

## FREQUENCY VARIATION FOR INDUCTION MOTOR CONTROL

<sup>1</sup>Mbachu, C. B. and <sup>2</sup>Nnake, E. J.

<sup>1</sup>Department of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria.

<sup>2</sup>Department of Electrical/Electronic Engineering, Federal Polytechnic, Oko, Nigeria.

E-mail: <sup>1</sup>dambac@gmail.com, <sup>2</sup>emajid2004@yahoo.com.

### **Abstract**

*Machine control, especially that of induction motors, is an essential consideration on the program of any industrial world. Efficient machine control, not only saves power consumption, but increases productivity. Three-phase induction motors produce mechanical power by electromagnetic induction and run on a 3-phase ac supply. They require efficient speed control, to enable them do variable speed operations, save power consumption and reduce machine noise. In this research work, a new switching device called Mos-Controlled Thyristor (MCT) for frequency drive is introduced. Based on the new switching device and AT89C52 microcontroller, an enhanced frequency drive for controlling the speed and torque of 3-phase 15kW squirrel cage induction motor is modeled. Different voltages ranging from 342V to 415V and frequencies ranging from 50Hz to 60Hz are used in a systematic manner to simulate the system based on the new switching device. The simulation program is written in C language and tested with Proteus 7.6 simulation software. Voltage and frequency have significant impact on the actual speed and torque of the motor. Simulation results show that with the new model, the torque (56.66Nm) developed by the motor which is constant throughout each speed range is directly proportional to the ratio (6.7) of the applied voltage and the frequency of the supply and the selected speeds (1450, 1510, 1570, 1630, 1690 and 1750 rpm) are locked irrespective of change in load. This is unlike other models where magnetic saturation and conduction drop of IGBT lead to voltage/frequency imbalance resulting in excessive drawing of current by the motor and overheating. This new control method has a speed regulation of  $\pm 2$  to 3% of maximum frequency, speed response of 3Hz, speed control range of 1: 40 and efficiency of 88%, as further advantages. Comparison of the system with other speed control techniques shows improved energy-saving, cost effectiveness and safety in operation.*

Keywords: Volts Per Hertz, MCT, IGBT, Frequency Drive

### **1.0 INTRODUCTION**

The control of induction motors is very important in that it saves cost and boosts production. The two principal quantities that determine the speed and torque of induction motors is the stator voltage and frequency. Many researchers have tried to control the speed of induction motor using several methods but each has its own shortcoming. For example, Parekh (2004) used variable frequency and constant voltage (VF) method to control 3-phase ac induction motor. The disadvantage of this method is that if the frequency is decreased keeping voltage constant, then saturation of air-gap flux takes place. At low frequency, the reactance will decrease and the motor current decreases correspondingly, the developed torque also decreases. MaliPatil et al (2012) used variable voltage variable frequency (V/F) method to control the speed of 3-phase ac induction motor, but used Insulated Gate Bipolar Transistors (IGBTs) at the inverter stage.

The drawback of this method is that IGBT develops high voltage drop, causing high conduction losses. IGBT suffers high forward conduction drop, high switching losses and therefore much heating of the motor windings. This can lead to burning of the motor windings during maximum loading. Aspalli et al (2012) used constant volts per hertz (V/F) method for induction motor speed control on closed loop but used IGBTs at the inverter power

stage thereby running into the same IGBT problems. Shirke et al (2003) who employed volts per hertz (v/f) control method have their operation dependent on changing the firing angles of Insulated Gate Bipolar Transistor (IGBT) which has its own shortcomings of not being able to operate big motors and excessive switching losses that heat up motor windings. It also creates voltage-frequency imbalance.

Chitra et al (2006) designed induction motor speed control using fuzzy logic controller. According to Mannan et al (2012), the disadvantage of this method is core losses. Yedamale (2002) used V/F control method in open loop for his induction motor speed control but used IGBTs at the inverter stage. The idea of open-loop in this method is not the best for accurate and qualitative output. Also, the IGBT problem continues in this method. Pavithra et al (2012), used Direct Torque Control (DTC) method, which involves control of both torque and flux simultaneously, to control the speed of induction motor. This method suffers parameter sensitivity problem, even though not like other vector control methods. Also, the generation of only six non-zero voltage vectors by the voltage source inverter is a drawback. Metwally et al (2012) used sensorless vector control method for their induction motor control but have the same problem of parameter sensitivity. Cheles (2008) used sensorless Field Oriented Control (FOC) method for induction motor control using field awakening. This method falls into vector control principles and has the same problem of parameter sensitivity. The frequency variation method involves varying the voltage and frequency simultaneously in such a way that they bear a balanced and constant ratio to each other. This is done using a frequency drive that is instructed, through pulse width modulation (PWM), by a microcontroller (AT89C52) that makes use of program uploaded to it.

To complement the work of the drive, a power electronics switch, the Mos-Controlled Thyristor (MCT), that has minimal conduction losses and high switching frequency is used in a Voltage Source Inverter (VSI) to carry out the switching instructions. An MCT is basically a thyristor with two MOSFETs built into the gate structure. One MOSFET is used for turning on the MCT and the other for turning off the device. It is a thyristor with an insulated gate terminal. It has advantages of low forward conduction drop, fast turn-on and off times, low switching losses and therefore less heating of the motor windings, unlike the IGBT or thyristor alone.

## 2.0 MATERIAL and METHOD

The block diagram and flow chart of the proposed three phase induction motor speed control using frequency variation control are shown in Figures 1, 2 and 3. The system consists of three phase full bridge rectifier, filter, three phase full bridge inverter, control unit and speed sensing unit. In this project the three phase full bridge rectifier is designed using a pair of uncontrolled power diodes per phase, switching in a complementary way to give a six pulse current output. As the output of rectifier is not a stable DC, a capacitor of 220 $\mu$ F, 900V is used as a filter. This filtered output is fed to the three phase full bridge MCT (Mos-Controlled Thyristor) based inverter. The inverter consists of six MCT's.

There is also a snubber circuit against each switch to protect the switches from high  $\frac{dv}{dt}$  and  $\frac{di}{dt}$ . Then the output of this inverter is given to the induction motor. The control unit gives the required gate pulses to all the six MCT switches with opto isolation.

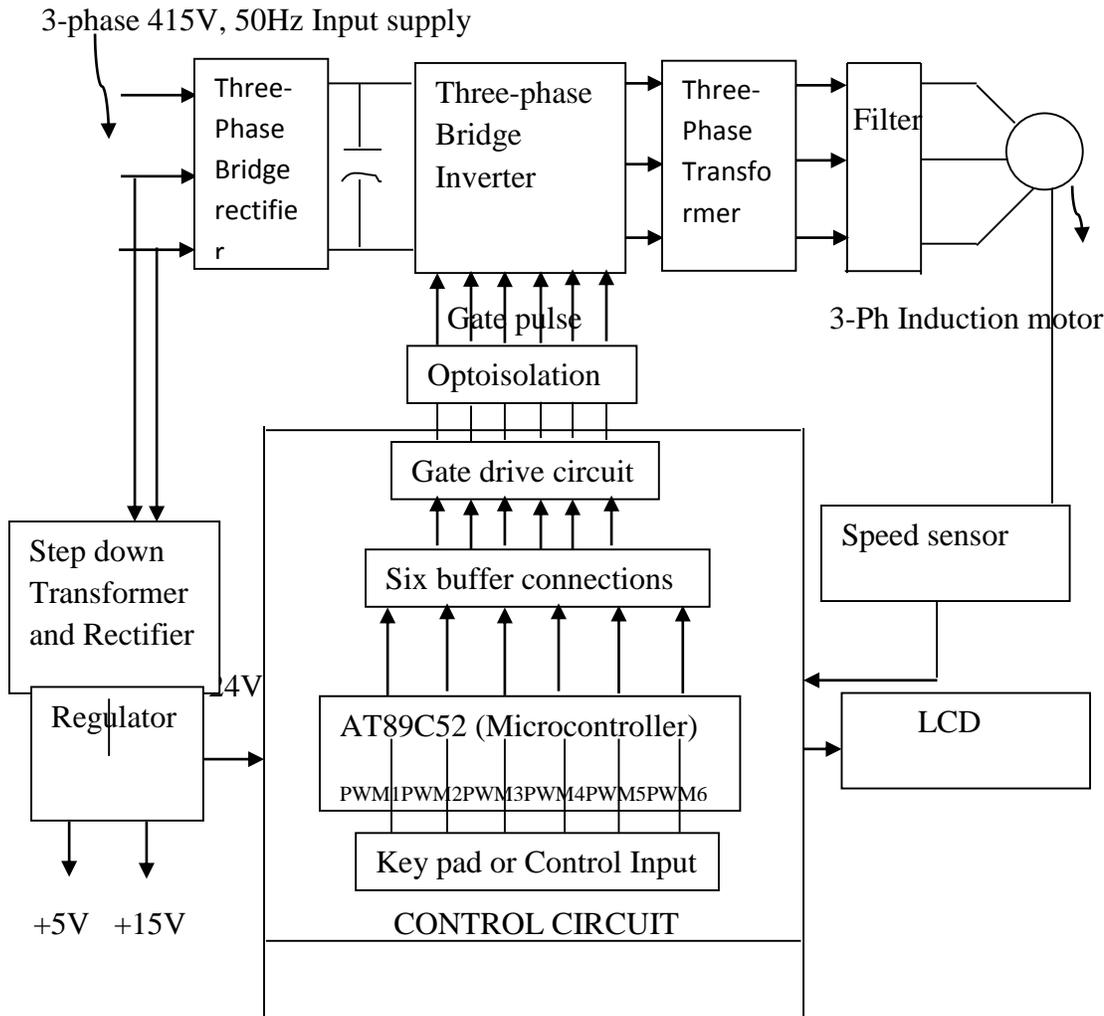


Figure 1: The system block diagram of speed control of 3-phase ac squirrel cage induction motor

## 2.1 THE FREQUENCY VARIATION CONTROL

Frequency variation is achieved in this system by varying the reference input to the microcontroller, using the key pad. Each speed range tallies with a particular frequency. When this input is made by pressing a button on the key pad, the microcontroller sums it up with the feedback speed (in rpm) supplied by the sensor and gives out an error signal. It is this error signal that is used to modulate the switching frequency of the MCTs, through pulse width modulation to give the desired frequency and consequently, the required motor speed. Thus, pulse width modulation (PWM) signals generated from the microcontroller control the six MCT switches. Pulse width modulation is a digital modulation technique whereby the width of a pulse carrier is made to vary in accordance with the modulation voltage. The phase voltage is determined by the duty cycle of the PWM signals. These PWM signals derive a varying voltage from the power circuit. The 3-phase inverter drives the 3-phase motor and the output speed it produces is compared with a set value derived from the key pad through the microcontroller and speed correction is made accordingly.

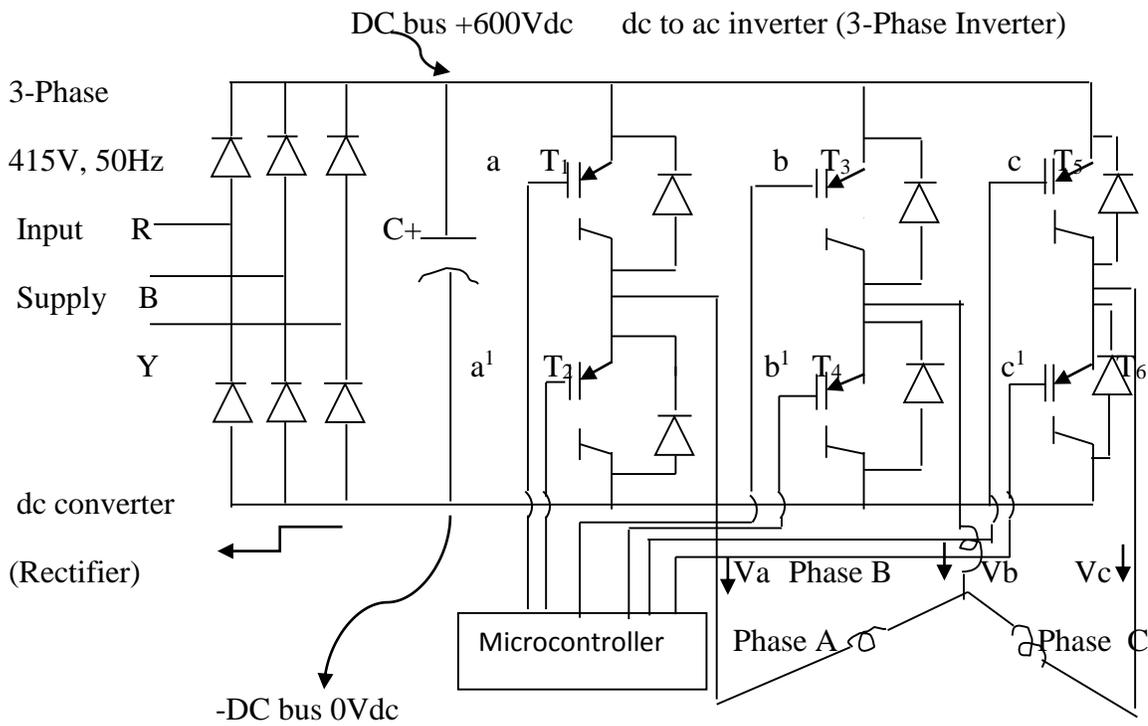


Figure 2: 3-Phase Inverter

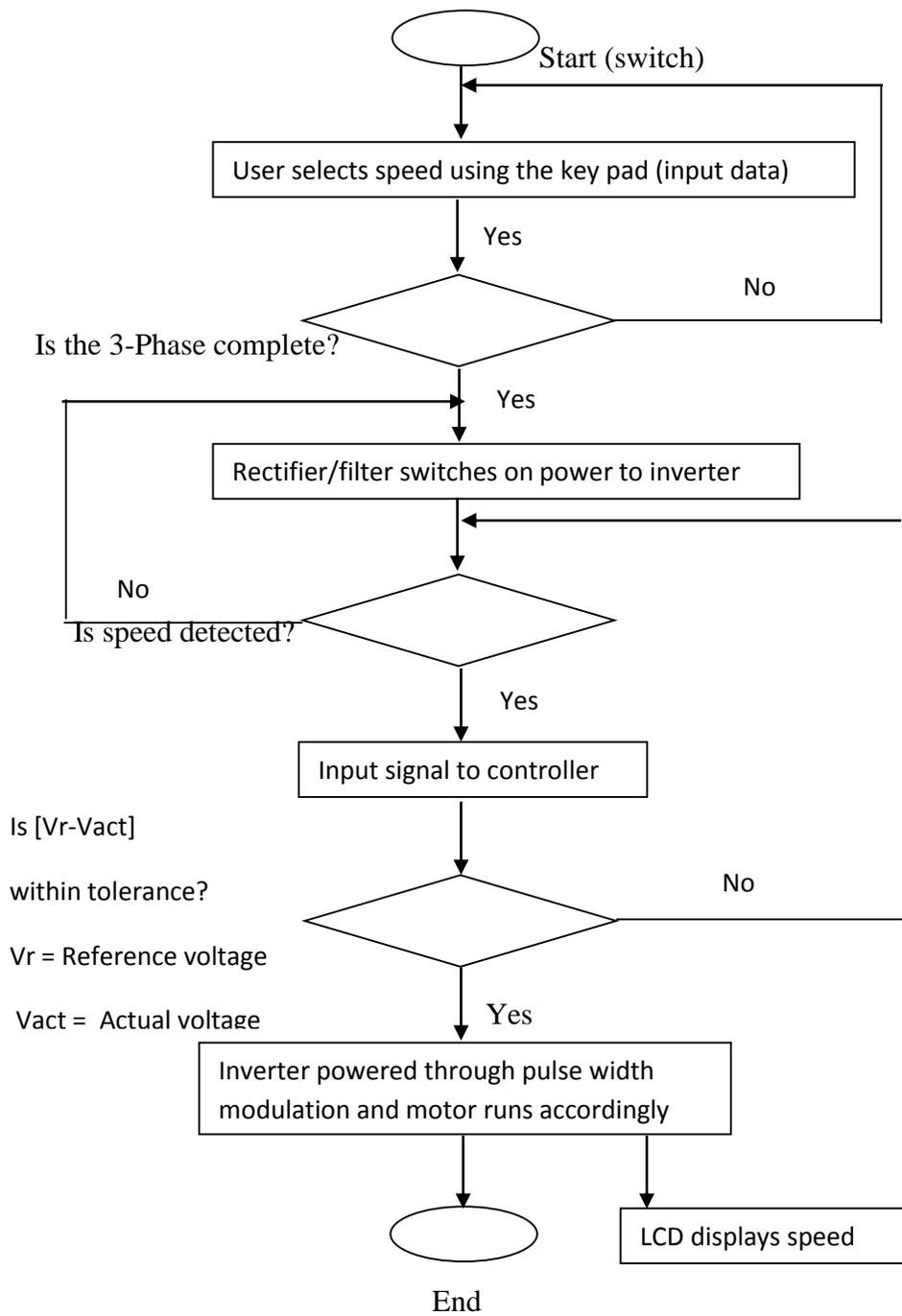


Figure 3: System Flowchart

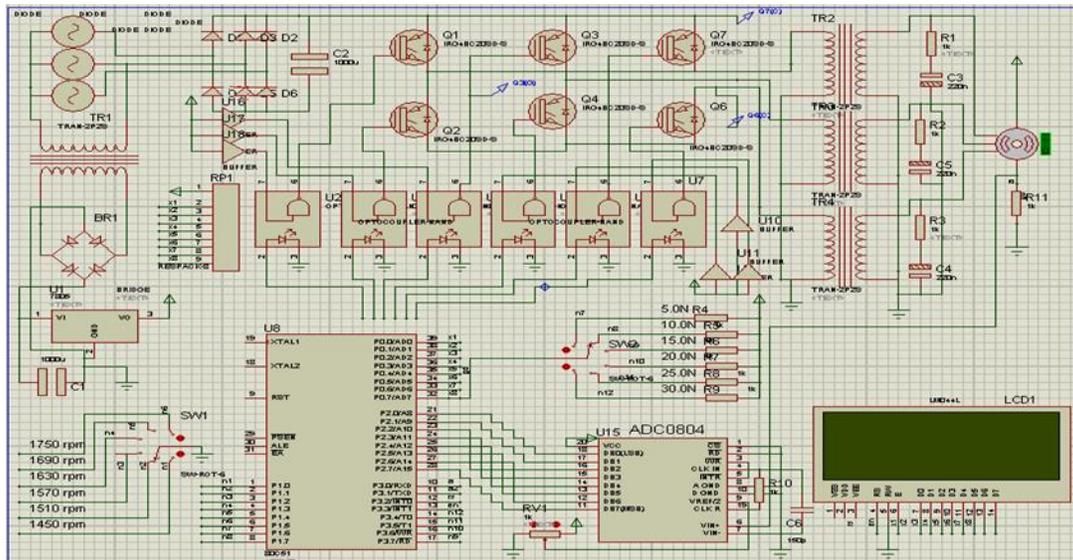


Figure 4: Main Circuit Diagram

### 3.0 SIMULATION RESULTS and ANALYSIS

The simulation results realized for selected speed and load are as shown in the tables and graphs below. The speed-torque characteristics of the new control method are also compared with the existing method.

Table 1: Result for variable speed/frequency and fixed load: 10N

S/No	Reference Speed (r.p.m.)	Frequency (Hz)	Stator Voltage (V)	V/f ratio	Actual Speed (r.p.m)
1.	1450	50	350	7.0	1450
2.	1510	52	364	7.0	1510
3.	1570	54	378	7.0	1570
4.	1630	56	392	7.0	1630
5.	1690	58	406	7.0	1690
6.	1750	60	411	6.9	1750

Table 2: Result for variable load and fixed speed, 1450 rpm

S/No	Load (N)	Frequency of the output voltage (V)	Current (A)	Actual Speed (rpm)	Maximum Torque (N-m)
1.	5	50	0.86	1450	56.73
2.	10	50	0.87	1450	56.73
3.	15	50	0.88	1450	56.73
4.	20	50	0.89	1450	56.73
5.	25	50	0.90	1450	56.73
6.	30	50	0.90	1450	56.73

Table 3: Speed-Torque characteristics/Speed variation for 90° of thyristor firing angle

S/No.	Speed in per unit (pu)	Torque in per unit (pu)
1.	0.55	0.79
2.	0.51	0.85
3.	0.50	0.88
4.	0.45	0.91
5.	0.42	0.93
6.	0.35	0.94
7.	0.34	0.95
8.	0.30	0.96
9.	0.23	0.97
10.	0.18	0.98
11.	0.00	1.00

*Quadi et al (2011)*

Table 4: Speed-Torque characteristics/Speed variation for 70° of thyristor firing angle

S/No.	Speed in per unit (pu)	Torque in per unit (pu)
1.	1.12	0.86
2.	1.05	0.89
3.	0.92	0.91
4.	0.82	0.93
5.	0.79	0.94
6.	0.72	0.95
7.	0.60	0.96
8.	0.50	0.97
9.	0.23	0.98
10.	0.18	0.99
11.	0.00	1.00

*Quadi et al (2011)*

Table 5: Speed-Torque characteristics/Speed variation for 50° of thyristor firing angle

S/No.	Speed in per unit (pu)	Torque in per unit (pu)
1.	1.10	0.94
2.	0.95	0.95
3.	0.80	0.96
4.	0.60	0.97
5.	0.40	0.98
6.	0.20	0.89
7.	0.00	1.00

Table 6: Speed-Torque characteristics/Speed variation of the new v/f control method

S/No.	Speed in per unit (pu)	Torque in per unit (pu)
1.	0.8	0.2
2.	0.85	0.4
3.	0.9	0.6
4.	0.95	0.8
5.	1	1
6.	1.05	1.2

Frequency in Hz

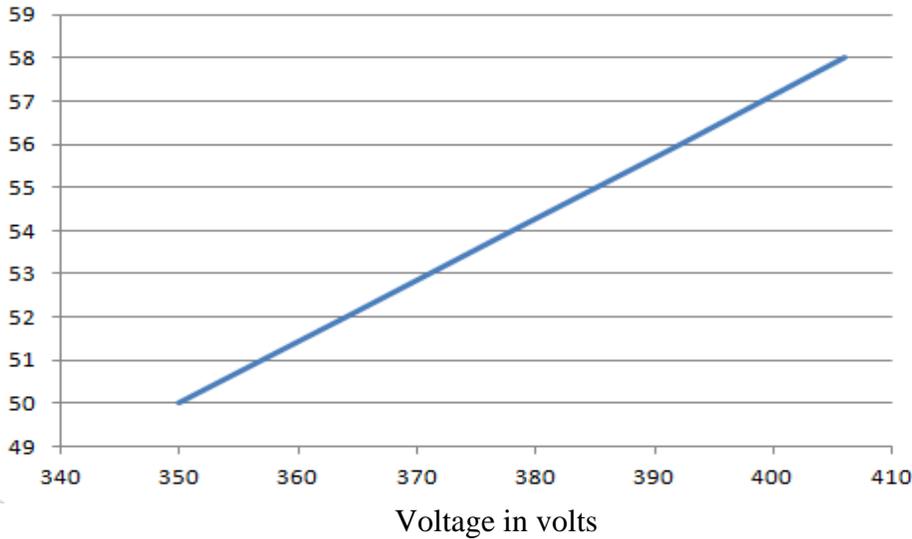


Figure 5: Characteristics of stator voltage magnitude versus frequency (10N load)

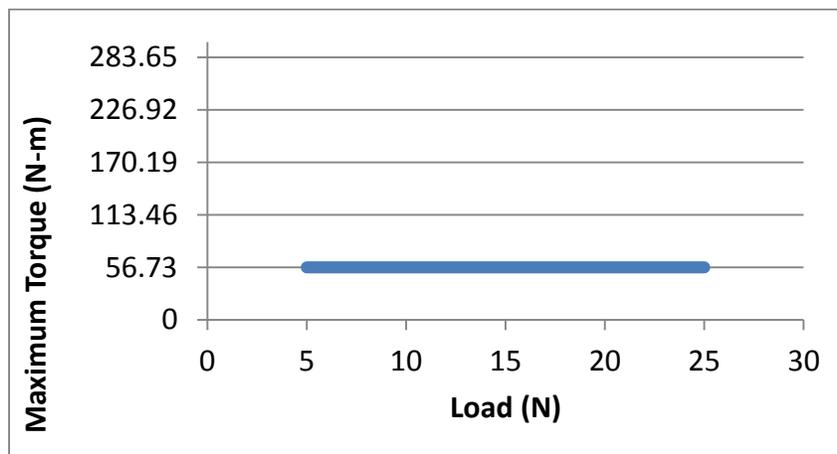


Figure 6 Characteristics of Maximum Torque versus Load for set speed as 1450 rpm

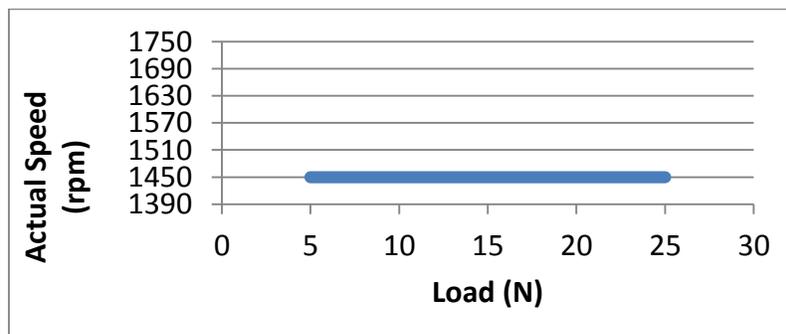


Figure 7 Characteristics of Actual speed versus Load for set speed as 1450 rpm

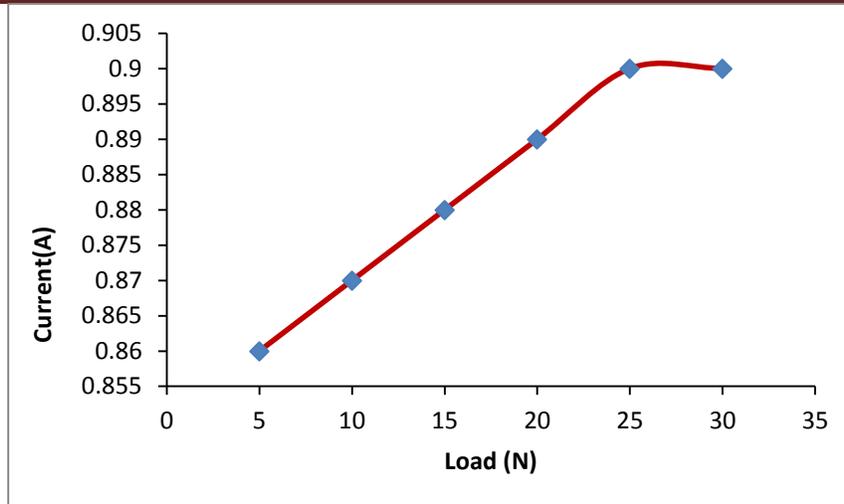


Figure 8 Characteristics of current versus Load for set speed as 1450 rpm

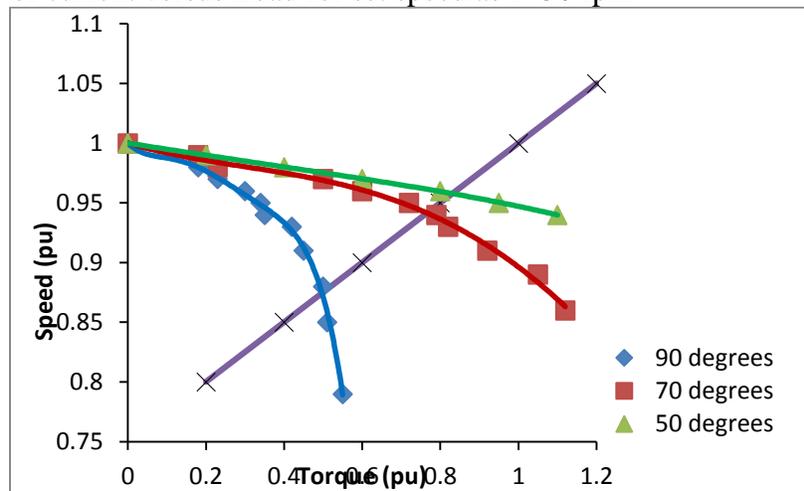


Figure 9: Comparison of Quadi et al (2011) firing method with the new v/f method.

#### 4.0 DISCUSSION OF RESULTS

Figure 5 is a plot of stator voltage magnitude versus frequency at 10N load. It shows linear relationship between voltage and frequency of the motor implying voltage-frequency (V/f) balance. The graphs do not show any curvature within limits of designed voltage and loads indicating that the motor is free of saturation. Figure 6 is a plot of maximum torque versus load for set speed as 1450 rpm. The graph shows a constant maximum torque throughout the designed range of loads. This implies that this control method can sustain constant-torque applications such as hoists, cranes, mills, mixers and some other process control systems. In the existing control methods, the torque may fluctuate and make the motor wobble over a wide range of loads. This is one of the disadvantages of existing motor control methods which this method avoids. Figure 7 is a plot of Actual speed versus Load for set speeds as 1450 rpm. The plot shows that for each set speed, the speed remains steady throughout the designed range of load (10 to 30N).

This is one of the cardinal objectives of this control method. Figure 8 is a plot of current versus load at 1450 rpm. This graph shows that more current is drawn as the load increases. The experiment shows that the lowest phase voltage that can give a diode output voltage of about 600Vdc is 342V. Therefore, 342V is the minimum phase

voltage that can power the system. Below this phase voltage the diode goes far below 600Vdc and cannot power the inverter. The relationship between the phase voltage and diode output voltage is linear and so from 342 to 415V the diode output voltage increases and powers the system effectively, but from 341 to 0V the system is unable to start. The intercept on the  $V_m$  axis shows that at 342V the diode voltage is 564Vdc which means that the three phase diode rectifier cannot function at a lower phase voltage.

Experiment by Eltamaly et al (2007) and Quadi et al (2011) show that saturation occurs in the thyristor firing control and other vector control methods. This is caused by their non-linear flux-current relation (magnetic characteristic) This affects the speed-torque characteristics negatively as can be seen in Quadi et al's (2011) firing angles of 50, 70 and 90 degrees respectively in Figure 7. Conversely, this new method where stator voltage is made to balance with the frequency provides a linear speed-torque characteristic as shown in Figure 9. The magnetic capacity of the motor's magnetic circuit is supposed to be designed to be in line with its voltage/frequency balance. If the frequency increases, the voltage per Hertz (V/Hz) goes up. This means that the motor needs a larger magnetic circuit. Without it, the magnetic circuit can be overloaded. This is saturation and it leads to a rapid increase in current draw and a corresponding increase in temperature, a motor's chief enemy.

## CONCLUSION

Frequency variation control of three phase squirrel cage induction motor has been verified and presented. This control method has advantage over other control methods in that it minimizes switching and core losses which cause saturation, overheating and burning of motor windings, by the use of MCT and the control program uploaded to the microcontroller (AT89C52). Based on the discoveries of this work, it is recommend that forums be created for effective collaboration between industries and the research institutes/universities for the purposes of technology transfer. Areas of further work on this project include upgrading the design to take care of correct positioning of instruments and machines in industries, a case where the angular position of a shaft has to be controlled from some remote position with great accuracy. Such system is called a remote position control servomechanism, and has applications including the automatic control of gun positions, servo-assisted steering of vehicles and ships, positioning of control rods in nuclear reactors and automatic control of machine tools. Thus, a potentiometer can be used to sense shaft position and, using negative feedback mechanism principle; correct positioning of instruments can be achieved. Again, position servos may incorporate limit switches for protection. A limit switch toggles when a shaft or a mechanism reaches some extreme position, or predefined mechanical limit.

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