DESIGN AND SIMULATION OF SPEED CONTROL OF SINGLE PHASE INDUCTION MOTOR USING SPWM CONTROL TECHNIQUE

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***Abstract*—The induction motors run only at their rated speed when it is connected to the supply, Now a days controlling the induction motor speed efficiently is a main concern in terms of saving energy. In conventional methods wastage of energy is more while controlling the speed of induction motor. This paper presents PWM method for V/F control of single phase induction motor. After comparing different methods and analyzing simulations of different methods, V/F speed control method of induction motors prove to be the most multilateral. By using PWM method constant V/F ratio can be achieved. Basic requirements for induction motor speed control by V/f method is control card, MOSFET driver and dc link converter. A good control of V/f ratio and smooth speed control can be conducted from this scheme. The objectives of adopting this method are covered as to implement a control system which reduces human efforts, reduce the energy consumption of the motor applications, increase flexibility of the motor by giving it wide area of speed control, to satisfy maximum demand placed on motor, make speed controlling system more friendly and develop a system which can increase efficiency and save electrical energy.**

Keywords—PWM, V/F control, Single phase induction motor, DC link converter, Efficient speed control

I. INTRODUCTION

Induction Motors account for more than 85% of all motors used in industry and domestic applications. In the past they have been used as constant-speed motors as traditional speed control methods have been less efficient than speed control methods for DC motors. However, DC Motors require commutators and brushes which are hazardous and require maintenance. Thus Induction Motors are preferred[1]. The advantages of Induction motor are their ability to operate from a single phase power supply. Therefore, they can be used whenever a single phase power is available. Recently, electronic power and control systems have matured to allow these components to be used for motor control in place of mechanical gears.

The electrical based speed control technique can control the speed precisely and give energy efficient outputs which can be understood by this fan flow example which illustrates that if electrical drive system and mechanical louver based system is compared the input power of both system has large deviation in value. Mechanical louver are most likely to use more power for the required flow rate compared to electrical drive as illustrated in the figure 1 below, which can state how this proposed scheme may create huge power consumption difference in domestic as well as industrial power consumption[2].

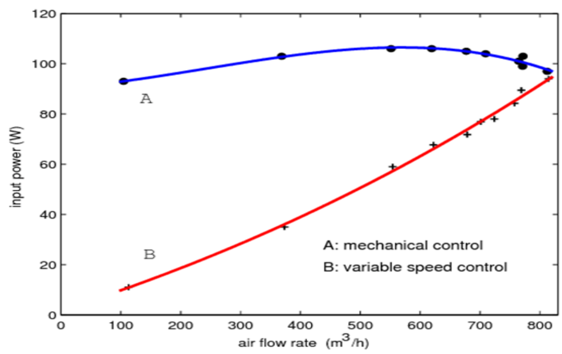

Figure 1 power consumption of fan motor at various air flow rates obtained by a mechanical louver and variable speed control

These electrical drives not only control the motor's speed, but can improve the motor's dynamic and steady state characteristics. Induction motor control is complex due to its nonlinear characteristics. While there are different methods for control like, Variable Voltage Variable Frequency, Volts/Hertz are the most common methods for speed control in open loop. This method is most suitable for applications without position control requirements or the need for high accuracy of speed control[3].

II. SYSTEM DESCRIPTION

The concept used in this motor control is to implement two basic circuit which are shown in figure 2. This method will give open loop speed control of single phase induction motor. It consists of control card, uncontrolled full bridge rectifier, MOSFET based H-bridge inverter, MOSFET driver.

Single phase ac supply is given to the bridge rectifier circuit two diodes conduct at a time for positive half cycle and two diodes conduct at a time for negative half cycle and pulsating dc output is achieved. Filter is used to achieve pure dc from pulsating DC. Constant dc supply is

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given to H bridge inverter module. Controlled AC output is given to the induction motor. Required speed is given as input from keypad which is given to the SPWM generator calculates the required PWM to achieve desired speed and gives signal to the driver circuit driver circuit generates PWM and it is given to the inverter module and desired output voltage and frequency is achieved which results as constant required speed.

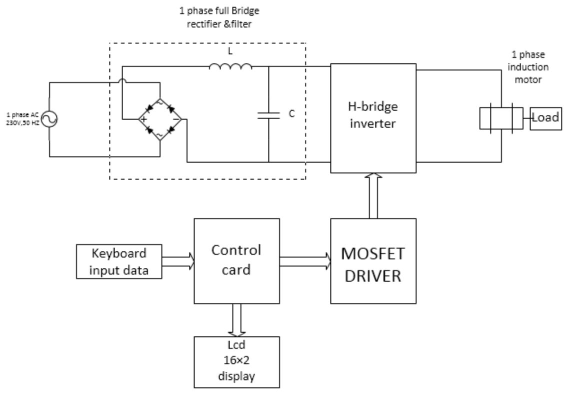

Figure 2 Block diagram

A. *SPWM(sinusoidal pulse width modulation)*

Figure 4 explains the generation of a sinusoidal PWM signal, which finds more applications in industries. the gating signal can be generated by comparing a sinusoidal reference signal(Vr) with a triangular carrier wave(Vc) and the width of each pulse varied proportionally to the amplitude of a sine wave evaluated at the center of the same pulse. The output frequency can be found by using the frequency of the reference signal. The RMS output voltage can be controlled by modulation index "m" and in turn modulation index is controlled by peak amplitude. The number of pulses per half cycle depends on the carrier frequency.

$$V_O = V_S\left(\sum_{m=1}^{2P}\frac{\delta m}{\pi}\right)$$

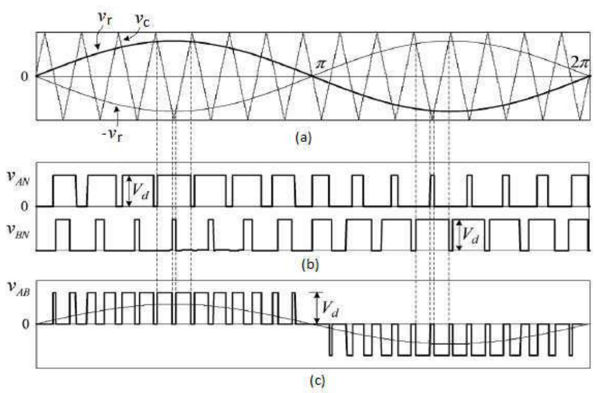

Figure 3 Sinusoidal pulse width modulation

B. *V/F speed control*

The torque developed by the motor is directly proportional to the magnetic field produced by the stator. So, the voltage applied to the stator is directly proportional to the product of stator flux and angular velocity. This makes the flux produced by the stator proportional to the ratio of applied voltage and frequency of supply. Therefore by varying the voltage and frequency by the same ratio, the torque can be kept constant throughout the speed range[4]. V/F is the most common speed control of an induction motor. The torque developed by the induction 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. Figure 4 shows the torque-speed characteristics of the induction motor with V/F control. The voltage and frequency reaches the maximum value at the base speed[5].

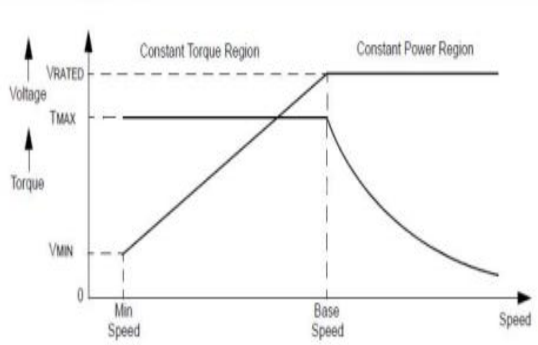

Figure 4 V/f control characteristics

Stator Voltage (V) =[Stator Flux (Φ)] x [Angular Velocity]
V = Φ* 2 Π f
Therefore, Stator Flux(Φ) = V/f

Ns= $\frac{120f}{p}$

Ns= Synchronous speed
Synchronous speed is dependent on the frequency and pole so by changing frequency speed can be varied.

III. REALIZATION OF DC LINK CONVERTER

A. *DC link converter*

For solid state power conversion devices it is required to use DC link converter. AC power is first converted into DC power through the use of rectifiers composed of suitable power semiconductor components like diodes or thyristors. The purpose of this conversion into DC power is that, it is easier to manipulate DC waveforms which are basically a straight line than AC waveforms which are sinusoidal. The capacitor works with the rectifier and acts as a storage of DC power and filters out the variations of the DC voltage prior to further processing of the inverter section of inverting. The output of the rectifier section together with the capacitor is the DC link of the power conversion equipment. The filtered DC power in the DC Link is then fed into the inverter section.

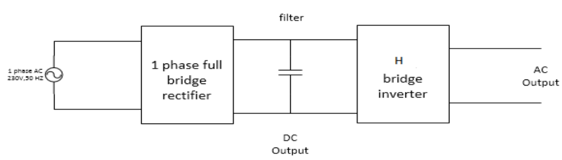

Figure 5 DC link converter

The inverter section composed of fast switching semiconductor devices like insulated gate bipolar transistors or MOSFETs, converts and processes the stable DC voltage in the DC Link to produce AC power with the correct or desired frequency and/or voltage level. In simple words the DC Link is just the section between the rectifier and inverter in a solid state power conversion equipment.

B. Filter design

Placing a large capacitor parallel with the load may produce the output voltage that is essentially direct current. In the full wave circuit , the time that capacitor discharge is smaller than that for the half wave circuit because of the rectified sine wave in the second half of each period. By using an output filter, if a capacitor is used through the load and an inductor is used in series with the load, the load current will be smoother and ripple effect will be lowered[6].

C. Pulse genrator

It is generated by a microcontroller chipset based arduino on ATmega328. There are 14 digital input and output pins (6 of them are used as PWM outputs), 6 analog inputs, one of the features of the arduino is it has PWM, and this is a technique of obtaining analog results with digital standards. A square wave is created by the digital control, the signal is switched as on and off, and this on-off style simulate voltages between full on (5 Volts) and full off (0 Volts) by changing the part of the time signal expend on versus the time that the signal expends off. The duration of "on time" is called the pulse width[7]. To get varied analog values, by writing the proper code the pulse width will modulate.

D. MOSFET driver

The structure of an power MOSFET is such that the gate forms a nonlinear capacitor. Charging the gate capacitor turns the power device on and allows current flow between its drain and source terminals, while discharging it turns the device off and a large voltage may then be blocked across the drain and source terminals. The minimum voltage when the gate capacitor is charged and the device can just about conduct is the threshold voltage (V_{TH}). For operating an power MOSFET as a switch, a voltage sufficiently larger than V_{th} should be applied between the gate and source terminals.

Isolation is the electrical separation between various functional circuits in a system such that there is no direct conduction path available between them. This allows individual circuits to possess different ground potentials. Signal and power can still pass between isolated circuits using inductive, capacitive, or optical methods. For a system with gate drivers, isolation may be necessary for functional purposes and it might also be a safety requirement.

IV. DESIGN SPECIFICATION

A. Rectifier and filter specificatiom

Taking maximum load current for prototype value of diode is selected for rectifier
Diode specification
Model number= 6A4
V_{RMS}= 280V
V_{DC}= 400V
I_{AV}= 6A

Selection of filter capacitor

Filter is required to achieve smooth DC from pulsating DC to reduce ripple voltage.

$$C = \frac{I_{(load\ )} \times \Delta t}{f \times V_{ripple}}$$

Where,
C= capacitor value in farads
$I_{(load)}$= load current in amperes
t = time in seconds
f = power frequency
V_{ripple} = ripple voltage

C = 471μF

B. Inverter design specification

The input resistance of MOSFET is high and they are voltage controlled devices. Therefore the gate driving circuit for MOSFET is simpler. Power MOSFET can be operated at high frequency that's why MOSFET is selected as a switch.

MOSFET model number= IRF630
V_{ds}=200V
I_D=9A
Switching frequency= 1Mhz
$V_{gs(max)}$=20V
$T_{d\ on}$= 8ns

C. MOSFET driver specification

TLP250 is used to drive each MOSFET because, The TOSHIBA TLP250 consists of a light emitting diode and a integrated photo detector. TLP250 is suitable for gate driving circuit power MOSFET.
V_{cc}=10-35V
12V is our design requirement
Isolation voltage= 2500$V_{rms(min.)}$
Operating frequency= 25khz

V. PERFORMANCE TEST

Speed control technique is simulated in MATLAB software. For simulation purpose the input voltage is taken as 230v,50Hz and the output desired at the rectifier side is achieved. H- bridge Inverter output is simulated with the SPWM(sinusoidal pulse width modulation) technique for gating purpose. Single phase split phase motor is used for simulation. Rectifier and filtering circuit is combined into the box. Output waveforms are observed.

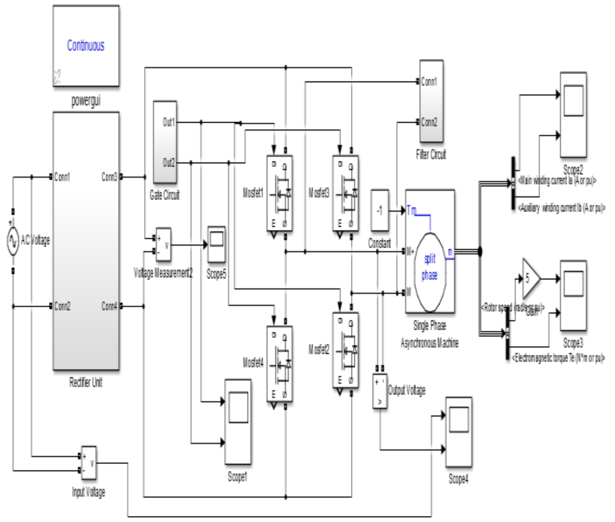

Figure 6 MATLAB circuitry for speed control

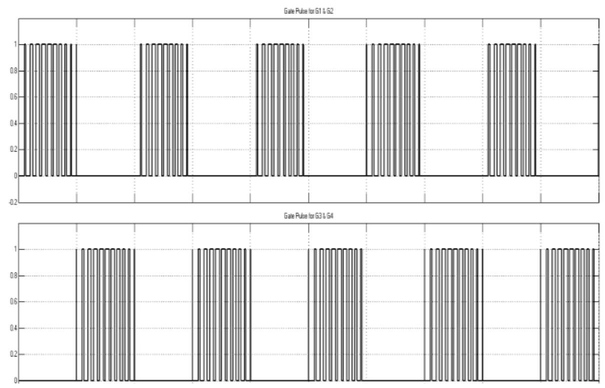

Figure 7 Gate pulse for G1 and G2

Gate pulse G1 and G2 are shown in figure 7 where G1 is the gate pulse for MOSFET 1 and MOSFET 2. Where G2 is gate pulse for MOSFET 3 and MOSFET 4.

Filtered output waveforms:

SPWM signals are generated using pulse generator signals are observed. All the characteristics are observed without filtration of the output waveforms. After filtration waveforms are changed which are shown as below. After filtering FFT analysis is done to measure total harmonic distortions. Motor speed is observed in simulation and output voltage of H-bridge inverter is obtained nearly sine wave.

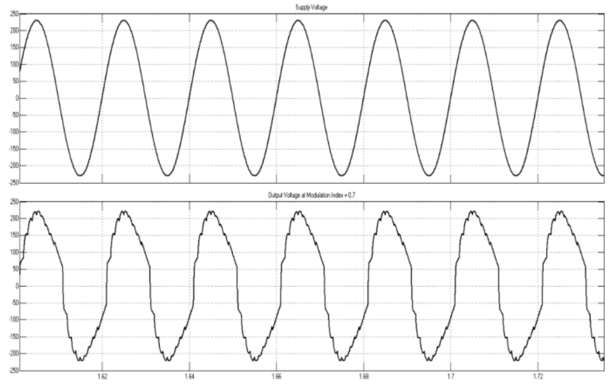

Figure 8 Supply voltage and Output voltage at modulation index=0.7

Output voltage of DC link converter is shown in figure 9 which can be seen nearly sinusoidal. Output of inverter is given to the single phase induction motor. Maximum output voltage is observed 230V.

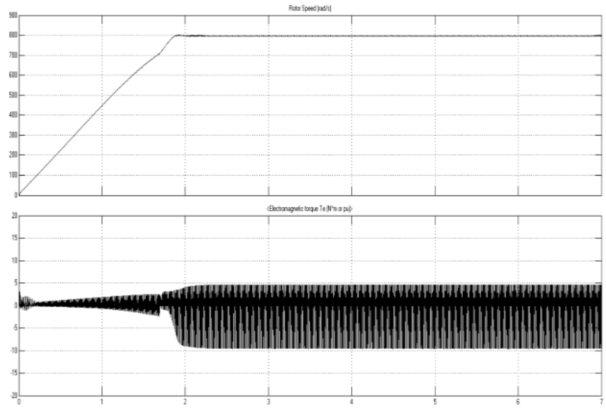

Figure 9 Rotor speed and Electromagnetic torque

Rotor speed curve is shown in figure 9. At start motor takes time to get maximum speed after that it runs on constant speed. Electromagnetic torque is illustrated in figure 9.

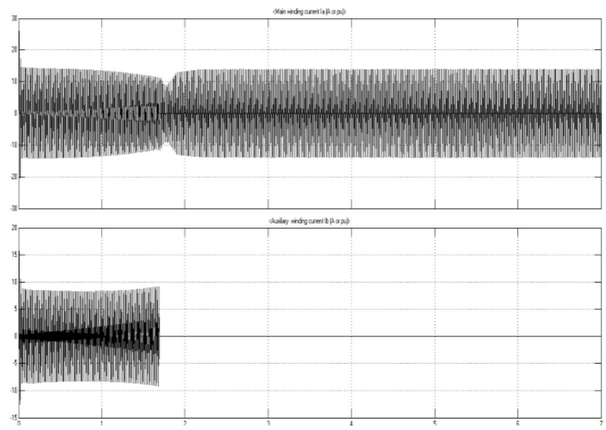

Figure 10 Main winding current and Auxiliary winding current

Main winding current and Auxiliary winding current is simulated which is shown in figure 10 where we can observe how auxiliary winding of split phase induction motor disconnects from circuit after achieving 70% to 80 % speed.

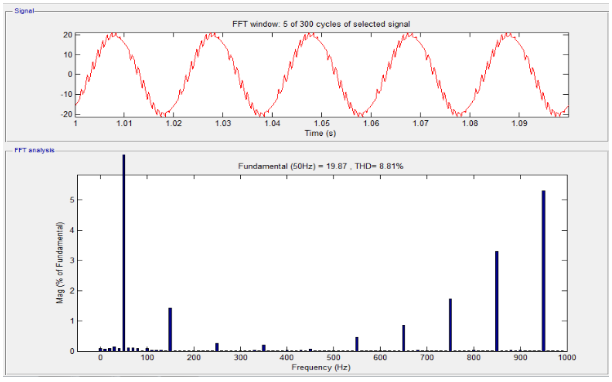

Figure 11 FFT Analysis THD 8.81%

FFT analysis of output waveform is done in MATLAB. Total Harmonic Distortion result 8.81% is observed.

VI. HARDWARE AND RESULTS

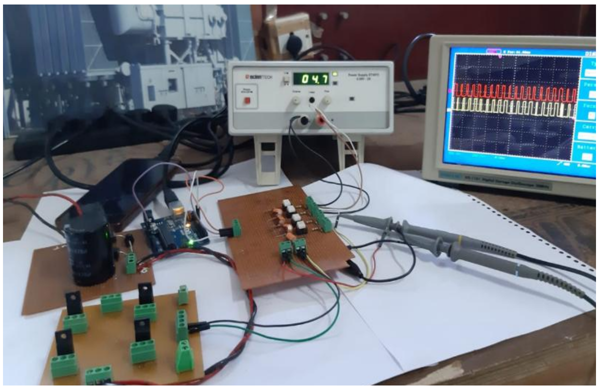

Figure 12 Hardware model

DC link converter and control card is developed. SPWM generation and the output of TLP250 is observed. The voltage level of TLP Is kept on low voltage for testing purpose. Output waveforms are shown in figure 13 and 14.

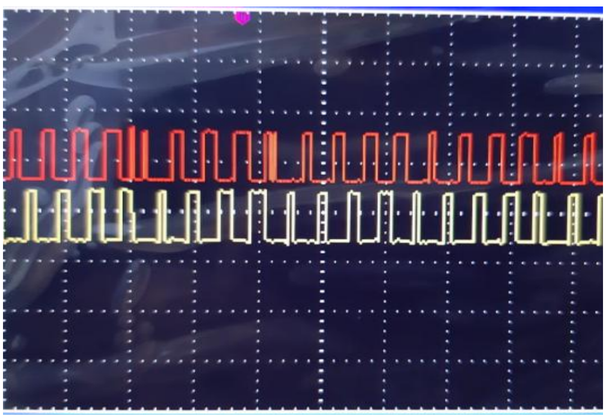

Figure 13 TLP250 output

PWM is generated by pulse generator in order to verify the simulation results. Which are observed for 50Hz reference signal. Signal Amplitude, Dead band generation, and phase shift is observed in the Digital Oscilloscope and calculated.

SPWM is shown in figure 14. It is generated with modified program where angle delta between two pulses can be adjusted by program changes. observed delta is shown in figure 14. For healthy switching of MOSFET switches deadband angle is required which,

Delay time = 0.184ms

Rectifier unit is tested and output voltage is observed at different input voltage as shown in Table 1.

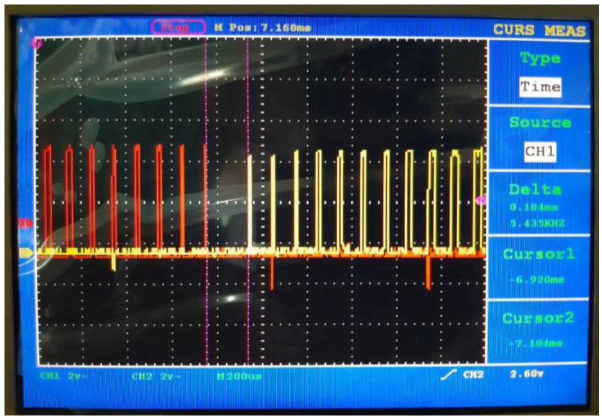

Figure 14 Delay time between two pulses

TABLE 1. Comparison of Rectifier Output Voltage

No.	I/P Voltage RMS(V)	O/P Theoretical (V)	O/P Practical (V)	Percentage Error (%)
1	60	84.82	83.6	1.44
2	110	155.54	154.4	0.73
3	150	212.1	211	0.5
4	200	282.6	281.2	0.49
5	230	325	323.9	0.33

VII. CONCLUSION

PWM based speed control of induction motor is efficient compared to mechanical control. After analyzing different PWM techniques, sinusoidal PWM technique is implemented for variable voltage variable frequency, V/F speed control. Proposed scheme is developed using DC link concept. Simulation is carried out in MATLAB for smooth control of induction motor using SPWM. Control signals are generated for MOSFET based H-bridge inverter. It is observed that by changing modulation index we can achieve variable inverter output which provide smooth and efficient speed control for induction motor.

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