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Development of Enhanced Frequency Drive for 3-Phase Induction Motors Submitted By

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ABSTRACT: 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 dissertation, 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 (6.7:1) 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 ± 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. The contributions of this research aim to make Volts per Hertz speed control method based on MCT a reliable better alternative to other well known methods in speed control of three-phase induction motors.

Key words: Volts per Hertz,MCT, IGBT, frequency drive

I. INTRODUCTION

The speed control of induction motor is a crying need for the real world industrial applications. AC induction motors are used in many industrial applications such as appliances (washers, blowers, refrigerators, fans, vacuum cleaners, compressors, etc), HVAC (heating, ventilation and air conditioning), industrial drives (motion control, centrifugal pumps, robotics, etc), and automotive control (electric vehicles). In adjustable speed applications, the ac motors are powered by inverters. This is the reason why a power electronic device such as a frequency drive is needed to vary the rotor speed and torque of the induction motor. A frequency drive controls the rotational speed of an ac electric motor by controlling the frequency of the electric power supplied to the motor. There is every need to develop a motor control system that is economical and environmental friendly. To preserve the environment and to reduce green-house gas emissions, Atmel Corporation (2005) noted that governments around the world are introducing regulations requiring white goods manufacturers and industrial factories to produce more efficient appliances. Presently, almost the whole industrial activities are based on electric motors, especially the 3-phase ac induction motors. The need to increase quality of industrial products and services necessitates that the level of machine control be increased so as to increase the level of control on finished and semi-finished parts, both qualitatively and quantitatively. Induction motors are robust, reliable and durable but when power is supplied to an induction motor at the recommended specifications, it only runs at its rated speed. This poses a problem to industrial applications that have variable speed operations. For example, a washing machine may use different speeds for each wash cycle. Also, the induction machine as good as they are, without speed control, present high system's average power consumption and the motor generates a lot of noise. According to Jamadar et al (2013), high efficiency, reduced noise, extended reliability at optimum cost is the challenge facing many industries which use electric motors. Even when there is a control method, it has to be a method that is efficient enough as to save energy and preserve the life of the machine. Inefficient control method can bring about a quick death or collapse of the machine. Wynn et al (2008) observed that reduced motor life is caused by voltage and current imbalance. There is need for a motor control system that is able to maintain a steady variation of speed corresponding to voltage variation; a voltage variation that will bear a constant ratio to the corresponding supply frequency, and make the torque developed for each speed range constant. The speed of a driven load often needs to run at a speed that varies according to the operation it is performing. From the records of Analog Devices (2000), a correct variable-speed operation of three-phase induction motor also requires the supply of a balanced set of three-phase voltages of variable frequency. The speed in some cases such as pumping may need to change dynamically to suite the conditions, and in other cases may only change with a change in process. The aim of this research is to model a motor speed control system with enhanced energy saving, cost effectiveness and safety for a 15kW 3-phase ac squirrel cage induction motor.

The Objectives Are As Follows:

- To introduce a new hardware device, MCT, necessary for improved switching action of inverters, for the purpose of controlling induction motors.
- To develop a new algorithm that enhances speed control of induction motors.
- To determine the variation of motor speed corresponding to the applied voltage and frequency variation.
- To determine the voltage variation that will bear a constant ratio to the corresponding frequency of the supply voltage.
- To determine the torque developed by the motor that will be constant throughout each speed range since the torque developed by an induction motor is directly proportional to the ratio of the applied voltage and the frequency of the supply.
- To determine the stable speed at which the induction motor will run with negligible fluctuation for a wide range of loads.
- To determine the maximum torque that will be fairly constant, exerted by motor for each set speed for variable loads of a three-phase induction motor.
- To determine the constant volts per hertz and stable inverter line to line output voltage for a three phase ac induction motor.

This research is limited to software design, as well as computer simulation using appropriate specialized software application package, Proteus 7.6, for virtual implementation in order to confirm the workability of the system with practical results. The salient features that motivated the research are basically high efficiency, low cost and high reliability. The industrial benefit of this research is that this work is an aspect of industrial automation. It also benefits domestic appliances. Thus, the project when implemented has the potentials of energy savings, process optimization, and smooth machine operation, extending equipment life while reducing maintenance, less noise, cost effectiveness and increased production through tighter process control.

II. METHODOLOGY OF WORK

The choice of motor control method depends on how efficient, reliable and safe a method is. The different methods of speed control of induction motor can be broadly classified into scalar and vector control methods. The two methods can be further classified as variable frequency constant voltage control, variable voltage constant frequency, variable voltage variable frequency i.e. volts per hertz control, firing of thyristors/transistors, fuzzy logic and Rotor voltage control. The method adopted in designing this project is Volts per Hertz or variable voltage variable frequency using MCT as the switching device. MCT is a new device in the field of semi-conductor-controlled devices. It 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. The device is mostly used for switching applications and has other characteristics like high frequency, high power, and low conduction drop unlike the popular Insulated Gate Bipolar Transistor (IGBT). According to Bose (1992), MCT is a high-power high-frequency low conduction drop switching device. At present, the device is not available commercially.

The System Block/Circuit Diagram, Flow Chart And Explanation

The block diagrams, main circuit diagram and flow chart of the proposed three phase induction motor speed control using frequency variation control are shown in Figures 1, 2, 3 and 4. 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 220μF, 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.
3-phase 415V, 50Hz Input supply

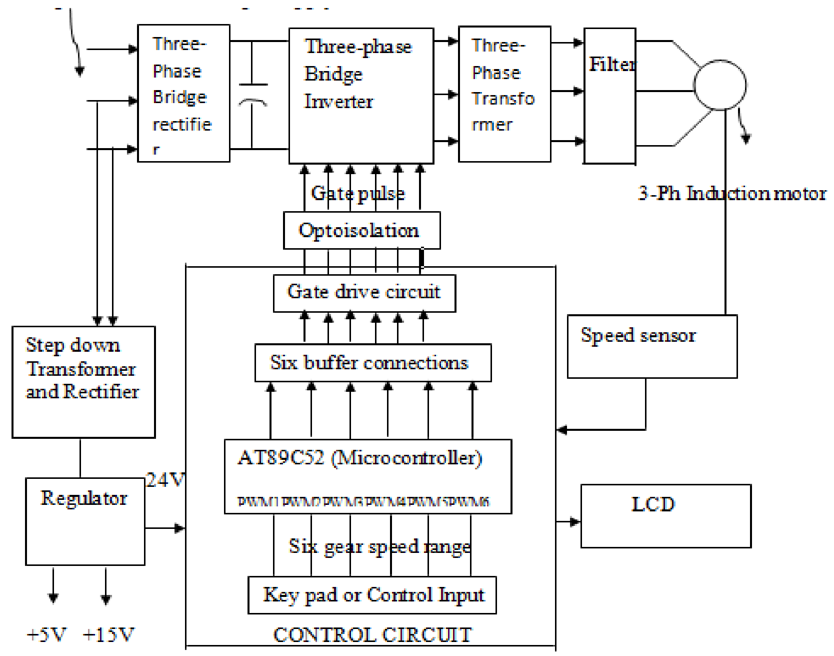


Figure 1: The system block diagram of speed control of 3-phase ac squirrel cage induction motor

The Frequency Variation Technique

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.

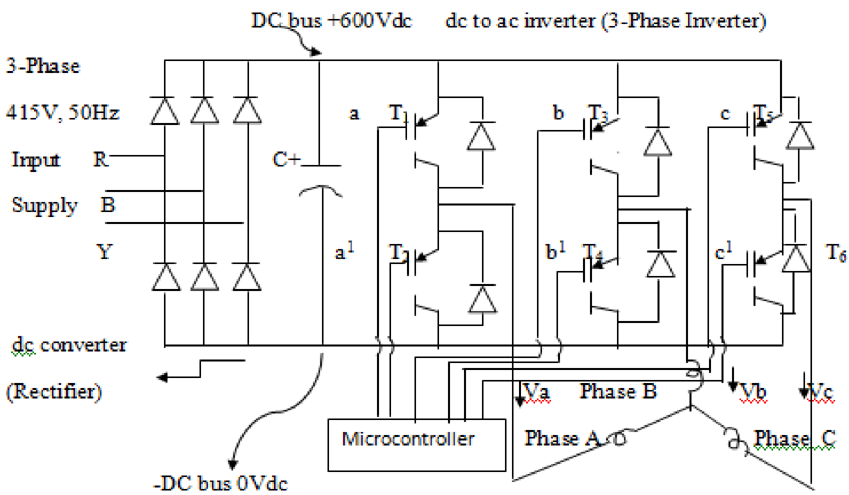


Figure 2: 3-Phase Inverter

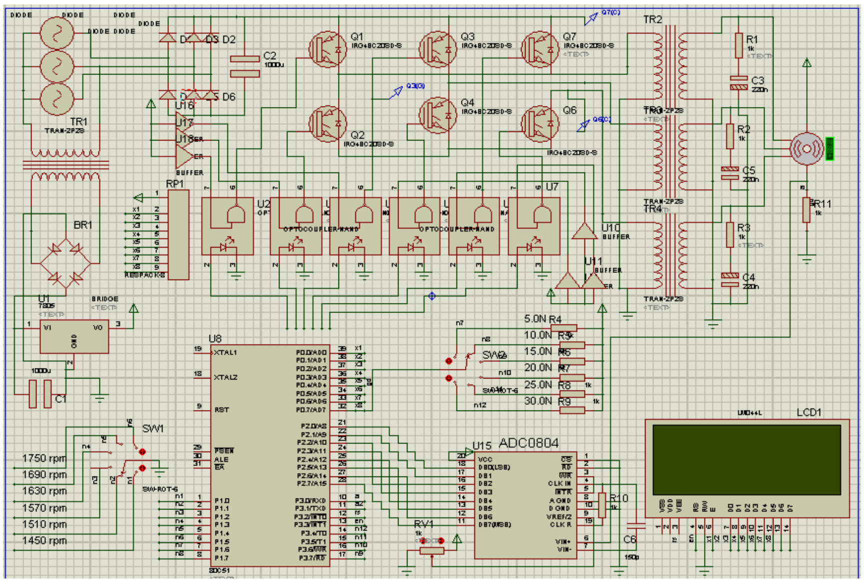
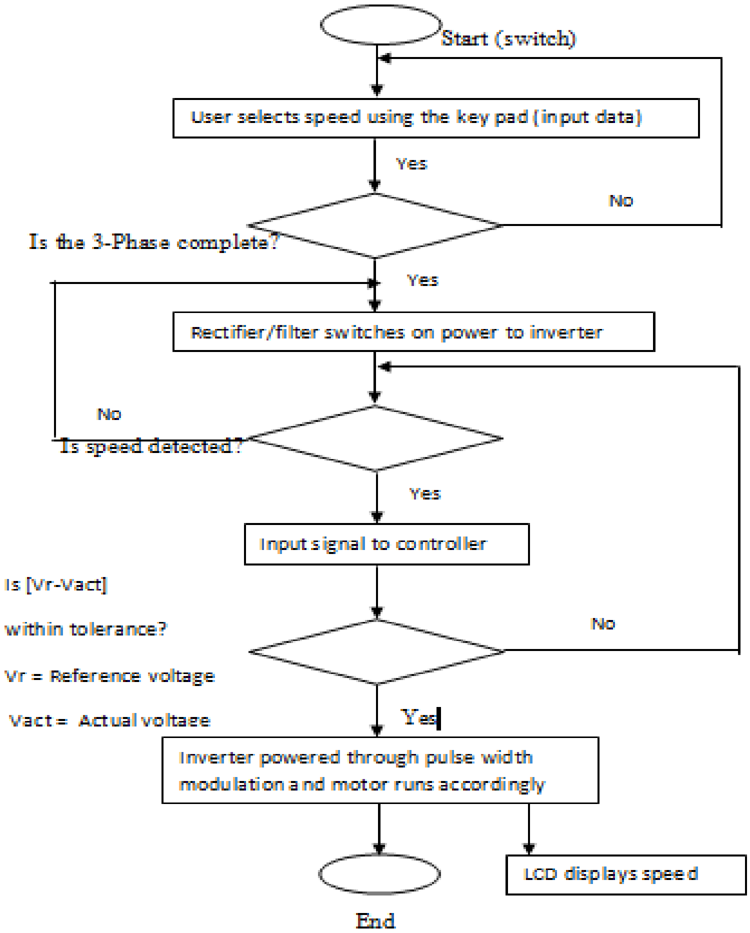


Figure 3: Main circuit diagram



Simulation Results/Comments

The simulation results realized for selected speed and load are as shown in the tables 1-5 and graphs (Figures 5-10) below. The speed-torque characteristics of the new control method is compared with the existing method by

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 speed/frequency and fixed load: 15N

S/No.	Reference Speed (r.p.m.)	Frequency (Hz)	Stator Voltage (V)	V/f ratio	Actual Speed (r.p.m.)
1.	1450	51	342	6.7	1450
2.	1510	53	355	6.7	1510
3.	1570	55	370	6.7	1570
4.	1630	57	384	6.7	1630
5.	1690	59	398	6.7	1690
6.	1750	60	402	6.7	1750

Table 3 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

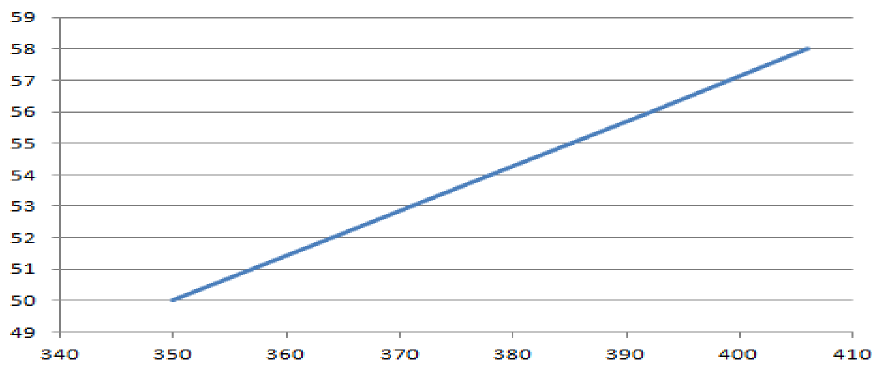
Table 4 Result for variable load and fixed speed: 1510 rpm

S/No.	Load (N)	Frequency of the Output voltage (V)	Current (A)	Actual Speed (rpm)	Maximum Torque (N-m)
1.	5	52	0.90	1510	56.66
2.	10	52	0.91	1510	56.66
3.	15	52	0.93	1510	56.66
4.	20	52	0.94	1510	56.66
5.	25	52	0.95	1510	56.66
6.	30	52	0.95	1510	56.66

Table 5: 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



Voltage in volts

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

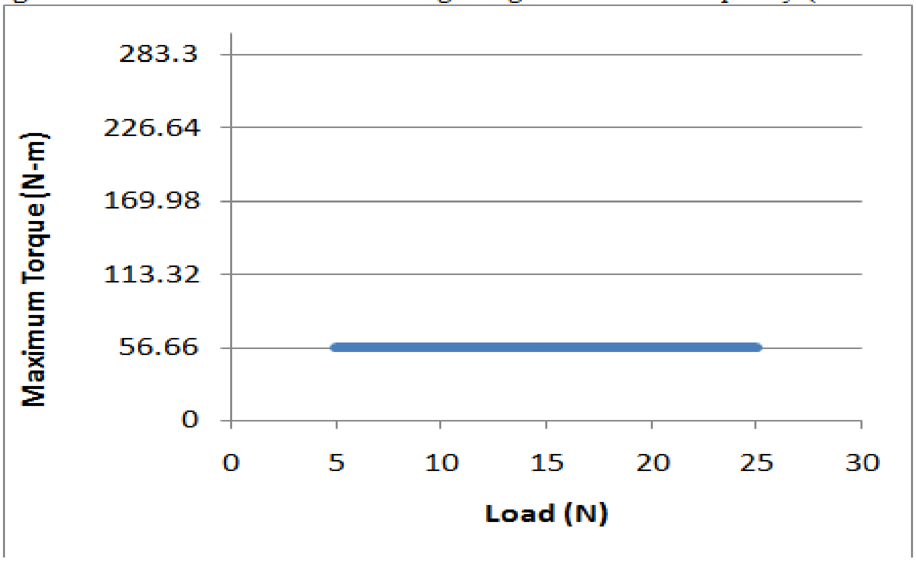


Figure 6 Characteristics of Maximum Torque versus Load for set speed as 1510 rpm

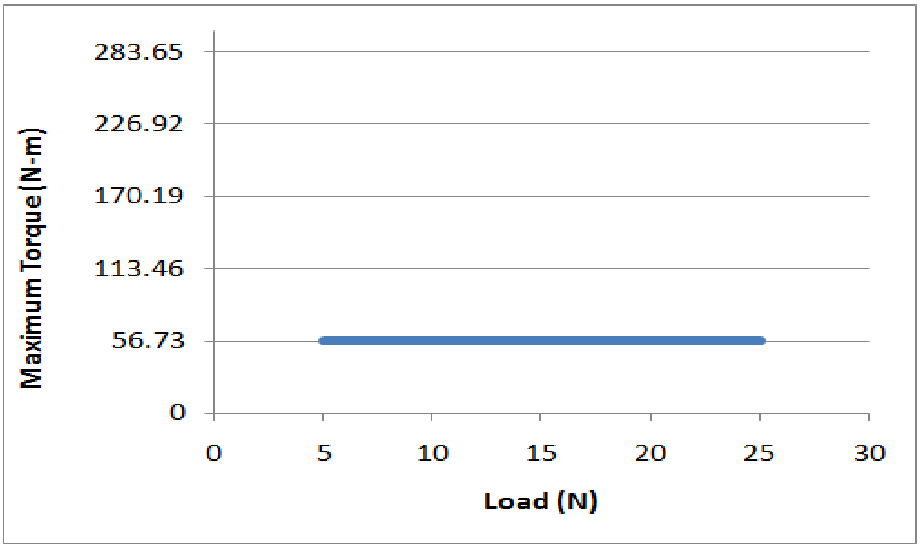


Figure 7 Characteristics of Maximum Torque versus Load for set speed as 1450 rpm

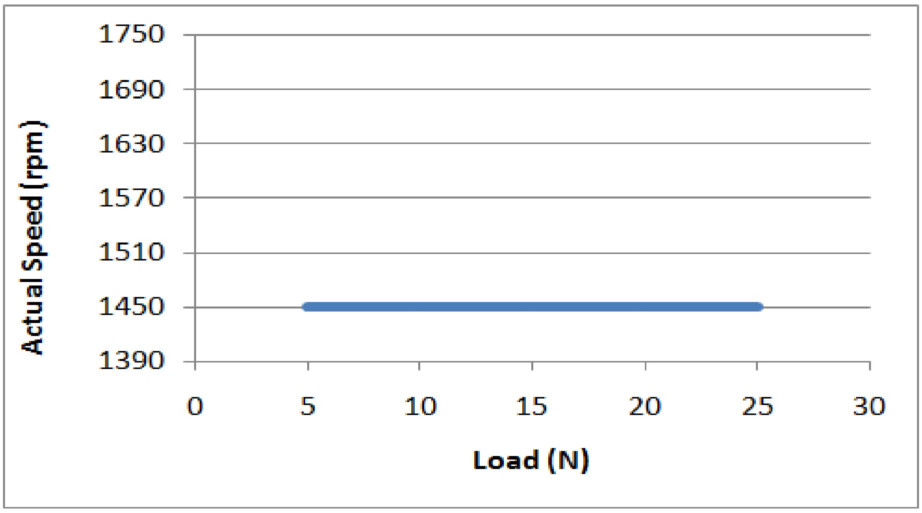


Figure 8 Characteristics of Actual speed versus Load for set speed as 1450 rpm

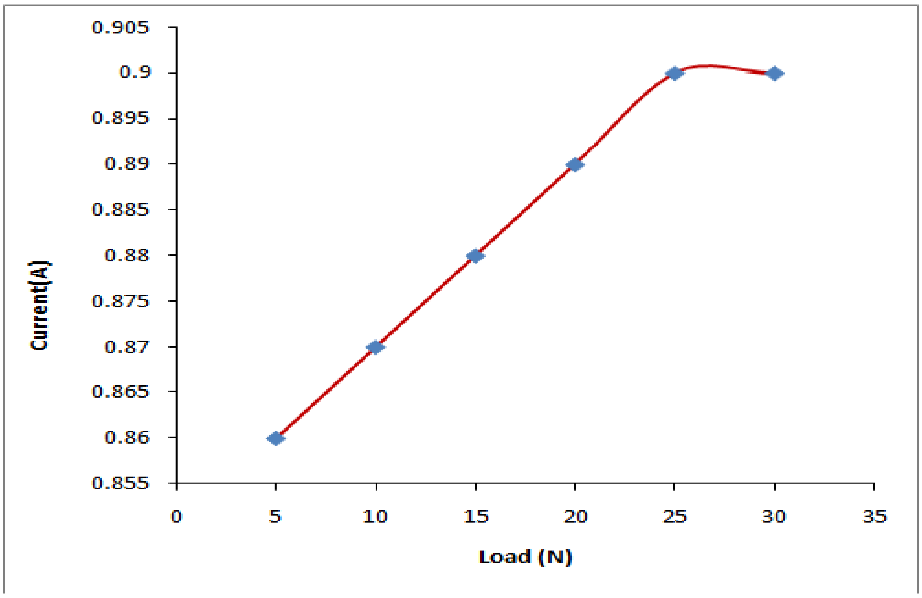


Figure 9 Characteristics of current versus Load for set speed as 1450 rpm

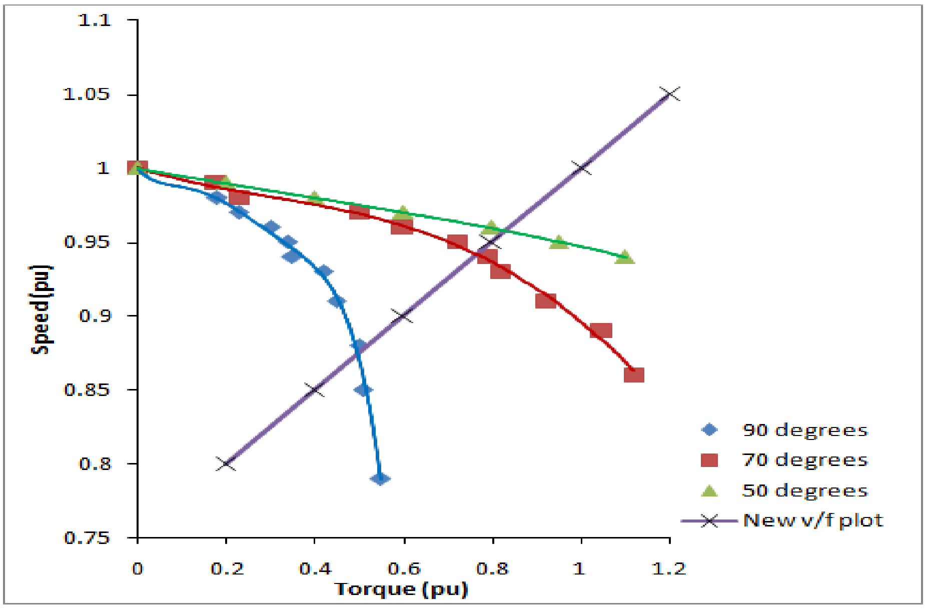


Figure 10 Comparison of Quadi et al (2011) firing method with the new v/f method

4.2 Discussion Of Results

Figures 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. Figures 6 and 7 are plots of maximum torque versus load for set speed as 1510 and 1450 rpm respectively. The graphs show 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 8 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 9 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 Vm 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 10. 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.

III. CONCLUSION

A control scheme for the control of the speed of 3-phase ac squirrel cage induction motor is proposed, verified and established in this research work. Frequency variation control of three phase squirrel cage induction motor has been presented. The complete system is developed and tested. The 3-phase ac induction motor speed control has its software developed in embedded C programming language and uploaded to the controller. The software design contains the source codes which were used to generate the signal for the switching of the inverter thyristors (MCTs). Regulation of speed is achieved with variable duty cycle and variable switching frequency of the issuing pulses from the control circuit. The new hardware switch, the MCT, caused an improved switching action of the inverter in that it produced a minimal conduction drop/switching losses that cause overheating of motor, and at a good switching frequency. This enabled the motor windings to sustain a wide range of loads for a long time without burning out. An algorithm capable of enhancing the speed control of induction motors was developed. The program codes developed in embedded C language was used to control the operation and functionality of the system.

The variation of motor speed corresponded to the system linear voltage-frequency relationship which resulted in constant torque and stable speed for each set speed and wide range of loads. In other words, the induction motor ran with stable speed and negligible fluctuation for a wide range of loads. Speed of the motor is acquired with high accuracy. The selected rpm is locked irrespective of change in load. The maximum torque of the motor was found to be fairly constant and the Voltage per Hertz (V/Hz) line to line output was linear and stable. The speed of the induction motor is varied from 1450 to 1750 rpm and the corresponding frequency range is varied from 50Hz to 60Hz. The drive is operated at an input voltage of 3-phase 415V and the corresponding readings of the stator voltage, stator current, rectifier output voltage and frequency values at different speeds are taken. With the variation of stator voltage, frequency is also varied so as to maintain the V/f ratio constant. The inverter line to line voltage recorded is very smooth compared to single phase. Hence, this three phase induction motor V/f control by microcontroller is more stable, efficient and economical. A speed control scheme for 3-phase squirrel cage induction motor that is able to vary its speed, save resources, maintain speed for a wide range of loads, maintain voltage/frequency balance and maintain torque for each set speed, for variable loads have been achieved from this work. The validity of the system is verified by test results and measurements which demonstrate the performance, response and the functionality of the system. There is a very good stability when controlling the six-gear speed range. The results show that the induction motor can be controlled almost similar to a dc motor by the use of frequency variation method. The microcontroller based control is utilized to generate the pulses required for the switching of the power thyristors (MCTs). With the microcontroller, an intelligent control approach is implemented to reduce the overall cost and to improve the reliability of the system. The instruction program is created in C language. Motor reliability, performance and life cycle cost which are key elements of a successful motor application were all realized in this work. The drive can be used for variable speed applications, in conveyors, rolling mills, gasoline pumps, printing machines, washers, dryers, fan, textile mills, cement mills, sugar mills, machine tools, paper mills, centrifugal pumps, turbo compressors and other sensitive control applications.

IV. RECOMMENDATIONS

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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