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Direct Torque Control of Induction Motor Using Switching Techniques

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Abstract—*This paper presents PIC microcontroller based PWM inverter controlled four-switch three-phase inverter (FSTPI) fed Induction Motor drive. The advantage of this inverter that it uses four switches instead of conventional 6 switches. Therefore, it has lesser switching losses, lower electromagnetic interference (EMI), less complexity of control algorithms and reduced interface circuits. Experimental work is carried out and result is presented to demonstrate the feasibility of the proposed approach. Simulation is carried out using MATLAB SIMULINK and in the experimental work, a prototype model is built to verify the simulation results. PIC microcontroller is used to generate the Pulse Width Modulation pulses for FSTPI to drive the single-phase Induction Motor.*
Keywords_Four Switch Three Phase Inverter (FSTPI), Induction Motor (IM), Pulse Width Modulation (PWM), Total Harmonic Distortion (THD), Peripheral Interface Controller (PIC).

1. INTRODUCTION

Induction motor plays a very major-role in industry as a workhorse of industrial world. They are smaller, cheaper, maintenance free, robust, highly efficient and adaptable in volatile environment compared to other machines . In past, DC motors were used for variable speed applications because of its fast dynamic performance. Because of the development in power electronics, induction motor is now replacing DC motors and is commonly used as a variable speed drive with comparable performance.

In order to control the speed of an induction motor, there are different methods like Scalar control, Vector control, Sensor less scalar and vector control and direct torque control. Due to the coupling effect in scalar control, F. Blaschke (1972), Hasse and Leonhard introduced vector control which became popular in industry due to the decoupled control as in case of a DC motor . A standard six - switch three phase voltage source inverter has six switches in three legs with a pair of complementary power switches per phase. A reduced switch count voltage source inverter i.e. four switch three-phase inverter (FSTPI)] uses only two legs, with four switches. The advantage of this inverter due to the use of 4 switches instead of conventional 6 switches which results in lesser switching losses, lower electromagnetic interference (EMI), less complexity of control algorithms and reduced interface circuits. Several articles report on FSTPI structure direct torque control of induction motor is developed by Depenbrock, Takahashi and Nogouchi in 1985 where the torque and flux are directly controlled using hysteresis band controllers. Implementation of DTC requires instantaneous flux and torque estimation and the inverter voltages required for desired speed can be attained from the lookup table.

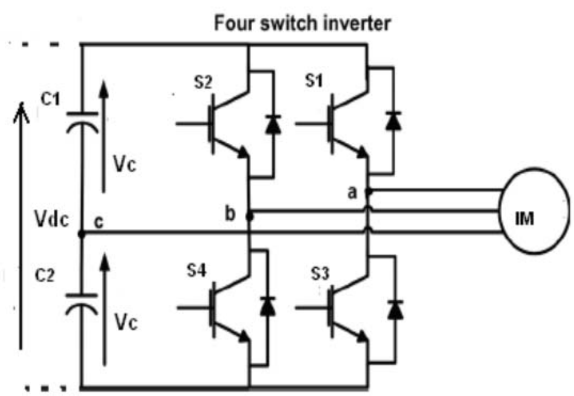
Compared to DTC, vector control requires additional estimators and modulation techniques like SVM to generate reference signal for inverter to have desired speed control, causing high computation burden on DSP . With recent development in power electronics the four switch three-phase inverter (FSTPI) has been proposed for low and medium power application, which reduce the cost as well as operational losses of the induction motor drive with improved reliability and efficiency, Direct torque control using four switch three phase inverter (FSTPI) has been proposed by Mohamed Azab and Orille. Also in case of failure of one leg of the six switch three phase inverter (SSTPI), it can be replaced by FSTPI without interrupting the operation in applications where reliability is very important. In recent years, with the increasing use of microcontrollers in power electronics, it becomes possible to use it to generate the pulse width modulation (PWM) signals to control the speed of the induction motor. The microcontroller provides the variable frequency signal that controls the applied voltage on the gate drive, which provides the required PWM frequency at the output of the power inverter. Low cost PIC16F877A microcontroller has been chosen for implementation for ease in development and fast response. In addition, PIC16F877A has high-performance RISC CPU with only 35 single-word instructions, all single-cycle instructions except for program branches, which are two-cycles, and operating speed of 20 MHz

2. PROPOSED TOPOLOGY

In the experimental work, the single phase half bridge rectifier converts AC power into DC. The DC power is fed to FSTPI. The FSTPI converts the DC power to controlled 3-phase AC power. The 3-phase induction motor is driven by the FSTPI. PIC microcontroller 16f877A is thereby used to generate the controlled PWM pulse for FSTPI. The controlled PWM pulses of microcontroller are fed to the gate of MOSFETs of FSTPI through the driver circuit to drive the IM.

3. PRINCIPLE OF SWITCHING OPERATION

The power circuit of the FSTPI fed Induction Motor drive is shown in Fig. 1. The circuit consists of 4-switches S1, S2, S3 and S4 and split capacitors C1 and C2 . The 3-phase AC input, which is of fixed frequency, is rectified by the rectifier switches. The power circuit is the three-phase four-switch inverter. Two phases 'a' and 'b' are connected to the two legs of the inverter, while the third phase 'c' is connected to the middle point of the dc-link capacitors, C1 and C2. The 4 power switches are indicated by the binary variables S1 to S4, where the binary '1' signifies to an ON state and the binary '0' signifies to an OFF state. The terminal voltages V*as* , V*bs* and V*cs* of a 3-phase Y-connected Induction Motor can be expressed as the function of the states of the upper switches as follows.



4. SWITCHING TABLE

Switching states		Output voltages		
S1	S2	V_{as}	V_{bs}	V_{cs}
0	0	$-V_c/3$	$-V_c/3$	$2V_c/3$
0	1	$-V_c$	V_c	0
1	0	V_c	$-V_c$	0
1	1	$V_c/3$	$V_c/3$	$-2V_c/3$

5. PWM GENERATION IN MICROCONTROLLER

8-bit PIC16F877A microcontroller was chosen to obtain the pulses for the FSTPI to drive the Induction Motor. This Microcontroller has a 25 MHz processor, 33 input/output (I/O) pins, interrupts, counters, timers, I/O ports, RAM, and ROM/EPROM. The peripheral interface controllers (PICs) are the integrated circuits which is based on CMOS technology. The main parts of a PIC are RAM, EPROM, EEPROM, and Peripheral Interface Adaptor (PIA). These components are inserted in the same integrated circuit to reduce the size, the cost of the system and make design of the system easier. The address bus, the data bus and the control bus connecting the components are placed in the PIC circuit by the manufacturer. Because of these advantages, PICs have always been preferred devices in practical control applications. PIC16F877A used in this work operates at 20 MHz clock frequency and runs each instruction as fast as 200 ns. Flash Program Memory is up to 8K×14 words. Data memory is partitioned into four banks which has the General Purpose Registers and the Special Function Registers. Bits RP1 and RP0 are the bank select bits. Each bank extends up to 7Fh (128 bytes). It contains 1 K EEPROM as a program memory, 15 special hardware registers, 36 general purpose registers and 64 byte EEPROM as a data memory. PICs have been preferred control devices just because of their low cost, less energy consumption and small volume. The microcontroller has been programmed to vary the frequency of the PWM signal that controls the frequency of the voltage applied at the gate drives, and as a result of this the switching frequency of the inverter is controlled.

6. SYSTEM HARDWARE DESIGN

The complete prototype of the experimental setup is shown in Fig. 9. The details of the components used in this experiment are given in **Table 2**. The potential transformer is used to provide the power to PIC microcontroller board and driver circuit board. A single phase diode bridge rectifier and filter circuit is used to convert AC to DC. Four MOSFETs and 2-split capacitors are used to form FSTPI. The output of FSTPI is connected to the hp single Induction Motor. Oscilloscope is used to display the PWM pulses and the output current waveform of i_a .

The microcontroller based control system hardware has been programmed to vary the frequency of the PWM signal that controls the frequency of the FSTPI. The PWM module gets two inputs – duty cycle and frequency. frequency can be configured within the range 20Hz – 2 kHz and the duty cycle can be varied from 0% to 100%. The PWM signals of the MCU are applied to the gate of MOSFET through gate driver circuit. The gate driver provides isolation, low impedance and high current supply to drive the MOSFET. By controlling the input voltage to the analog ADC, the output frequency of the Microcontroller can be controlled.

7. CONCLUSION

Application of FSTPI in DTC based control assures good response of IM drives for various speed and load conditions. The test results shows the good response of the motor in forward and reverse modes of operation which proves its application in different quadrant operations. In case of systems with six switch three phase inverter, the reliability can be improved by switching over to the FSTPI mode, improving the reliability of the system. A PIC microcontroller based PWM controlled FSTPI fed Induction Motor drive has been designed and implemented successfully. The simulation and hardware implementation results are presented to verify the feasibility of the system. The implementation of the proposed work shows the practical industrial application of FSTPI.

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