1 shows the different modes of operation and the corresponding output phase voltage of the FSTPI.

PI Controller and PWM generation design using VisSim/ECD

VisSim/ECD is an environment for model based development of embedded control systems. Using a block diagram approach, it is possible to create a working model of the control system quickly. It can use a simple PID control as well as a complex multi-phase vector controller with packet-based RS 485 protocol and dynamic IC EEPROM read/write. With the model in a diagram form, the system can be simulated and code can be generated. Simulation mode is fast and easy to prototype, optimize, and debug before the code is generated. Once the users are happy with simulated performance, they can just click the compile button to generate highly efficient “C” code and compile it to a target executable file. VisSim/ECD is unique in its ability to generate highly efficient, high sample rate, and low jitter target executables. The benefits of VisSim Embedded Controls Developer are:

1. Removes the requirement for one or more dedicated programmers
2. Speeds the edit-debug cycle
3. Speeds implementation of on-chip peripheral drivers by providing a simple block and configuration dialog interface.

In VisSim/ECD, the user can select the block(s) representing the controller or filter. VisSim then automatically generates C code and compiles, links and downloads the algorithm to the target DSP. The VisSim GUI is retained while the algorithm executes on the DSP to enable the user to validate the performance of algorithm on the target. The user can plot responses of position, current and velocity or view the effects of changing gain of corresponding values (http//www.vissim.com).

The complete closed loop PI controlled based FSTPI fed induction motor drive is developed using the VisSim/ECD software as shown in Figures 3 to 5. Figure 3 shows the main control block diagram of the drive system using VisSim/ECD software. The block (4 switch inv.out) consists of several sub blocks. In this block, the inputs are the reference speed (set speed) value, proportional constant value (Kp) and Integral constant value (Ki). The output of

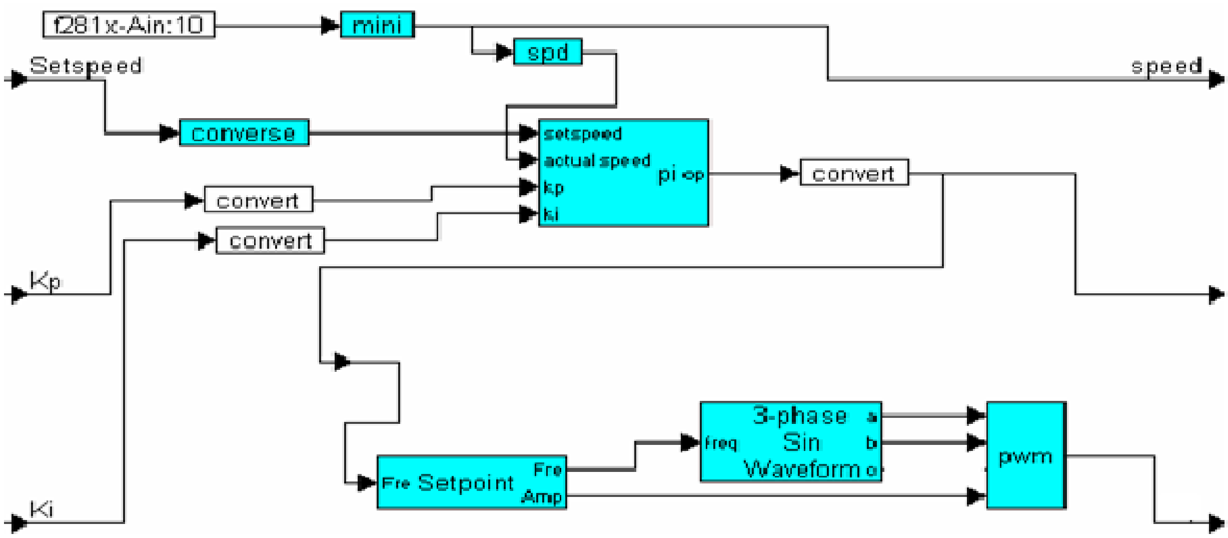

Figure 4. The internal PI control design block of system in VisSim/ECD.

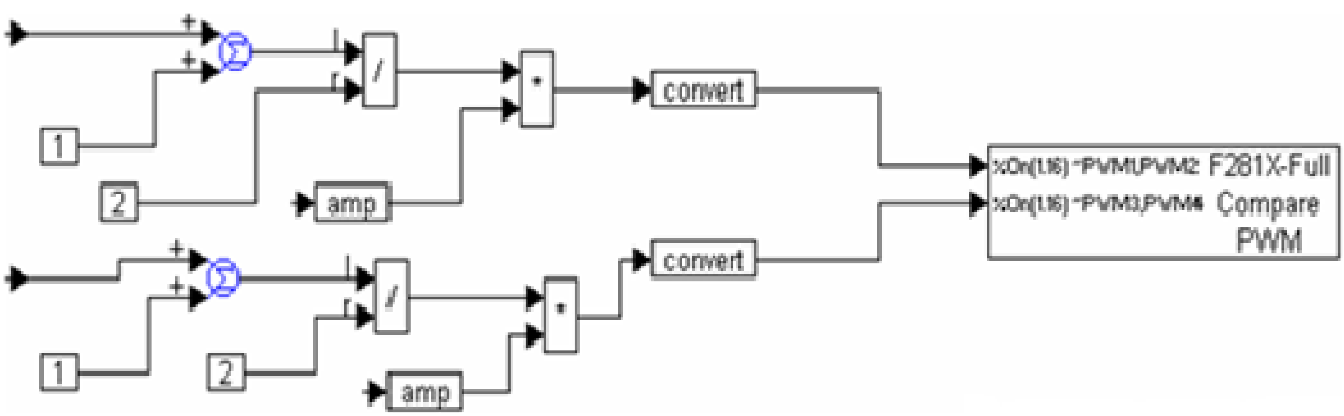

Figure 5. The internal design block of 3-phase sinusoidal PWM waveform block in VisSim/ECD.

this block is the actual speed value of induction motor. The set speed value, K_p value and K_i value are taken as 1415 rpm, 0.025 and 0.003 respectively. When the run command is given in VisSim/ECD window, the motor starts and the corresponding speed of motor is displayed in GUI of VisSim/ECD. In this experimental work, it is seen that the speed of motor starts at zero speed, increases linearly and reaches the set speed in 10 s. The peak overshoot occurs up to 1500 rpm at the 15th second and settles at steady state after 5 s (in 20 s).

The internal structure of PI control block of the system is shown in Figure 4 which is the sub block of 4switch_inv.out block of Figure 3. In this block, set speed and actual speed is compared and fed to the PI controller. The output of PI controller is fed to the frequency block. The frequency is varied according to the output command of PI controller. The internal design block of the three-phase sinusoidal PWM waveform block in VisSim/ECD is shown in Figure 5. This block is the sub block of PWM block as shown in Figure 4.

The designed SPWM block outputs are PWM1, PWM2, PWM3 and PWM4. The output of this PWM block is targeted to DSP TMS320F2812 controller through JTAG. The DSP processor generates the timing PWM pulses through Event Manager according to the set values in VisSim/ECD blocks for four switches of FSTPI.

Hardware descriptions

The experimental setup consists of a PC which is loaded with VisSim/ECD software. High performance DSP TMS320F2812 processor trainer kit, three-phase 4-switch IGBT based voltage source inverter module, driver and isolation circuit (Each gate driver has optical isolation in its initial stage), speed and current sensors and 3-phase 5 hp induction motor with spring balance load.

The control of SPWM based FSTPI drive is implemented using 150 MHz DSP TMS320F2812 processor with a sampling frequency of 10 kHz. The controller of TMS320F2812 combines the power of CPU with on-chip memory and peripherals. The controller offers 60 MIPS (million instructions per second) performance. This fast performance is well suited for processing control parameter in applications where large amount of calculations are to be computed quickly (TMS320F2812, Handbook of Digital Signal Processors, 2010). The speed sensor is used to sense the speed of the induction motor. The sensor output is fed to the ADC of DSP trainer kit. The complete experimental hardware setup used for this drive

Table 2. Hardware details of the system.

Components	Rating
DSP TMS320F2842 controller	High-performance 32-Bit CPU on-chip memory JTAG boundary scan support; Opto isolated serial ports are terminated with 9 pin D male connector up to 38X baud rate. 3 switches are provided for user application increment and decrement
Inverter module	IGBT 400 V, 25A with driver circuit, Full bridge diode converter, capacitor -2000 µF
Induction motor	5 hp, 3-phase, 400 V, 50 Hz, 1500 rpm

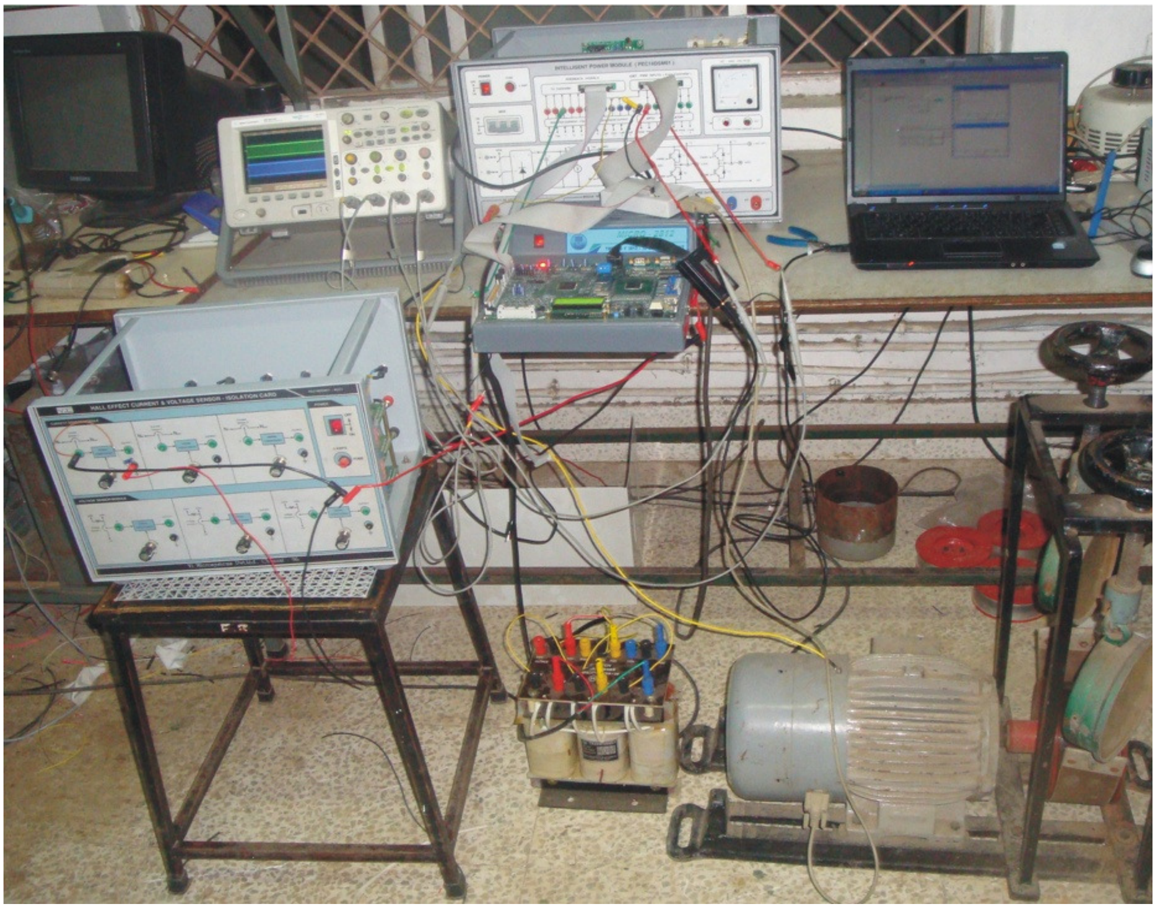

Figure 6. Complete experimental implementation of drive system.

system is given in Table 2. Figure 6 shows the complete experimental hardware setup of the drive system.

RESULTS AND DISCUSSION

Real time experimental results of FSTPI drive are obtained from the GUI of VisSim/ECD software and digital storage oscilloscope. When the "go" command of VisSim/ECD is clicked in PC, the motor starts and speed increases from "0" to set value. The speed of motor in rpm with respect to time in second curve is displayed in plot window in GUI of VisSim/ECD. Figure 7 shows the VisSim/ECD is clicked in PC, the motor starts and speed increases from "0" to set value. The speed of motor in rpm with respect to time in second curve is displayed in plot window in GUI of VisSim/ECD. Figure 7 shows the obtained speed of the induction motor (rpm) with respect to time in seconds. It is seen that the speed of induction motor starts from zero, increases linearly with respect to time and reaches at the set speed of 1415 rpm in 10th second. Overshoot occurs at the 10th second for a period

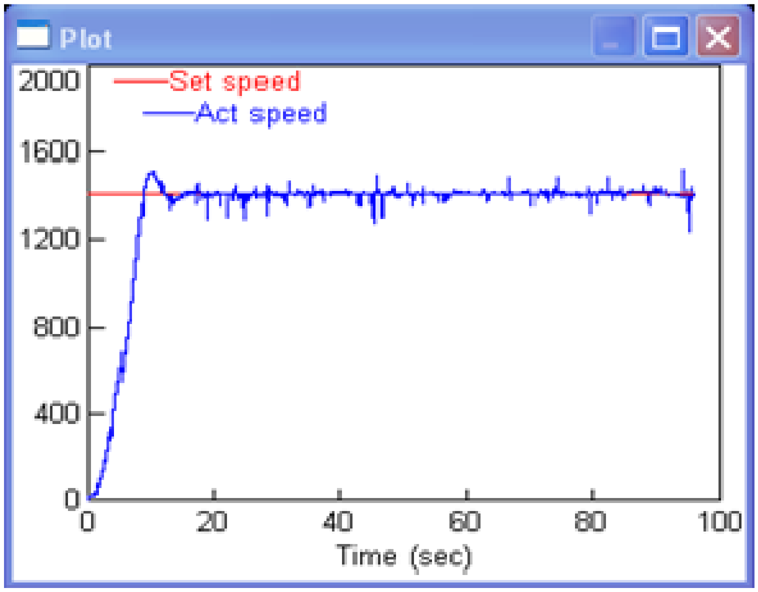

Figure 7. Speed of induction motor in no load condition.

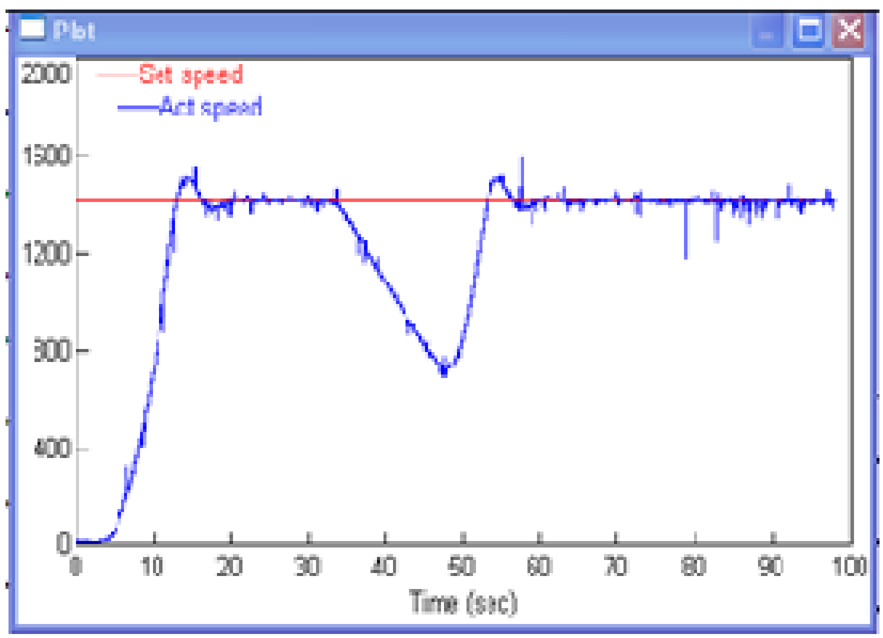

Figure 8. Speed of induction motor with medium load.

of 5 s. After 5 s, the speed of induction motor settles at set speed of 1415 rpm.

The PI controller action is tested by applying different load during running condition. Figure 8 shows that when load is applied at the 35th second, the speed decreases rapidly form set speed that is 1415 rpm and reaches 800 rpm at the 48th second. Due to PI controller action, it reaches the set speed at the 52nd second and settles at the 60th second.

A large load applied at the 20th second is shown in Figure 9 when the motor was running at set speed. The speed rapidly decreases up to 400 rpm at the 23rd second. Due to the PI controller action, the speed reached its set value at the 28th second and finally settles at the 35th second.

From Figures 8 and 9, it is observed that due to the suitably chosen value of PI controller (K_p and K_i), the speed of motor settles quickly. Figures 10 and 11 show the sinusoidal PWM pulses of the FSTPI are obtained

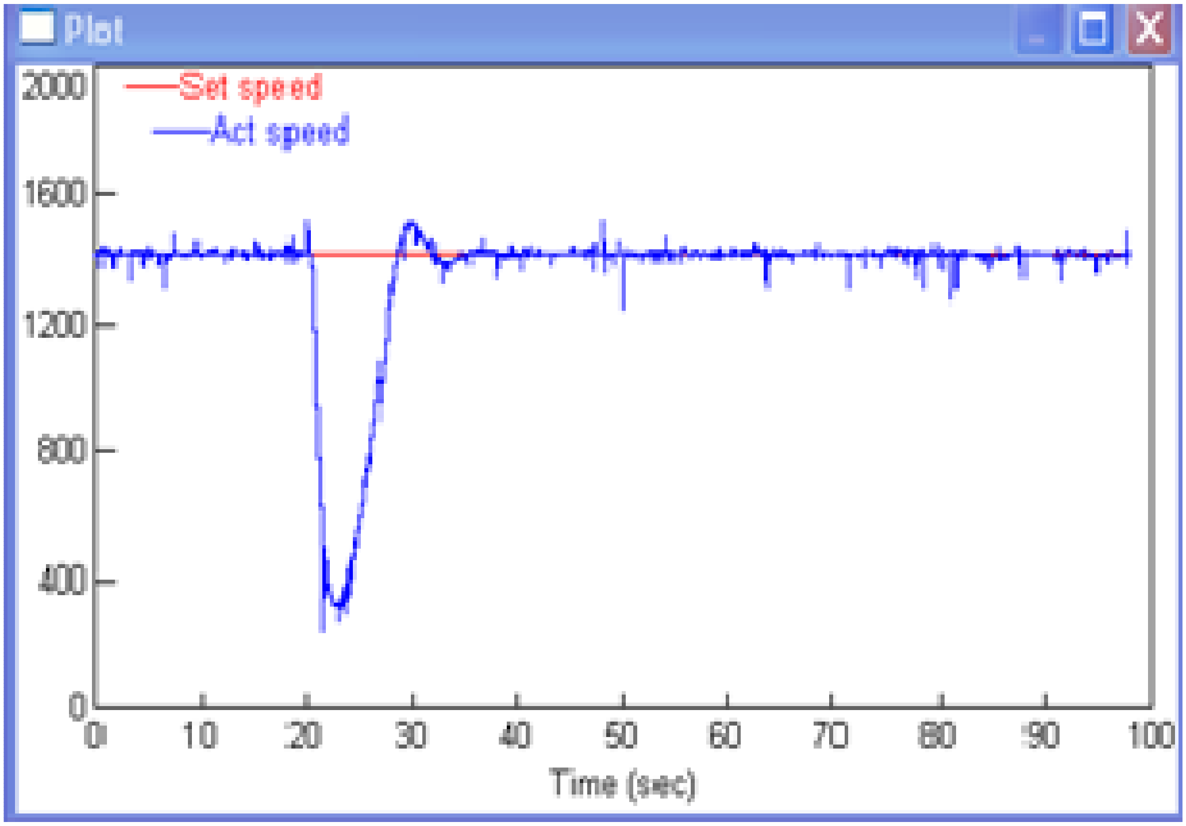

Figure 9. Speed of the induction motor with large load.

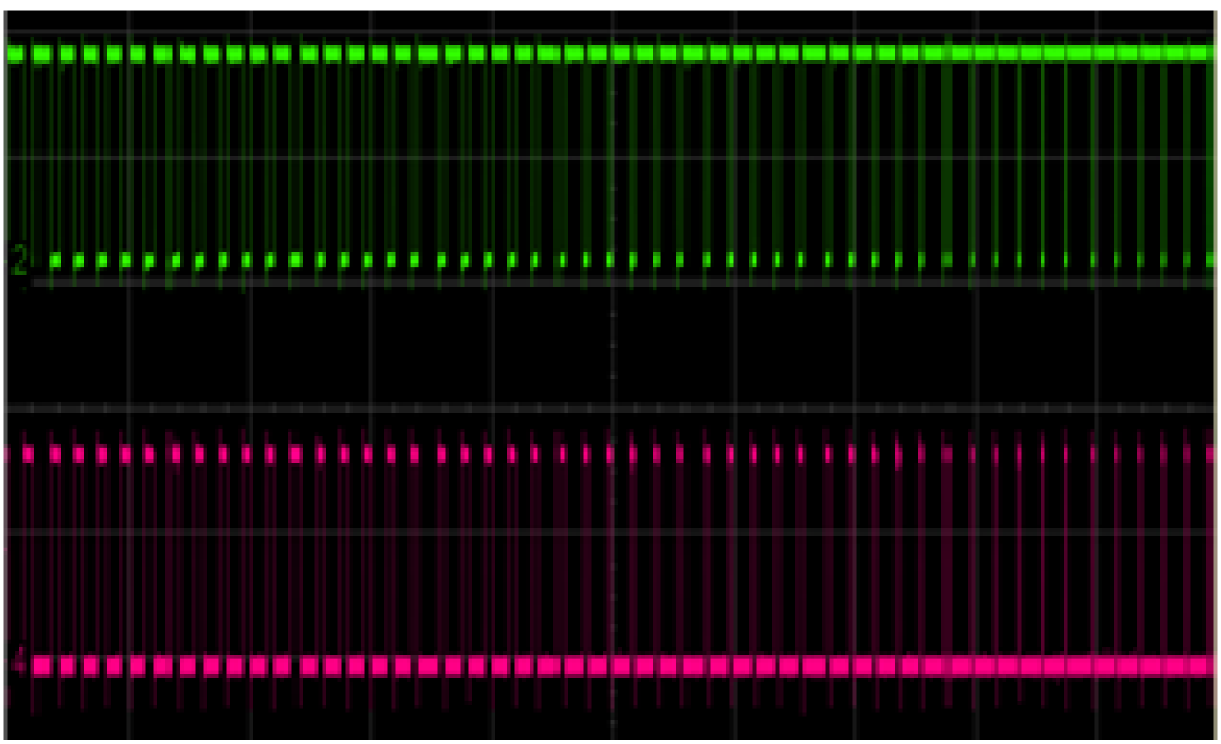

Figure 10. SPWM waveform of S1 and S3 of FSTPI (Volt [50] V/div vs. time in [10] ms/div).

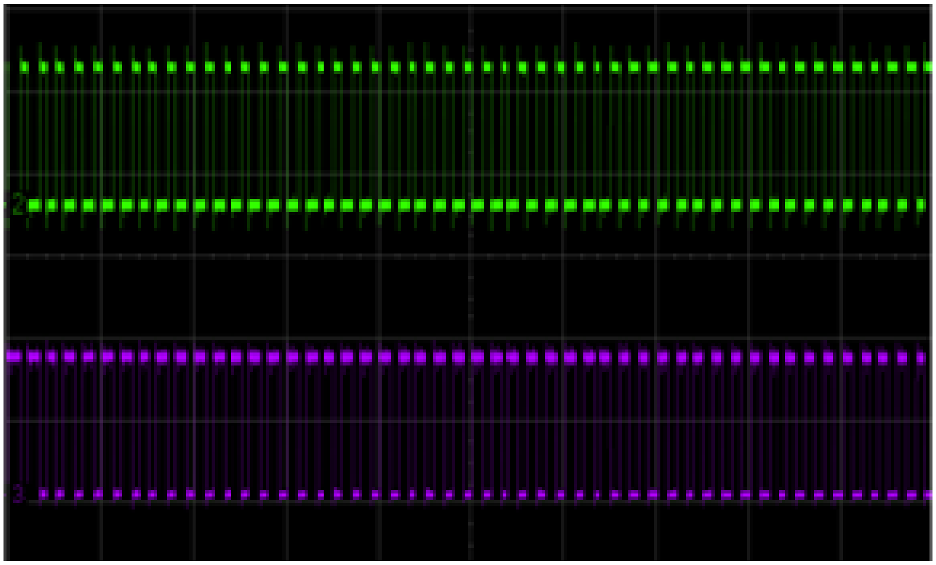

Figure 11. SPWM waveform of S2 and S4 of FSTPI (Volt [50] V/div vs. time in [10] ms/div).

through oscilloscope. The SPWM controlled pulses are generated through VisSim/ECD software designed block and loaded in DSP board to control the FSTPI fed Induction motor.

Conclusion

A PI closed loop controlled cost effective inverter fed three-phase 5 hp induction motor drive using VisSim/ECD software with DSP processor has been carried out successfully. In this work, a high performance TMS320F2812 digital signal processor (DSP) with VisSim/ECD software, FSTPI and 5 Hp induction motor is used. The results, that is, the output speed of the induction motor at different load conditions are presented. The performance of this drive system is satisfactory. The limitation of this FSTPI drive system is the capacitors are subjected voltage stresses and this drive is suitable for low and medium rated power applications.

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