IMPLEMENTATION OF AC INDUCTION MOTOR CONTROL USING CONSTANT V/HZ PRINCIPLE AND SINE WAVE PWM TECHNIQUE WITH TMS320F28027

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Abstract

This paper presents the hardware implementation of V/f control of induction motor using sine wave PWM method. Because of its simplicity, the V/F control also called as the scalar control, is the most widely used speed control method in the industrial applications. In this method the ratio between stator voltage to frequency is maintained constant so that the stator flux is maintained constant. As the stator flux is maintained constant, the torque developed by the motor depends only on the slip speed and is independent of the supply frequency. Thus we can control the speed and torque of induction motor by simply controlling the slip speed of induction motor. The complete control is achieved with the help of TMS320F28027 Development Board. One of the basic requirements of this scheme is the PWM inverter. The gating signals are generated using sine wave PWM technique. Implementation issues such as PWM signal generation, ramp control, v/f control, inverter design are discussed. The results are discussed based on the various waveforms.

KeyWords*: v/f control, Induction motor, PWM, and Scalar control.*

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1. INTRODUCTION

The electrical machine which converts electrical energy to mechanical is the workhorse in a drive system. Earlier all the variable speed control applications are dominated by the DC machines. But the evolution of power semiconductor devices and power electronic converters, the scenario has now changed. Although the majority of variable speed applications use DC machines, progressively they are replaced by ac drives. Among all types of AC machines induction motor with cage type rotor is very popular in the industrial applications. Induction motor cannot be ignored because of their advantages such as less maintenance, rugged construction, higher efficiency, low cost etc. Induction machines are also available in the ranges from fractional horse power (FHP) to multi-megawatt capacity. Single phase and multiphase motors are also available at ease.[1]

Earlier the conventional speed control methods such as stator voltage control, pole changing and frequency control are used. But these methods are not able to provide highly precise and accurate demanded speed as required by the industry. Due to the evolution and advances in the power semiconductor devices and power electronic converters the speed control of induction motor becomes highly precise and accurate. The switching power converters can easily regulate voltage and frequency of the supply voltage and thus higher performance can be achieved. Different speed control methods have been developed. Among all these methods, the V/Hz or scalar control is the most common and easy to implement. In this method stator flux is maintained constant by keeping the ratio between stator voltage to frequency constant. As the stator flux is constant the torque produced by motor depends only on the slip speed and independent of the supply frequency. Thus speed and torque can be controlled by simply regulating the slip speed. Thus induction motor gives improved performance with higher torque producing capacity. Also the dynamic response becomes faster as the power electronic converter can control the transient voltages and current applied to the motor under transient conditions.

One of the basic requirements of this method is the PWM inverter which allows the variation in stator voltage and frequency. The output of PWM inverter is controlled by pulse width modulated signals also called as gating signals. The gating signals are applied to the gate of power transistor which generates the turn ON / turn OFF instances. These PWM signals are of variable pulse width with fixed frequency and magnitude. The PWM pulses will vary according to the modulating signal. In every PWM period there is one pulse of fixed magnitude. The frequency of PWM signal which is same as that of the carrier signal is much higher than that of the modulating signal having fundamental frequency. Thus the pulse pattern of PWM signal will have the same pattern as that of the modulating signal. A modulating signal of sinusoidal nature will have PWM signal whose pulse width will vary in sinusoidal manner. Also the energy delivered to the motor and load will depend upon the modulating signal. Depending upon the nature of the modulating signal different PWM methods can be described. These methods involves sinusoidal PWM (SPWM), Sine + 3rd Harmonic PWM, space vector PWM (SVPWM) and current controlled PWM (CCPWM). The SPWM technique is used in this application. [2]

1.1 V/Hz (Scalar) Controlof IM

When an induction motor is supplied by ac voltage source rotating magnetic field is set up in the stator winding. The stator magnetic field is then linked with the rotor winding which produces torque and the motor starts rotating.The normal operating speed of induction motor is always belowthesynchronous speed which is determined by supply frequency and the no. of poles. Thus the speed of induction motor can be varied by simply varying the supply frequency which can be easily varied with the help of sinusoidally modulated PWM inverter. The steady state equivalent circuit of induction motor is shown in figure 1. As shown in the figure the stator resistance Rs is assumed to be zero and Ll is the total leakage inductance referred to stator. The stator leakage inductance (Ls) is embedded into the rotor leakage inductance (Lr).

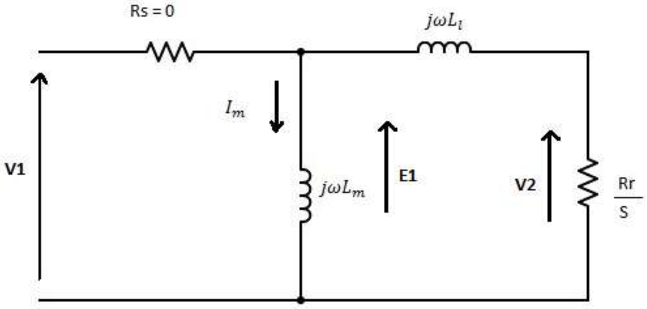

Fig-1: Simplified Steady-State Equivalent Circuit of Induction Motor

The magnetizing inductance Lm is moved in front of the total leakage inductance (L_l = Ls + Lr). If the voltagee drop across stator resistor is neglected then the supply V1 will be approximately equal to E1 given as

$$V1 \approx E1 = 2\pi f\,\lambda m \qquad (1)$$

whereλm is the stator flux linkage due to the airgap flux. According to above equation the airgap flux is directly proportional to the ratio of supply voltage V1 and frequency f. Hence the supply voltage should be varied in proportion to the frequency f such that the airgap flux is maintained constant at all speeds. So in V/Hz control the supply voltage V1 and the supply frequency f of the SPWM inverter are proportionally increased. However at low input voltage because of the voltage drop across stator impedance the airgap flux reduces with loss of torque. At no load condition where the slip is very small and the motor speed is near to the synchronous speed compensation for stator resistance drop is to be added to overcome the drop. However if the motor is lightly loaded at low speeds the airgap flux increases and the motor can overheat. From the equivalent circuit of figure 1 neglecting the rotor leakage inductance the equation for torque and rotor current I_2 can be given as

$$I_2 = \frac{s\omega_1 E_1}{R_2\omega_1} = \frac{\lambda_m}{R_2} s\omega_1 \qquad (2)$$

and

$$T = 3P\frac{R_2}{\omega_r} I_2^2 \qquad (3)$$

where sω1 is the slip frequency.

The above two equations implies that the rotor current can be limited by limiting the speed in turn limits the developed torque. In actual implementation, the ratio between the stator voltage V and frequency f is normally based on the rated values, or motor ratings. The typical V/Hz profile can be shown in the figure 2. Inherently, there arethree speed ranges in the V/Hz control which are as follows:

At fc=0Hz: When the motor is operated at low speeds the voltage drop across the stator resistance cannot be ignored.As this drop is to be compensated the V/Hz profile is not linear in this region. This region is said to be compensation region. The cutoff frequency (fc) and the suitable stator voltage required to nullify the voltage drop may be theoretically calculated from the steady state equivalent circuit with $R_s \neq 0$.

At fc = frated Hz:In this region the V/Hz profile maintain a constant relationship. The stator voltage is proportionally increased with the frequency. The slope corresponds to the amount of air gap flux in the machine. This region is said to be linear region.

At fc >frated Hz: In this regionthe V/Hz ratio cannot be maintained constant because the stator voltages cannot be exceeded beyond the rated values in order to avoid the insulation breakdown at stator windings. Thus the resulting airgap flux would be reduced, and the developed torque would also reduce correspondingly. This region is thus said to be “field weakening region”. So to avoid this, constant V/Hz principle is disobeyed at such frequencies. [3]

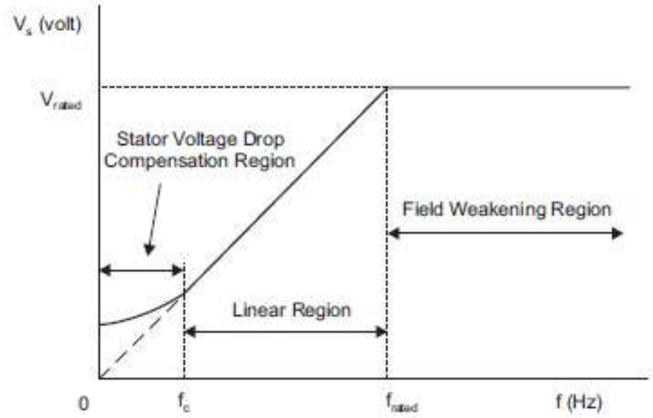

Fig-2: Stator Voltage Versus Frequency Profile Under V/Hz Control

The torque speed curve of induction motor with constant airgap flux is shown in figure 3. As shown in figure the torque produced is the function of slip speed only because of constant stator flux. It is independent of the supply frequency. Thus by adjusting the slip speed, the torque and speed of an AC induction motor can be controlled with the constant V/Hz principle.

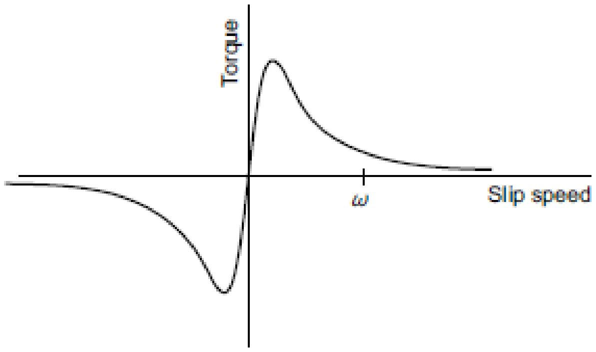

Fig-3:Torque Versus Slip Speed of an Induction Motor With Constant Stator Flux

2. Sine wave PWM Methodology:

The main purpose of static power converter is to produce an AC waveform from a DC supply voltage. Static power converters, particularly inverters, are made from the power electronic switches and the ac voltage obtained from them is of discrete nature. To control the power on and off of the switches specific pulses are to be generated. These pulses are generated using modulation techniques. The modulation technique also controls the amount of time and the switching instants of a power switch. As the output waveform of inverter is not sinusoidal, the modulation technique ensures the fundamental component to behave as such. The modulating techniques are mostly of carrier-based type (e.g., sinusoidal pulse width modulation, SPWM), the space-vector (SV) technique, and the selective-harmonic-elimination (SHE) technique. In all SPWM is simple and cost effective. [2]

2.1 Principle of Sine Wave PWM:

The sinusoidal PWM technique is very famous amongstthe industrial converters. This is basically a carrier based PWM technique. In this method the modulating signal is the fundamental sine wave and the carrier signal is the high frequency triangular wave. Figure 4 explains the general principle of SPWM, where a high frequency triangle carrier wave of frequency (fc) is compared with the modulating wave (which is a fundamental frequency sine wave) and the points of intersection determines the switching instances of the power switches. [3]

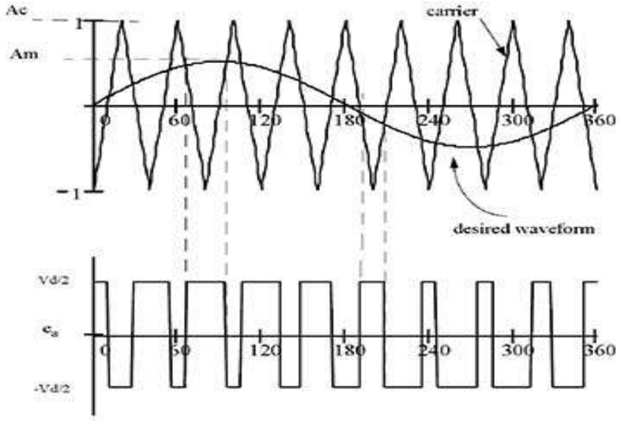

Fig-4: Principle of Sinusoidal PWM for VSI

2.2. Digital Implementation of SPWM:

Pulse Width Modulation (PWM) is a method of encoding a voltage onto a fixed frequency carrier wave. The frequency of the PWM will be fixed while the duty cycle will vary between 0% and 100%. Thus the duration of on time will be proportional to the output signal voltage. For example, a 0% duty cycle produces a 0V output while a 100% duty cycle produces a peak-to-peak voltage Vp-p equal to the input/output supply voltage to the microcontroller which is generally equal to 3.3 volts. So a 50% duty cycle would produce an output voltage equal to 1.65V. The PWM method has an advantage of having low cost way of implementing a digital-analog converter (DAC). Thus by time-varying the duty cycle percentage, a sine wave can be generated.

The basic idea of generating a sine wave using the PWM technique is to first digitize the sine wave and encode the duty cycle corresponding to each sample point. The no of samples can calculated as

$$Total\ No\ of\ samples = \frac{F_c}{F} \tag{4}$$

Where Fc is the frequency of carrier signal and F is the frequency of modulating signal i.e. sine wave. See figure 5.
For example if the frequency of carrierwave is 600Hz and frequency of sine wave is 50Hz then the total no of samples will be 12 according to equation 3. 12 samples points means that sample is taken at an angular step of 30° of a circle. The sine value of each sample and its corresponding duty cycle is shown in Table 1.

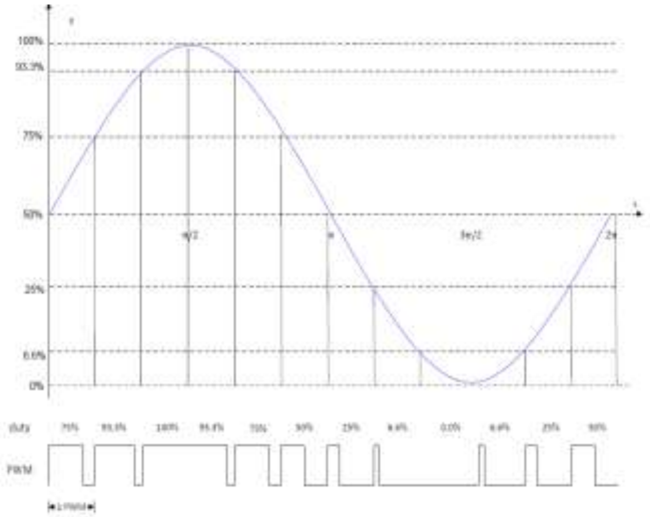

Fig-5: 12 Sample Points Sine Wave With the Corresponding Modulated PWM

Thus we can generate the sine wave with this method and different values of carrier frequency can be taken. Higher the carrier frequency means more the no of samples and less is the quantization error.

Table-1:**12**-Sample Digitized Sine Table

Degree	Radian	sine(Radian)	Normalize to 0	%
0	0.0000	0.0000	1.0000	0.50
30	0.5233	0.4998	1.4998	0.75
60	1.0467	0.8658	1.8658	0.93
90	1.5700	1.0000	2.0000	1.00
120	2.0933	0.8666	1.8666	0.93
150	2.6167	0.5011	1.5011	0.75
180	3.1400	0.0016	1.0016	0.50
210	3.6633	-0.4984	0.5016	0.25
240	4.1867	-0.8650	0.1350	0.07
270	4.7100	-1.0000	0.0000	0.00
300	5.2333	-0.8673	0.1327	0.07
330	5.7567	-0.5025	0.4975	0.25

The digitized sine wave is then compared with the triangular wave to get the PWM signals. These signals are used to switch the power devices which give the desired AC output having the fundamental frequency.[3]

3. F28027 Microcontroller:

The F28027 microcontroller is from the C2000 family from Texas instruments. The kit has all the hardware and software features required to build applications using F28027 microprocessor. It is a low cost experimenter board specially made for motor control applications. It has 32K flash and 6K SARAM on chip memory. The clock frequency is 60MHz with a instruction cycle time of 16.67ns. the Enhanced PWM makes it easier to generate the PWM waveforms. The control algorithm is constructed in the Code composer software and then dumped in the flash memory by using the JTAG emulation tool which allows direct interface with the PC for easy programming, debugging and testing. It requires 5V supply to run the board through USB port. The detailed description of the board is given in the figure below.

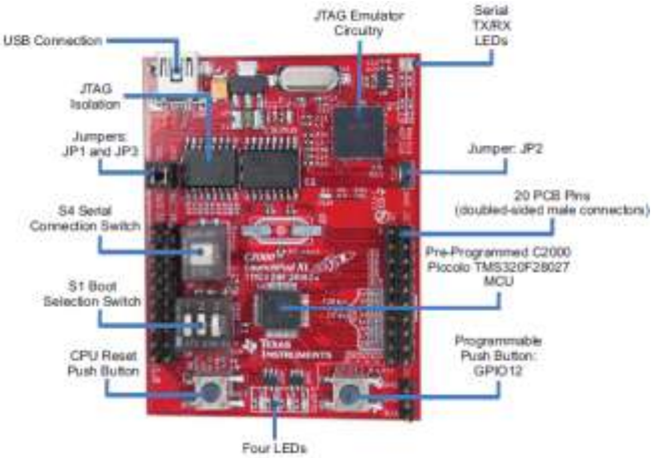

Fig-6:LAUNCHXL-F28027 Board Overview

4. System Overview:

Thissection describes the complete implementation of V/F control scheme of induction motor. It comprises of three sections namely, block scheme of implemented control system, Experimental setup based on F28027 and the Experimental results. The control algorithm has been implemented based on microcontroller TMSF28027 from Texas Instruments Company. The TMS320F28027 is a 32 bit floating point microcontroller devoted for drive application. The complete system is designed for 42V rms.

4.1. Block scheme of implemented control system:

The Block diagram of V/F drive is shown in the figure 7. The AC supply is first rectified to get the DC link voltage. In the scalar control mode the algorithm obtains the command voltage vector based on the reference frequency. The command voltage vector is realized by sine pulse width modulation (SPWM). The three phase voltage source inverter converts the DC link voltage to 3-phase AC using the command signals. The scalar control maintains the V/F ratio constant. The output 3-ph AC voltage is fed to the induction motor which gives the desired motor characteristics.

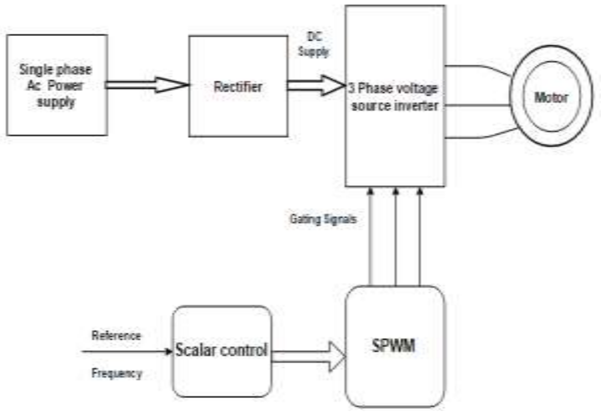

Fig-7: Block Diagram of V/F Drive Scheme

4.2. Experimental setup based on TMS320 F28027:

The Experimental setup of V/F control of induction motor using Sine wave PWM technique is shown in figure 9. The whole system is designed for 42 V for experimental purpose. The 230V, 50 Hz mains AC supply is stepped down to 42 volts and then it is rectified and filtered to obtain DC link voltage. The DC voltage is then converted to AC supply using 3 phase voltage source inverter. The gating signals for power devices are generated using the F28027 microcontroller. The detailed explanation about the whole system is given below:

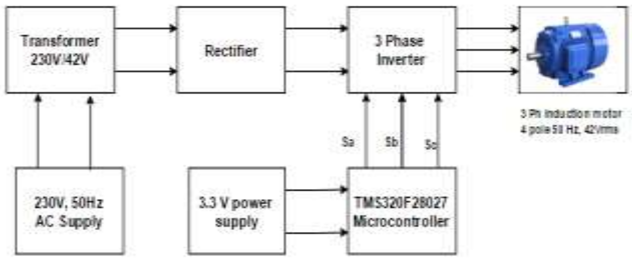

Fig-8: Structure of Experimental setup

Fig-9: Experimental setup

4.2.1. Rectifier: The rectifier converts the 42V single Phase AC supply to DC. Single phase 400V, 25A bridge rectifier IC is used. The rectified voltage is then filtered using capacitor to filter out the ripple voltage. The peak value of output secondary voltage from the transformer is

$$V_p = 1.414 * V_{rms} \quad (5)$$

This voltage will be reduced due to the diode drop and the ripple voltage. The ripple voltage calculations must be done to reduce the ripple content to a safe value. The current through capacitor is given by

$$i = c\frac{\delta v}{\delta t} \quad (6)$$

for a finite time interval the instantaneous slope (δv/δt) must be changed to a constant slope. Then the change in voltage is given by

$$\Delta v = \frac{i\Delta t}{C} \quad (7)$$

Where Δv is ripple voltage, i is load current, Δt is ripple interval. As in full wave rectification for each cycle there are two cycles of the rectified voltage. Hence the ripple frequency will be twice the supply frequency. But in half wave rectification, the ripple frequency is same as the supply frequency. Thus the ripple interval Δt is 1/100 s for full wave rectification and 1/50 s for half wave at 50Hz line frequency, and C is capacitance.

It may be more convenient to relate Δt as frequency instead. Substitute 1/f for Δt in equation (5)

$$\Delta v = \frac{i}{f*c} \quad (8)$$

Now f represents ripple frequency (100Hz for full wave rectification and 50Hz for half wave rectification). Thus using equation (6) the voltage ripple can be calculated as

$$\Delta v = \frac{3A}{100Hz * 5100\mu f} = 5.88V$$

Figure 10 shows the complete rectifier circuit.

Fig-10: Rectifier Circuit

4.2.2. Inverter: Inverter circuit is used to convert the Dc supply to AC. The gating signals generated from the microcontroller are fed to non-inverting buffer so as to drive the LED of optical isolator. The optical isolator also serves the purpose of optical isolation between the control circuit and the power circuit. The optical isolator used isTLP250. The output of isolator is then given to the MOSFET gate driver IC IR2111. The output of driver IC is given to the MOSFET's which then produces the required AC output. The detailed description of each component is given below.
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1. Hex Buffer SN7407: The SN7407 is a TTL hex bufferwhich has high-voltage open-collector outputs. This helps to interface with high-level circuits such as MOS logic circuits orfor driving high-current loads such as lamps or relays. These devices perform the Boolean functionY = A in positive logic. The supply voltage Vcc is 5V and the high level output voltage is 30V with an output current of 40mA. The output of buffer IC is given to optical isolator to drive the LED. The SN7407 comes in 14 pin DIP package IC.

2. Optical Isolator TLP250: The TLP250 consists of a light emitting diode witha integrated photodetector. The TLP250 comes in 8 pin DIP package IC. TLP250 is suitable for gate driving circuit of IGBT or power MOS FET. But in this circuit it is used for optical isolation between the control circuit and the power circuit.

3. MOSFET Driver IC IR2111: The IR2111(S) is a high voltage, high speed power MOSFET and IGBT driver.It has high and low side output channels designed for half bridge applications. Also the CMOS technology enables the monolithic construction.HVIC (High Voltage IC) is a high voltage IC which can directly drives gates of power device using the input signal from the microcontroller.The bootstrap method is used to drive the high side MOSFET. One of the key features of this IC is that internal delay is provided which prevents short circuit of the high and low side devices during transition. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts. The typical connection diagram is shown below.

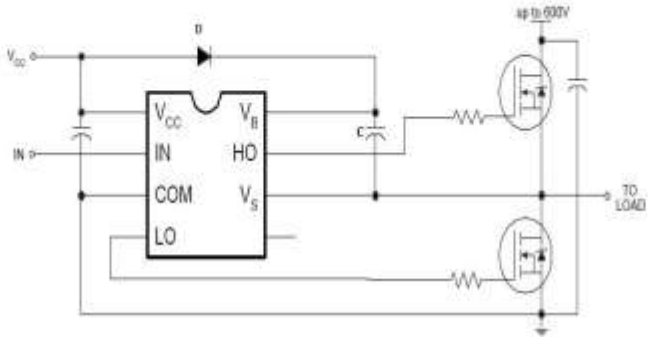


Fig-10:Typical connection diagram**.**

The Diode D and the Capacitor C in the above figure forms the bootstrap circuit. This circuit is used to generate the floating voltage required for driving the high side circuitry.

4. MOSFET IRFP250: The IRFP250 isa N-channel MOSFET with Drain-source Voltage V_{DSS} is 200V and output drain current I_D is 33A at $Tc = 25°C$. The maximum gate to source voltage V_{GS} is ±20. Because of the high current and high switching speed it is suitable for the DC to AC converters.

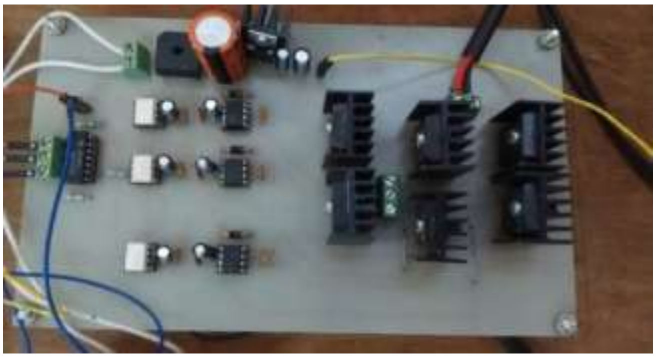
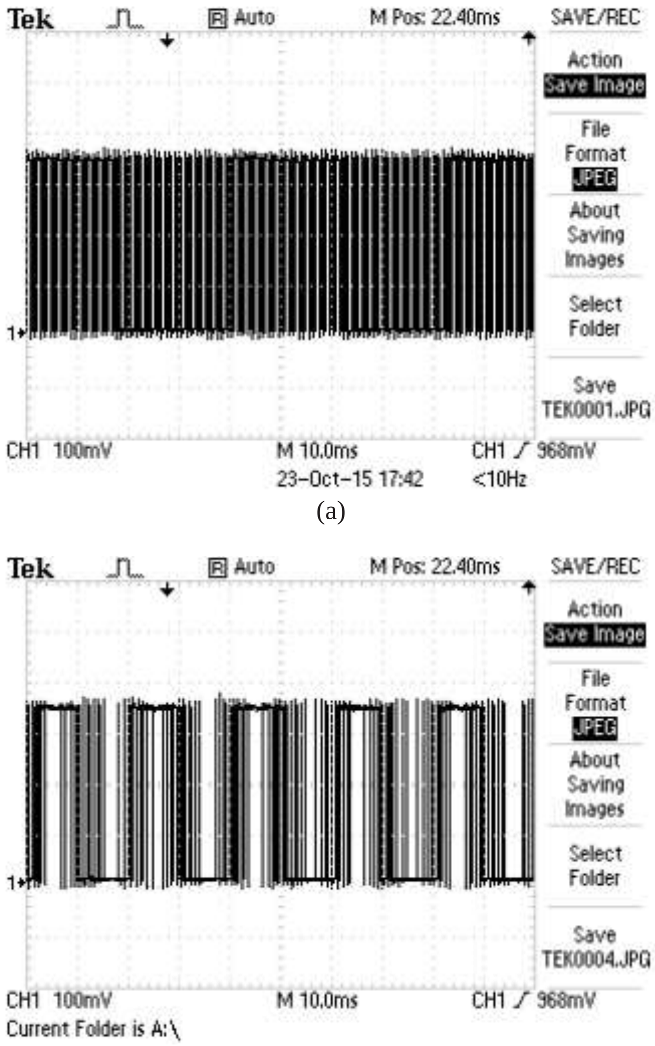


Fig-11: Inverter Circuit

The three phase output AC voltage from the inverter circuit is used to drive the induction motor. The complete circuit of inverter is shown in the figure 11.

5. Experimental Results

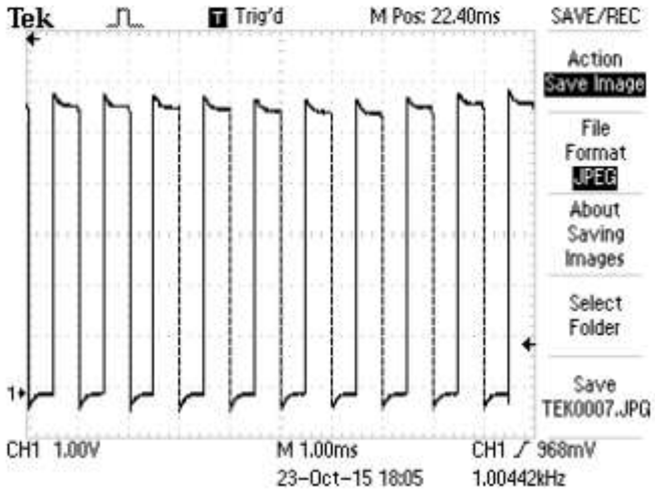
The Experimental results are explained in this sectionto show the effectiveness of the discussed hardware circuit. Figure 12 and figure 13 show the PWM waveforms obtained for the sine wave PWM technique and voltage waveforms at 1Hz and 50Hz respectively. A motor controlled by digital power converter is used in this setup. The TMS320F28027 launchpad is used to run the motor control algorithm. The converter is designed to interface with the TMS320F28027 Launchpad using opto-isolator. The motor is 4-pole 3-phase AC induction motor rated at 50Hz, 42V and 0.25Hp. It can be seen that little or no harmonics are present at no load condition in the voltage waveforms but ripple content upto 5% is noticed in the voltage waveform on load.



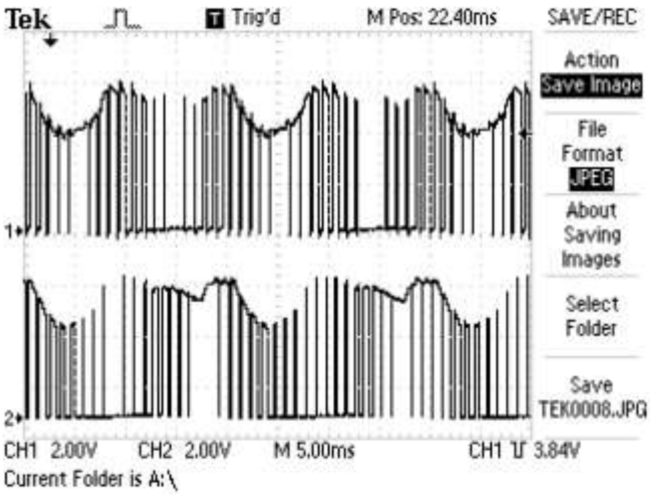
(a)

(b)

Fig-12 (a) PWM voltage waveforms at f=1Hz. (b) PWM voltage waveforms at f=50Hz



(a)



(b)

Fig-13 (a) output voltage waveforms at f= 1Hz. (b) output voltage waveforms at f=50Hz

6. CONCLUSION

Induction motor drives are most widely used in the industrial applications. Various speed controlled methods have been developed. Out of which the V/HZ is the most common and easy to implement. The work carried out in this paper mainly focused to develop a V/Hz controlled induction motor drive using the sine wave PWM technique. The control is achieved with the microcontroller TMS320F28027 of the C2000 family. Because of the safety issues the overall work is done for 42V supply voltage. A 0.25 Hp, 42V, 3-phase, 50 Hz induction motor based V/Hz drive circuit has been developed. The ramp control is used to start the motor with some acceleration time which allows limiting the starting current to a safe value. An approximately 5sec acceleration time is set for this purpose. The C2000 launch pad made it simpler to generate the control signals for the power MOSFETS. It has been observed that the induction motor operates smoothly and the circuit woks properly. The respective waveforms are also shown. As this model has been developed for 42V, it can be made for the rated 440V, 3-phase as required for the industrial applications.

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