RESEARCH ARTICLE OPEN ACCESS

Loss Minimization Technique in Scalar-Controlled Induction Motors

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ABSTRACT:
Core losses are a menace to 3-Phase Induction Motors (3PHIM) and can only be taken care of by adjusting their voltage/frequency ratios using an efficient Voltage Source Inverter (VSI) like the MCT-Inverter. Scalar-controlled induction motors have their speeds controlled by controlling their stator voltages and frequencies in such a way that the ratio of the stator voltage to the frequency is always kept constant. The drive technology of most scalar-controlled 3-phase induction motors utilizes Voltage Source Inverters such as IGBT-Inverter to achieve variable voltage variable frequency. This scheme is considered to save energy in electrical drive, especially when IGBT-Inverter is used to implement variable voltage variable frequency. However, more energy savings and less energy losses are still possible when IGBT is replaced with Mos-Controlled Thyristor (MCT), as the switching device. This is because of the sterling characteristics of MCT as compared with IGBT. Again, this is unlike vector control methods where thyristor can be fired to bring about a change in speed. In this research, a new switching device called Mos-Controlled Thyristor (MCT) for minimizing losses in scalar-controlled induction motors 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 core losses. Comparison of the system with other speed control techniques shows improved energy-saving, cost effectiveness and safety in operation. Thus, Volts per Hertz speed control method based on MCT is a better alternative to other well known methods in speed control and loss minimization of three-phase induction motors.

***Key words*:** Voltage Source Inverter, Volts per Hertz, MCT, IGBT.

Date of Submission: 24-06-2017 Date of acceptance: 14-08-2017

I. INTRODUCTION:

Losses in 3-phase induction motors are of two types namely: fixed losses and variable losses. Fixed losses consist of core loss, friction loss and windage loss while variable losses consist of stator/rotor ohmic losses, stray load loss and brush contact loss. In all these losses, core losses create a major concern in 3-phase induction motors due to its dependability on voltage and frequency values, which determines the optimal magnetic flux created in the motor. Core losses are constant for constant values of voltage and frequency. It consists of eddy current loss and hysteresis loss. Since stator voltage and frequency are the two variables that determine the flux and the flux per current determines the speed of the motor, it then follows that a suitable VSI like the MCT-Inverter can be used to take care of the v/f ratio of the 3-phase induction motor in order to minimize losses. This is the aim of this research. 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. By this, energy losses would have been minimized to the lowest ebb. 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. Aderemi et al (2009) rightly said that energy, for obvious reasons is regarded as the prime mover of any economy, and the engine growth around which all sectors of economy revolve. 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. METHODS

The method adopted in this research for verifying loss minimization in scalar controlled induction motors is Volts per Hertz or variable voltage variable frequency using MCT as the switching device, and using a 3-phase 15kW squirrel cage induction motor as test case. 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 records of Raj et al (2009) reveal that the behavior of an induction motor drive is described by three independent variables namely: the speed, the terminal voltage and the frequency, when the parameters of the motor and its power supply are in place. At any operating speed and torque of the motor, an optimal voltage/frequency (v/f) ratio, which gives the optimal flux, can be found that meets the requirement of the operating point, and minimizes the overall losses. This is basis of MCT-inverter operation.

THE SYSTEM BLOCK/CIRCUIT DIAGRAM, FLOW CHART AND EXPLANATION

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, 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. 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.

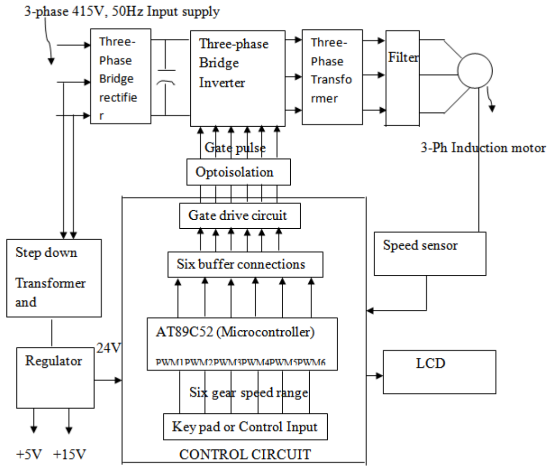

Figure 1: The system block diagram of speed control of 3-phase ac squirrel cage induction motor

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.

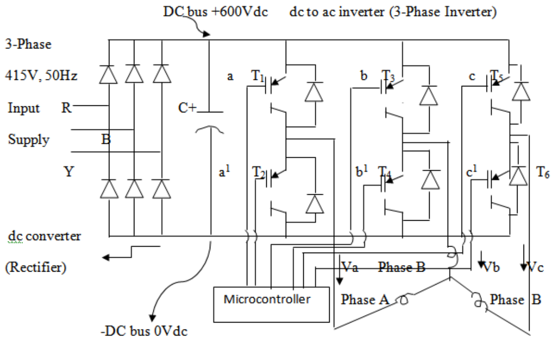

Figure 2: 3-Phase Inverter

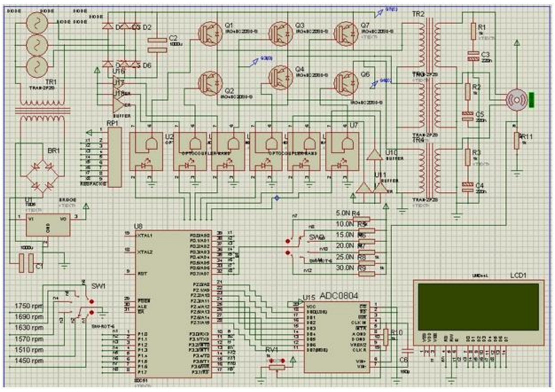

Figure 3: Main circuit diagram

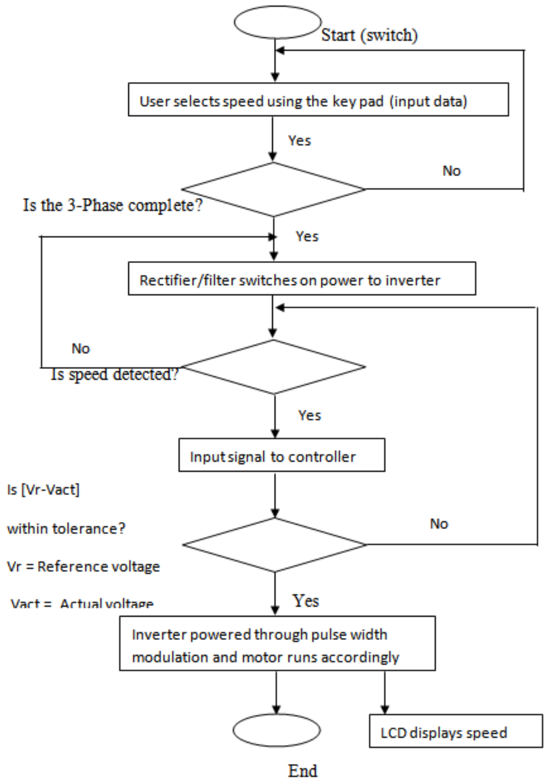

Figure 4: System Flowchart

III. SIMULATION RESULTS

The simulation results realized for selected speeds and load are as shown in the following tables and graphs:

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: Flux versus Magnetizing current (Magnetic characteristic) Eltamaly et al (2007)

S/No.	Flux (Wb)	Magnetizing current (A)
1.	0.2	3
2.	0.4	5
3.	0.6	7.5
4.	0.8	10
5.	1.0	13
6.	1.2	16
7.	1.3	45
8.	1.3	48

Table 4: Flux versus Magnetizing current (Magnetic characteristic) (New v/f method)

S/No.	Flux in per unit (pu)	Magnetizing current in per unit (pu)
1.	0.2	10
2.	0.4	20
3.	0.6	30
4.	0.8	40
5.	1	50
6.	1.2	60

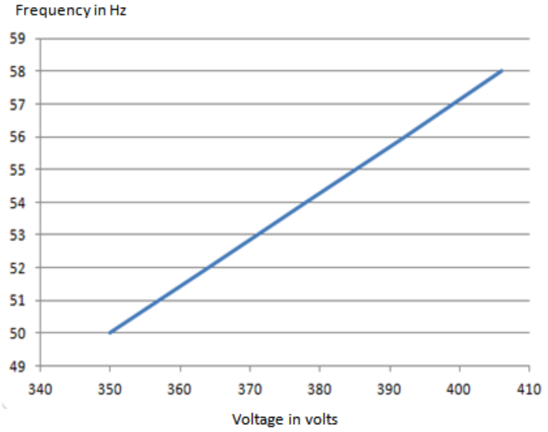

Figure 1 Characteristics of stator voltage magnitude versus frequency (10N load)

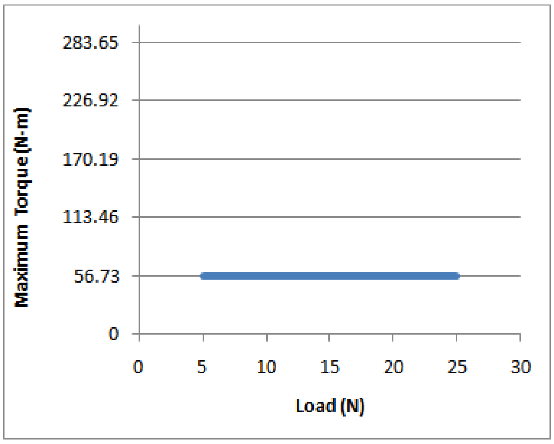

Figure 2 Characteristics of Maximum Torque versus Load for set speed as 1450 rpm

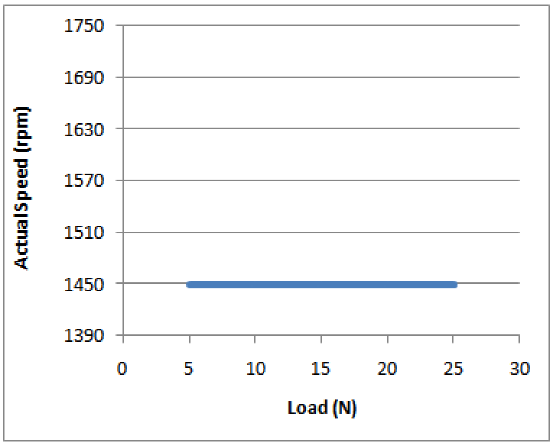

Figure 7 Characteristics of Actual speed versus Load for set speed as 1450 rpm

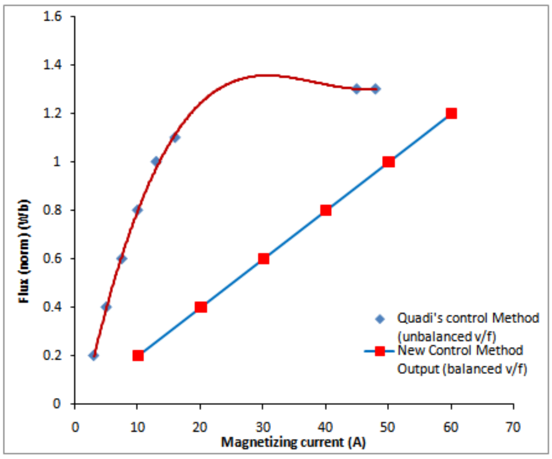

Figure 3 Comparison of magnetic characteristic of existing and new control method

IV. DISCUSSION OF RESULT

Figures 1 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 2 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. Figure 3 is a plot of speed versus Load for set speed as 1450 rpm. The speed is locked through a wide range of loads. Tables 3, 4 and Figure 3 compare the magnetic characteristic of the old and present control method showing that the flux-magnetizing current relationship is linear for the new v/f method and non-linear for the existing methods, as seen in Eltamaly et al's (2007) experiment. Thus, energy losses are minimized in this model. All these are possible because of linearity of voltage/frequency relationship and negligible switching losses made possible by MCT.

V. CONCLUSION:

From the foregoing, the loss minimization technique in induction motors made possible by the resulting magnetic characteristic caused by the new system and the improved switching/switching pattern of the new model, has been verified. The control scheme utilizes the MCT-inverter and the program uploaded to the microcontroller (AT89C52) to manipulate the stator voltage and frequency in such a way as to give maximum energy output and minimal losses.

VI. 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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Engr. E.J. Nnake. “Loss Minimization Technique in Scalar-Controlled Induction Motors .” International Journal of Engineering Research and Applications (IJERA), vol. 7, no. 8, 2017, pp. 14–19.