

# FPGA Implementation for Speed Monitoring and Speed Control of AC Motor using V/F Control

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**ABSTRACT** The demand for the control of electric power for electric motor drive system and industrial control existed for many years. The Variable-speed drives are created when a motor is combined with a power electronics converter. By introducing variable speed to the driven load, it is possible for the optimization of efficiency of the entire system and results in greatest efficiency gains. This paper presents the need of Speed monitoring and speed Control in AC Motors. AC motor drives are widely used in control applications such as the speed of pump speeds, conveyor systems, machine tool speeds, and other applications that require variable speed. Out of the various methods of controlling Induction motors, V/f Control has proven to be the most versatile and precise method. In this, PWM Inverters have been modeled and their output is fed to the Induction Motor drives. A LabVIEW code was developed to successfully implement Closed-Loop V/F Control on a PWM-Inverter fed to a 3-phase Induction Motor and the Torque was found to be constant for various rotor speeds. It was observed that using a Closed-Loop scheme with a PID Controller gave a very superior way to control the speed of an Induction motor by maintaining a constant maximum torque. This method falls under the category of VVVF drives, which is based on Sinusoidal pulse width modulation (SPWM). SPWM plays an important role in the minimization of switching power losses and lower order harmonics in the power converters used in controllers.

**KEYWORDS:** Induction Motor, Voltage/frequency (V/f), Sinusoidal Pulse Width Modulation (SPWM), Proportional Integral Derivative (PID), Inverter.

## I. INTRODUCTION

Electrical Energy already constitutes more than 30 % of all energy usage on Earth. And this is set to rise in the coming years. Its massive popularity has been caused by its efficiency of use, ease of transportation, ease of generation, and environment-friendliness. Part of the total electrical energy production is used to produce heat, light, in electrolysis, arc-furnaces, domestic heating etc. Another large part of the electrical energy production is used to be converted into mechanical energy via different kinds of electric motors-DC Motors, Synchronous Motors and Induction Motors. Induction Motors are often termed the “Work horse of the Industry” [2]. This is because it is one of the most widely used motors in the world. It is used in transportation and industries, and also in household appliances.

Monitoring of AC motor is necessary for operating efficiently. There are many undesirable things that can happen to electric motors and can reduce its efficiency and cause premature failure [1]. The economic loss from premature motor failure can be devastating. In most cases, the price of the motor itself is trivial compared to the cost of unscheduled shutdowns of the process. Both high and low voltages can cause premature motor failure, as well as voltage imbalance. So the best life and most efficient operation occur when motors are operated at voltages close to the nameplate ratings. Monitoring of AC motor provides not only reduction of cost in electricity bill, but also extends the life of the electrical motors while preventing unexpected failures.

# International Journal of Innovative Research in Science, Engineering and Technology

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The main objective of the project is to develop a model to implement V/f control of an induction motor. In order to do that, one must be familiar with the PWM Inverter which drives the induction motor. Hence, PWM signal generation, and Inverter topologies are also studied and simulated.

M.S.Aspalli, Asha.R, P.V. Hunagund proposed design and analysis of a three phase induction motor drive using IGBT's at the inverter power stage with volts hertz control (V/F) in closed loop using dsPIC30F2010 as a controller [8]. Speed control of motor is acquired with the accuracy of  $\pm 15$  rpm. Hence in this work more than 90% accuracy of speed control is recorded. Mr. Bidwe Umesh. B, Mr. Shinde Sanjay. M proposed Speed Control of Three Phase Induction Motor Using Fuzzy-PID Controller [9]. The work reveals that that speed controlling of induction motor With Fuzzy-PID controller is smooth and easy than PID controlling method. Ravi Prakash, Prof. Rishi Kumar Singh, Rajeev Ranjan Kumar presented a paper on Variable Voltage Variable Frequency Speed Control of Induction Motor Using FPGA-Xilinx [11]. Here the line current THD of VSI fed three-phase induction motor without using filter is 12.91%. Due to which the torque ripple and losses in system are also high. By using second order Filter, line current THD decreases to 1.35%.

The rest of the paper is organized as follows. In Section II, we provide a brief description of AC Motor construction & working. In Section III, we introduce description of Hardware and Software used. Proposed work is described in Section IV. Section V deals with important Simulation Results and output. Finally, we conclude this paper in Section VI.

## II. AC MOTOR DRIVES

Induction Motors account for more than 85% of all motors used in industry and domestic applications. This motor is also called as asynchronous motor because it runs at a speed less than its synchronous speed [13]. There are basically two types of induction motor that depend upon the input supply - single phase induction motor and three phase induction motor. Single phase induction motor is not a self starting motor but three phase induction motor is a self-starting motor. The speed of the rotor will depend upon the AC supply and the speed can be controlled by varying the input supply [5].

The three-phase induction motors are most commonly used in industrial applications. In particular, the squirrel-Cage induction motors are widely used in home and industrial applications because these machines are very economical, rugged and reliable [4]. Thus the three phase induction motor is Self-starting, less armature reaction, robust in construction, economical and easier to maintain.

The speed of induction motor depends on various factors, like supplied voltage, frequency, number of poles. There are different methods for controlling the speed from stator side and rotor side.

The constant V/F control method is the most popular method of Scalar control [6]. If the ratio of voltage to frequency is kept constant, the flux remains constant. It maintains the air- gap flux of AC Induction motor constant in order to achieve higher run-time efficiency. The torque-speed characteristics of the V/F control reveals that the starting current is low, the stable operating region of the motor is increased and the speed range of the motor becomes wider. One of the most advantages is soft start capability in which motors are ramped up to speed instead of being abruptly thrown on line. This useful feature reduces mechanical stresses on the motor and leads to lower maintenance cost as well as a longer motor life.

## III. SOFTWARE & HARDWARE DESCRIPTION

The speed monitoring and speed control of Induction Motor is done by integrating hardware and software. Multisim software serves the purpose of simulation of circuits. LabVIEW software is used for controlling part [7] and the NI hardware's are used for Input/output processing and implementation purpose. One benefit of LabVIEW over other development environments is the extensive support for accessing instrumentation hardware.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

The NI cRIO-9074 integrated system combines a real-time processor and a reconfigurable field-programmable gate array within the same chassis for embedded machine control and monitoring applications [12]. It integrates a 400 MHz industrial real-time processor with a 2M gate FPGA and has eight slots for NI C Series I/O modules. The NI 9401 is an 8-channel, 100 ns bidirectional digital input-output module for any NI CompactRIO chassis. The NI 9225 C Series analog input module [15] has a full measurement range of 300 Vrms for high-voltage measurement applications such as power metering, power quality Monitoring, motor test, battery stack testing, and fuel cell tests. The NI 9227 C Series current input module was designed to measure 5 Arms nominal and up to 14 A peak on each channel with channel-to-channel isolation.

## IV. RELATED WORK

In the proposed work, some of the circuits are modelled using Multisim 14.0 which will be discussed below and then developed as hardware. The controlling mechanism is developed and coded using LabVIEW [3].

### A. Rectifier

A Rectifier is an electric device that converts Alternating Current (AC), which periodically reverses direction, to direct current (DC) that flows in only one direction. The process is known as rectification. Rectifier circuits may be single-phase or multi-phase. Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC (HVDC) [14]. For an uncontrolled three-phase bridge rectifier, six diodes are used, and the circuit again has a pulse number of six. For a three-phase full-wave diode rectifier, the ideal, no-load average output voltage is

$$V_{dc} = V_{av} = \frac{3\sqrt{3}V_{peak}}{\pi} \quad \text{----- (1)}$$

The Multisim simulated Uncontrolled 3 phase Bridge Rectifier output Waveform is shown in Fig. 1

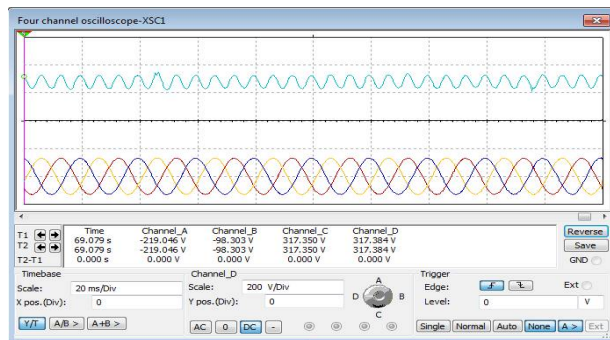


Fig.1 3 Phase Bridge Rectifier-Output Waveform

### B. PWM Inverter

An Inverter is a circuit which converts a DC power input into an AC power output at a desired output voltage and frequency. This conversion is achieved by controlled turn-on and turn-off devices like IGBT's. Ideally, the output voltage of an Inverter should be strictly sinusoidal. However the outputs are usually rich in harmonics and are almost always non-sinusoidal. Square-wave and quasi-square-wave voltages are acceptable. The Power Circuit of the 3-Phase Inverter consists of 6 bidirectional IGBT's arranged in bridge-form. The input to the circuit is a 12 V DC supply from a battery. The output waveform is shown in Fig.2.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

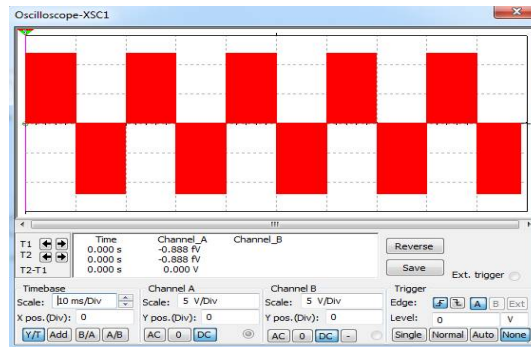


Fig.2 Output voltage for 3-Phase PWM Inverter with Resistive Load

The PWM signals are obtained by comparing a sine wave with a pulse train and modulating the pulse width accordingly. These PWM signals are applied to the gates of the IGBT's so as to trigger them. The following output was obtained when the control circuit was simulated in the NI LabVIEW 15.0 environment integrated with the power circuit in the Multisim 14.0 environment as shown in Fig 3.

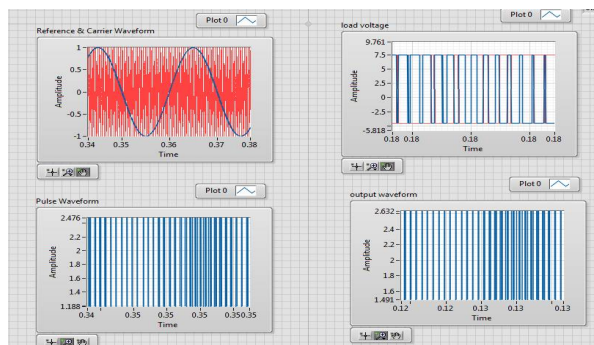


Fig. 3 Front Panel for PWM inverter in LabVIEW

### C. Gate Driver Circuit

A gate driver is a power amplifier that accepts a low-power input from a controller IC and produces a high-current drive input for the gate of a high-power transistor such as an IGBT or power MOSFET. When gate current is applied to a transistor to cause it to switch, a certain amount of heat is generated which can, in some cases, be enough to destroy the transistor. Therefore, it is necessary to keep the switching time as short as possible, so as to minimize switching loss. To prevent this from happening, a gate driver is provided between the output signal and the power transistor as shown in Fig.4.

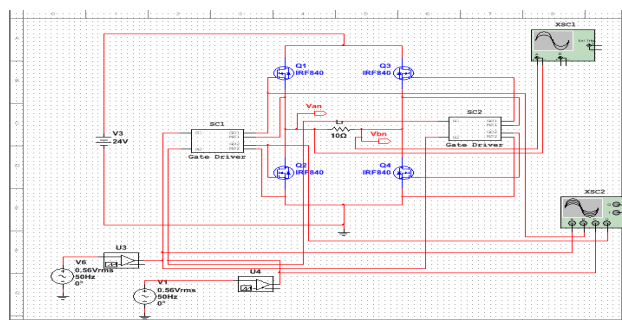


Fig.4 Gate Driver Circuit for Inverter using Multisim

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

The output waveform of the Gate driver circuit is shown in Fig. 5 where the voltage is amplified with respect to its input.



Fig.5 Output Waveform of Gate Driver Circuit

## V. SIMULATION RESULTS

The NI LabVIEW and NI Multisim environment is used for the modeling and simulation purpose. The pulse control is generated using NI LabVIEW control design simulation loop [10]. It is simulated with the step size of 0.00005s. The sine and triangle waveforms are generated using point by point waveform method. This will calculate the amplitude of the waveform for each step-size. The sine and triangle waveforms are compared and when the sine is higher than the triangle waveform the upper switch of each leg is turned on and the complimentary of this logic is used to turn on the bottom switch of each leg. For three phase pulse generation, three sine waveforms are used having the phase such as  $0^\circ$ ,  $120^\circ$  and  $240^\circ$ .

The inverter is modeled in the Multisim environment. Diode rectifier is used as input to the inverter. Three phase squirrel cage induction motor is used as load for the inverter model. The pulse inputs are received from the LabVIEW and the output voltage, current and motor speed are measured in the Multisim and send to the LabVIEW environment using NI LabVIEW Co-simulation blocks. The measured speed is compared with set point and based on the error value, the reference sine waveform frequency and amplitude is adjusted. To maintain the air gap flux as constant, V/f method is used and V/f ratio is maintained constant as 8.

The pulse output from NI 9401 module is connected to the six pulse input of the IGBT gate driver input option. The gate driver will increase the 5V pulses to 15V output and solve the pole voltage issue for turning on the top switch of each leg. The inverter output is connected the motor. The NI 9225 and NI 9227 modules are used to measure the voltage and current respectively. The voltage module AI channel 0-2 are connected in parallel each phase with neutral and current module AI channel 0-2 are connected in series with each phase. The values acquired using analog input modules are sent to FIFO for DMA access as shown in Fig.6. These values are read at RT VI and used for the closed loop operation.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016



Fig.6 Overall test setup

The hardware implementation is tested and their corresponding output waveform is shown in Fig.7 and Fig.8 for different RPM value under different test condition.

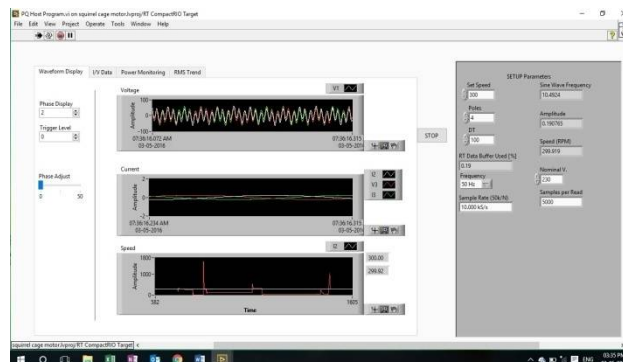


Fig.7 Test condition 1: Set point speed 300RPM running condition and actual motor runs at 299.19RPM

In Fig.7, the set point speed is taken to be 300 RPM for which the output of actual motor results at 299.19 RPM. From this, it is evident that the developed system has a precision of  $\pm 0.5$  RPM. This is followed by test condition 2 which supports the precision factor as shown in Fig.8.

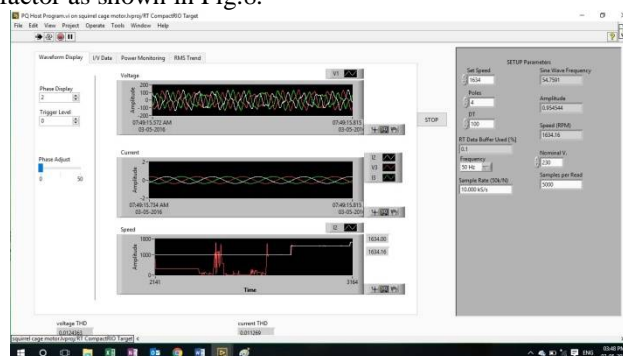


Fig.8 Test condition 2: Set point speed 1634RPM running condition and actual motor runs at 1634.16RPM

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

## VI. CONCLUSION AND FUTURE WORK

The speed control the motor is achieved using the inverter setup and pulse generation is controlled using cRIO. The Digital output pulses are generated using sine PWM technique. The reference sine waveform amplitude and frequency is generated based on the logic for v/f control method to maintain the air gap flux as constant. Whenever the frequency is changed to control the speed of the motor, the output voltage is also changed in the same ratio to maintain the air gap flux as constant. We can able to control the speed of the motor at the rate of  $\pm 0.5$  RPM. Whenever the load is applied, the speed of the motor is reduced accordingly. Immediately, the output frequency is increased to achieve the set point speed. In this project the pulse generation is controlled in FPGA and the logic is controlled by the real-time controller. This will check the reference set speed for every 100 ms and control the reference waveform to reach the set speed. To avoid the sudden change in the load, for every iteration 40% of speed difference is changed until it reaches the desired set point. This method reaches the set point in 3-5 seconds.

Currently this method is used for three phase squirrel cage induction motor only. In future this project may be expanded for the other AC motors and DC motors. For AC motors, this project uses the sine PWM method. This method can be improved using space vector PWM technique for achieving the high output voltage with less harmonic contents.

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## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

### BIOGRAPHY



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