

Speed Control of Induction Motor using Digital Signal Processor TMS320F28027F

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Abstract. Single-phase induction motors are widely used today. A single-phase induction motor is operated using a single-phase inverter. The Single-phase inverter consists of four MOSFETs, two for the high side and two for the low side. The Single-phase induction motors are a constant speed motor. As a corollary, the speed control of the Single-Phase Induction motor becomes a very important necessity. Speed control of the Single-Phase Induction motor can be done in many ways. The method followed in this paper is voltage control/ (V/F Control). By controlling the duty cycle of the MOSFETs, we can control the output of the inverter and there by control the speed of the Single-Phase Induction motor. The inverter has been interfaced with MATLAB, which generates pulses and sends them to the Digital Signal processor. Texas Instrument's low-cost Piccolo F2802x MCUs are ideal for a variety of applications, such as washing machines, compressors, pumps, fans, electric bicycles, tools, treadmills, compact drives, sewing and textile machines, lifts and hobby motors. This paper focuses on closed loop control of single-phase induction motor using this Micro Controller, F2802x Digital Signal Processor using feedback obtained through a Hall Sensor.

Keywords— TMS320F28027F, Code Composer Studio (CCS), ESP32, IR Sensor, Induction motor, v/f control, voltage source inverter (VSI).

1 Introduction

Single-phase induction motors are extremely robust, easy to construct and simple to maintain. They are also very economical. As a result, today, they are most widely used in pumps, compressors, high-speed vacuum cleaners, drilling machines, pressing machines, grinding machines, flourmills etc. All these applications need speed control. Single-phase induction motors are constant speed motors, i.e., they do not run at synchronous speed. But in industrial applications, according to the load, control of the speed of the induction motor is a necessity to meet the requirements. Therefore, speed control of the induction motor is very important. Through the speed control of the induction motors, the efficiency can be increased.

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Control of AC machines is a difficult job, so control of AC machines is generally done using complex algorithms. To work with such complex algorithms, we need some simple solutions. Digital Signal Processor based methods are found to be very satisfactory, and they can perform the associated signal calculations related to speed control quickly and easily.

A Single-Phase Induction machine gets its input from Alternating current. This is generated using a single-phase inverter. A single-phase inverter takes the input of Direct Current and inverts it into Alternating Current using switches such as MOSFETs. By controlling the input given to the inverter through the duty cycle of triggering pulses given to the switches, its output voltage can be controlled. Using an H bridge inverter, it needs 4 switches and 4 triggering pulses. These pulses are generated using DSP. A Digital Signal Processing (DSP) analyses the signal and adjusts the input signal to improve the performance of the signal. It uses various mathematical operations and algorithms to produce a higher standard signal than the original signal. It first converts analog signals into digital signals, then applies signal-processing techniques, and produces a higher standard signal than the input signal.

2 SPEED CONTROL OF SINGLE-PHASE INDUCTION MOTOR

The speed of the induction motor is controlled by modifying the currents in the induction motor.

$$N = N_s(1 - s) \quad (1)$$

$$T = [3 \times 60 / 2\pi N_s] \quad (2)$$

$$T \propto s V_2^2 \quad (3)$$

$$B_m \propto V/f \quad (4)$$

The speed of the induction motor is given in equation (1), where N is the speed of the induction motor and N_s is the synchronous speed. The speed of the induction motor can be changed by changing the synchronous speed or the slip. [1]

The torque equation of the single phase induction motor is given in equation (2) where T is the torque and s is the slip. E_2 is the secondary side EMF and R_2 and X_2 are the load impedance. From equation (2), it can be observed that for a given torque and load, by varying the rotor voltage and rotor resistance the slip for the speed control of induction motor can be varied. From the stator side of the induction motor, there are 4 methods of speed control. Voltage control method, Frequency control method, Pole changing method, Stator resistance method. In the above torque equation, it can be observed that during running of the induction motor, the slip is very less. So $(sX_2)^2$ term can be neglected. So the torque becomes directly proportional to the Stator voltage as shown in equation (3).

Equation (3) evidently shows that the torque will also drop if the supply voltage is reduced. If the voltage reduces for a given load, the slip will increase while reducing the speed to maintain the load torque constant. Voltage can be reduced to a suitable value; the motor will become unstable if we reduce the voltage below this value. This type of speed control of induction motor is rarely employed since it results in an overheated induction motor because a minor change in speed necessitates a considerable voltage reduction. [2]

The most widely used and feasible method is the Frequency control method. The flux density of the stator core is inversely proportional to the applied frequency. The flux density needs to be maintained at a constant value.

Therefore, to maintain the maximum flux density as constant, we must vary the voltage and frequency together as observed from equation (4). This method cannot be possible for frequencies greater than the rated frequency as voltage also needs to be increased. Voltage cannot be increased above a certain value because of insulation constraints. This method

requires variable voltage and variable frequency converters, which makes this method an expensive one. Still, this method offers a wide range of speed control without affecting the efficiency of the motor. This paper utilizes V/F control of single-phase induction motor to obtain optimal speed control.

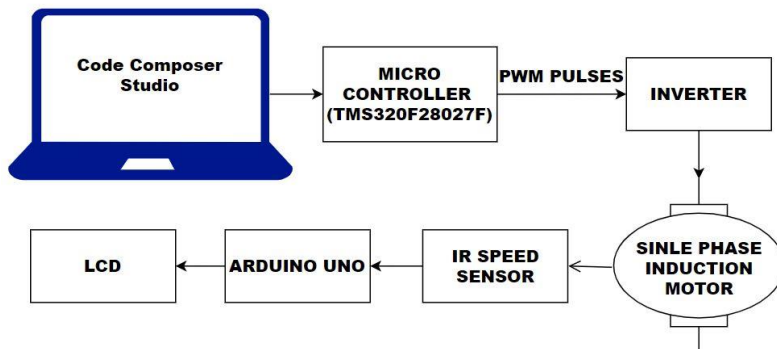


Fig. 1. Block Diagram of Speed Control of Induction Motor

Fig 1 shows the block diagram of the speed control process. The Simulink Model is connected to the Micro Controller in case of operation using MATLAB. The Code Composer Studio code is uploaded into the flash memory of the DSP in case of potentiometer operation. The DSP is connected to the Inverter which is connected to a DC Source which is obtained by rectifying the AC voltage and the filtering it. The Inverter is then connected to the Single-Phase Induction motor[3].

3 Simulink Models of Inverter Operation

3.1 Simulink Model for SPWM generation

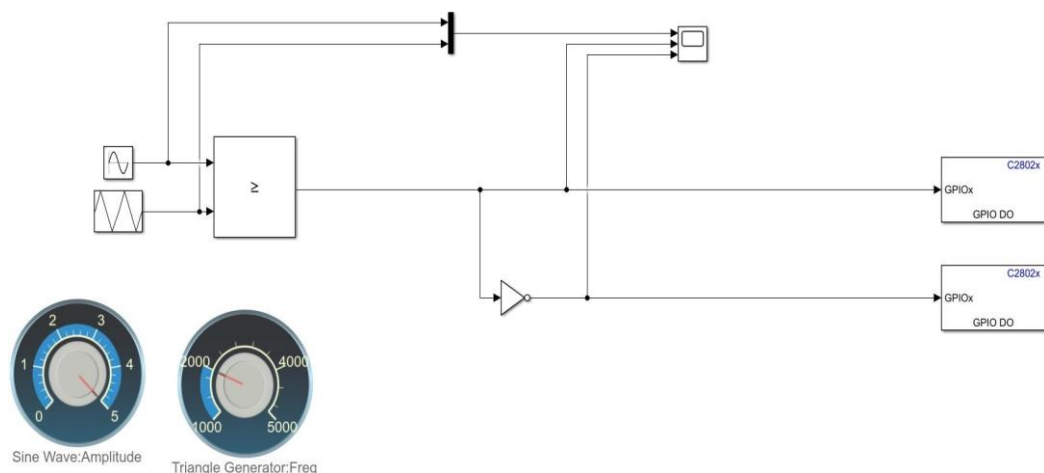


Fig. 2. Simulink Model for SPWM generation

Fig 2 shows the Simulink model for PWM generation. Pulse width modulation technique changes the average output power of an electrical signal by precisely slicing into discrete parts. By using the PWM technique, a continuously varying analog signal is converted into

a series of digital signals. A PWM signal is generated using a comparator. The comparator compares the two input signals and generates a PWM signal.

The PWM technique used here is the Sinusoidal PWM. The Sinusoidal wave (reference signal) of frequency 50Hz and amplitude 1 and the Triangular wave (carrier signal) of frequency 20KHz and amplitude 1 are the two input signals given to the comparator. The output PWM signals of the above model as observed in scope are depicted in Fig 3.

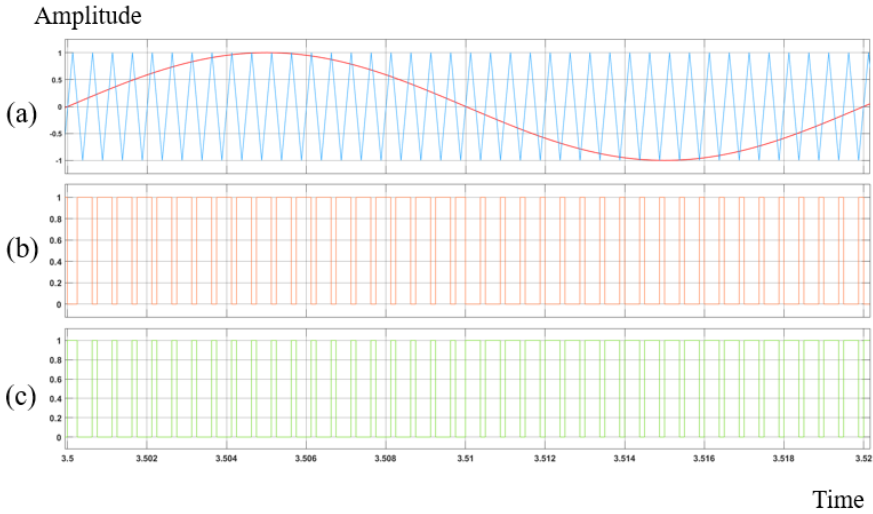


Fig. 3. SPWM generation with Carrier Frequency at 20 kHz; a. Red-Fundamental Signal (Sine: 50Hz), Blue-Carrier Signal (Triangular); b. Switching Pulses for Switches 1&3; c. Switching Pulses for Switches 2&4

3.2 Simulink Model of Single-Phase Inverter

The below figure is the MATLAB simulation model of a single-phase Inverter where MOSFETs are used as switches and the switching pulse for the MOSFETS are given using the sinusoidal PWM technique. Two MOSFETs in the same leg are given complimentary signals, which are generated above (Fig3). The output voltage and output current of the inverter as observed in scope are shown in Fig 5 respectively [4]-[8].

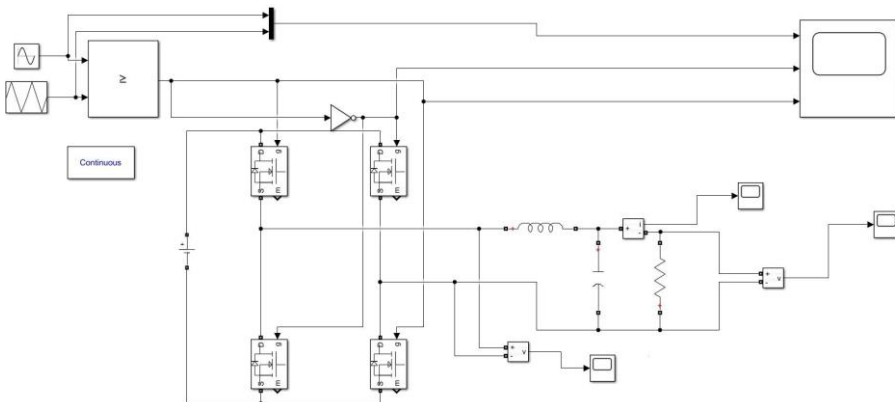


Fig. 4. MATLAB (Simulink) Model of Single-Phase Inverter

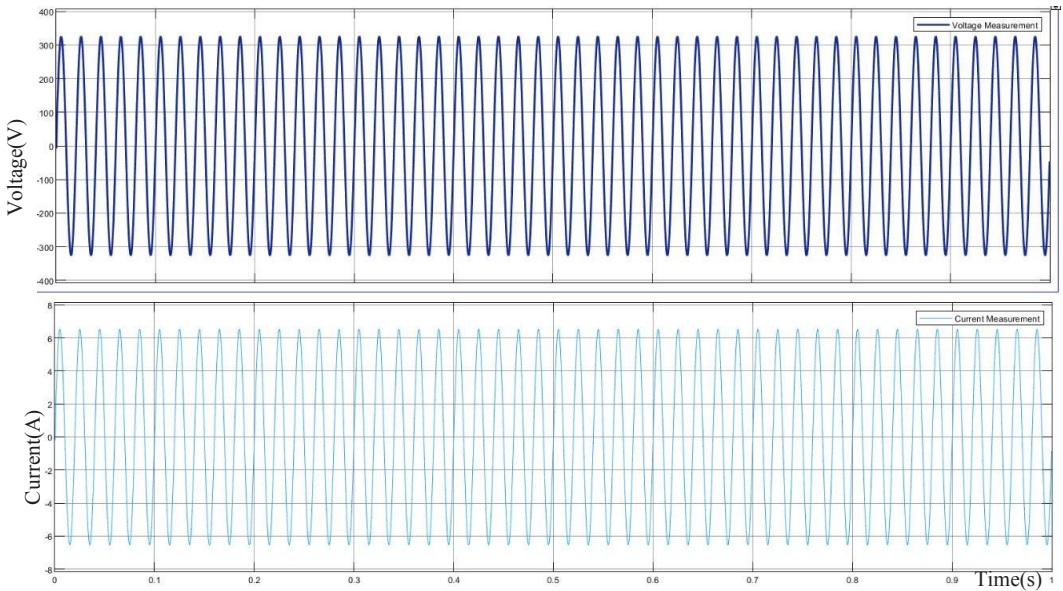


Fig. 5. Output Voltage and Current of Single-Phase Inverter with R Load

The above waveforms are the ones obtained after applying an L-C filter whose values are calculated based on various circuit parameters. The RMS value of the output voltage and current as observed in the scope of MATLAB are voltage being 232.3V and current being 4.627A.

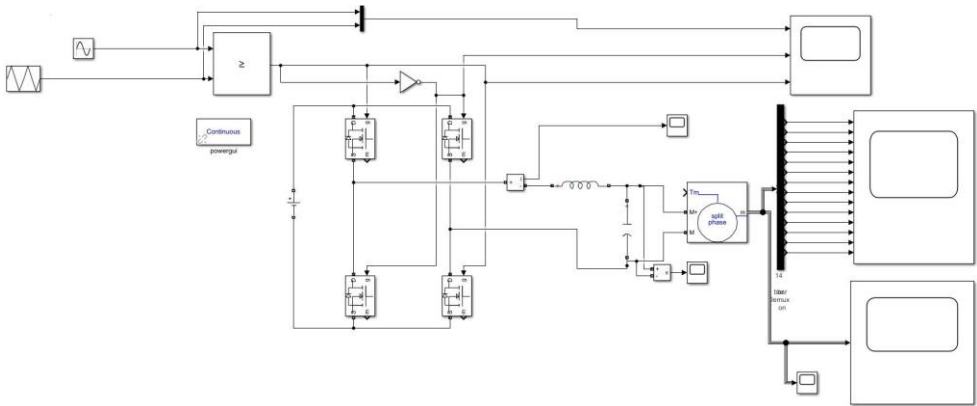


Fig. 6. MATLAB (Simulink) Model of Single-Phase Inverter Drive for Single Phase Induction Motor

In the above figure, the previously designed single-phase inverter (with filter) is connected to a single-phase induction motor. To observe the simulation results, a 1x10 DE-MUX has been connected to the scope in the MATLAB and the obtained simulation results [9] are shown below. Outputs of the Single-phase inverter connected to a Single-phase induction motor are given in Fig 8.

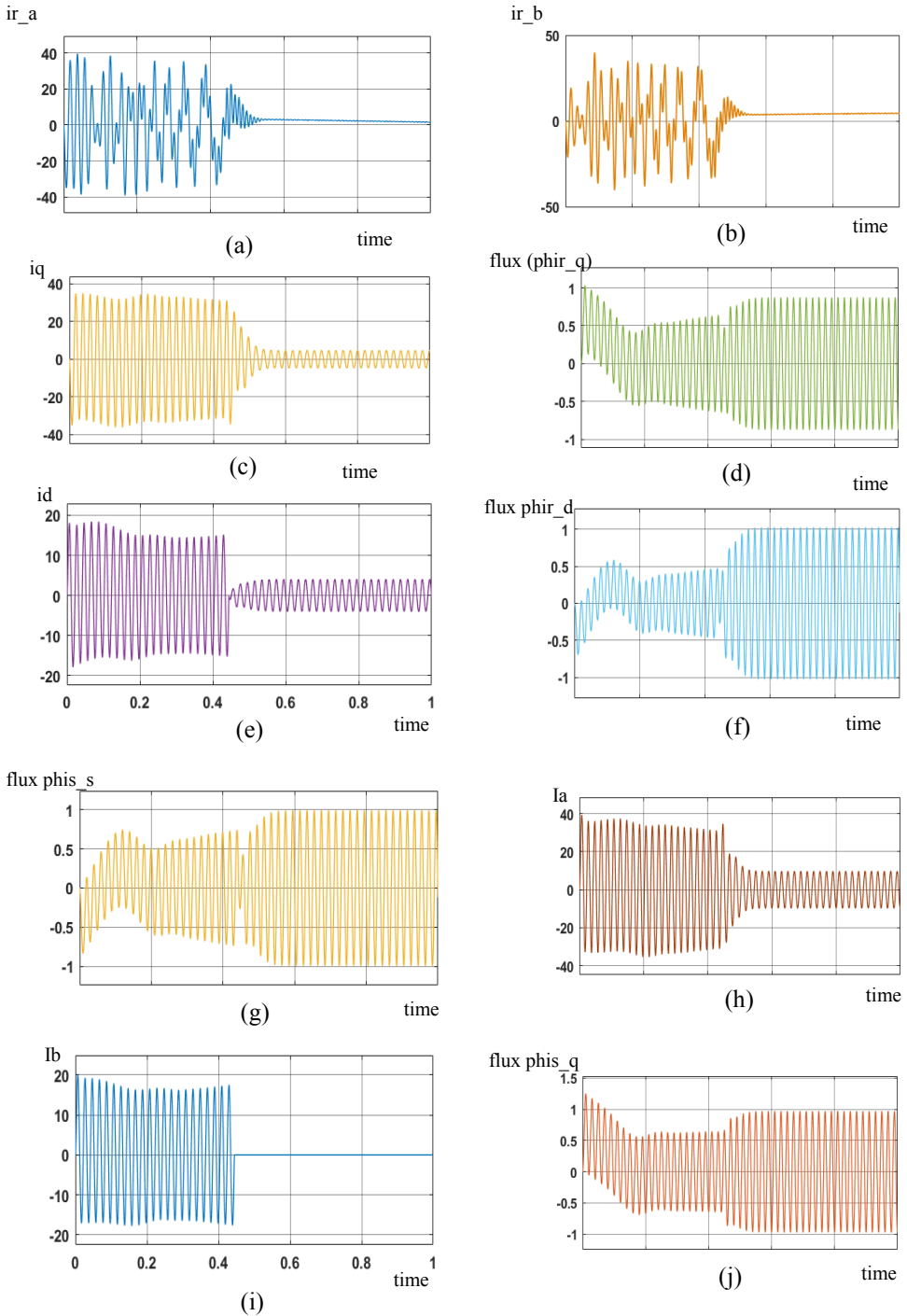


Fig. 7. Output of Rotor and Stator Measurements in (pu); (a) Rotor current ir_a ; (b) Rotor current ir_b ; (c) Rotor current iq ;(d) Rotor flux $phir_q$; (e) Rotor current id ; (f) Rotor flux $phir_d$;(g) Stator flux $phis_q$ (h)Stator main current Ia ; (i) Stator Auxiliary Winding Current Ib ; (j) Stator flux $phis_s$

4 Hardware Implementation

4.1 Amplitude Modulation

The circuit connection for Amplitude Modulation is shown in Fig 9. Amplitude Modulation is the variation of the duty cycle of the generated PWM pulses by varying the amplitude of the reference signal (i.e., the Amplitude of the Sinusoidal Signal in this case) while keeping the Amplitude of the Carrierwave (i.e., Triangular wave in this case) constant [10]-[12].

The Amplitude modulation here is done for the carrier wave i.e., triangular wave with frequencies of 1 kHz, 2 kHz, 3kHz, 4 kHz and 5 kHz. For each of those frequencies, the amplitude was varied from 1 to 5. The output waveforms for amplitude 5 are shown in Fig 10.

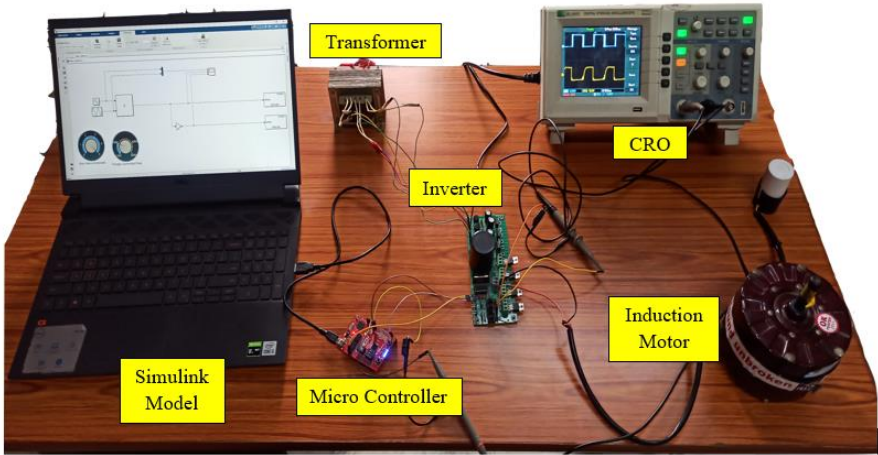


Fig. 8. Induction motor connected to Inverter controlled using MATLAB.

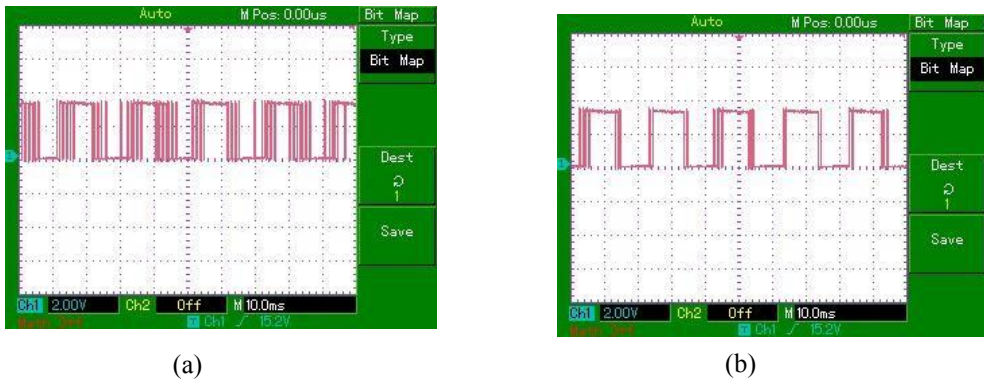


Fig. 9. PWM Output with carrier wave frequency 5 kHz; (a) Sinusoidal wave amplitude 1, Frequency 50Hz; Triangular Wave Amplitude 1, Frequency 20 kHz; (b) Sinusoidal wave amplitude 2, Frequency 50Hz; Triangular Wave Amplitude 1, Frequency 20kHz.

A MATLAB (Simulink) Model has been built for PWM generation and has been deployed to the DSP. The Duty Cycle of the PWM Pulses is varied using the MATLAB Model and is given as real time input to the Inverter. A Step-Down Transformer of 220V/15V is connected on primary side to the power supply and the secondary side to the inverter. The output of the DSP is given to the inverter [6]. This PWM pulse from the Micro Controller is given to 4 MOSFETs using opto couplers. The voltage from the transformer is used in order to amplify the pulses that are given from the DSP with the help of opto couplers. The output of the inverter is given to the Single-Phase Induction Motor and the waveforms are observed in the CRO.

Table. 1. Motor Parameters obtained from Amplitude Modulation

Amplitude Modulation	Voltage (V)	Current (A)	Speed (RPM)
0.2	199	0.3	1449
0.3	201	0.4	1458
0.4	203	0.5	1462
0.5	208	0.5	1473
0.6	213	0.6	1479
0.7	217	0.6	1483
0.8	221	0.6	1488
0.9	224	0.7	1492
1	229	0.7	1497

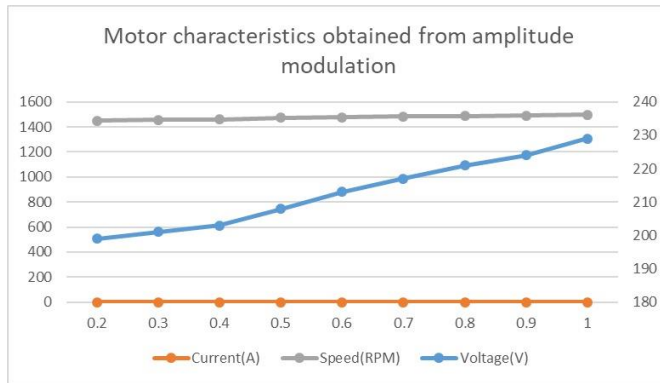


Fig. 10. Characteristics of Induction motor obtained from Amplitude Modulation (X-axis: Amplitude; Y-axis: (L) Speed, Current & (R) Voltage)

The characteristics of an Induction motor under no load condition for various amplitude modulations are plotted in the Fig.10. It can be observed that as amplitude modulation increases from 0.2 to 1, the speed varies from 1449 RPM to 1497 RPM, voltage varying from 199 V to 229 V and the current varies from 0.3A to 0.7A. These variations are observed in Table.1.

4.2 External Analog Signal Based Speed Control of Induction Motor

A PWM Generator program from Code Composer Studio is uploaded into the flash memory of the DSP. A potentiometer of variable resistance from 1Ω to 10kΩ is connected to the DSP to vary the Duty Cycle of pulses generated from the Micro Controller [7][8]. A Step-Down Transformer of 230/15V is connected on primary side to the power supply and the secondary side to the inverter. The output of the DSP is given to the inverter. This PWM pulse from the DSP is given to 4 MOSFETs using opto couplers. The voltage from the transformer is used

in order to amplify the pulses that are given from the DSP with the help of opto couplers. The output of the inverter is given to the Single-Phase Induction Motor and the waveforms are observed in the CRO. The speed, voltage and current of the Induction motor are also verified using the respective apparatus (speed sensor and multimeter.) and the obtained results are shown in Table 1.

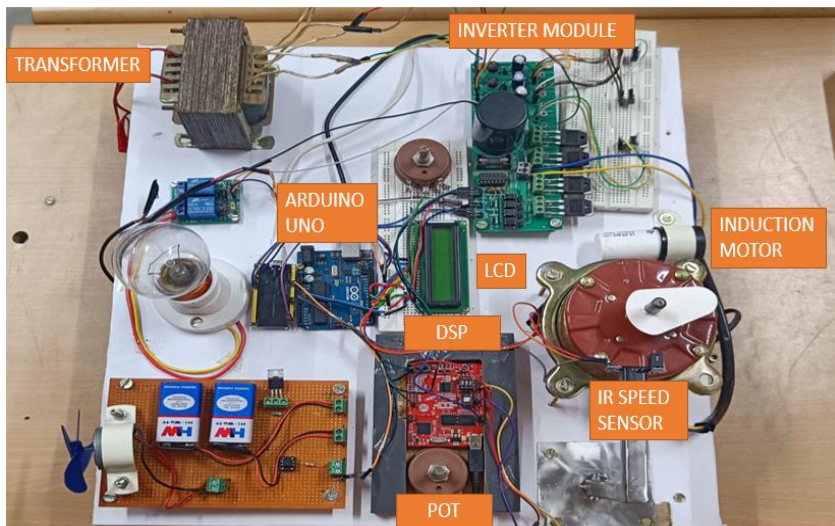


Fig. 11. Induction motor connected to Inverter controlled using a Potentiometer (as project was also merged with another concept of IOT for further development, additional components have been added on hardware platform that is not in scope of this paper).

Table 2. Parameters of Induction motor under no load condition

DUTY CYCLE (%)	VOLTAGE(V)	CURRENT(A)	SPEED(RPM)
30	193	0.3	2701
40	218	0.3	2794
50	228	0.6	2897
60	219	0.3	2791

The characteristics of an Induction motor under no load condition for various Duty cycles are plotted in the Fig.12. It can be observed that Duty cycle varies from 30% to 60%, the speed varies from 2701 RPM to 2791 RPM (maximum speed being 2897 at 50% duty cycle), voltage varying from 193 V 219 V (maximum being 228V at 50% duty cycle) and the current varies as 0.3A and 0.6 A. These variations are observed in Table 2.

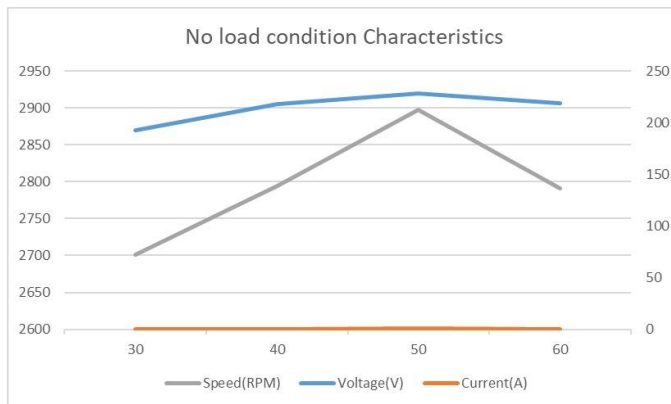


Fig. 12. Characteristics of Induction motor under no load condition (X-axis: Duty Cycle; Y-axis: (L) Speed, Current & (R) Voltage)

4.3 Speed Control of Loaded Induction Motor

A PWM Generator program from Code Composer Studio is uploaded into the flash memory of the Micro Controller. A potentiometer of variable resistance from 1 Ω to 10k Ω is connected to the Micro Controller to vary the Duty Cycle of the pulses generated from the Micro Controller. A Step-Down Transformer of 230/45V is connected on primary side to the power supply and the secondary side to the inverter[9]. The output of the Micro Controller is given to the inverter. This PWM pulse from the Micro Controller is given to four MOSFETs using opto couplers.

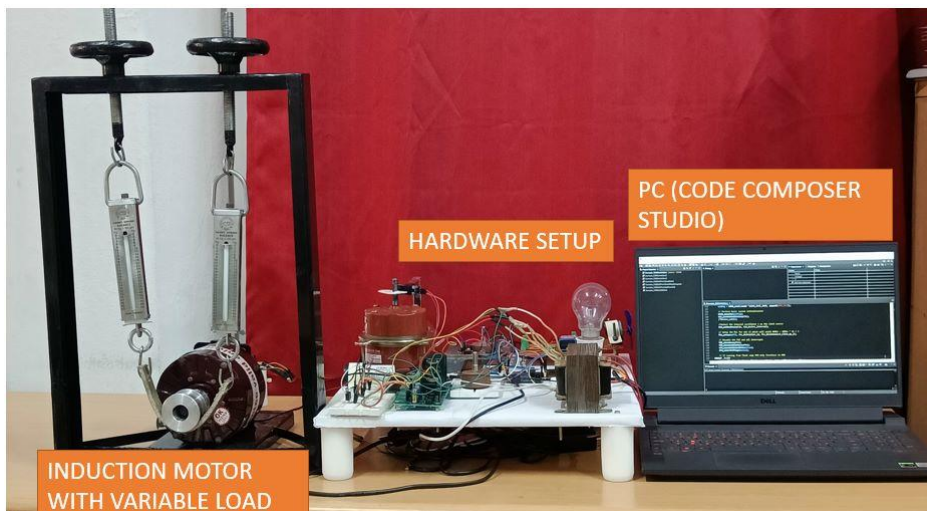


Fig. 13. Load setup for speed control of Induction motor

The output of the inverter is given to the Single-Phase Induction Motor and the waveforms are observed in the CRO. The speed, voltage and current of the Induction motor under various load conditions are also verified using the respective apparatus (Digital Tacho meter and multimeter.) and the obtained results are shown in Table 2.

Table.3. a Parameters of Induction motor at 40% Duty cycle under various load conditions.

VOLTAGE(V)	CURRENT(A)	LOAD(KG)	SPEED(RPM)
224	0.6	0	1481
221	0.6	0.5	1457
216	0.7	1	1453
207	0.7	1.5	1438

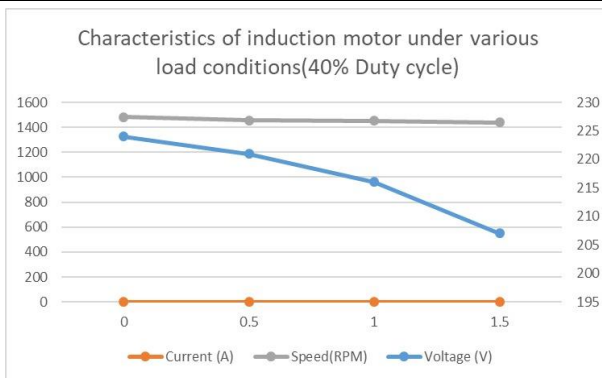


Fig. 14. Characteristics of induction motor under various load conditions at (40% Duty cycle) The characteristics of an Induction motor under loaded condition for various loads and a constant duty cycle of 40% are plotted in Fig.14. The Load is varied from 0kg to 1.5 kg for which corresponding change in voltage, current and Speed are 224 V to 207V,0.6A to 0.7A, 1481 RPM to 1438 RPM respectively. The respective values can be observed in Table.3. a

Table.3. b Parameters of Induction motor at 50% Duty cycle under various load conditions

VOLTAGE(V)	CURRENT(A)	LOAD(KG)	SPEED(RPM)
230	0.6	0	1496
225	0.6	0.5	1481
218	0.7	1	1464
203	0.7	1.5	1428

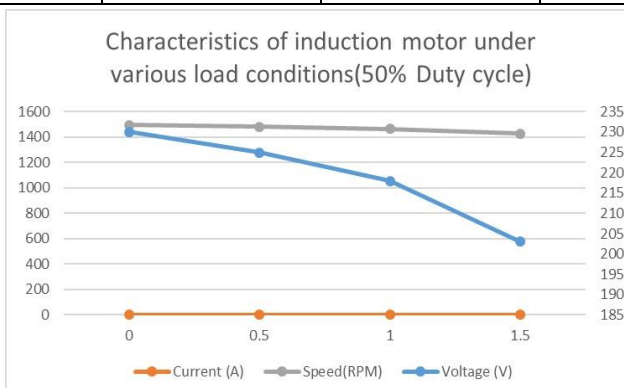


Fig. 15. Characteristics of induction motor under various load conditions at (50% Duty cycle) The characteristics of an Induction motor under loaded condition for various loads and a constant duty cycle of 50% are plotted in Fig.15. The Load is varied from 0kg to 1.5 kg for which corresponding change in voltage, current and Speed are 230V to 203V,0.6A to 0.7A, 1496 RPM to 1428 RPM respectively. The respective values can be observed in Table.3. b

Table.3. c Parameters of Induction motor at 60% Duty cycle under various load conditions.

VOLTAGE(V)	CURRENT(A)	LOAD(KG)	SPEED(RPM)
226	0.6	0	1484
224	0.6	0.5	1469
219	0.7	1	1458
209	0.7	1.5	1445

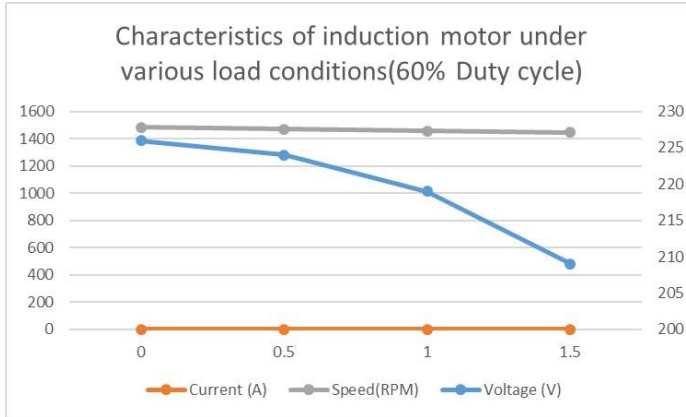


Fig. 16. Characteristics of induction motor under various load conditions at (60% Duty cycle)

The characteristics of an Induction motor under loaded condition for various loads and a constant duty cycle of 60% are plotted in Fig.16. The Load is varied from 0kg to 1.5 kg for which corresponding change in voltage, current and Speed are 226 V to 209V,0.6A to 0.7A, 1484 RPM to 1445 RPM respectively. The respective values can be observed in Table.3. b.

5 Conclusion

PWM Pulses are generated using MATLAB via Simulink. These generated pulses are then given to inverter module where they are amplified and are then used for the switching operation of the MOSFETS in the inverter. The output of the inverter is connected to an Induction Motor. Another method used in this paper is the variation of duty cycle of the pulses generated from DSP with the help of an external analog signal, which is given, with the help of a Potentiometer. These generated pulses are again given to the inverter where they are amplified and are then used for the switching operation of the MOSFETS in the inverter. The output of Inverter is connected to an induction motor and various parameters of the induction motor are observed. An induction motor with variable load is also connected to the inverter and the parameters under various load conditions are observed.

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