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Field Programmable Gate Array (FPGA) Controller Application for Four Switch Three Phase Inverter (FSTPI) Drive

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ABSTRACT

Over the past few years, Field Programmable Gate Array (FPGA) technology has greatly influenced digital circuit design. Due to various advantages like fast computation speed, flexibility in hardware structure it replaces micro controllers & digital signal processing (DSP) devices for specific application like speed control of induction motor. This paper presents application of FPGA controller to control the speed of 3 ϕ induction motor. 4 switch 3 ϕ inverter (FSTPI) is used to fed induction motor instead of conventional six switch three phase inverter (SSTPI). The performance of the present scheme is verified by simulation.

Keywords- Field Programmable Gate Array (FPGA) , Digital Signal Processor (DSP), Pulse Width modulation (PWM) , Four Switch Three Phase Inverter (FSTPI) , Six Switch Three Phase Inverter(SSTPI).

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I. INTRODUCTION

In Paint shop, Paper, Pulp, Chemical industries lots of pumps, fans, and compressor are used for various application uses Induction motor. Most of the times these pumps were throttle which causes pressure spikes in pipe line. Induction motor running with variable speed instead of constant speed can save up to 40% energy consumption. In direct online starts, the driven equipment is subject to a high stress. AC drives gradually ramp the motor up to the operating speed, decreasing the mechanical stress using single-speed starting methods results in abrupt motor starts and in a high level of current from the supplying network to the motor. Using AC drives, the current from the supply will be much lower, and the high starting torque is still available when needed.

Speed performance of new components and flexibility inherent of all programmable solutions give today many opportunities in the field of digital implementation for industrial control systems. This is especially true with software solutions such as microprocessors or DSPs (Digital Signal Processors). However, specific hardware technologies such as Field Programmable Gate Arrays (FPGAs) can also be considered as an appropriate solution in order to boost the performance of controllers. Several articles report on FPGA Architecture [9] and their application to AC motor speed control [4-6] indeed, these generic components combine low cost development, use of convenient software tools and more and more significant integration density. FPGA technology is now considered by an increasing number of designers in various fields of application such as wired and wireless telecommunications, image and signal processing, where the always more demanding data through puts take advantage of the ever increasing density of the chips. Still, more recently, other application fields are in growing demand, such as medical equipment, robotics, automotive and space and aircraft embedded control systems. For these embedded applications, reduction of the power consumption, thermal management and packaging, reliability and protection against solar radiations are of prime importance. Finally, industrial electrical control systems are also of great interest because of the ever increasing level of expected performance, while at the same time reducing the cost of the control systems. Indeed, FPGAs have already been used with success in many different electric system applications such as power converter control (PWM inverters, power factor correction, multilevel converters, matrix converters[2], soft switching, and STATCOM and electrical machines control induction machine drives, SRM drives motion control, multi-machines systems, Neural Network control of induction motors, Fuzzy Logic control of power generators, speed measurement) . This is because an FPGA-based implementation of controllers can efficiently answer current and future challenges of this field.

A field programmable gate array is a set of digital logic gates and configurable logic blocks which can be reprogrammed to meet the desired motor-control features. While the assembly and high level languages like Care used by microcontrollers and DSPs, the technology independent hardware description languages including

VHDL and Verilog are used to program FPGAs. This paper presents a general method to generate pulse width modulated (PWM) signals for control of four-switch, three phase voltage source inverters[3][7], even when there are voltage oscillations across the two dc-link capacitors. The method is based on the so called space vector modulation [10-11], and includes the scalar version. The proposed method provides a simple way to select either three, or four vectors to synthesize the desired output voltage during the switching period. In the proposed approach, the selection between three or four vectors is parameterized by a single variable. This permits to implement all alternatives, thus allowing for a fair comparison of the different modulation techniques. The influence of different switching patterns on output voltage symmetry, current waveform, switching frequency and common mode voltage is examined.

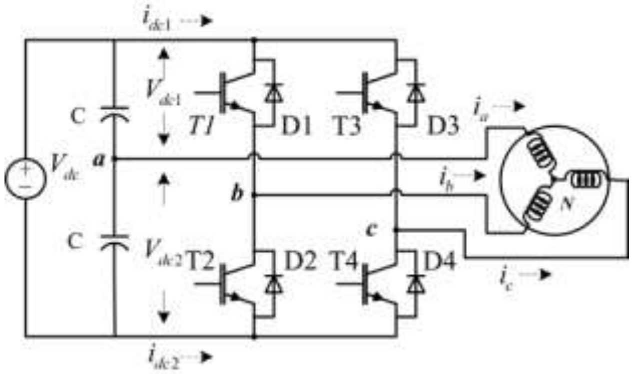

Fig. 1: Four switch three phase inverter drive

II. MOTIVATION

The FPGAs (field programmable gate array) provide programmable system-on-chip designing environments by incorporating the programmability of programmable logic devices and the architecture of gate arrays which makes it an appreciate solution for drive applications. Unlike traditional solutions based on microprocessors and digital signal processing (DSP) devices, the FPGAs introduce hardware parallelism which replaces sequential execution.

Space vector Modulation technique has become the most popular and important PWM technique for Three Phase Voltage Source Inverters for the control of AC Induction, Brushless DC, Switched Reluctance and Permanent Magnet Synchronous Motors. SVPWM gives 15% enhanced fundamental output with better quality. Space vector is better technique in comparison with PWM & SPWM because of its lesser THD wider linear modulation range easier digital realization .As compare with six switch three phase inverter (SSTPI) Four switch three phase inverter (FSTPI) has lesser number of switches hence cost & losses are minimized.

Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application.

States		Switch ON		Output voltage		
S_b	S_c			$32V_{an}$	V_{bn}	V_{cn}
0	0	T2	T4	$\frac{2\,V_{dc2}}{3}$	$\frac{2V_{dc2}}{3}$	$\frac{V_{dc2}}{3}$
0	1	T2	T3	$\frac{V_{dc2}-V_{dc1}}{3}$	$\frac{-(V_{dc2}+V_{dc1})}{3}$	$\frac{(2V_{dc1}+V_{dc2})}{3}$
1	0	T1	T4	$\frac{V_{dc2}-V_{dc1}}{3}$	$\frac{(V_{dc1}+V_{dc2})}{3}$	$\frac{-(2V_{dc2}+V_{dc1})}{3}$
1	1	T1	T3	$\frac{-2V_{dc1}}{3}$	$\frac{V_{dc1}}{3}$	$\frac{V_{dc1}}{3}$

TABLE I: Switching states and output voltages

III. SPACE VECTOR

The FSTPI topology consists of a two-leg inverter as illustrated in Fig. 1. The dc-link is split into two voltage sources, to the middle of which one load phase is connected. For convenient analysis, the inverter is considered for implementation by ideal switches (T1-T4) (i.e., with no dead time and no saturation voltage drop). This means, the switching states of leg b (T1-T2) and leg c (T3-T4) can be denoted as binary states variables S_b and S_c .To prevent the short circuit of the dc-link, the simultaneous closed states of two switches in each leg are usually forbidden. Therefore, a binary '1' will indicate the close state of the upper switch, whereas a binary '0' will indicate the close state of the lower switch. The basic voltage vectors can be defined according to the switching states. the phase-to-neutral voltages V_{an} , V_{bn} , V_{cn} , are given as follows.

$$V_{an} = V_{dc\,1} / 3(- S_b - S_c) + V_{dc\,2} / 3(2- S_b - S_c) \qquad (1)$$

$$V_{bn} = V_{dc\,1} / 3\,(-2.S_b - S_c) + V_{dc\,2} / 3(2.Sb - S_c) \qquad (2)$$

$$V_{cn} = V_{dc\,1} / 3\,(2.S_c - S_b) + V_{dc\,2} / 3(2\,.S_c - S_b - 1) \qquad (3)$$

Where V_{dc1} , $V_{dc\,2}$ are the upper and lower dc-link capacitor voltages, respectively.

Considering all the possible combinations of (S_b S_c) phase-to-neutral voltages values are given in TABLE I.

The Clarke transform applied to the stator voltages yields as follows.

$$\begin{bmatrix} V_{\alpha s} \\ V_{\beta s} \end{bmatrix} = \frac{2}{3} \begin{vmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{vmatrix} \begin{vmatrix} V_{aN} \\ V_{bN} \\ V_{cN} \end{vmatrix}$$

Where the $V_{\alpha s}$ and $V_{\beta s}$ are the α and β axis stator voltage, respectively. The voltage vectors are expressed by $u_s = V_{\alpha s} + j_* V_{\beta s}$ Therefore, the four active voltage vectors (V_1 to V_4) in the plane are given in

TABLE II.

Switching states(S_b S_c)	Voltage vectors $\vec{v_s}$	Vector
00	$2.V_{dc2}/3$	V_1
10	$(V_{dc2} - V_{dc1})/3 - j\sqrt{3}(V_{dc1} + V_{dc2})/3$	V_2
11	$(V_{dc2} - V_{dc1})/3 + j\sqrt{3}(V_{dc1} + V_{dc2})/3$	V_3
01	$-2.V_{dc2}/3$	V_4

TABLE II: Active voltage vector

It is clearly revealed that in TABLE II the inverter can only produce four basic nonzero voltage vectors. The basic voltage vectors change in amplitude and angle in case of dc-link voltage are not equal. If the values of the upper and lower capacitance are big enough to keep the capacitor voltages a constant value of V_{dc} /2 , the four voltage vectors produced by the four kinds of switching combination are presented in Fig. 2(a). Otherwise, a ripple in the two capacitor voltages leads to a deviation of these vectors from the previous positions. The vector positions are presented in Fig. 2(b), (c) in the situation of $V_{dc1} < V_{dc2}$ and $V_{dc1} > V_{dc2}$, respectively. Therefore, the vector positions are calculated as given in Fig. 2.

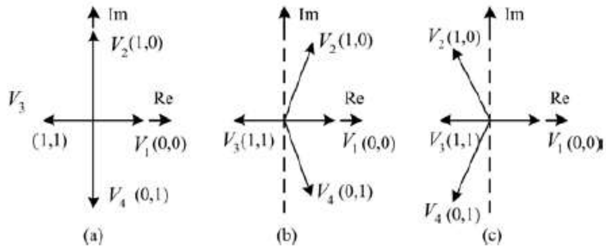

Fig. 2: Basic voltage vectors of the inverter in the case of a) $V_{dc1} = V_{dc2}$ b) $V_{dc1} < V_{dc2}$ c) $V_{dc1} > V_{dc2}$

IV. PROPOSED TOPOLOGY

The block diagram of proposed topology based FSTPI fed IM drive is shown in Fig. 3. The diode bridge rectifier converts three phase AC to DC. The FSTPI is used to convert DC to three phases AC, which is used to drive the induction motor. The FPGA is used to generate PWM pulse to control the FSTPI. The FPGA processor output pulses are fed to the inverter through driver circuit to drive the Induction Motor through FSTPI.

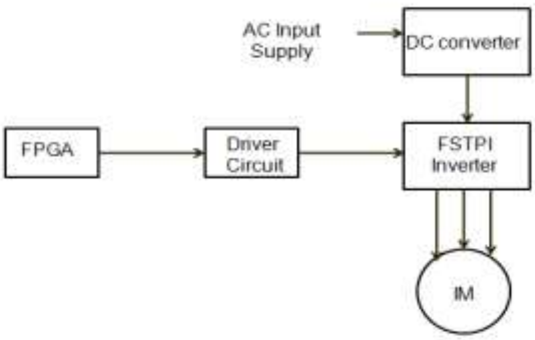

Fig. 3: Block diagram FPGA based FSTPI

V. SIMULATION OF FSTPI DRIVE

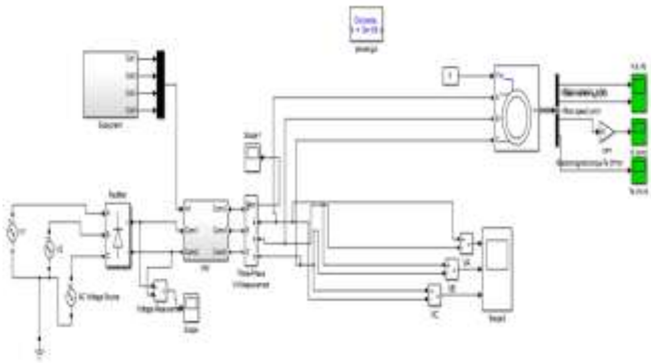

Fig.4: Simulation model of FSTPI drive

Fig. 4 shows the complete simulation circuit diagram of the system. Fig. 5 to Fig. 8 shows simulation results of FSTPI drive model.

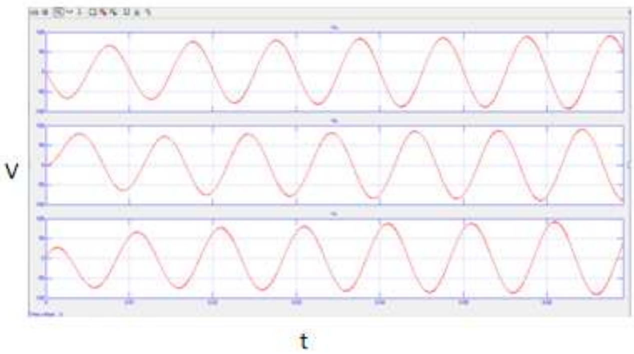

Fig. 5: Inverter output voltage

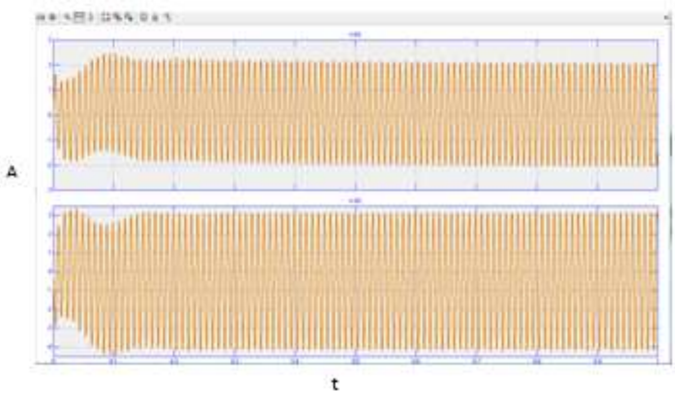

Fig.6: Motor current

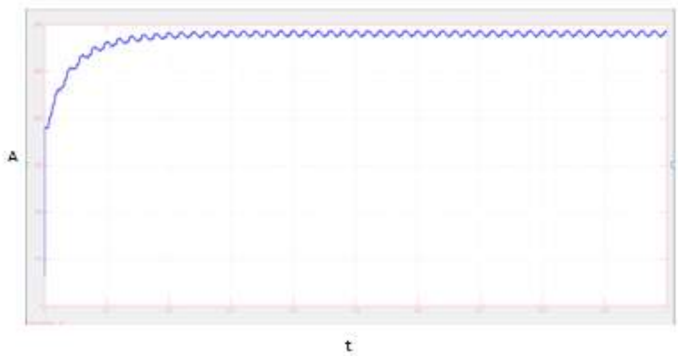

Fig.7: DC Link Current

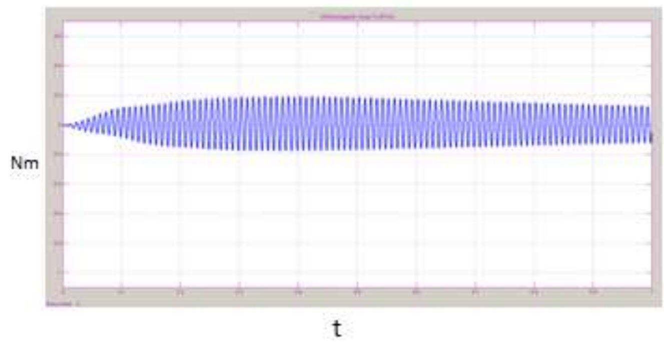

Fig.8: Output torque

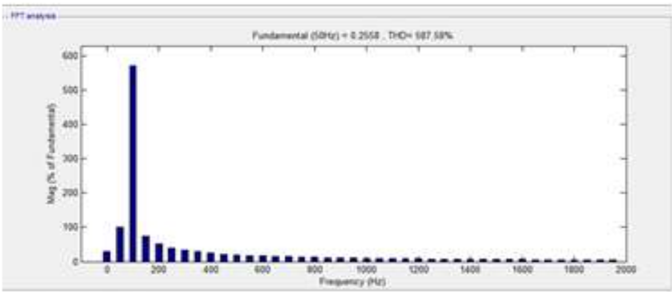

Fig.9: Harmonic Analysis

VI. ADVANTAGES OF SVPWM

The advantages of SVPWM vis-a-vis Sine PWM are as follows:

- Line to line voltage amplitude can be as high as Vdc .Thus 100 % V_{dc} utilization is possible in the linear operating range.
- In the linear operating range, modulation index range is 0.0 to 1.0 in the Sine PWM; where as in SVPWM, it is 0 to .866. Line to line voltage amplitude is 15 % more in SVPWM with the modulation index = 0.866, compared to the Sine PWM with the modulation index = 1. Hence it has better usage of the modulation index depth.
- With the increased output voltage, the user can design the motor control system with reduced current rating, keeping the horsepower rating the same. The reduced current helps to reduce inherent conduction loss of the VSI.
- Only one reference space vector is controlled to generate 3 phase sine waves.
- The reference space vector is a two dimensional quantity, it is feasible to implement more advanced vector control using SVPWM.

VII. CONCLUSION

This paper presents a method to generate PWM signals for control of four-switch three-phase inverters with the help of FPGA controller. With the proposed approach, it was possible to study SVPWM scheme using four vectors to synthesize the desired output voltage during the switching period. The scalar version of the proposed modulation technique is implemented by software and easily included in drive software with a negligible increase in the computational effort. SVPWM control is more energy efficient compared with Sine PWM. Spartan FPGA is well suited give low cost solution, implementing drive control with SVPWM algorithm for 3 phase induction motor.

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