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Speed Control of Induction Motor Using Arduino

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Abstract:-This paper present the speed control of single phase Induction motor using Arduino with the controlling objectives PWM and SPWM . Induction motors are widely used Electrical Motors due to their reliability, low cost and robustness. However, Induction Motors do not inherently have the capability of variable speed of operation. Due to this reason, earlier dc Motors were applied in most of the Electrical Drives. But the recent developments in speed control methods of the Induction Motor have led to their large scale use in all Electrical Drives. Out of the several methods of speed control of an induction such as pole changing, frequency variation, variable rotor resistance, variable stator voltage, constant V/f control, slip recovery method etc., the closed loop constant V/f speed control method is most widely used. The design, analysis, and implementation of Single phase Inverter driving Induction Motor is completely carried out using Arduino.

Keywords*:*-Induction Motor, Pulse Width Modulation (PWM) Sinusoidal Pulse Width Modulation (SPWM),V/f (Voltage/frequency) Control and Arduino.

I. INTRODUCTION

An inverter is a power electronic device which converts electrical energy of DC form into AC and its various industrial applications are uninterruptible power supply (UPS), adjustable-speed AC motor drives and Induction Heating etc. The DC-AC inverters operate on Pulse Width Modulation (PWM technique). In PWM technique width of the Gate pulses are controlled or varied using different methods like by changing the ON time or OFF time of the pulses. The source voltage to an inverter maybe a battery, fuel cell, solar cell or other DC source but in most of the applications, it is fed from a rectifier.

There are two types of inverters as (1) voltage source inverters (VSI) (2) current source inverters (CSI). When an inverter has input DC source as a stiff DC voltage source at its input terminal with small or negligible impedance then it is called a VSI or voltage fed inverter (VFI). When the input DC source is an stiff DC current source with high impedance then the inverter is called a CSI or current fed inverter (CFI).In this the hard ware Implementation of single phase voltage source inverters will be discussed.

II. INVERTER

The Classification of inverters based on the supply given are of two types as:

- Single-phase Inverter
- Three-phase Inverter

A. Single Phase Inverter

The circuit diagram of a single phase full bridge inverter consists of two arms with a two switches in each arms with anti-parallel freewheeling diodes. These anti-parallel freewheeling diodes will discharge the reverse current flow in the circuit. When the load is R-L type the reverse load current flows through these diodes. Thus, these diodes provide an alternate path for inductive current to flow during the Turn OFF condition.

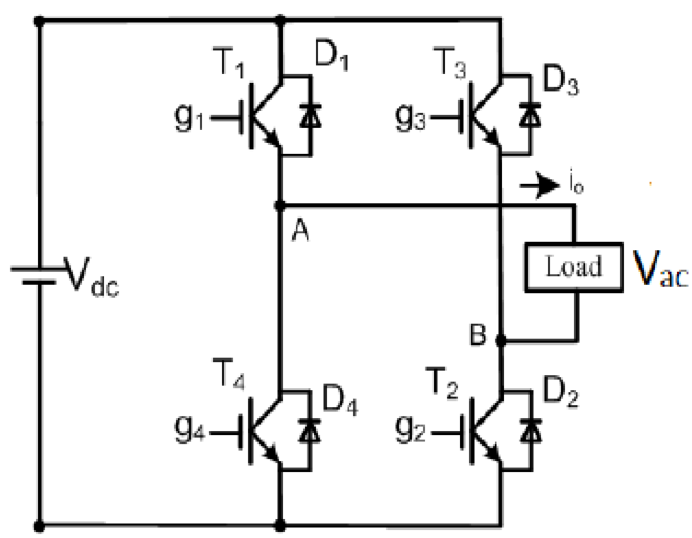

Figure 1. Single Phase Inverter

Period	Switches ON	Output voltages
0<t<T/2	T1, T2	$+V_{dc}$
T/2<t<T	T3, T4	$-V_{dc}$

Figure 2.Tabular Column of Operating sequence of Single Phase Inverter

T1, T2, T3 and T4 are the IGBTs. The IGBTs in each leg is operated alternatively so that they are not in same mode (ON /OFF) simultaneously. The IGBTs T1 and T2 will operate for positive half cycle of the supply voltage and IGBTs T3 and T4 will operate for negative half cycle of supply voltage such that the output voltage is shifted from one to another and hence change in polarity occurs in voltage waveform. If the shift angle is zero, the output voltage is also zero and maximal when shift angle is π.

B. Three Phase Inverter

The circuit diagram of a three phase bridge inverter consists of six IGBTs and the large capacitors connected at input terminal will make the DC input constant and to suppress harmonics which are fed back to the source. The IGBTs T1,T3 and T5 will have a of phase shift 120^0 between each other and in between T1 and T4 phase shift is 180^0 during operation, In six step inverter each step would be of 60^o interval .

The gating of IGBTs can be performed in two patterns. In one pattern, each IGBT conducts for 180^o and in the other IGBT conducts 120^o. But both patterns gating signals are applied and removed at 60^ointervals of the output voltage waveform.

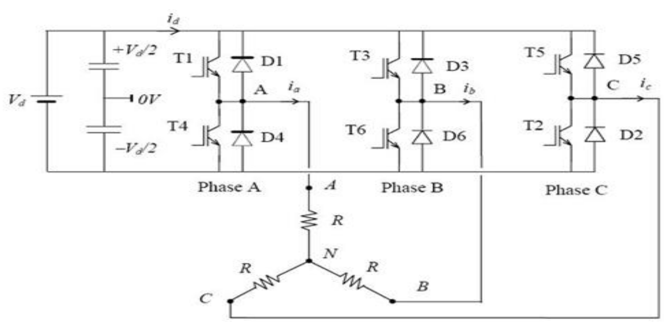

Figure 3. Three Phase Inverter

Modes	Switches ON	V_{ab}	V_{bc}	V_{ca}	V_{an}	V_{bn}	V_{cn}
I	1,5,6	$+V_{dc}$	$-V_{dc}$	0	$+V_{dc}/3$	$-2V_{dc}/3$	$+V_{dc}/3$
II	1,2,6	$+V_{dc}$	0	$-V_{dc}$	$+2V_{dc}/3$	$-V_{dc}/3$	$-V_{dc}/3$
III	1,2,3	0	$+V_{dc}$	$-V_{dc}$	$+2V_{dc}/3$	$+2V_{dc}/3$	$-V_{dc}/3$
IV	2,3,4	$-V_{dc}$	$+V_{dc}$	0	$-2V_{dc}/3$	$+V_{dc}/3$	$-2V_{dc}/3$
V	3,4,5	$-V_{dc}$	0	$+V_{dc}$	$-V_{dc}/3$	$+2V_{dc}/3$	$+2V_{dc}/3$
VI	4,5,6	0	$-V_{dc}$	$+V_{dc}$	$-V_{dc}/3$	$-V_{dc}/3$	$+2V_{dc}/3$

Figure 4. Tabular Column for Operating Sequence of IGBTs

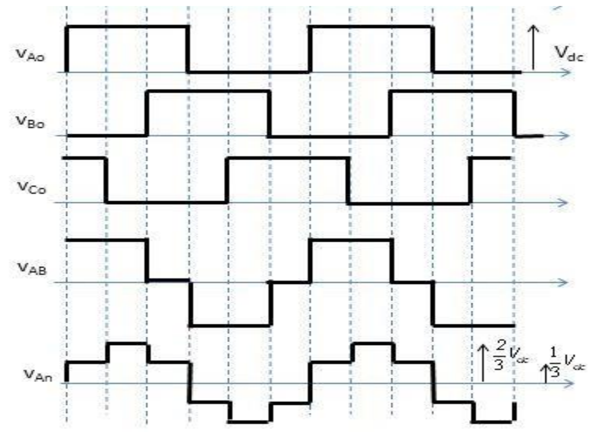

Figure 5. Output Line Voltage and Phase Voltage of Three Phase Inverter

C. Pulse Width Modulation Technique

a). Sinusoidal Pulse Width Modulation

In this modulation technique multiple numbers of output pulse per half cycle and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the Centre of the same pulse. PWM control requires the generation of both reference and carrier signals that are feed into the comparator.

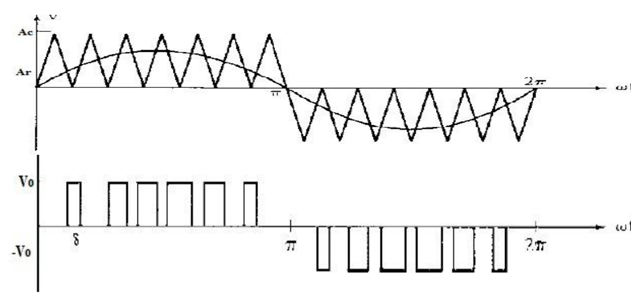

Figure 6. Sinusoidal Pulse width Modulation

The rms ac output voltage

$$v_o = v_s\sqrt{\frac{p\delta}{\pi}} \rightarrow v_s\sqrt{\sum_{m=1}^{2p}\frac{\delta_m}{\pi}}$$

Where p=number of pulses and δ= pulse width

Modulation Index=$\frac{vc}{v\Delta}$

III. INDUCTION MOTOR

An Induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque and this torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motors rotor can be either wound type or squirrel cage type.

Three phase squirrel cage induction motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Applications of three phase induction motor are for fixed-speed services, variable frequency drives, (VFDs) variable-torque centrifugal fan, pump and compressor.

A. Construction

The stator of an induction motor consists of poles carrying supply current to induce a magnetic field that penetrates the rotor. To optimize the distribution of the magnetic field, the windings are distributed in slots around the stator, with the magnetic field having the same number of north and south poles. Induction motors are most commonly run on single-phase or three-phase power, but two-phase motors exist; in theory, induction motors can have any number of phases. Many single-phase motors having two windings can be viewed as two-phase motors, since a capacitor is used to generate a second power phase 90° from the single-phase supply and feeds it to the second motor winding. Single-phase motors require some mechanism to produce a rotating field on start-up. Cage induction motor rotor's conductor bars are typically skewed to reduce noise.

B. Equivalent Circuit

The useful motor relationships between time, current, speed, power factor and torque can be obtained from the analysis of the Steinmetz equivalent circuit (also termed T-equivalent circuit or IEEE recommended equivalent circuit), a mathematical model used to describe how an induction motor's electrical input is transformed into useful mechanical energy output. The equivalent circuit is a single-phase representation of a multiphase induction motor that is valid in steady-state balanced-load conditions.

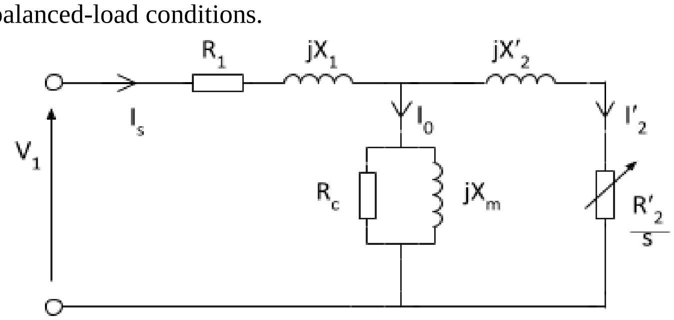

Figure 7. Equivalent Circuit of an Induction Motor

An induction motor is similar to a transformer the magnetic circuit of which is separated by an air gap between the stator winding and the moving rotor winding. The equivalent circuit can accordingly be shown either with equivalent circuit components of respective windings separated by an ideal transformer or with rotor components referred to the stator side as shown in the following circuit and associated equation.

C. Principle of operation of Induction Motor

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance.

The rotating magnetic flux induces currents in the windings of the rotor, in a manner similar to currents induced in a transformer's secondary winding(s).The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors.

The induction machine's essential characters that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors. For rotor currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion.

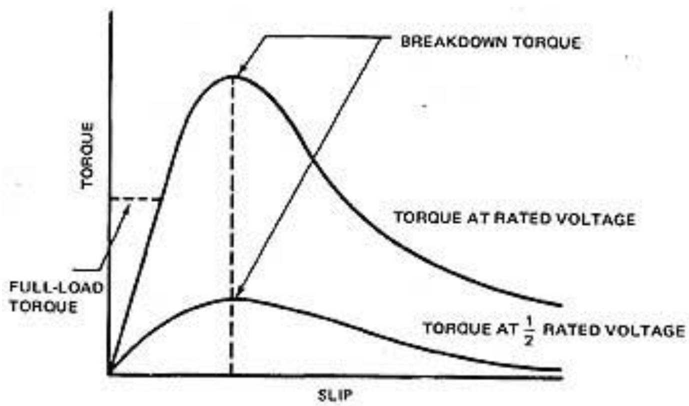

Figure 8. Torque-Slip Characteristics of an IM

The typical speed-torque relationship of a standard NEMA Design B poly phase induction motor is as shown in the curve. Suitable for most low performance loads such as centrifugal pumps and fans, Design B motors are constrained by the following typical torque ranges.

- Breakdown torque, 175-300 percent of rated torque
- Locked-rotor torque, 75-275 percent of rated torque
- Pull-up torque, 65-190 percent of rated torque.

D. Speed control Methods

speed control methods of an induction motors such as pole changing, frequency variation, variable rotor resistance, variable stator voltage, constant V/f control, slip recovery method etc. The closed loop constant V/f speed control method is most widely used.

Synchronous speed can be controlled by varying the supply frequency. Voltage induced in the stator is $E1 \propto \Phi f$ where Φ is the air-gap flux and f is the supply frequency. As we can neglect the stator voltage drop we obtain terminal voltage $V1 \propto \Phi f$.
Thus reducing the frequency without changing the supply voltage will lead to an increase in the air-gap flux which is undesirable. Hence whenever frequency is varied in order to control speed, the terminal voltage is also varied so as to maintain the V/f ratio constant. Thus by maintaining a constant V/f ratio, the maximum torque of the motor becomes constant for changing speed.

E. Dynamic Modelling of Induction Motor

A dynamic model of the machine subjected to a control must be known in order to understand and design the vector controlled drives. Such a model can be obtained by means of either the two-axis theory or spiral vector theory of electrical machines. Following are the assumptions made for the model.

- Each stator winding is distributed so as to produce a sinusoidal mmf along air gap, i.e. space harmonics are negligible.(Sinusoidal induction repartition)
- The slotting in stator and rotor produces negligible variation in respective inductances.
- Mutual inductances are equal
- The harmonics in voltages and currents are neglected. Saturation, hysteresis and eddy effects negligible.
-

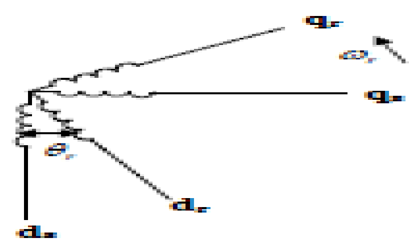

Figure 9. Two Axis Representation of IM

Equations corresponding to the two axis representation of Induction Machine are reduced through KVL as follows

$$V_{qs} = R_q\, i_{qs} + P(L_{qq}\, i_{qs}) + P(L_{qd}\, i_{ds}) + P(L_{q\alpha}\, i_d) + P(L_{q\beta}\, i_\beta) \text{---(1)}$$

$$V_{ds} = P(L_{dq}\, i_{qs}) + R_d\, i_{ds} + P(L_{dd}\, i_{ds}) + P(L_{dd}\, i_d) + P(L_{d\beta}\, i_\beta) \text{----(2)}$$

$$V_\alpha = P(L_{\alpha q}\, i_{qs}) + P(L_{\alpha d}\, i_{ds}) + R_\alpha\, i_\alpha + P(L_{\alpha\alpha}\, i\alpha) + P(L_{\alpha\beta}\, i_\beta) \text{----(3)}$$

$$V_\beta = P(L_{pq}\, i_{qs}) + P(L_{pq}\, i_{ds}) + P(L_{\beta\alpha}\, i_\alpha) + R_\beta\, i_\beta + P(L_{\beta\beta}\, i_\beta) \text{----.(4)}$$

$$L_{\alpha\alpha} = L_{\beta\beta} = L_{rr} \qquad L_{\alpha\beta} = L_{\beta\alpha} = 0$$
$$L_{dd} = L_{qq} = L_{ss} \qquad L_{dq} = L_{qd} = 0$$

$$L_{\alpha d} = L_{d\alpha} = L_{sr}\cos\theta_r$$
$$L_{\beta d} = L_{d\beta} = L_{sr}\sin\theta_r$$
$$L_{\alpha q} = L_{q\alpha} = L_{sr}\sin\theta_r$$
$$L_{pq} = L_{q\beta} = -L_{sr}\cos\theta_r$$

With respect to the fictitious rotor

$$i_\alpha = i_{drr}\cos\theta_r + i_{qrr}\sin\theta_r \quad i_\beta = i_{drr}\sin\theta_r + i_{qrr}\cos\theta_r$$

with respect to the arbitrary reference frame

$$i_{ds} = i^c{}_{ds}\cos\theta_c - i^c{}_{qs}\sin\theta_c$$
$$i_{ds} = i^c{}_{ds}\cos\theta_c + i^c{}_{qs}\sin\theta_c$$

Matrix Equation of the Induction Motor describing the voltage analysis

$$\begin{pmatrix} V^c_{qs} \\ V^c_{ds} \\ V^c_{qr} \\ V^c_{qr} \end{pmatrix} \Rightarrow \begin{pmatrix} R_{s}+L_s\,p & -w_c\,Ls & L_m.P & -w_c\,Ls \\ -w_c\,Ls & R_s+L_s\,p & -w_c\,Ls & L_m.P \\ L_m.P & -(W_c-W_r)L_m & R_s+L_s\,p & -(W_c-W_r)L_m \\ -(W_c-W_r)L_m & L_m.P & -(W_c-W_r)L_m & R_s+L_s p \end{pmatrix} \begin{pmatrix} V^c_{qs} \\ V^c_{ds} \\ V^c_{qr} \\ V^c_{dr} \end{pmatrix}$$

Torque: $V=[R]\,i + [L]\,Pi + [G]w_r\,i + [F]\,W_c\,i$

$I^t.V = i^t[R] + i^t[L]P\,i + i^t[G]\,w_r\,i + i^t[F]\,w_c i$

$i^t[L]P\,i$ Rate of change of stored magnet energy

$i^t[G]\,.w_r\,I$ Air gap power = Mech Rot speed x Air gap
$W_nT_e = P_a = i^t[G]\,I \times W_r$
$T_e = P/2\; i^t[G]\,i$

$$[G]\,i = i^t \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -l_m & 0 & -l_r \\ l_m & 0 & l_r & 0 \end{pmatrix} \begin{pmatrix} i^c_{qs} \\ i^c_{ds} \\ i^c_{qr} \\ i^c_{dr} \end{pmatrix}$$

$$I^t[G]\,i = L_m\,[i^c_{qs}\,i^c_{dr} - i^c_{ds}i^c_{qr}]$$
$$T_e = 3/2\,.P/2\;L_m\,(i^c_{qs}\,i^c_{dr} - i^c_{ds}\,i^c_{qr})$$
$$T_e = 3/2.\;P/2\;.\;1/w_b\,[\,\psi^c_{ds}\,.i^c_{qs} - \psi^c_{qs}\,.i^c_{ds}]$$

Through the above analysis speed, torque of an Induction Motor can be controlled by voltage current parameters.

IV. SIMULINK

Matlab is an interactive software system for numerical computations and graphics. Modelling, Simulink provides a graphical user interface. Simulink includes comprehensive blocks libraries of sinks, linear, nonlinear components and connectors. We can create our own blocks. Models are hierarchical with increasing levels of model details. This approach provides insight into how a model is organized and how its parts interact.In this analogy the simulation unit of the Single phase Inverter , three phase Inverter driving Induction Motor in both open loop systems are been simulated.

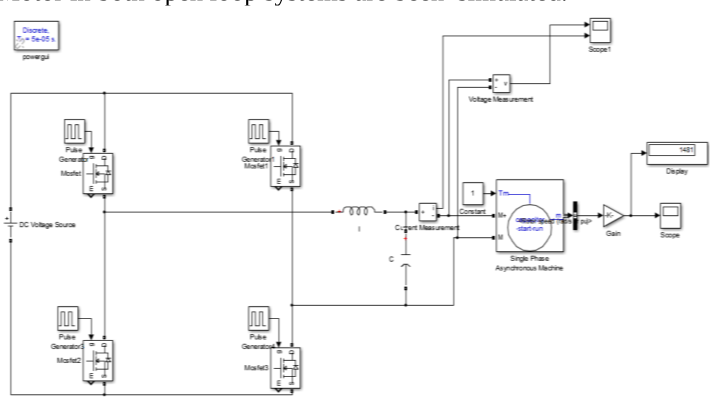

Figure 10. Simulink of Single Phase Inverter Driving IM in Open loop

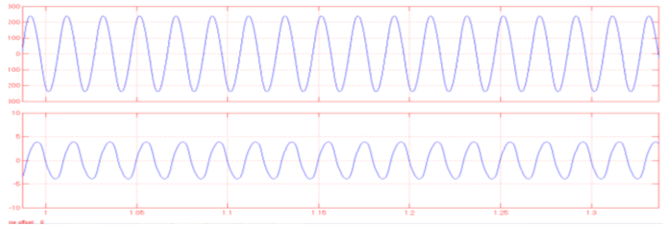

Figure 11.Output voltage and current of the single phase Induction Motor in open loop.

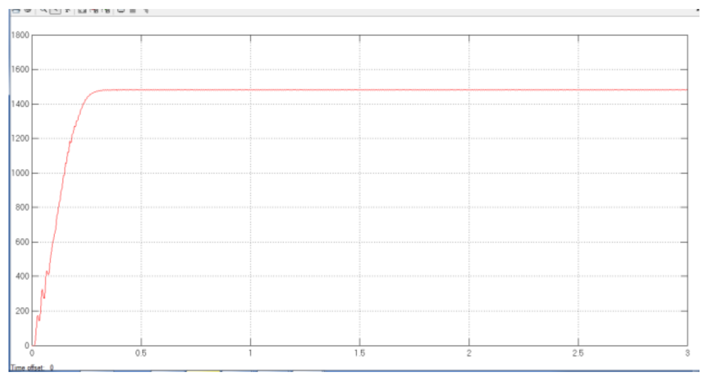

Figure 12.Output Voltage, Current and Speed of the Single Phase Induction Motor In Open Loop.

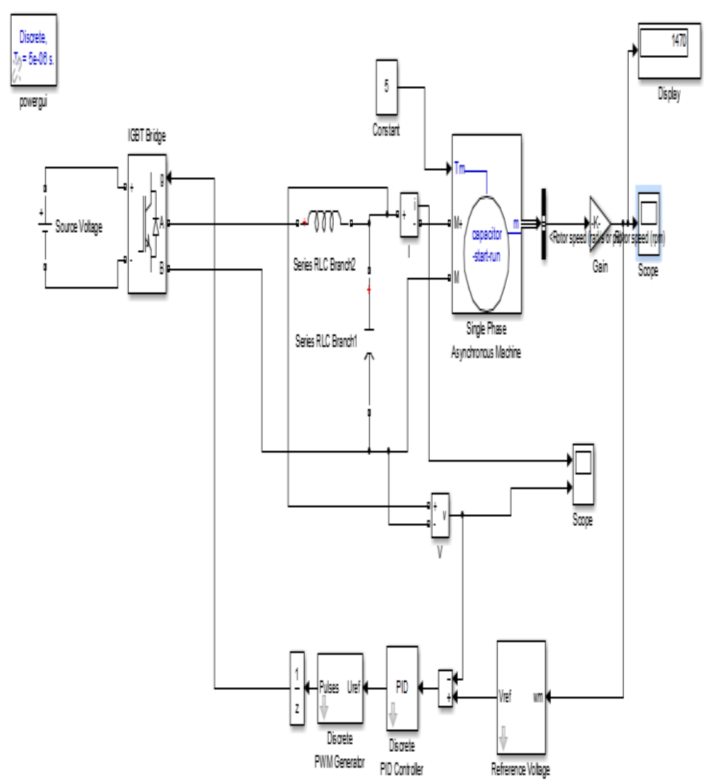

Figure 13. Simulink of Single Phase Inverter Driving IM in Closed loop

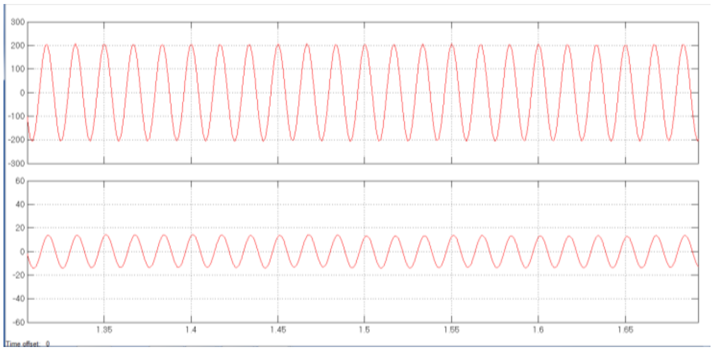

Figure 14. Output voltage and Current of the single phase Induction Motor in closed loop.

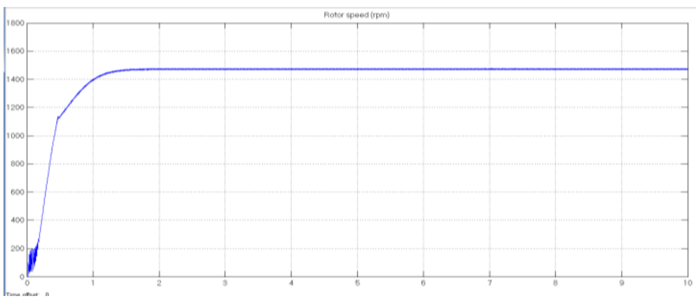

Figure 15. Speed of the Single phase Induction Motor in Closed loop.

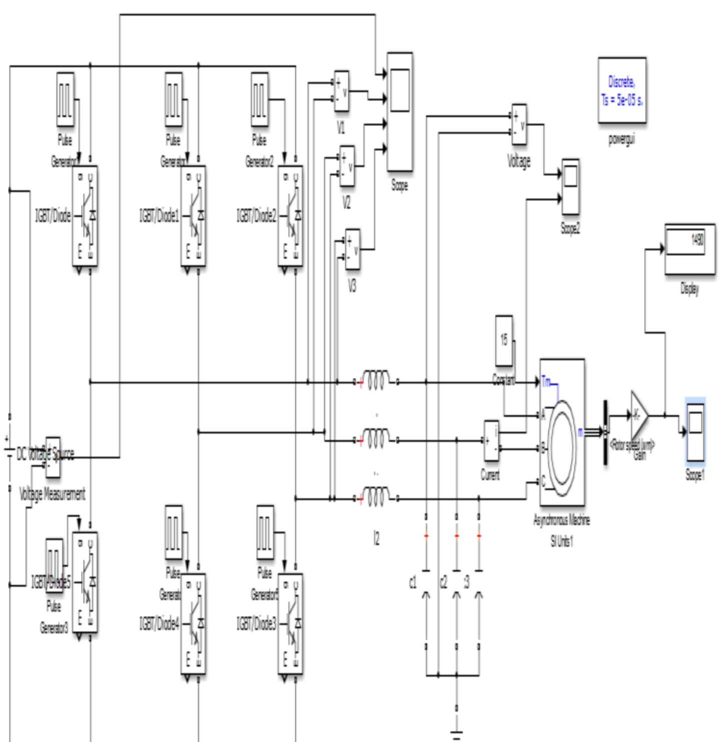

Figure 16. Simulink of the Three Phase Inverter Driving Three Phase IM In Open Loop

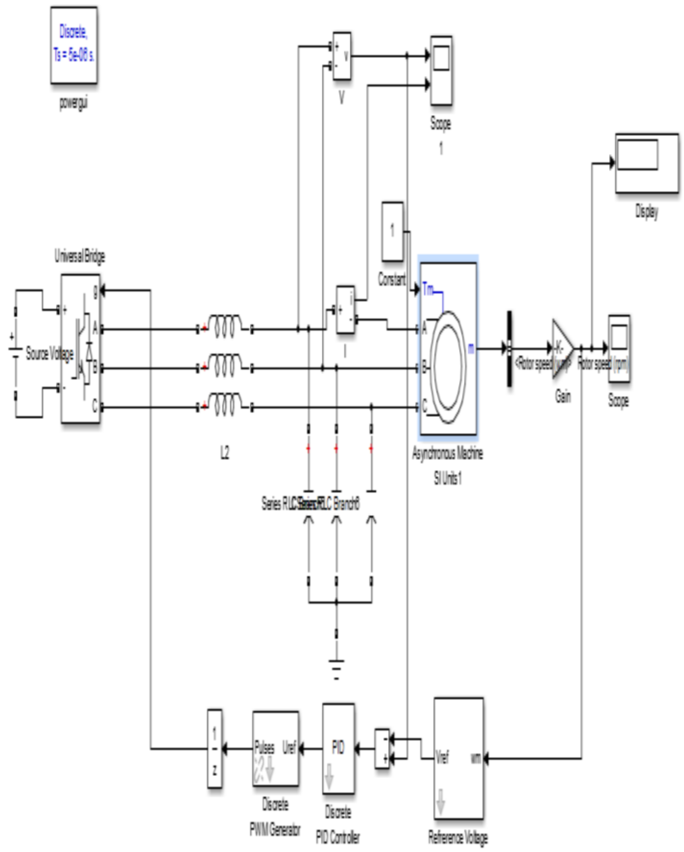

Figure 17. Simulink of the three phase Inverter driving three phase IM in closed loop

Figure 18. Gate pulses Generate by SPWM for Driving three phase inverter.

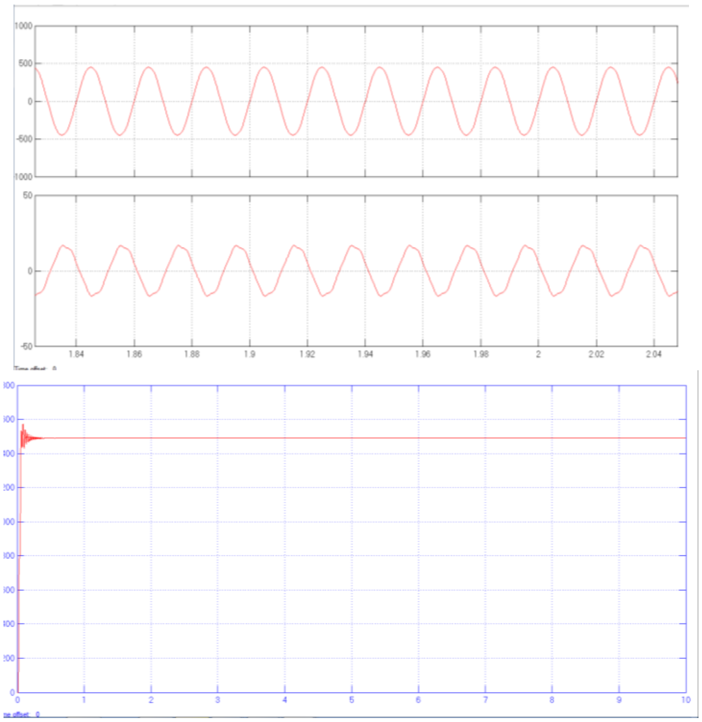

Figure 19. Output phase voltage, Phase current and Speed of a three phase IM.

V. ARDUINO

Arduino is an open-source electronics prototyping platform based on flexible, easy-touse hardware and software. It is an single board microcontroller, descendant of the open source wiring platform designed to make the process of using electronics in multidisciplinary projects. Arduino Uno, a microcontroller board based on the ATmega328 is used in this project. The hardware consists of a simple open hardware design for the Arduino board with an on-board input/output support. The software consists of a standard programming language compiler and the boot loader that runs on the board. Arduino hardware is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications, and a Processing-based integrated development environment. Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software running on a computer (e.g. Flash, Processing, Max MSP ,Meguno link).

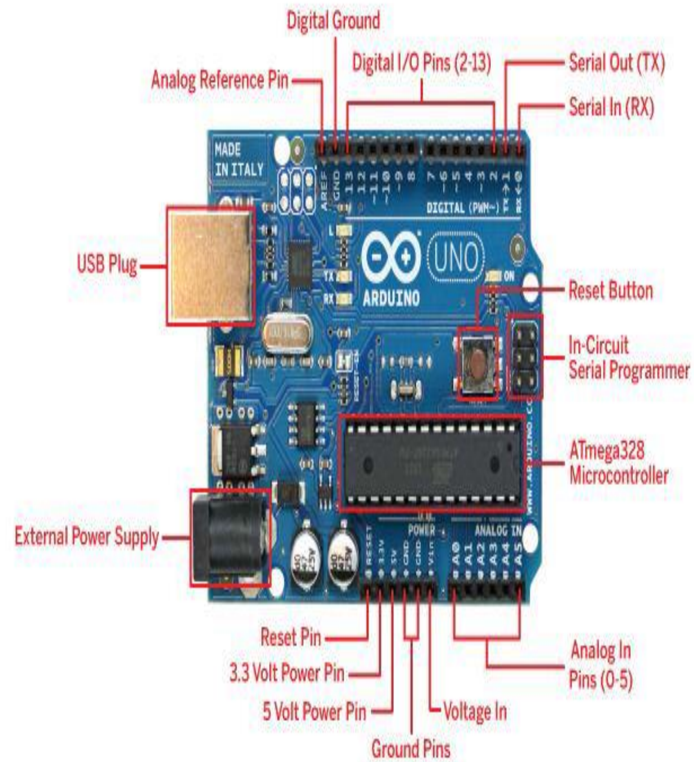

Figure 20. Block Diagram of Arduino UNO

Figure 21. Arduino Program for Single Phase Inverter

VI. HARDWARE

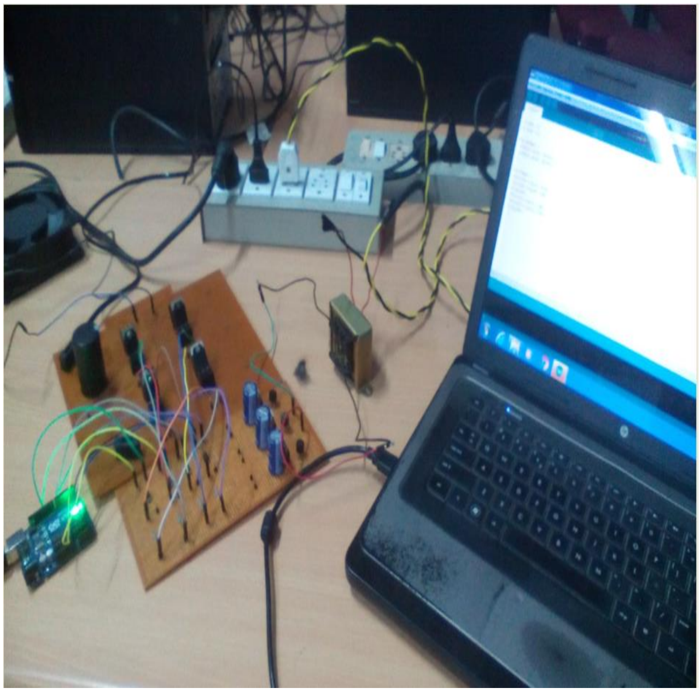

Figure 21. Hardware Implementation of Single Phase Inverter Driving Induction Motor.

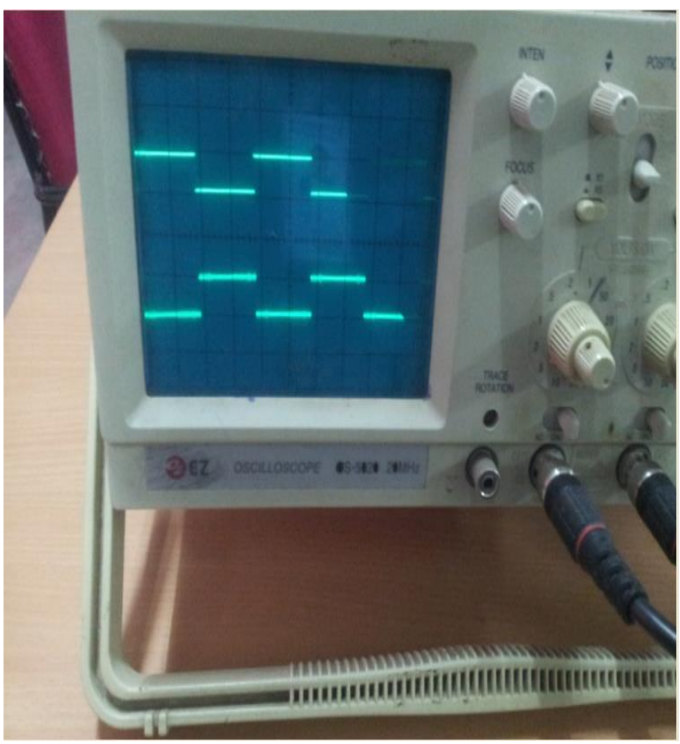

Figure 22. Pulses of IGBT Switches T1,T2,T3and T4.

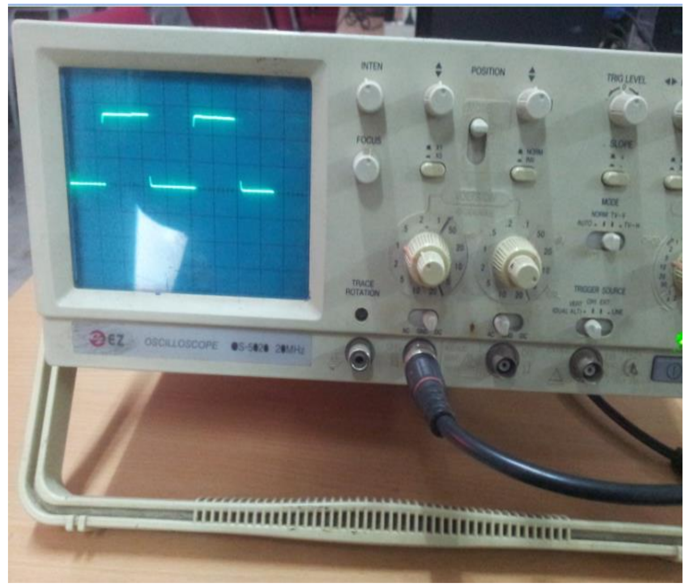

Figure 23. Pulses to IGBT Switches T1and T4.

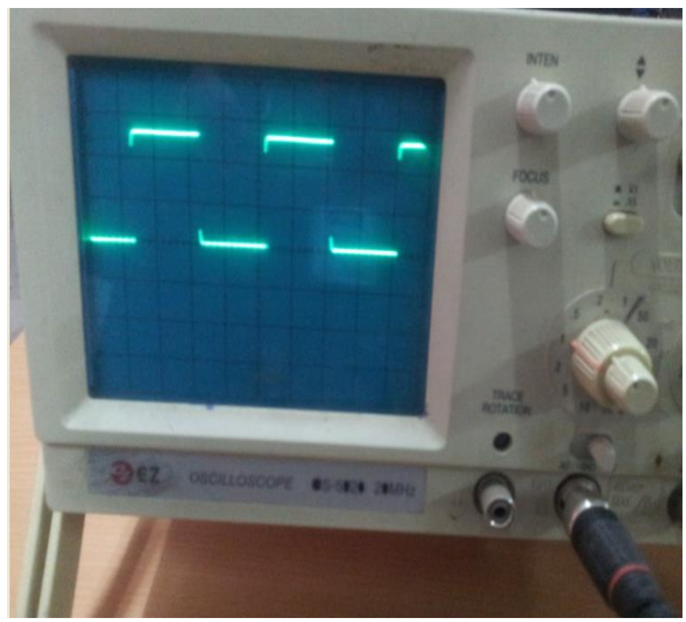

Figure 24. Pulses to IGBT Switches T2 and T3

VII. CONCLUSIONS

This paper work provides the successful attempt to design, analyze, and implementation of Single phase Inverter driving Induction Motor is carried out using Arduino. The speed control of single phase or three phase Induction motor is achieved by using inverter, with PWM or SPWM techniques in Matlab/ Simulink Environment, to the hardware pulses are generated by using Arduino. These generated pulses can be used to control the speed of Induction motor by varying the width of pulses. Further it can be extended to implement hardware unit for controlling speed of three phase IM in both open and closed loop.

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