Single Phase Induction Motor Speed Control by Stator Voltage Control (AC Voltage Controller)

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Abstract – **Until recent years, numerous researches for motor drives focus on the three phase induction motor (TPIM) performance and is out of interest for the single phase induction motor (SPIM). The SPIM is commonly used at low power intensity since it has the uncomplicated construction and economic advantage. Electrical machine has both main winding and auxiliary winding in general. Typically, these windings are fed by only one single-phase source, and the speed of the motor is not controlled. This paper establishes a speed control of single phase induction motor by stator voltage control. An AC voltage controller is proposed for the stator voltage control of single phase induction motor. It controls the motor speed by adjusting the thyristor firing angles. It is suitable to control speed adjustment of induction motor in compressors, blowers, fans, pumps and many other application. To verify the feasibility of this proposed speed control, simulation is carried out.**

Keyword – single phase induction motor; stator voltage control; AC voltage controller; thyristor.

I. INTRODUCTION

SPIM is used widely in common power devices such as most of general electrical home appliances. But this type of motor cannot get rotational magnetic field itself (self-start). Capacitor that connected in series to the auxiliary winding which parallel with main winding makes SPIM possible to start since the current phase of auxiliary winding becomes leading. Then, it generates magnetic field that pulsate as the time passes; the Double Revolving Field Theory (DRFT) and the Cross Field Theory have been used for modelling the SPIM performance.

There are no rotating fields generally in SPIM, but as a substitute a pulsating field on the winding axis is created. This static pulsating field may be resolved in two fields and rotating in opposed path. When rotor is equally static and the reverse torque is created, the rotor does not remain self starting.

Theoretically, the double revolving field theory (DRFT) confirm that a single – phase AC current supplies the main winding so as to generate a pulsating magnetic field that can be separated into two fields, and it will revolve in opposite direction which create magnetic fields in SPIM. The produced magnetic field basically exists due to the relations between the fields and the current induced in the rotor bars which direct to the reversing torque generation. During this environment, the motor will not initiate when the main field is in energized. On the other hand, if an external torque moves the motor in any direction, then the motor will start to alternate.

Figure 1 and Figure 2 represent an equivalent circuit for each field. The upper part of circuit represents the motor's forward rotating component and the lower part of circuit represents the motor's backward rotating component.

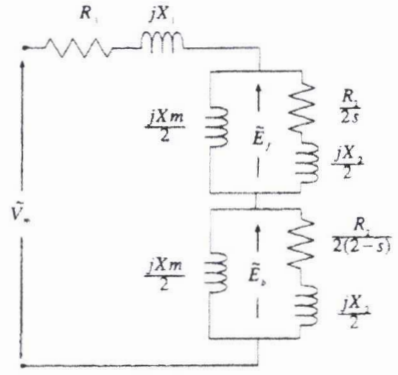


Figure 1: DRFT for SPIM

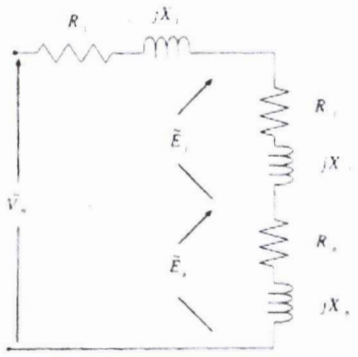


Figure 2: DRFT for SPIM

The constraints for forward and backward winding terminal voltage can be calculated as:

$$R_f = \left(\frac{R_2 X_m^2}{2s}\right)\frac{1}{(R_2/s)^2 + (X_2 + X_m)^2}$$

$$R_b = \left(\frac{R_2 X_m^2}{2(2-s)}\right)\frac{1}{[R_2/(2-s)]^2 + (X_2 + X_m)^2}$$

$$X_f = \left(\frac{X_m}{2}\right)\left[\frac{(R_2/s)^2 + X_2(X_2 + X_m)}{(R_2/s)^2 + (X_2 + X_m)^2}\right]$$

$$X_b = \left(\frac{X_m}{2}\right)\left[\frac{[R_2/(2-s)]^2 + X_2(X_2 + X_m)}{[R_2/(2-s)]^2 + (X_2 + X_m)^2}\right] \quad (1)$$

R and X, are the stator winding resistance and leakage reactance. X_m is the magnetizing reactance. The core loss is normally deducted with the frictional losses because it can be assumed constant. The average electromagnetic torque is calculated as:

$$T_{ave\,mech} = \frac{I_m^2(R_f - R_b)}{\omega_s} \quad (2)$$

Where ω_s is the synchronous speed and I_m is the stator winding rms current. The pulsating air gap flux wave causes ripple in the electromagnetic torque. The pulsating torque maximum amplitude by ignoring friction and windings losses:

$$T_{e\,max} = \frac{I_m^2\sqrt{(R_f - R_b)^2 + (X_f - X_b)^2}}{\omega_s} \quad (3)$$

Within single phase, the voltage across each of the motor's magnetizing branches is affected by the e.m.f induced by the forward and backward rotating fields. Additionally, the voltage across each of "half magnetizing reactance" will typically bigger in scalar amount than the total induced voltage because of the vector accumulation. The result of total level magnetization is reliant on both of the forward and backward field components and reliant to the motor operating condition too.

The scalar control law must be analyzed through Equation (1) to (6), since there is no direct independent method of controlling the magnetizing currents. The main winding terminal voltage can be calculated by means of referring Figure 2:

$$\tilde{V}_m = \tilde{I}_m[(R_1 + jX_1) + (R_f + jX_f) + (R_b + jX_b)] \quad (4)$$

Assessment of I_{xmf} and I_{xmb} can be determined by using current division analysis, as of the equations below:

$$\tilde{I}_{xmf} = \frac{\tilde{I}_m(R_f + jX_f)}{\left(\frac{jX_m}{2}\right)}, \quad \tilde{I}_{xmb} = \frac{\tilde{I}_m(R_b + jX_b)}{\left(\frac{jX_m}{2}\right)} \quad (5)$$

Equations below are used to evaluate the power losses for rotor resistance:

$$P_{loss,f} = \left(\tilde{I}_m - \tilde{I}_{xmf}\right)^2 R_2/2$$

$$P_{loss,b} = \left(\tilde{I}_m - \tilde{I}_{xmb}\right)^2 R_2/2 \quad (6)$$

Parameters of SPIM can be calculated through Equations (1) to (6) by means of DRFT which based on forward and backward fields.

SPIM speed control is popular in a large amount of motor control function since it cut energy utilization and audible noise and provides variable speed. Basically, stator voltage control of an induction motor is used generally for three purposes:

(a) To control the speed of the motor.

(b) To control the starting and braking behavior of the motor.

(c) To maintain optimum efficiency in the motor when the motor load varies over a large range.

It is simple in hardware and reliable as far as speed control application is concerned. The stator voltage control in this proposed speed control systems is by means of a power electronic controller; thyristors in phase control mode are used. Two thyristors in anti parallel are connected in the circuit that creates it as an AC voltage controller. The control is implementing by varying the thyristors firing angle.

The basic concept of speed control by means of stator voltage control is experimentally explored in this paper through SPIM modelling and the thyristors controls are discussed in this paper. The scheme could be implemented to actual SPIM adjustable speed control.

II. METHODOLOGY

A. SIMULATION CIRCUIT

The block diagram that illustrated in Figure 3 will be used to study the speed control of a SPIM in this paper. Figure 4 shows the circuit that being simulated with MATLAB/SIMULINK software; consist of a single – phase supply, AC voltage controller and SPIM. R-L load represented the motor steady state condition due to the fact that they return the core losses in the stator and rotor and the inductance loss for the winding. A voltage of 240V or average voltage of 339.411V and frequency of 50Hz will be supplied to circuit.

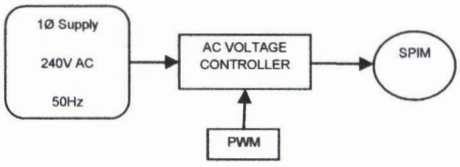


Figure 3: Block Diagram for the Circuit

B. AC VOLTAGE CONTROLLER

When a thyristor switch is connected between an AC supply and load, the power flow can be controlled by varying the rms value of the AC voltage applied to the load. This type of power circuit is identified as AC voltage controller. Since the input voltage is in AC supply, there is no need of extra commutation circuitry because the thyristor is line commutated and the circuits for AC voltage controller are simple and moderately economical. AC switch can be implemented either using a single triac with a single isolated gate circuit but for lower power applications; it can employ two back to back thyristors with two isolated gate circuits, using two diodes and two thyristors with a single isolated gate circuit, or with four diodes and a single thyristor with a single isolated gate circuit. The power flow to the load can be controlled by the ON-OFF or phase angle control techniques.

C. THYRISTOR

Thyristors are now commonly used for power control in both DC and AC circuits. Commonly used methods for voltage control are:

(a) Phase - angle control.

(b) Integral cycle control.

(c) Pulse width modulation control.

Applications of voltage controller consist of industrial heating, induction heating of metals, lighting control, primary transformer control for electrochemical processes and the speed control of induction motor driven loads. A pair of phase-controlled inverse-parallel connected thyristors or a triac is commonly used to obtain the desired voltage variation in phase-angle control. By delayed thyristor firing angle, the rms value of the load voltage and thus current and power should be controlled.

D. PWM

PWM (Pulse Width Modulation) control is employed to vary the rms amplitude of the output voltage. Sinusoidal PWM and uniform PWM technique have been used generally to develop performance and efficiency of AC voltage controller. This type of technique is normally used in industrial application to reduce the total harmonic distortion (THD) and low-order harmonics. A pulse being injected to the thyristors through subsystems that located within the circuit; the unipolar signal type of PWM is used.

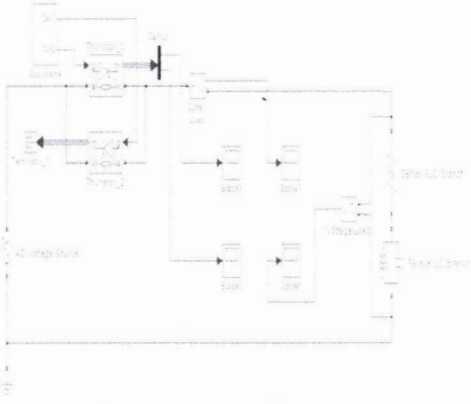


Figure 4: Circuit Simulation Block Diagram

III. RESULT

This part signifies the output of the AC controller itself via thyristor in the circuit. Figure 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14 characterize the thyristor current, thyristor voltage, load voltage and gating pulse for each thyristor at different phase angle. For this simulation, two different phase being manipulated in terms of time value which is 0 second – $1x10^{-3}$ second and 0 second – $2x10^{-3}$ second. In addition, frequency also can be applied to control the output. The frequency could be altered at the PWM of the thyristor instead of altering it at the AC source and it will be represented by this equation:

$$\text{Frequency} = f \times ts$$
$$= 100 \times pi \quad (7)$$

The induction motor is model by a RLC load in the circuit simulation. The load value is permanent all the way through the process. The resistance, R value is 50Ω, the inductance is 5mH, and the capacitance is 100μF.

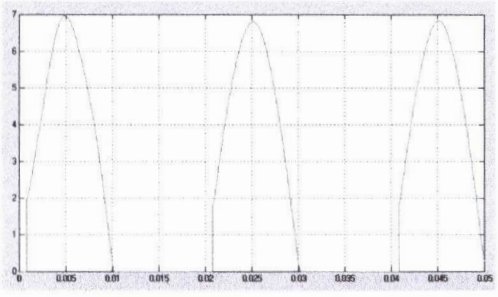


Figure 5: Thyristor Current at 1st Phase Angle

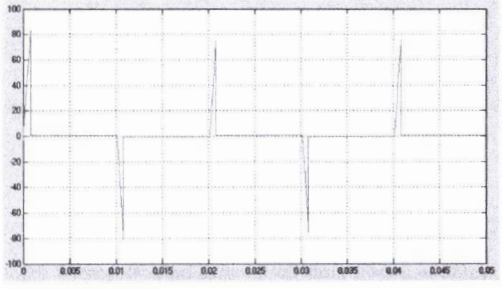


Figure 6: Thyristor Voltage at 1st Phase Angle

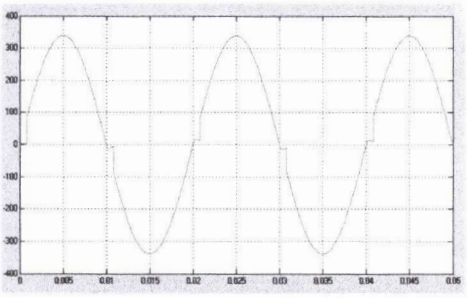


Figure 7: Load Voltage at 1st Phase Angle

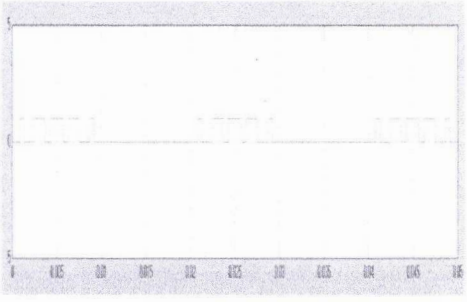


Figure 8: Gate Pulse of T_1 at 1st Phase Angle

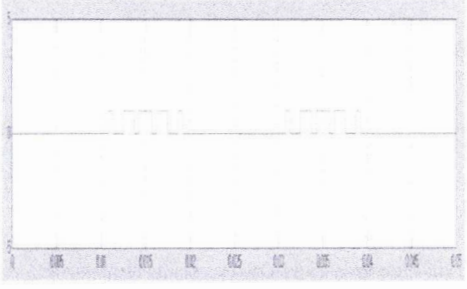


Figure 9: Gate Pulse of T_2 at 1st Phase Angle

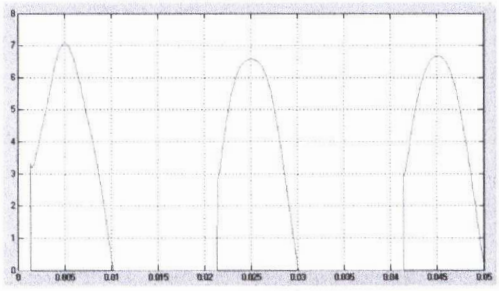


Figure 10: Thyristor Current at 2nd Phase Angle

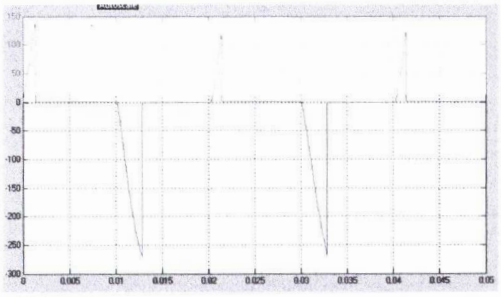


Figure 11: Thyristor Voltage at 2nd Phase Angle

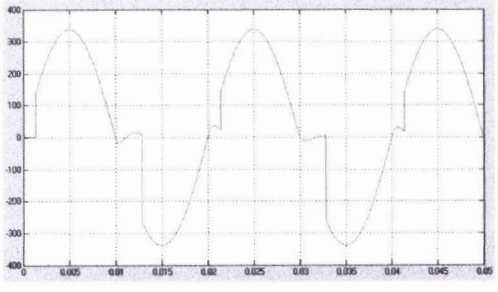


Figure 12: Load Voltage at 2nd Phase Angle

The voltage varies due to variable phase – angle by referring to Figure 5, 6, 7, 10, 11 and 12. The voltage motion turn out to be larger and this will affect the load speed; such that when phase – angle vary, the voltage magnitude also vary due to time. Theoretically, when the stator voltage of an induction motor is altered, the magnetic field rotational rate will vary directly proportional to the speed changes of the motor.

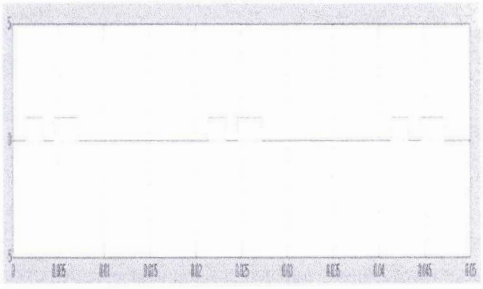


Figure 13: Gate Pulse of T_1 at 2nd Phase Angle

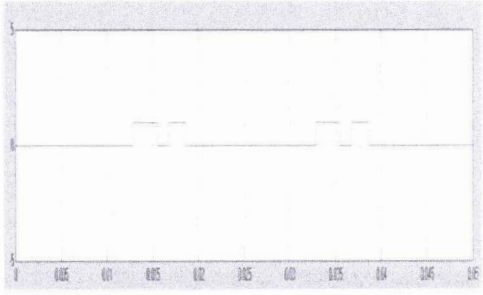


Figure 14: Gate Pulse of T_2 at 2nd Phase Angle

There should be a small alteration in the motor speed due to the fact that the phase - angle varies with the voltage because, the voltage from all the figure above came from the input voltage of the induction motor. Therefore, parameters such torque, power and slip will vary as the speed changes and this can be verified throughout calculation.

Figure 15, 16, 17, 18, 19, 20, 21, 22, 23 and 24 illustrate the output waveform when two different frequency values are used to control the output. It verifies that the output will differ due to the variable frequency. It is different than phase – angle control; nevertheless it will offer an impact to the torque, slip and power of the induction motor.

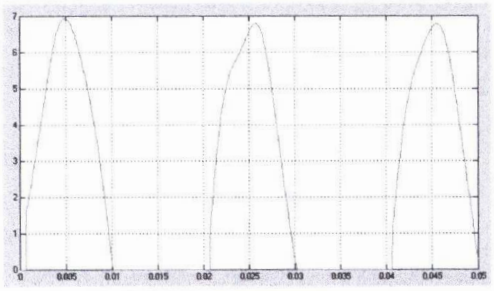


Figure 15: Thyristor Current at 100Hz

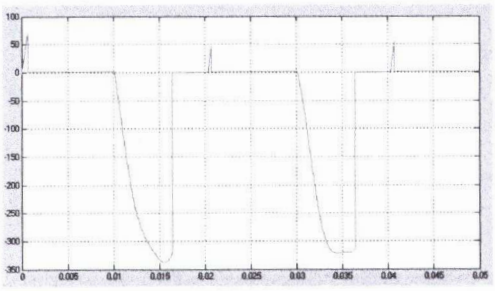


Figure 16: Thyristor Voltage at 100Hz



Figure 17: Load Voltage at 100Hz

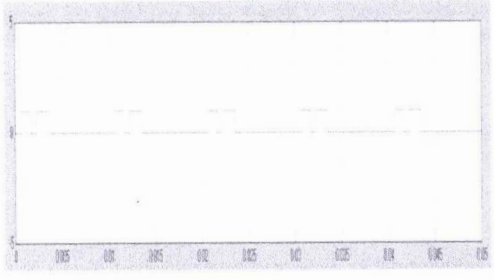


Figure 18: Gate Pulse of T_1 at 100Hz

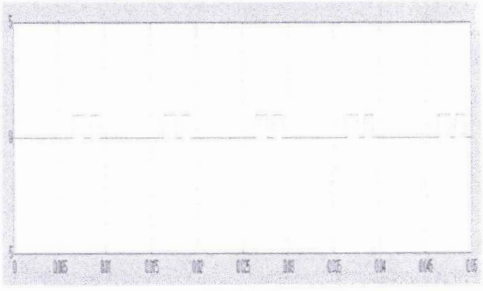


Figure 19: Gate Pulse of T_2 at 100Hz

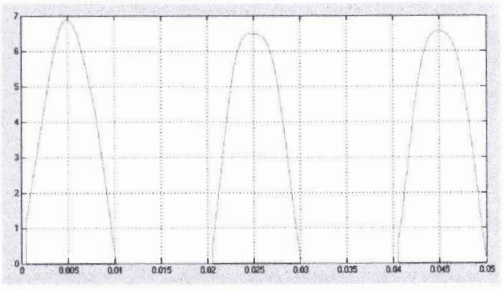


Figure 20: Thyristor Current at 200Hz

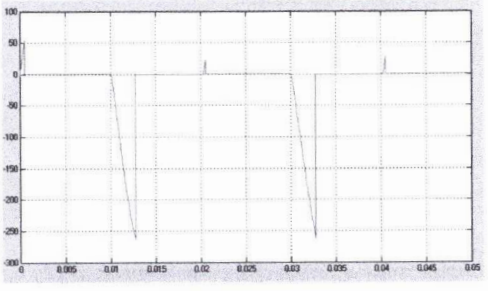


Figure 21: Thyristor Voltage at 200Hz

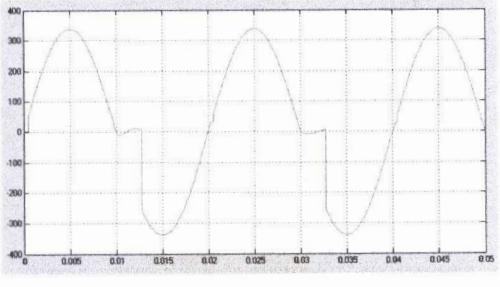


Figure 22: Load Voltage at 200Hz

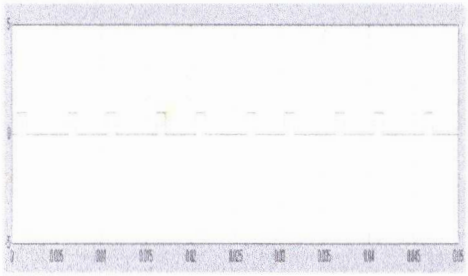


Figure 23: Gate Pulse of T_1 at 200Hz

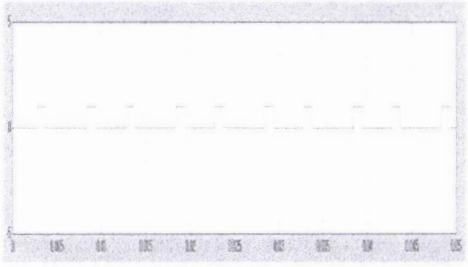


Figure 24: Gate Pulse of T_2 at 200Hz

IV. CONCLUSION

This paper presents a modelling and simulation of SPIM by applying the speed control of AC voltage controller. The speed control of the induction motor is experimentally explored by controlling the firing angle and frequency optionally. It can be concluded with the aim of SPIM can be driven from the stator voltage control method based on phase – angle and thyristor characteristic as of the simulation results. The motor speed can be simply in tune and controlled via the proposed speed control.

V. ACKNOWLEDGEMENT

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VI. REFERENCE

[1] Muhammad H. Rashid, "Power Electronics, Circuit, Devices and Applications," – 3rd Edition 2004.

[2] V.R Moorthi, "Power Electronics: Devices, Circuits and Industrial Applications," Oxford University Press, 2005.

[3] Chapman, Stephen J, "Electrical Machinery and Power System Fundemental ,"– 1st Edition (McGraw Hill in Electrical and Computer Engineering) 2002.

[4] Hamad S.H, S.M. Bashi, I. Aris, N.F. Mailah, "Speed Drive of Single-Phase Induction Motor," National Power Conference (PECon) 2004 Proceedings, pp: 121 – 125.

[5] Dubey, G. K., Doradla, S. R., Hoshi, A. and Sinha, R. M., "Thyristorized Power Controllers", Book, John Wiley & Sons, India, 1986.

[6] Sen P.C. (Paresh Chandra), "Principle of Electric Machines and Power Electronics," – 2nd Edition 1996.

[7] W.J. Monill, "The revolving field theory of the capacitor motor," Trans.AIEE, vol. 48, pp. 614 - 629, April 1929.

[8] Gopal K. Dubey, "Fundamentals Of Electrical Drives," Toppan Company (S) Pte Ltd, Singapore.

[9] Hamed, S. and Chalmers, B., " Analysis of variable-voltage thyristor controlled induction motors" IEE Proc., Vol. 137(3), Pt. B, pp. 184-193, May 1990.