DsPIC based Fixed Speed Induction Motor Drive

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***Abstract*-The induction machine is used as the most common motors in different applications. It is the workhorse of aindustry. But they require much more complex methods of control, more expensive and higher rated power converters than DC and permanent magnet machines. This work presents control of a three phase induction motor using three phase inverter with constant Volts per Hertz control (V/f) method and pulse width modulation. Frequency control with flux proportional to V/f and voltage proportional to the speed seems to be the best solution. PWM gives a high quality output voltage using DsPIC. Three phase inverter output gives a better feed to the induction machine without extra components needed by the motor and also produces a higher starting torque and reduced speed pulsation amplitude.**

In the proposed scheme, dsPIC33FJ128MC706 controller is used to produce PWM signals. A 3-phase, 415V, 1440RPM, 3HP Induction motor is used as load for testing the developed hardware. Storage oscilloscope is used to store the gate pulses and waveforms.

Index Terms—Induction motor, dsPIC, Volts per Hertz control (V/f) method

I. INTRODUCTION

Many industrial applications require variable speed and constant speed for improvement of quality product. The rapid advances in automation and process control leads to continually growing of the field adjustable speed drives. Modern Technology offers various alternatives in the selection of speed drive system.

Three-phase Induction Motors are widely applied in several industrial sectors for applications such as HVAC (heating, ventilation and air-conditioning), industrial drives (motion control, robotics), automotive control (electric vehicles), etc. In the world which is facing severe energy crisis, the golden rule is “energy saved is energy generated”. Use of variable speed drives for industrial applications is one way to generate energy.

Till the advent of thyristor and thyristor power converters the DC Motor had been very popular in the area of adjustable speed drives, even though it suffers from many disadvantages. Due to progress of semiconductor technology and advent of microprocessor has renewed the research and development towards control of AC drives.

Because of advances in solid state power devices and microprocessors, variable speed AC induction motors powered by switching power converters are becoming more and more popular. Switching power converters offer an easy way to regulate both the frequency and magnitude of the voltage and current applied to a motor. As a result much higher efficiency and performance can be achieved by these motor drives with less generated noises. The most common principle of this kind is the constant V/Hz principle [1]. By doing this, the magnitude of the magnetic field in the stator is kept at an approximately constant level throughout the operating range. Thus, constant torque producing capability is maintained. When transient response is critical, switching power converters also allow easy control of transient voltage and current applied to the motor to achieve faster dynamic response.

The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from period to period according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turn off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, such that the energy delivered to the motor and its load depends mostly on the modulating signal.

Digital control of induction motors results in much more efficient operation of the motor, resulting in longer life and lower power dissipation. Although various induction motor control techniques are in practice today, the most popular control technique is by generating variable frequency supply, which has constant voltage to frequency ratio. This technique is popularly known as V/F control [2]. This work describes the design of a 3-phase AC induction motor drive with volt per hertz control using 16 bit High-Performance Digital Signal Controllers. The system is designed as motor control system for driving 3-phase AC induction motor. The dsPIC33Fj128MC706 device contains extensive Digital Signal Processor (DSP) functionality with high-performance 16-bit microcontroller architecture. The use of this 16 bit Digital Signal Controllers (DSC) yield enhanced operations, fewer system components, lower system cost and increased efficiency. According to the requirement a software program is written and is fed to the DSC for the necessary action. The controller circuit essentially takes the reference speed and actual speed of the motor into account [3]-[4].

Depending upon the difference between the reference speed and actual speed the DSC decides the frequency of gate pulse of MOSFETs. The conventional approach of motor control is to first convert the line voltage into DC. DC is again converted to single/three phase AC as per load requirements. The output voltage, frequency or both of the inverter can be controlled by the application of power electronics and microcontroller.

II. AC INDUCTION MOTOR

The AC induction motor is a rotating electric machine designed to operate from a 3-phase source of alternating voltage. For variable speed drives, the source is normally an inverter that uses power switches to produce approximately sinusoidal voltages and currents of controllable magnitude and frequency. Slots in the inner periphery of the stator accommodate 3-phase winding a, b & c. The turns in each winding are distributed so that a current in a stator winding produces an approximately sinusoidally-distributed flux density around the periphery of the air gap. When three currents that are sinusoidally varying in time, but displaced in phase by 120° from each other flow through the three symmetrically-placed windings. A radially-directed air gap flux density is produced that is also sinusoidally distributed around the gap and rotates at an angular velocity equal to the angular frequency ω_s of the stator currents.

Construction

The most common type of induction motor has a squirrel cage rotor in which aluminum conductors or bars are cast into slots in the outer periphery of the rotor. These conductors or bars are shorted together at both ends of the rotor by cast aluminum end rings, which also can be shaped to act as fans. In larger induction motors, copper or copper-alloy bars are used to fabricate the rotor cage winding.

Working

As the sinusoidally-distributed flux density wave produced by the stator magnetizing currents sweeps past the rotor conductors, it generates a voltage in them. The result is a sinusoidally-distributed set of currents in the short-circuited rotor bars. Because of the low resistance of these shorted bars, only a small relative angular velocity ω_r between the angular velocity ω_s of the flux wave and the mechanical angular velocity ω of the two-pole rotor is required to produce the necessary rotor current. The relative angular velocity ω_r is called the slip velocity. The interaction of the sinusoidally-distributed air gap flux density and induced rotor currents produces a torque on the rotor [8]. The typical induction motor speed-torque characteristic is shown in Fig.1.

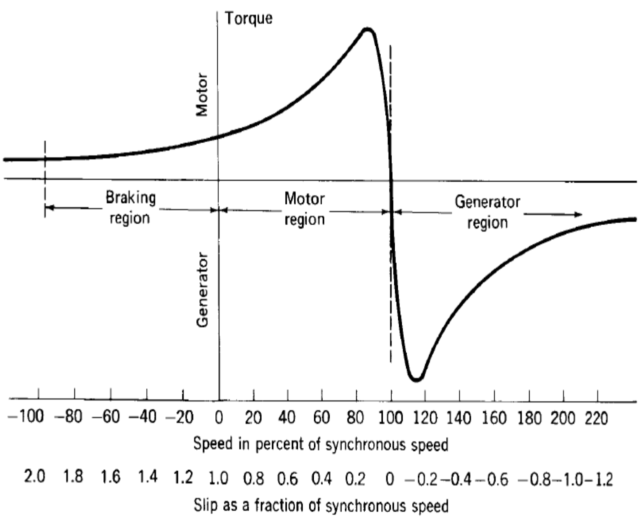

Figure1. AC Induction motor Speed-torque Characteristic

III. V/F CONTROL OF THREE-PHASE INDUCTION MOTOR

The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, thevoltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the fluxproduced by the stator proportional to the ratio of applied voltage and frequency of supply. Therefore by varying the voltageand frequency by the same ratio, the torque can be kept constant throughout the speed range. The below relations justify theabove explanation.

Stator voltage (V) α [Stator Flux (Φ)] × [Angular Velocity (ω)]

$$V \propto \Phi \times 2\Pi f$$

$$\Phi \propto V/f$$

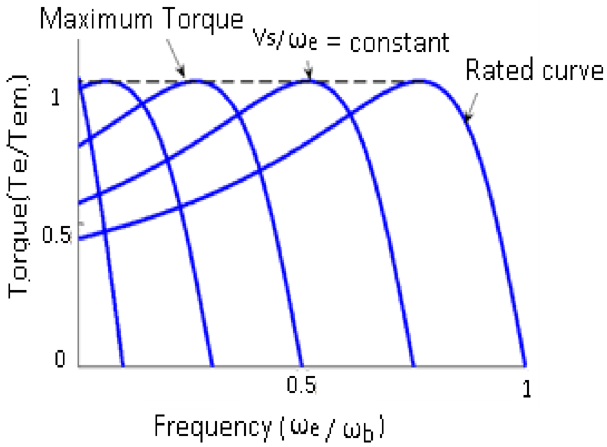

Figure 2. Torque-speed characteristics of the induction motor

This makes constant V/F is the most common speed control of an induction motor. The torque developed by theinduction motor is directly proportional to the V/F ratio. If we vary the voltage and frequency, keeping their ratio constant,then the torque produced by induction motor will remain constant for all the speed range. Fig.2 shows the torque-speedcharacteristics of the induction motor with V/F control. The voltage and frequency reaches the maximum value at the basespeed.We can drive the induction motor beyond the base speed. But by doing so only frequency varies but not voltage.

Hence the ratio of V/F will no longer remain constant. Since the torque developed by the induction motor is directlyproportional to the V/F ratio will not remain constant throughout the speed.

Other than the variation in speed, the torque-speed characteristics of the V/F control reveal the following:

- ❖ The starting current is low.
- ❖ The stable operating region of the motor is increased. Instead of simply running at its base/ rated speed (N_B), themotor can be run typically from 5% of the synchronous speed (N_S) up to the base speed. The torque generated bythe motor can be kept constant throughout this region.
- ❖ Since almost constant rated torque is available over the entire operating range, the speed range of the motorbecomes wider. User can set the speed as per the load requirement,

thereby achieving the higher efficiency.Because of above reasons V/F control method is used in this work.

IV. IMPLEMENTATION OF V/F MOTOR DRIVE

A) System overview

The basic block schematic of three-phase induction motor drive is shown in Fig.3. It has three-phase full bridge rectifier, three-phase full bridge inverter, control circuit, speed sensing unit and output filter. In the proposed work the three-phase bridge rectifier is designed using power diodes. Each power diode is protected from high dv/dt. The output of rectifier is filtered by 1000μF capacitors. The three-phase inverter hasMOSFET switches, with the Snubber circuit for each switch. The filtered output is applied to the three-phase induction motor. The digital control of motor is achieved by applying gate pulses from the control circuit to each of the MOSFET switch through optoisolation.

B)Power circuit design

The power circuit is designed using MOSFET. These MOSFETs are protected against surge voltages usingSnubber circuit. The 3-phase induction motor is connected to 3-phase bridge inverter. A passive filter atthe output of power circuit is used to filter the harmonics as shown in Fig.4. If the upper and lower switches of the same leg are switched on atthe same time then this will cause DC bus supply to short. To prevent the DC bus supply from being shorted, certain deadtime must be given between switching off the upper switch and switching on the lower switch and vice versa.

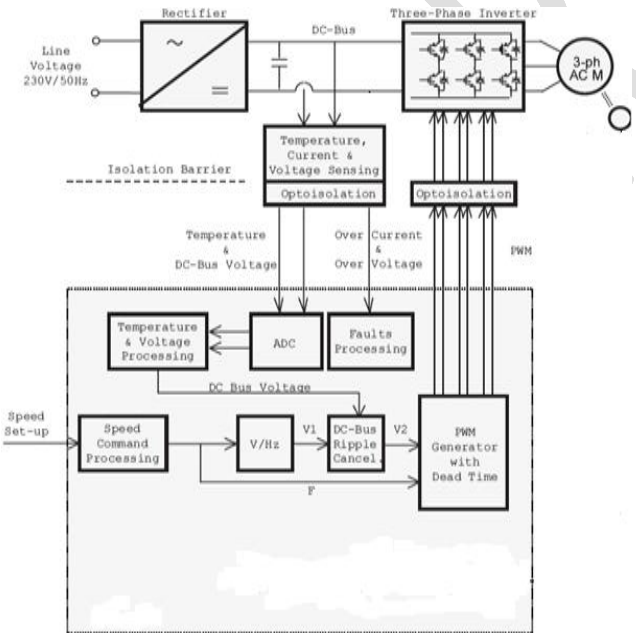

Figure 3. Block diagram of complete system

Hardware mainly consists of:

- Isolation transformer
- Bridge rectifier
- Power Board
- Control Board
- Three Phase Inverter
- 3Φ Motor

Figure 4. Image of Power Board

C). Control Circuit

In this work Microchip‟s dsPIC33Fj128MC706 digital signal controller is used. Microchip‟s dsPIC33FJ128MC706 digital signalcontrollers place unprecedented performance in the hands of 16-bit MCU designers. The dsPIC DSC has the "heart" of a 16-bit MCU with robust peripherals and fast interrupt handling capability and the "brain" of a DSP that manages highcomputation activities, creating the optimum single-chip solution for embedded control of three-phase induction motor.

It also consists of six opto-coupler for isolating the control and power circuits as shown in Fig.5. In this work an optocoupleris used to isolate the gate drive circuit and the MOSFET-based power circuit. Six MOSFETs of the power circuit are controlled bythe Pulse Width Modulation (PWM) signals generated by the control circuit. These PWM signals are required to derive avarying AC voltage from the power circuit.

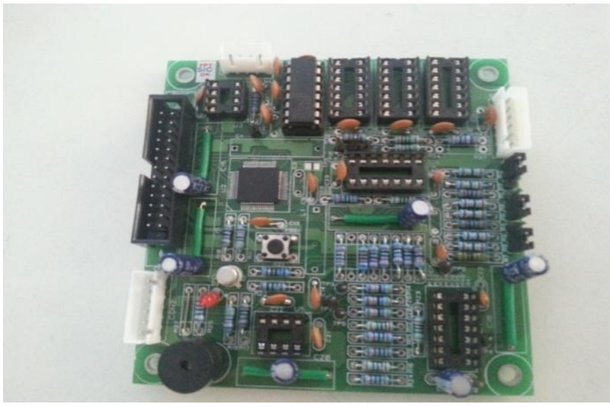

Figure 5. Control Board Image

V. RESULTS AND DISCUSSIONS

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter.

The PWM maximum voltage obtained is 3.6V. As per data sheet, the PWM voltage is between 3.3-5V. Hence after testing dsPIC with auxiliary power board the expected PWM pulses are obtained for 50% of duty cycle as shown in Fig.6.

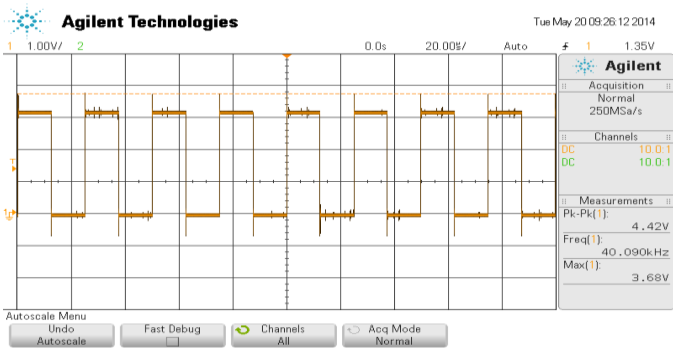

Figure 6. Gate pulse for single phase from control board

In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as Pulse-Width Modulation (PWM) Control as shown in Fig.7.

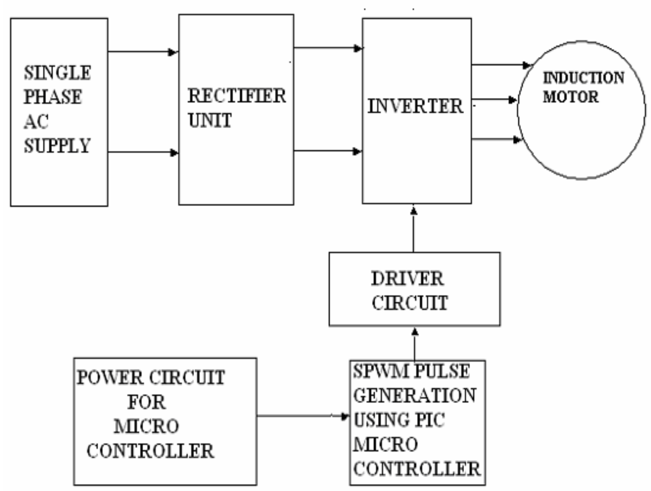

Figure 7. Block diagram of hardware implementation

Proper switching of MOSFETs is tested using incandescent bulb separately for each phase with PWM pulses as shown in Fig.8.

Figure 8.Single Phase testing image

Through power board DC power and gate signals is given to respective pins of MOSFET as per schematic to drive the motor at required speed.

The Variable Voltage Variable Frequency drive for a three phase induction motor is successfully developed andtested in power electronics laboratory and the photograph of the complete project setup is shown in Fig.9.Digital Storage Oscilloscope (DSO) is used to store gate pulses and inverter output voltage waveforms.

As the torque almost remains constant the actual speed also remains constant which is almost near to set speed with an error of ±15 RPM.

Figure 9.Photograph of the complete designed system

CONLUSION

A new generation dsPIC approach for the V/F control of three-phase induction motor has been presented. This completesystem is developed and tested in power electronics laboratory. Speed control of motor is acquired with the accuracy of ±15rpm. Hence in this approach 98% accuracy of speed control is recorded. The variation of stator voltage and frequency is doneproportionally, such that V/F ratio is constant. The inverter line to line voltage recoded is very stable and very smooth withthe use of filter. Hence this three-phase induction motor V/F control by DSC is more stable, efficient and economical.

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