Study on single phase induction motor conditions using voltage level method

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Abstract—**This paper presents an analysis of the performance of single phase induction motor (SPIM) by varying the duty cycle of buck chopper. This paper also aims to study the behavior of SPIM characteristics under variable motor conditions. The chopper also has been used to control the voltage input for the single phase isolated gate bipolar transistor (IGBT) bridge inverter. The inverter used PWM technique to supply the motor. The work was conducted by using a digital computer simulation (MATLAB software). In this paper, the simulation results showed the good results of a simple SPIM.**

Keywords-component; single phase induction motor, varying duty cycle, variable motor conditions

I. Introduction

Single phase induction motors are commonly used in many applications. It is commonly used mainly due to its reliability, lowest maintenance and simple in construction. The single phase induction motors are often used rather than three phase motors because some of the places where the three phase power are usually not available. The single phase motors also commonly used because of the easy installation. The single phase motors usually used for home equipments such as refrigerators, fans, blenders, washing machine and so on.

Occasionally a manufacturing defect can resulted in early motor failure. However, most failures resulted from inappropriate application. Not choosing the correct motor type and horsepower can cause repeated motor failure and equipment downtime. The motor also should not too small for the application, thus resulting in electrical stresses that cause premature motor failure. But neither should specify a motor too powerful, either because of its power or its inherent design characteristics. It can also have serious effects. Therefore, the parameters of motor should be carefully chosen.

Ningze Tong et al [1], have carried out their research to analyzed the locked and rating operation of SPIM by using voltage source circuit coupled finite element methods. First, the 2D model with slide boundary is presented. Then, the simulation result at rated speed is discussed. They concluded that it is possible to estimate the magnetic characteristics of power apparatus by using the finite element method (FEM) taking account of the terminal voltage.

Deghedie et al [2], have presented a novel high performance hysteresis current controlled single phase induction motor (SPIM). The system eliminates the use of any capacitors either during starting or running conditions. The first technique changes the ratio between the magnitudes of the main and auxiliary winding currents while keeping them in quadrature. The second technique varies the phase-shift angle with equal main and auxiliary currents. Simulation results showed that the first technique gives smoother, quicker response, less torque pulsations and wider range of motor speed control than the second technique. Also, the first control technique gives higher starting torque and efficiency than the conventional capacitor-start and capacitor-start capacitor-run motors.

The numbers of SPIM used are increasing every single year in most areas, which means that there are mostly failures resulted. In such cases, it is important to improve the performance characteristics of the SPIM. The voltage and phase angle sequence control strategy of the auxiliary winding of the SPIM is employed to eliminate the centrifugal switch and the starting condenser [3].

Lettenmaier et al [8] have carried out their research to examine the operation of SPIM using a new electronically controlled capacitor. The system used a dc capacitor switched by a transistor H bridge. The system used to replace standard SPIM capacitor configuration to achieve improve machine performance.

There are several ways to control the speed of SPIM such as by pole changing, line voltage, rotor resistance and line frequency [6, 7]. Many researchers examine the operation of a single phase induction motor by varying frequency [4]. Methods of using multi frequency and new Binary Rate Multipliers (BRM) technique to control the speed of SPIM gives rise to suitable energy supply to motor at any instant [5].

The method of voltage control to the motor terminals is a convenient and economical way of achieving speed control [7, 9]. By using a triac, voltage applied to the motor can be control in both positive and negative half-cycles.

The model of the single winding, single phase induction motor using the double revolving field theory (DRFT) can be represented as in Fig. 1. The DRFT states that at pulsating flux density or mmf can be described using two rotating or revolving waves, one in the forwards direction, and one in the backwards direction, each with half of the magnitude of the fundamental.

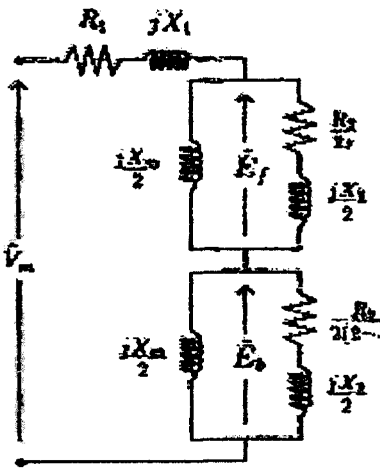

Fig. 1: Single phase induction motor model using DRFT

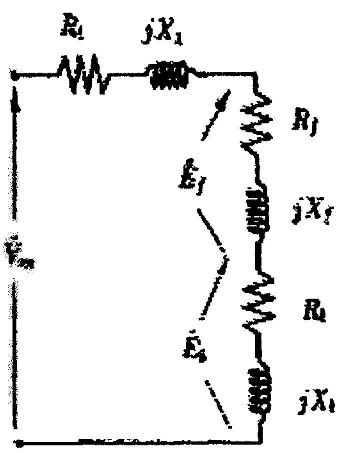

Fig. 2: Simplified model of the single phase induction motor

The parameters of the simplified model of the single phase induction motor as in Fig. 1 where the forward and backward impedance of the motor are defined as:

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

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

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

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

The torque developed by an induction motor is proportional to the square of the applied voltage. The method of varying the applied voltage used to control the speed of the motor over a limited range. As the terminal voltage applied to the motor decreases, the torque also decreases. When the torque decreases, the speed of single phase induction motor also reduces. This method of control is sometimes used on small motor driving fans.

In this paper, the voltage applied to the motor is controlled by varying the duty cycle or pulse width duration of dc chopper. The output of chopper supplied dc voltage to ac inverter and converted to ac voltage to deliver to the motor.

II. UNCONTROLLED RECTIFIER

The concept used in this motor control is to implement the variable voltage level to control the input applied to the motor. There are 4 circuits involved in this operation of circuit that are rectifier circuit, chopper circuit, inverter circuit and Pulse-Width Modulation (PWM) circuit. Rectification refers to the process of converting an ac voltage or current source to dc voltage and current. The rectifier used is the type of single phase uncontrolled full bridge rectifier. The used of full bridge rectifier rather than split power supply configuration is because it can be used in applications that ranging from 100 W to 100 kW while the split power supply type used only for applications ranging under 100 W [10]. The capacitor used in the rectifier circuit is to prevent the motor voltage to be reflected back to the input of circuit. The equation related to define the output voltage of rectifier is [10]:

$$V_{DC} = V_{RMS}\sqrt{2} \quad (2)$$

Where

V_{DC} = output voltage of rectifier (V)
V_{RMS} = input voltage of rectifier (V)

III. DC CHOPPER

The operation of buck chopper is simple by using the switch like IGBT to control the inductor. The output of rectifier is supplied to DC chopper which used to controls the voltage level. The output of chopper is controls by varied the duty cycle or pulse width duration. The chopper used to step down a DC voltage source and converted a fixed-voltage DC supply to a variable-voltage DC supply. The used of capacitor is to limit the output ripple of voltage for obtaining a more like a DC output. The value of capacitor is large in order to keep the voltage constant. The equations related to find the specifications of buck chopper are [10]:

$$k=\frac{V_a}{V_s}$$

$$\Delta I=I_2-I_1$$

$$L=\frac{V_s k(1-k)}{f\times\Delta I}$$

$$C=\frac{\Delta I}{\Delta V_c\times 8f} \qquad (3)$$

Where

k	= duty cycle
V_a	= input voltage of chopper (V)
V_s	= output voltage of chopper (V)
ΔI	= peak-to-peak ripple current (A)
L	= filter inductance (H)
f	= switching frequency (Hz)
C	= filter capacitance (F)
ΔV_c	= capacitor ripple voltage (V)

IV. AC INVERTER

The DC voltage is converted to AC voltage supply by using AC inverter to apply to the motor. The output of inverter is sinusoidal waveform. The inverter used four switches of IGBT to generate positive and negative pulses of single phase. The frequency is fixed and variable output voltage is obtained by varying the duty cycle of the chopper switch. When a positive voltage signal is generated, IGBT Q1 and Q3 turned on at the same time while IGBT Q2 and Q4 turned off. When a negative voltage signal is generated, IGBT Q2 and Q4 turned on while IGBT Q1 and Q3 turned off.

V. PWM SWITCHING TECHNIQUE

The Pulse Width Modulation (PWM) used to generate pulses that trigger the IGBT switches of the inverter. This technique is used to reduce the harmonic contains. In this work, the technique used is Sinusoidal PWM (SPWM). The modulation is generated by comparing a sinusoidal reference signal with a triangular carrier wave of certain frequency, f_c. The frequency of reference signal, f_r determined the inverter output frequency, f_o and its peak amplitude, A_r controls the modulation index, M and in turn the rms output voltage, V_o. the type of PWM used is unipolar PWM. The equations related to define the sinusoidal pulse width modulation are [10]:

$$\omega=2\pi f$$

$$f=\frac{1}{t} \qquad (4)$$

Where

ω	= frequency (rad/sec)
f	= switching frequency (Hz)

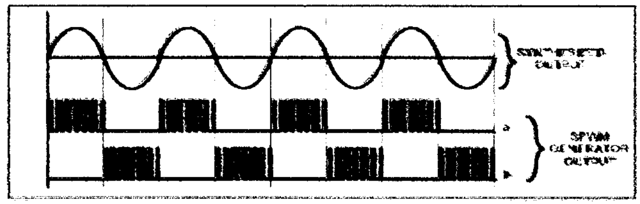

Fig. 3: Switching pattern of SPWM

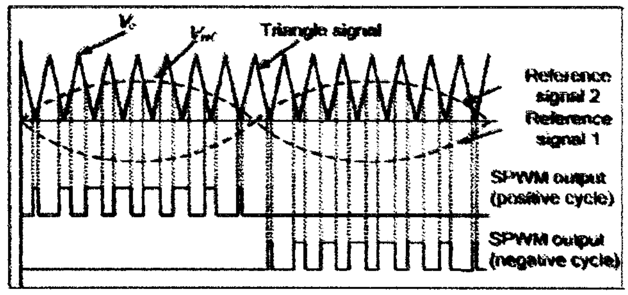

Fig. 4: Formation of SPWM

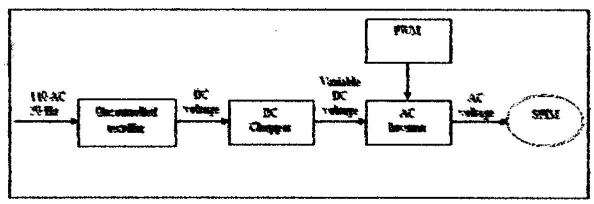

Fig. 5: Block diagram of the circuit

VI. SIMULATION OF THE SYSTEM

Simulation setup was made by using Matlab / Simulink software to analysis the performance of SPIM. Fig. 6 shows the complete circuit simulation diagram which consist of a single phase rectifier, DC buck chopper and AC inverter circuit. When in the steady state, the motor can be simulated as R-L. The resistance, R modeled as the losses in the stator and rotor cores while inductance, L as the losses in the winding. Fig. 7 shows the simulation result for the complete circuit and waveforms at rectifier output, chopper output and motor output.

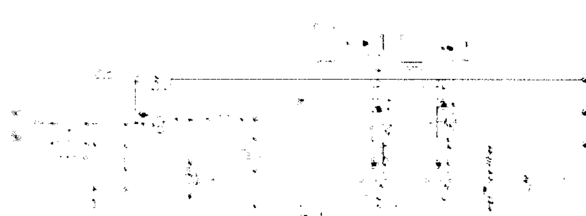

Fig. 6: Block diagram for simulation circuit

The supply voltage of the complete circuit is 120 Vac, 60 Hz. The output of the rectifier converted to dc voltage of 169.71 Vdc. The dc buck chopper used to convert dc fixed voltage to dc variable voltage. The specifications of the dc buck chopper used in the simulation were as follows:

IGBT with fall time, T_f = 1μs and tail time, T_t = 2μs, duty cycle, δ = 60%, inductance, L = 50 mH, resistance, R = 250 Ω and capacitance, C = 500 μF.

The specifications of the ac inverter used in the simulation were as follows:

Four IGBTs, DC supply voltage of the inverter = 100 Vdc, frequency of the output voltage = 50 Hz and modulation index, M = 0.8.

The motor used in the simulation circuit are resistance, R = 16.51 Ω, inductance, L = 57.3 mH and capacitance, C = 5000 μF.

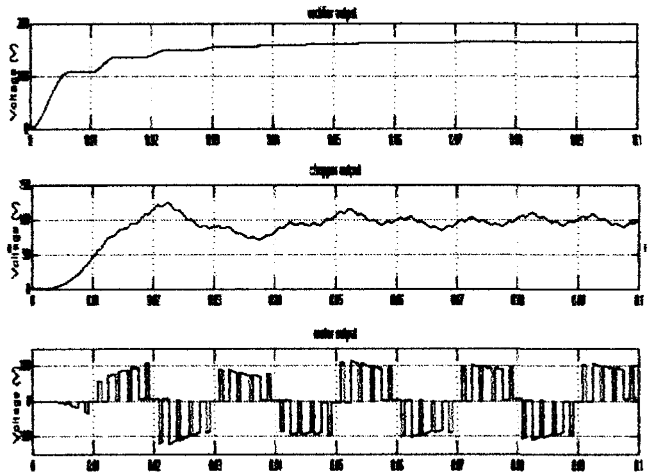

Fig. 7: Simulation result for complete circuit

Fig. 7 shows the rectifier output, chopper output and motor output. The rectifier output shows the value of dc voltage is 169.71 Vdc. The chopper output shows that the value of variable dc voltage is lower than the input voltage when operating in steady state. The motor output shows that there are positive and negative cycles of voltage signal generated through the inverter and show the desired type of unipolar PWM.

VII. RESULTS AND DISCUSSION

The simulation was carried out by using MATLAB / Simulink software. Using the data of ac voltage supply 120 Vac, frequency of 60 Hz is shown in Fig. 8, 9 and 10 from variable duty cycle.

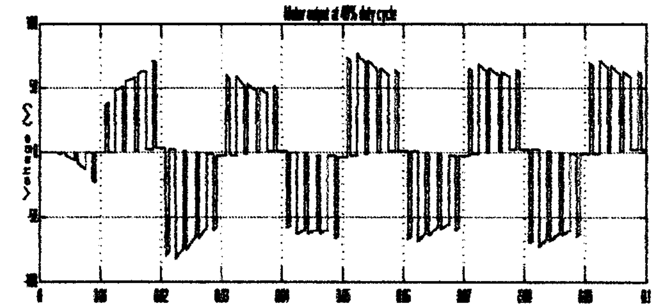

Fig. 8: Matlab simulation motor output voltage for 40% duty cycle.

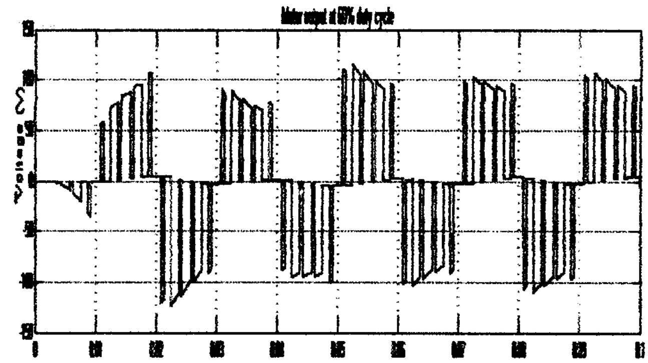

Fig. 9: Matlab simulation motor output voltage for 60% duty cycle.

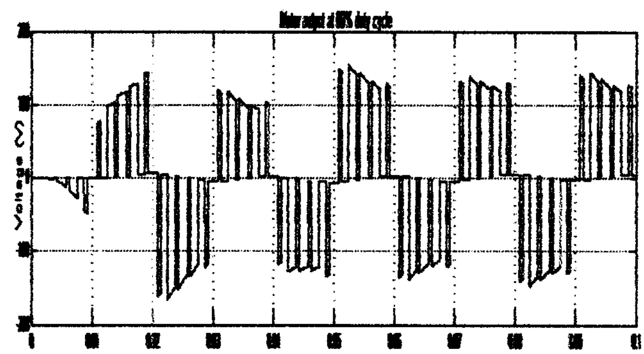

Fig. 10: Matlab simulation motor output voltage for 80% duty cycle.

As shown in these figures, the amplitudes for each voltage waveform are different with each other. Notice that in Fig. 8, the amplitude of voltage waveform is lower than the other waveform because of low duty cycle. When increasing the duty cycle to 60%, the amplitude of motor voltage also increased as shown in Fig. 9. It can be seen that the motor output voltage is increased when applying duty cycle of 80%.

Fig. 11 and 12 shows the motor output voltage when applying with variable motor conditions at 60% duty cycle.

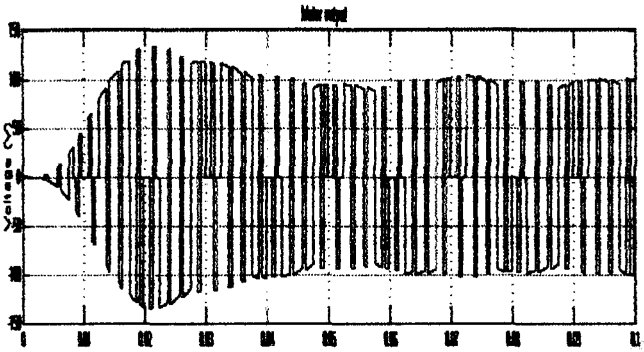

Fig. 11: Matlab simulation motor output voltage without C filter for 60% duty cycle with R = 16.51 Ω and L = 57.3 mH.

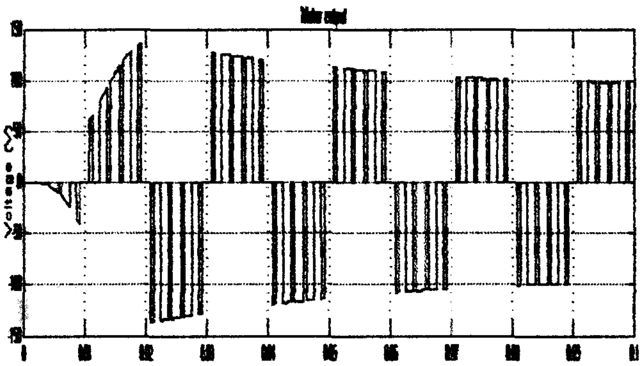

Fig. 12: Matlab simulation output voltage when the motor disconnected for 60% duty cycle.

From Fig. 11, it shows that there are no chops up effect occurred in the motor output voltage. This is due to the effect of no filter capacitor C used in the circuit. As in Fig. 12, the pattern of waveform is almost the same as in when the motor is used, there is difference between them. The difference can be seen at the peak of the motor output voltage. The peak is smooth because there is no resistor R or inductor L which means that no losses in the stator and rotor in winding represent in the circuit.

VIII. CONCLUSION

From the simulation results, it can be concluded that the single phase induction motor can be driven with variable voltage level using different duty cycle. As increased the duty cycle, the motor output voltage also increased. Therefore, the speed of SPIM can be easily control by varying the input voltage level of the motor. In this study, it can be concluded that SPIM should have LC filter in order to reduce harmonics when generated the motor.

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