SPEED DRIVE BASED ON TORQUE-SLIP CHARACTERISTIC OF THE SINGLE PHASE INDUCTION MOTOR

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Speed Drive Based on Torque-Slip Characteristic of the Single Phase Induction Motor

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Abstract

Most of the researches for adjustable speed drive focused on voltage amplitude control. However, its only control speed in the constraint limits. Adjustable frequency drives have not been widely used with single-phase induction motors. The scalar control law used for many three-phase inductions motor cannot be used in all operating regimes of the single-phase motor. Calculations show that the slip of the single-phase induction motor is not constant with changes in frequency at a constant load torque. A constant 'volts per hertz' law is found to give approximate rated torque over a portion of the upper speed range, but the maximum available torque decays rapidly below 50% of the base frequency. This paper aims to study the behavior of the single phase induction motor's torque and slip characteristic under variable frequency operation. By holding the level of magnetization constant, a control law can be achieved. This method will be implemented for the practical adjustable speed of the single-phase induction motor. If time permit, the final draft paper will include the practical experimental results to compare the simulation results in order to achieve satisfactory agreement for torque and slip behavior of single-phase induction motors driven from variable frequency supplies.

Keywords: ***Single-phase induction motor, speed drive, torque-slip characteristics, scalar control, adjustable frequency.***

I. INTRODUCTION

The double revolving field theory has been widely used for modeling the performance of single-phase induction motors (SPIMs) operating in steady state. This theory requires that the equivalent circuit parameters be known accurately. Through this theory the slip and torque characteristics of the SPIM can be predicted. These characteristics will be used as reference for controlling the ratio of volt per hertz. This method of control is usually known as scalar control.

Alternatively, other method to control the SPIM is voltage amplitude control. Hamad et al [1], have carried out their research to test the operation of a SPIM when operated in voltage amplitude control. A buck type chopper has been used to control the input voltage of a fully controlled single phase Isolated Gate Bipolar Transistor (IGBT) bridge inverter.

Collins et al [2], have examined the operation of SPIM when operated from a variable frequency power supply. The paper show that SPIM behave quite differently than the three phase induction motor at low frequency. They concluded that the SPIM can be successfully driven from a variable-frequency power supply with consideration to the motor's maximum available steady-state and dynamic torque.

This paper aims to study the behavior of the single phase induction motor's torque and slip characteristic under variable frequency operation which has advantage over voltage amplitude control for wide range speed control. By holding the level of magnetization constant, a control law can be achieved. This method will be implemented for the practical adjustable speed of the single-phase induction motor.

II. DOUBLE REVOLVING FIELD THEORY (DRFT)

The single-phase induction motor operation can be described by two methods. One is Double Revolving Field Theory and the other one is Cross-field theory. In this paper the emphasized is given to the DRFT where its equivalent circuit does not matter the auxiliary winding or shading coil. Theoretically, a single-phase ac current supplies the main winding that produces a pulsating magnetic field. This pulsating magnetic field could be divided into two fields, and they rotate in opposite directions. The interaction between the fields and the current induced in the rotor bars generates opposing torque. Under the condition, when only the main field energized, the motor will not start. However, if an external torque moves the motor in any direction, the motor will begin to rotate [3].

The pulsating fields have forward and backward rotating field. Each of the rotating field induces a voltage in rotor, which drives current and produces torque. An equivalent circuit as shown in Fig. 1 can represent each field. In this circuit, the upper circuit depicts the motor's forward rotating component and the lower circuit depicts the motor's reverse/backward rotating component. The circuit in Fig. 1 can be simplified to an equivalent circuit as shown in Fig. 2.

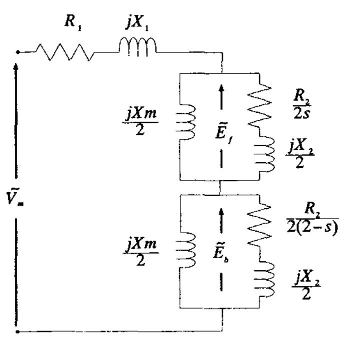

Fig. 1 DRFT for SPIM model.

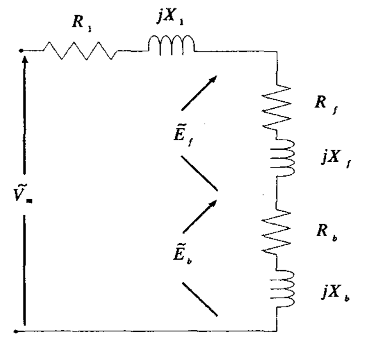

Fig. 2. DRFT for SPIM model (simplified).

The parameters for forward and reverse/backward impedances of the motor are calculated as:

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

R_1 and X_1 are the stator winding resistance and leakage reactance, R_2 and X_2 are the rotor resistance and leakage reactance. X_m is the magnetizing reactance. The core loss is normally subtracted 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 rms stator winding current. The pulsating airgap flux wave causes ripple in the electromagnetic torque. Neglecting friction and windage losses, the maximum amplitude of the pulsating torque is given by:

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

In three-phase induction motor, the voltage across the single magnetizing reactance is almost constant or similar to the stator terminal voltage. But in single phase, the voltage across each of the motor's magnetizing branches is affected by the emf induced by the forward and backward rotating fields. In addition, because of vector addition, the voltages across each "half magnetizing reactance' will usually be larger in scalar sum than the total induced voltage. This results total level of magnetization is dependent on both the forward and backward field components and also dependent to the motor operating condition.

Since there is no direct independent method of controlling the magnetizing currents, the scalar control law must be analyzed through Equations 1 to 6. From Fig. 2, the main winding terminal voltage can be calculated as:

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

By using the current division analysis, $\tilde{I}_{xmf}$ and $\tilde{I}_{xmb}$ can be determined from the equations below:

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

To calculate the power losses for rotor's resistance, the equations below is used:

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

Through Equations 1 to 6, torque and slip characteristic of the single phase induction motor can be predicted.

III. SIMULATION AND DISCUSSION

A. Motor Parameters

The motor's equivalent circuit parameters were experimentally determined under no load and locked rotor tests. The parameters used in the simulations are given in Table 1. The Simulation were carried out using MATLAB/SIMULINK package. Using this data, the torque-slip characteristics of the single phase induction motor is shown in Fig. 3 for a terminal voltage of 115 V and frequency of 60 Hz. The rated torque of the motor is 2.56 Nm and the simulations neglect all friction and windage losses.

Table 1: Parameters for the DRFT equivalent circuit for the main winding of single phase induction motor.

Main Winding	Value
R_{1m}	0.951Ω
X_{1m}	1.65Ω
X_2	1.46Ω
X_m	35.8Ω
R_2	1.02Ω

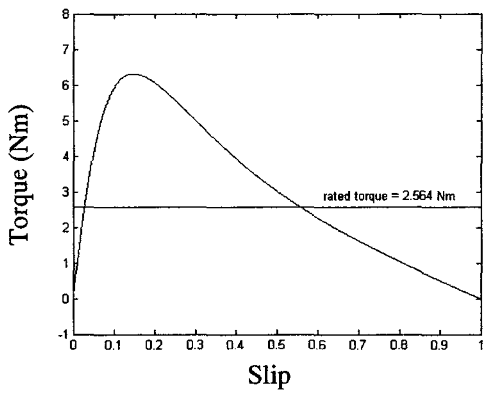

Fig. 3. Torque-Slip Characteristic for a single-phase induction motor at 115 V

This section discussed the comparison of the torque-slip characteristic of the single-phase induction motor and three-phase induction motor driven from variable frequency supplies. It is known that, the magnetizing current in the three-phase induction motor, normally held constant even the frequency is adjusted at very low value (where the ratio of the terminal voltage to frequency is always kept at constant). Therefore, the three-phase torque-slip curves are identical in variable frequency operation. Furthermore, the rated torque can be obtained from near synchronous speed all the way down to zero speed by keeping the level of magnetization constant.

The situation is different for the single phase induction motor, although the behavior is similar with three-phase induction motor but the available torque diminishes substantially as the frequency is reduced. Fig. 4 shows the torque slip characteristics for various frequencies when the terminal voltage to frequency (V/Hz) ratio is 115 V / 60 Hz or 1.92. It can be clearly seen that as the frequency is reduced the slip must increase to provide rated torque. The increasing slip is accompanied by sharp increases in line current as shown in Fig. 5.

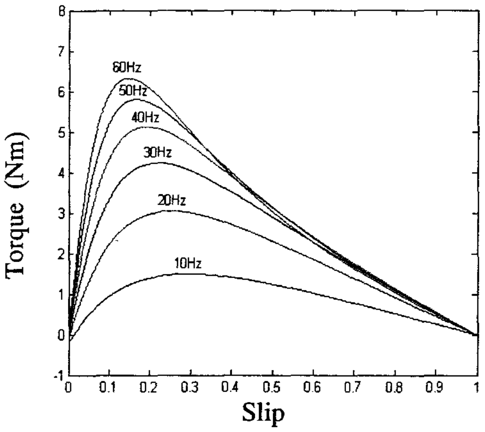

Fig. 4. Torque slip characteristics for various frequency using constant V/Hz ratio or 1.92

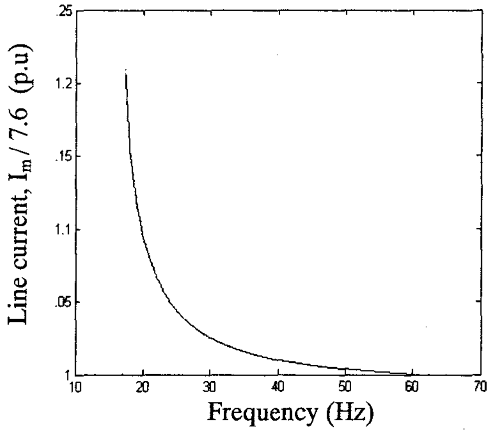

Fig 5. Per unit stator line current

B. Simulation Circuit

Fig. 6 shows the complete block diagram of the simulation circuit, which consists of a single-phase rectifier, buck chopper and inverter [4]. Matlab/Simulink software has been used as a tool for the simulation. The steady state condition of the motor has been represented using R-L load as they reflect the losses in the stator and rotor cores and also the inductance for the winding.

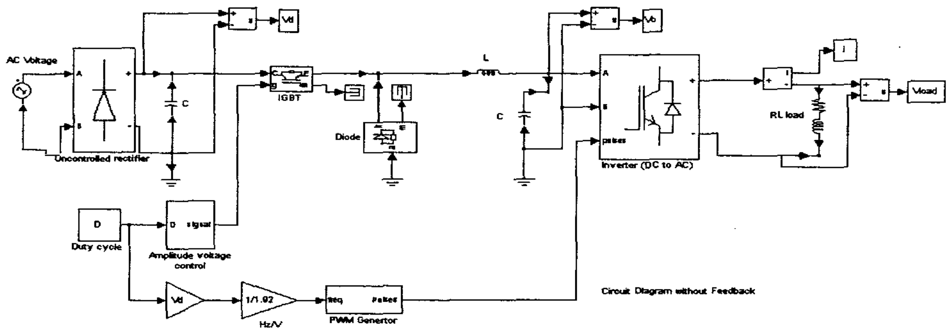

Fig. 6. Block diagram for simulation circuit

C. Simulation Results

Fig. 7 shows the simulation waveforms at the different point of the complete circuit, which is the rectifier output, chopper output and load voltage. Fig. 8 and Fig. 9 show the load voltages and the line currents at frequency of 60 Hz and 20 Hz respectively. For both frequencies, the voltage-frequency ratio is held constant at 1.92. From Fig. 9, it can be seen that, as the frequency becomes less than 50% of the base frequency (60Hz), the line current becomes higher.

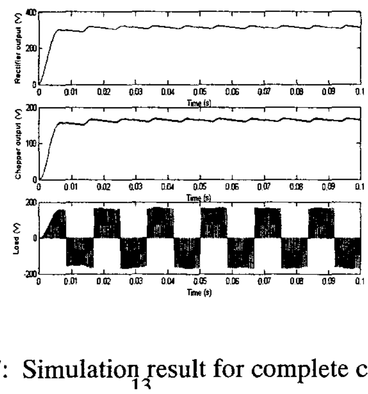

Fig. 7: Simulation result for complete circuit

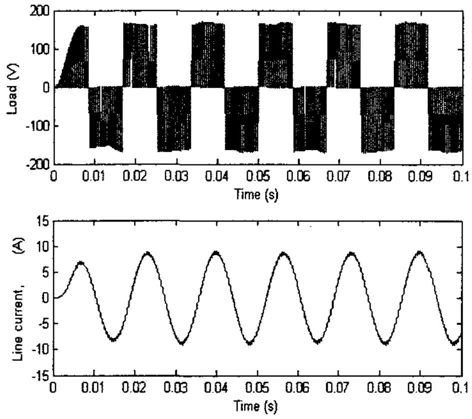

Fig. 8. Load voltage and line current at 60Hz

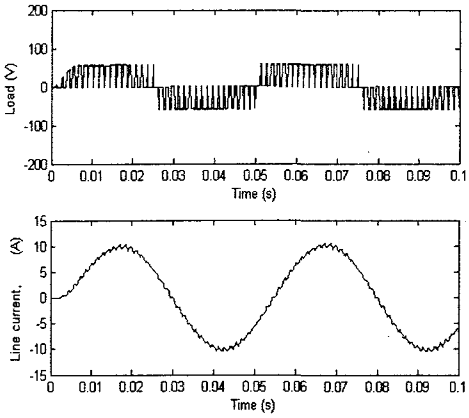

Fig. 9. Load voltage and line current at 20Hz

IV. HARDWARE DESCRIPTIONS

A full bridge rectifier will be used to convert the ac supply to a dc supply. The output of the uncontrolled rectifier applied to the input of buck converter which controls the voltage level. The controllers consist of DSP processor and PIC have been programmed according to Speed Control Module (SCM) based on Torque-Slip Characteristics. The DSP based controller senses the load current, I_m from the current transducer and speed from the incremental encoder. The output of DSP produces the desired amplitude of voltage to feed the buck converter. PIC is a support component to DSP in order to reduce the processing burden. The output of PIC provides the frequency using PWM technique which controls the inverter output. The last component of this set-up is the inverter which receives the dc signal from the chopper and converts it to ac power to feed the motor under control. The single phase induction motor is connected to a dynamometer, where the load torque could be electrically controlled. Figure 10 shows the hardware circuit implementation for this work.

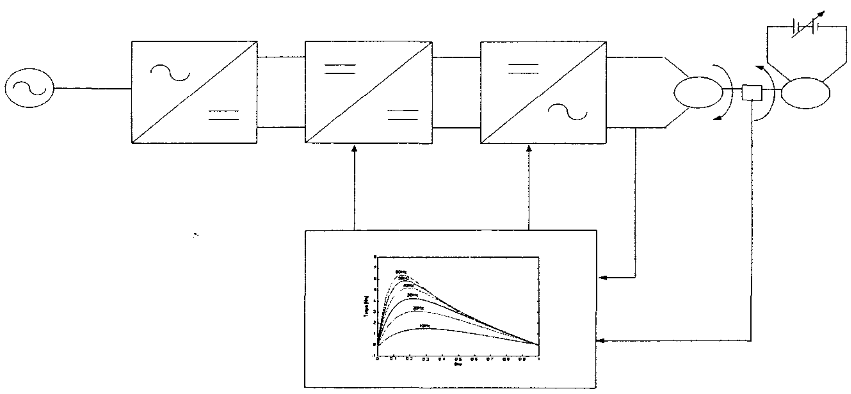

Fig. 10. Block diagram of the circuit

V. CONCLUSIONS

From the simulation results, it can be concluded that the single-phase induction motor can be driven from a scalar control method based on torque-slip characteristic. The motor's speed can be easily adjusted and controlled over the wide range using the propose drive system.

VI. REFERENCES

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