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IMPLEMENTATION OF DSP BASED COST EFFECTIVE INVERTER FED INDUCTION MOTOR DRIVE WITH VisSim

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The implementation of a Digital Signal Processor (DSP) based high-performance cost effective fed Induction Motor drive with VisSim/Embedded Controls Developer (ECD) is presented in this paper. In the experimental work VisSim/ECD software automatically converts the in built block diagram to C code and compiles, links, and downloads the code to DSP processor TMS320F2812. The DSP processor generates the required PWM to a cost effective *ie* four switch 3-phase (FSTPI) inverter. The power circuit of FSTPI fed drive system consists of an IGBT based FSTPI bridge inverter module feeding to a 5 hp three-phase squirrel cage induction motor. In this work the speed of induction motor output is shown by the GUI of VisSim/ECD and SPWM pulses, line voltages and line current output curves are shown using digital storage oscilloscope to demonstrate the feasibility of the system.

Keywords: FSTPI, VisSim, SPWM, DSP

1 INTRODUCTION

The most popularly widely used motor in motion industries is the AC induction motor as they are robust, reliable, simple, cheap and available in all power ratings. The squirrel cage type of induction motor is very popular in case of variable-speed drives. When AC power is provided to an induction motor, it runs at its rated speed. However, many applications need variable speed operations particularly in industries. Induction Motors have been widely used mainly for constant-speed applications. Recent progresses in power electronic devices such as isolated gate bipolar junction transistor (IGBT), and microelectronics such as fast digital signal processor (DSP) based microcontrollers, have made them suitable and efficient for variable-speed motor drives [1, 2]. 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 [1]. Most of Industrial applications need variable-speed motor drives.

The six switch three phase voltage source inverter (SSTPI) that is widely used in variable AC drives has three legs, with a pair of complementary power switches per phase. A reduced switch voltage source inverter (four switch three-phase voltage source inverter or FSTPI) uses only two legs, with four switches. Several articles report on Four Switch Three Phase voltage source Inverter (FSTPI) structure regarding inverter performance and switch control [3–8]. The advantages of FSTPI is the reduced cost of the inverter, lesser switching losses, lower EMI and less complexity of the control algorithms and interface circuits to generate PWM logic signals.

Digital Signal Processors (DSPs) provide high speed, high resolution and sensor less algorithms in order to reduce system costs. Providing a more precise control to achieve better performance often means performing more calculations. The use of some 1-cycle multiplication & addition instructions in the DSP speeds-up calculations. Generally fixed point DSPs are preferred for motor control for two reasons. Firstly, fixed point DSPs cost much less than the floating point DSPs. Secondly, for most applications, a dynamic range of 16 bits is enough. If and when needed, the dynamic range can be increased in a fixed point processor by doing floating-point calculations in software.

VisSim/Embedded Controls Developer (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 RS485 protocol and dynamic IIC 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. The VisSim target HotLink allows the users to download and interactively debug their algorithm while it runs on the target.

VisSim/ECD is unique in its ability to generate highly efficient, high sample rate, low jitter target executables. The benefits of VisSim Embedded Controls Developer are:

- Removes the requirement for one or more dedicated programmers
- Speeds the edit-debug cycle

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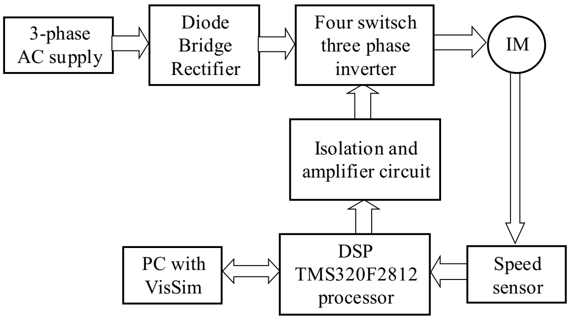

Fig. 1. Block Diagram of FSTPI Drive

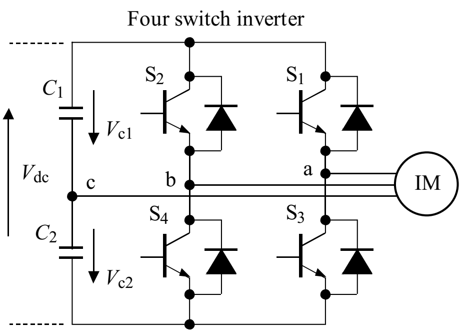

Fig. 2. FSTPI with Induction Motor

- Speeds implementation of on-chip peripheral drivers by providing a simple block and configuration dialog interface

But perhaps the biggest advantage is the increase in consistency and reliability that VisSim/ECD brings to the finished product. Because the generated code is done automatically, VisSim/ECD uses a smaller set of C language features to implement an algorithm, as well as generating syntactically and semantically correct C code. The user then selects the block(s) representing the controller or filter. VisSim automatically generates C code and compiles-links-downloads the algorithm to the target DSP. The results of the two simulations can then be easily compared to ensure that their behavior is identical. It is important to note that VisSim also automatically programs the analog and digital I/O for the TI F243, F2407 EVMs & LF2407 eZdsp (a time consuming, tedioustask). 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 visualize plot responses of position, current and velocity or view the effects of changing gain values [9].

In this paper, the use of four switch three phase inverter based drive using DSP processor and Vissim/ECD software is presented

2 PROPOSED TOPOLOGY

The block diagram of the proposed system is shown in Fig. 1. The drive system consists of a 3 phase AC supply, 3 phase diode bridge rectifier, 3 phase four switch inverter, 3 phase induction motor, speed and current sensors, personal computer (PC), DSP board (TMS320F2812), isolation and amplifier circuit. The standard AC supply is converted to a DC voltage by a 3 phase diode bridge rectifier. FSTPI is used to convert the DC voltage to the required AC voltage and the output is fed to 3 phase induction motor. Controlled actions are performed using VisSim software and DSP processor. The timing SPWM pulses from the DSP processor are fed to the FSTPI through isolation and driver circuit. The speed of the induction motor is sensed by the sensors.

3 OPERATION OF FSTPI

The power circuit of the FSTPI fed induction motor drive is shown in Fig. 2. The power inverter has 4 switches, S_1, S_2, S_3 and S_4 and a split capacitor. These switches are controlled in order to generate an AC output from the DC input. The two phases 'a' and 'b' are connected to two legs of the inverter, while the third phase 'c' is connected to the center point of the DC link capacitors, C1 and C2. The value of the capacitances C1 and C2 are equal.

Vc1 and Vc2 are the voltages across the DC link capacitors, V_{dc} is the voltage across the capacitor C1 and C2 ($V_{dc} = V_c/2$).

The four power switches can be assumed to be denoted by binary variables S_1 to S_4. Binary '1' corresponds to an ON state while binary '0' corresponds to an OFF state. The states of the upper (S_1, S_2) and lower (S_3, S_4) switches of a leg are complementary that is $S_3 = 1 - S_1$ and $S_4 = 1 - S_2$. Considering a 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 s in equations (1)–(3)

$$V_{as} = \frac{V_c}{3}(4S_1 - 2S_2 - 1)\,, \tag{1}$$

$$V_{bs} = \frac{V_c}{3}(-2S_1 + 4S_2 - 1)\,, \tag{2}$$

$$V_{cs} = \frac{V_c}{3}(-2S_1 - 2S_2 + 2)\,. \tag{3}$$

where V_{as}, V_{bs}, V_{cs} are the inverter output phase voltages. V_c is the voltage across the DC link capacitors, V_{dc} is the voltage across the capacitor C1 and C2 ($V_{dc} = V_c/2$). S_1, S_2 are taken as the switching functions for the 2-switches. In matrix form equations (1)–(3) can be written as

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

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

Table 1. Modes of operation of FSTPI and output voltages

Switching states		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	$\frac{V_c}{3}$	$\frac{V_c}{3}$	$-\frac{2V_c}{3}$

Table 2. Detail Hardware components and ratings

Components	Ratings
DSP TMS320F2812 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, 50 Hz, 1500 rpm

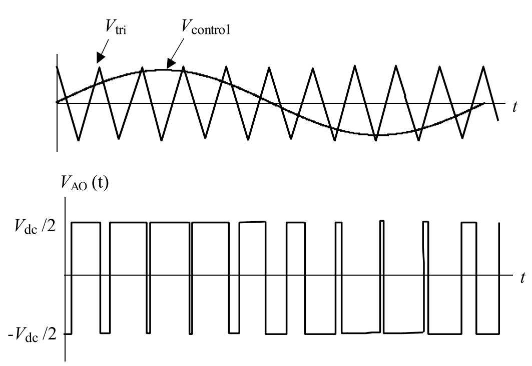

Fig. 3. Sinusoidal PWM

4 Sinusoidal PWM Generation Using VisSim and DSP Processor

The most commonly used control technique in inverter is sinusoidal Pulse Width Modulation (SPWM). The SPWM voltage is a pulse train of fixed magnitude and frequency with variable pulse width. The pattern is created by comparing a triangular carrier wave (V_{tri}) with a reference sinusoidal wave (V_{control}). This is as shown in Fig. 3.

The Sinusoidal PWM signals generated from the DSP (TMS320F2812) processor using Vissim software to control the 4-switches of FSTPI. A dead time is added between switching off the upper switch and switching on the lower switch and vice versa. This ensures that both switches are not conducting when they change their states from on to off, or vice versa.

For the induction motor drive, the three phase voltage references for a balanced system are given by equations (5)–(7).

$$V_{as}^{*} = V_m \cos \omega t \,, \tag{5}$$

$$V_{bs}^{*} = V_m \cos\big(\omega t - (2\pi/3)\big), \tag{6}$$

$$V_{cs}^{*} = V_m \cos\big(\omega t + (2\pi/3)\big), \tag{7}$$

In this paper SPWM scheme is adopted, A 90 degree phase shift sinusoidal waveform is compared with the triangular carrier waveform. The modulating index 0.8 and carrier frequency is 10 kHz is taken in this work.

5 SYSTEM SOFTWARE DESCRIPTION AND HARDWARE AND RESULTS

This experimental setup consists of a personal computer (PC), 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, 3-phase 5 Hp Induction Motor.

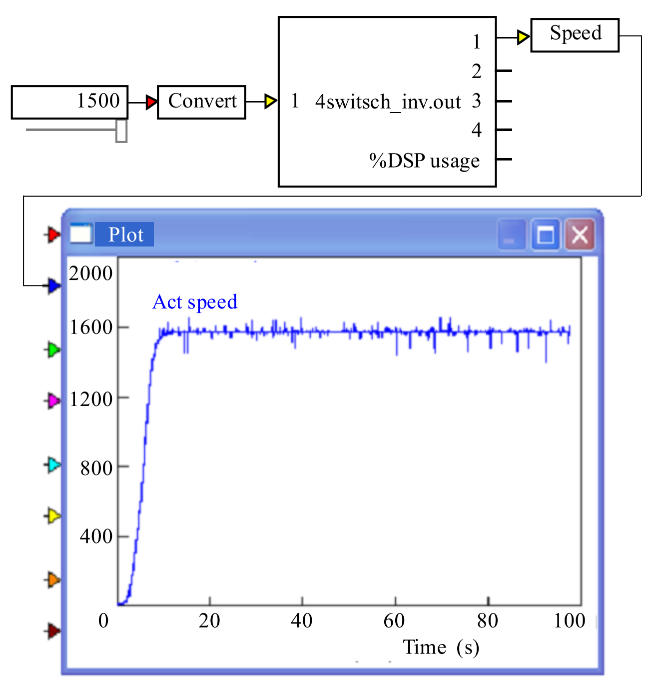

Fig. 4. VisSim block diagram with Speed of Induction Motor output in rpm/sec

The control SPWM based FSTPI drive is implemented by a 150 MHz DSP-TMS320F2812 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

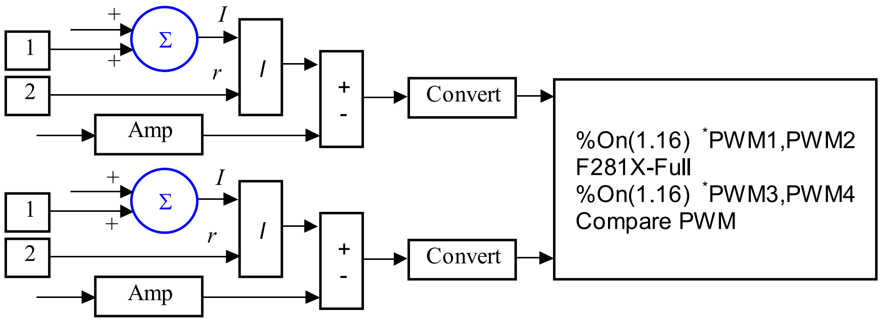

Fig. 5. VisSim block for PWM pulses for FSTPI Drive System

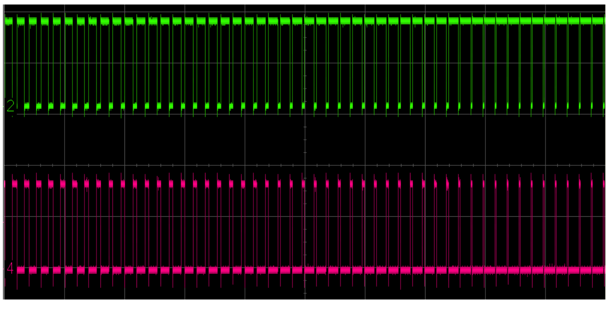

Fig. 6. SPWM pulses for switches S1 andS3

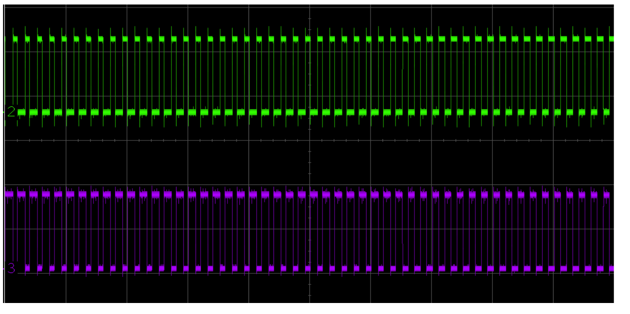

Fig. 7. SPWM pulses for switches S2 and S4

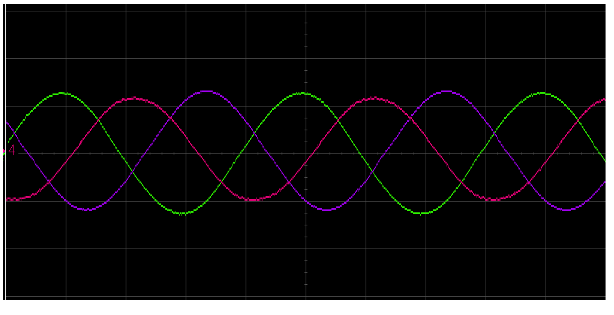

Fig. 8. Three phase current waveforms of FSTPI

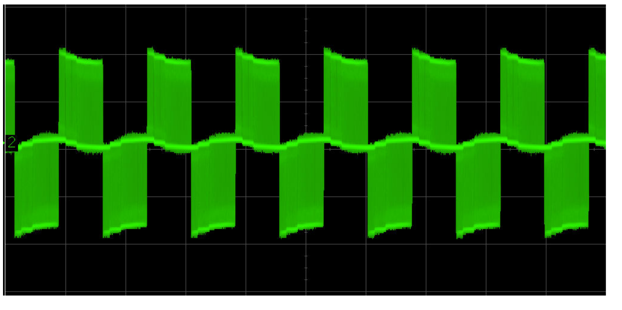

Fig. 9. FSTPI phase to phase output voltage Vab

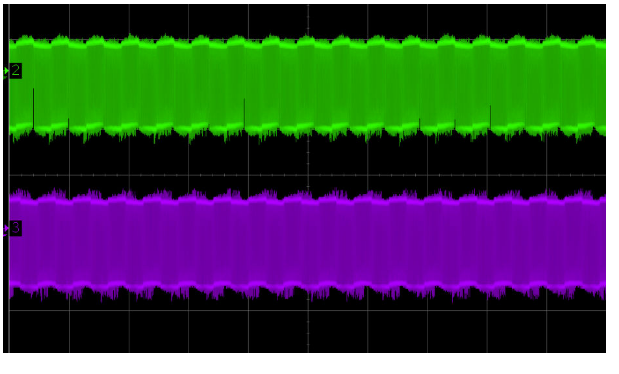

Fig. 10. FSTPI phase to phase output voltage Vbc and Vca

suited for processing control parameter in applications where large amount of calculation are to be computed quickly. The speed sensor is used to sense the speed of Induction Motor. The sensor output is fed to the ADC of DSP processor. The speed and current waveforms are obtained through GUI of VisSim software. The speed of the induction motor (rpm) curve and the current waveform of FSTPI are shown in Fig. 4. In this figure it is seen that the speed of induction motor increases linearly from time zero and reaches at steady state value in 10 second. The PWM pulses for FSTPI are calculated through VisSim software block as shown in Fig. 5. The output waveforms such as SPWM pulses for FSTPI, 3-phase current and 3-phasae line voltages of FSTPI with Induction Motor are obtained by using digital storage oscilloscope. The sinusoidal PWM pulses for the 4 switches of FSTPI are shown in Fig. 6 (S1 and S3) and Fig. 7 (S2 and S4). These SPWM pulses are obtained by comparing sinusoidal waveform and triangular carrier waveform. The switching frequency is selected as 10 Khz. The output current waveform of FSTPI with Induction Motor is shown in Fig. 8. It is observed that a balanced 3-phase output current waveform is obtained. Fig. 9 and Fig. 10 shows the AC output voltage waveform of the FSTPI. The Fig. 9 shows the output voltage of FSTPI Vab (between phase 'a' and 'b'). Figure 8 shows the output voltage Vbc (between phase 'b' and 'c') and Vca (between phase 'c' and 'a') of FSTPI. The complete hardware setup used is given in Table 2.

6 CONCLUSION

A DSP based FSTPI fed 3-phase 5 hp induction motor drive using VisSim embedded control software with DSP processor has been carried out successfully. In this work TMS320F2812 digital signal processor (DSP) with VisSim/ECD software, FSTPI and 5 Hp Induction Motor is used. The results of the FSTPI based drive system are obtained both from GUI of VisSim software and digital oscilloscope. The results obtained in this drive system are satisfactory.

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