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Development of Variable Speed Drive for Single Phase Induction Motor Based on Frequency Control

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Abstract— **The speed of the single-phase induction motor can be controlled by various types of speed control method. In this paper, a system to control the speed of induction motor using frequency method has been developed and tested. The system was included the PWM control circuit, driver circuit and H- Bridge inverter. The proposed of PWM control circuit is by using LM741 Operational Amplifier, 74AC08 AND logic and SN7404 Hex Inverter. IRF740 MOSFETS was used as switching elements to provide the alternating current to the motor. In this drive, the 12VDC power supply was used for frequency control circuit and driver circuit. While, the 240VDC power supply was used to feed the H-Bridge inverter. The frequency range of the constructed variable speed drive is 16Hz to 56Hz at the constant voltage. PSpice OrCAD simulation software has been used to design and simulate the developed circuits.**

Keywords: PWM control circuit, H-Bridge inverter, single phase induction motor, frequency control, PSpice OrCAD

I. INTRODUCTION

INDUCTION motors are widely used in many residential, commercial, industrial, and utility applications. This is because the motor have low manufacturing costs, wide speed range, high efficiencies and robustness [1]. However, because of the involved model nonlinearities, they require much more complex methods of control, more expensive and higher rated power converters than DC and permanent magnet machines [2].

Previously, the variable speed drives had various limitations such as poor efficiencies, larger space, lower speed and etc. However, the power electronics transformed the scene completely. Nowadays, variable speed drive was constructed in smaller size, high efficiency and high reliability [3].

The speed of a single phase induction motor (SPIM) can be controlled by various types of speed control methods such as Pole Changing [4], Stator Voltage Control [5], Supply Frequency Control [3] and Rotor Resistance Control [6]. Each method has the advantages and disadvantages but depends on what application of SPIM to use.

One of the methods to control the speed of SPIM is by using frequency controlled power supply. Various speed control algorithms for induction motor using frequency control have been devised in the literature. Lately, the control technique had involved the PID controllers [8], optimal control
[9], nonlinear [10], robust control strategies [11], fuzzy and neural [12, 13] approaches are to be mentioned.

In this paper, the frequency control method has been used to drive the SPIM. In this method, the SPIM has been controlled through the development of PWM control circuit. The H-bridge Inverter circuit consists of power MOSFETs were needed to be triggered. The triggering pulses are sending from the PWM control circuit. By this way, the H-bridge inverter produces the alternating current to feed the SPIM.

II. SPEED CONTROL OF INDUCTION MOTOR

A. Theory

Synchronous speed and rated speed are two speed terms used in the electric machine. Synchronous speed is the speed at which a motor's magnetic field rotates. Synchronous speed is the motor's theoretical speed if there was no load on the shaft and friction in the bearings. The two factors affecting synchronous speed are the frequency of the electrical supply and the number of magnetic poles in the stator. The synchronous speed is given by;

$$N_s = 120\frac{f}{P} \tag{1}$$

Where;

f = Electrical frequency of the power supply in Hz
P = Number of Poles
The rotor speed of an Induction machine is different from the speed of Rotating magnetic field. The percent

difference of the speed is called slip as shown in equation (2)

$$s = \frac{N_s - N_r}{N_s} \quad (2)$$

N_s = Synchronous speed
N_r = Rotor speed

The induction motor speed is directly proportional to the supply frequency and the number of poles of the motor .Since the number of poles is fixed by design, the best way to vary the speed of the induction motor is by varying the supply frequency. Voltage induced in stator is proportional to the product of supply frequency f_s and air-gap flux φ_m as shown in equation (3)

$$E = 4.44 N \varphi_m f_s \quad (3)$$

Where,
N= number of turns per phase

If stator drop is neglected, then E is equal to V as shown in equation (4). Then the supply voltage will become proportional to f_s and φ_m.

$$V = 4.44 N \varphi_m f_s \quad (4)$$

Any reduction in the supply frequency f_s keeping the supply voltage constant causes the increase of air-gap flux φ_m .Induction motors designed to operate at the knee point of the magnetization characteristic to make a full use of magnetic material. Therefore, the increase in flux will saturate the motor. This will increase the magnetizing current and distort the line current and voltage, increase in core loss and stator I^2R loss and produce a high-pitch acoustic noise. Also, a decrease in flux is also avoided to retain the torque capability of motor. Therefore, variable frequency control below rated frequency is generally carried out at rated air gap flux by varying supply voltage with frequency so as to maintain V/f ratio constant at the rated value.

B. Application

The design considerations for speed control system using frequency control have been divided into three parts. The development of PWM control circuit, driver circuit and H-Bridge inverter.

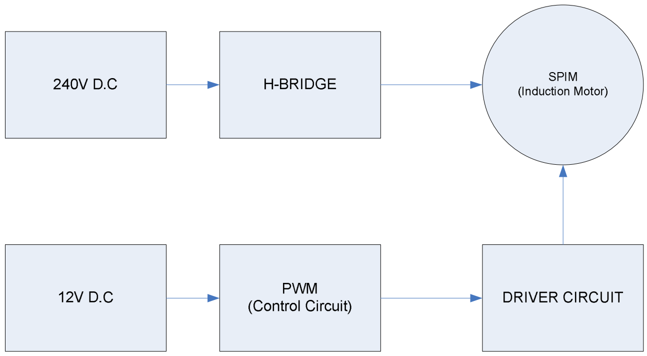

Figure 1. Block Diagram for Speed Control of SPIM

In this project, two separate power supply has been used which is 240 VDC and 12 VDC. The 240 VDC was used to feed to H-bridge inverter while 12 VDC was used in PWM control circuit and driver circuit as shown in Fig. 1

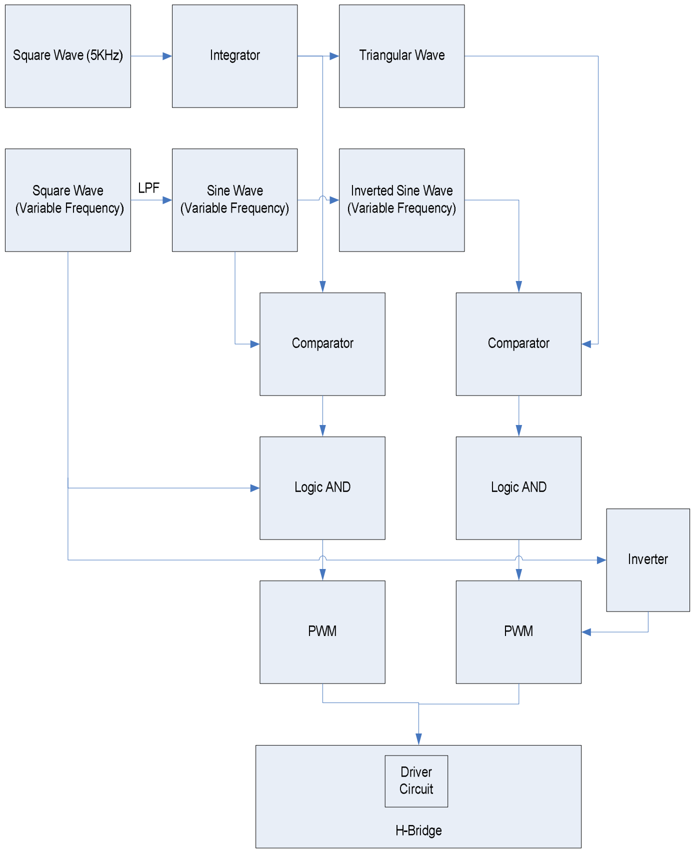

Figure 2. PWM Block Diagram

The PWM circuit was made using analog circuit which is more robust and low cost. In Fig.2 shown a block diagram how to generate PWM using conventional method. Operational amplifier LM741, logic AND gate 74AC08 and hex inverter SN7404 were used to generate PWM. Power transistors MJE 13002 and C124 were used as driver circuit to drive H-bridge inverter. Here, PWM driver circuit was used to provide the pulses by varying the variable resistor before the pulses were fed to the driver circuit.

Inverter circuit or H-bridge consists of four IRF720 power MOSFET to provide alternating current to the SPIM. The MOSFET has needed to be triggered by the PWM that generated from the control circuit. Single phase permanent capacitor induction motor was used as a loading part. The SPIM has 15 W power rating with 0.4 A current.

III. Development of SPIM Frequency Controller

A. Simulation of PSpice OrCAD

The simulation of the PWM or control circuit has been done using PSpice. The simulation need to do part by part to make sure the each component can generate the triggering pulses to trigger the power MOSFET.

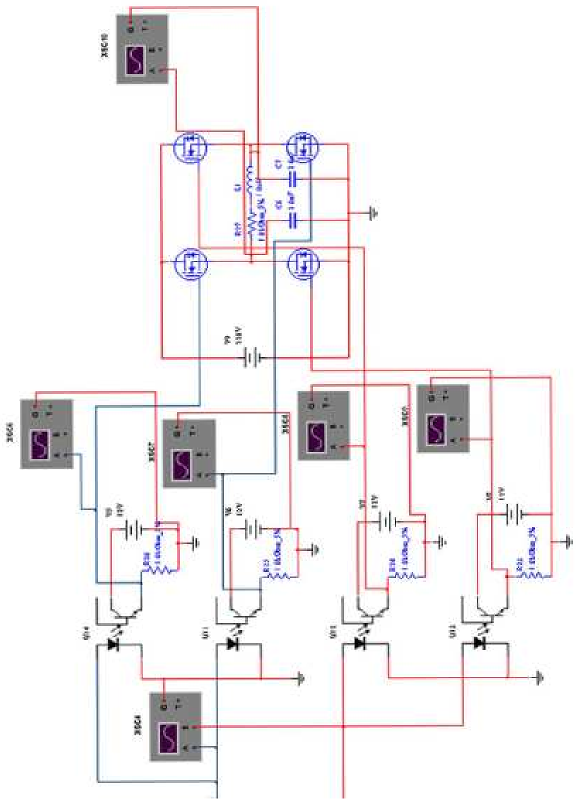

Figure 3. PSpice OrCAD Simulation circuit

Fig. 3 showed the part of the H-Brigde circuit using PSpice software.

B. Hardware Development

In the hardware development, PWM control circuit and H-Bridge inverter has been designed and built. For the controlling part, the sinusoidal pulse and the triangular pulse were generated separately.

Then, both pulses have been compared using comparator. The output was used to trigger the PWM based inverter circuit or H-bridge. The 240 VDC supply was used to feed the H-bridge. The DC supply has been inverted to drive the SPIM as a loading part.

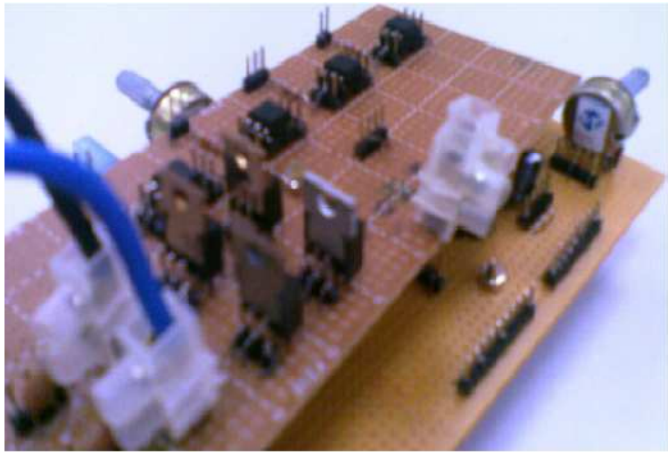

Figure 4. Hardware development H-Bridge board

Fig.4 and Fig.5 showed the hardware development board which consists of PWM control circuit and H-bridge inverter. The PWM control circuit consists of operational amplifier LM741, logic AND gate 74AC08 and hex inverter SN7404.

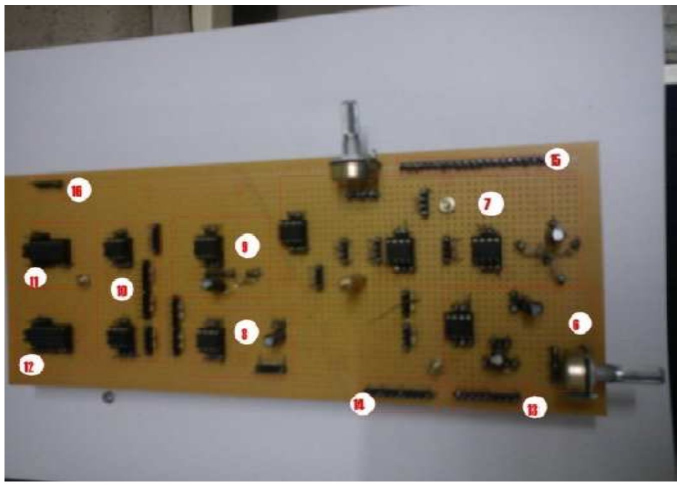

Figure 5. Hardware development PWM control circuit.

IV. Result and Discussion

The outputs of the control circuit has been used to trigger the power MOSFET. The PWM control circuit has successfully developed based on block diagram in Fig. 2. The PSpice simulation software has been used to make sure the control circuit able to generate the PWM continuously.

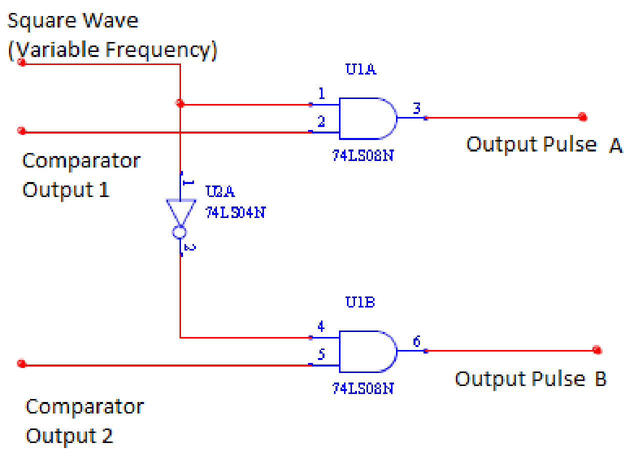

Figure 6. Part of Simulation Circuit

Fig.6 showed the outputs of comparator 1, comparator 2 and square wave of variable frequency from PSpice simulation. All the output signal were fed in to logic AND 7408 (U1A and U1B). Hex inverter 7404 was used to invert the square wave of variable frequency to the U1B AND gate. The output of PWM pulses was showed in Fig. 7-9.

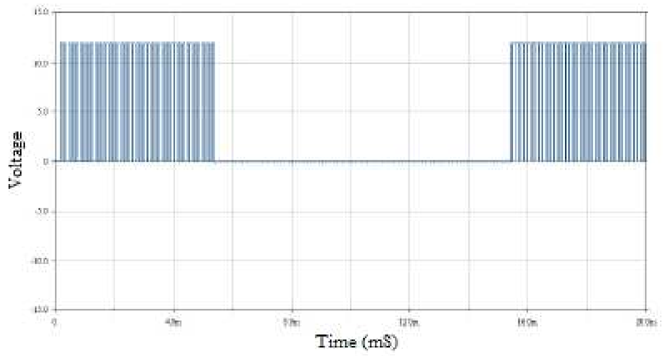

Figure 7. PWM output pulses A

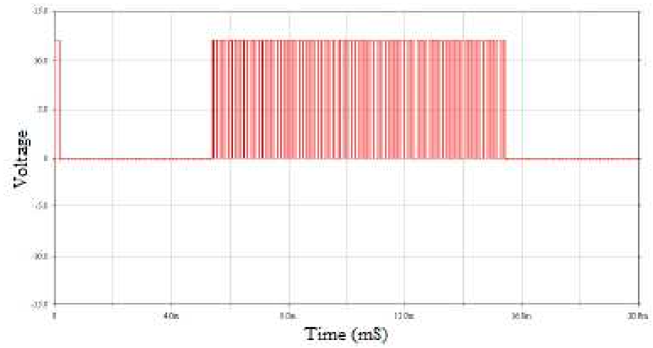

Figure 8. PWM output pulses B

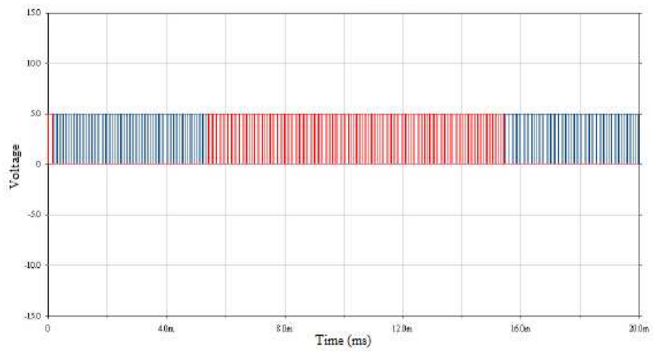

Figure 9. Combination of PWM output pulses A & B

The PWM pulses (Fig.9) was used to provide the pulses to the two driver circuits. The output from driver circuit was used to switch ON and OFF the power MOSFET based on timing diagram of the frequency control system. The timing diagram was showed in Fig.10.

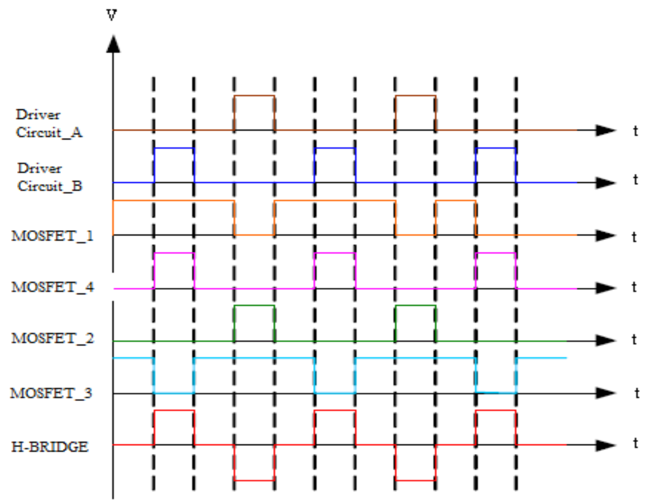

Figure.10 Timing Diagram

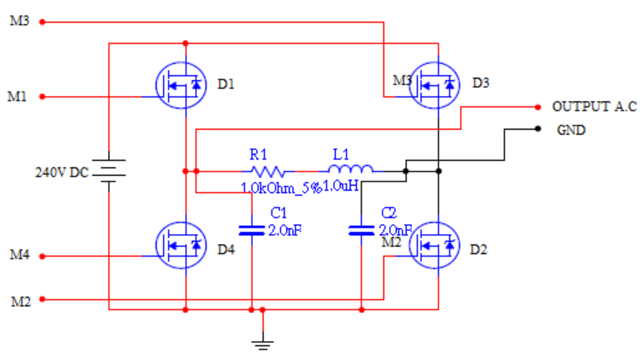

Figure11. H-Bridge inverter circuit

Only two MOSFET are able to switch ON and OFF at the same time. The circuit for the H-bridge inverter using PSpice and the simulation output was showed in Fig 11 and Fig 12 simultaneously.

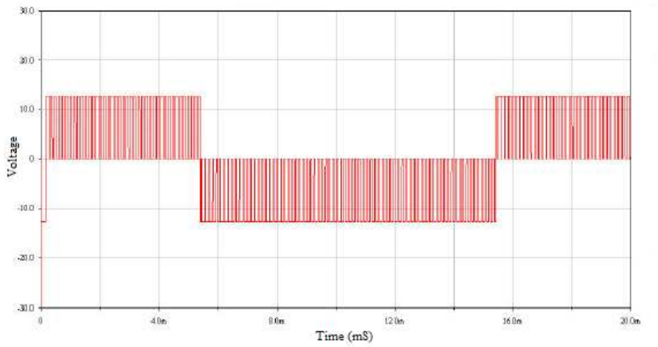

Figure12. H-Bridge output

The four MOSFET will receiving the triggering pulses from the driver circuit to turn ON and OFF continuously. There have six operation of the switching MOSFET(Fig.10) ;

- M_1-M_2 ON: Both create short circuits across the DC source and are invalid.
- M_3-M_4 ON: Both create short circuits across the DC source and are invalid.
- M_1-M_4 ON: Applies positive voltage (Vs) to the load. The positive current (I_L) passes through M_1-M_4 and the negative current ($-I_L$) is through D_1-D_4.
- M_2-M_3 ON: Applies negative voltage (–Vs) across the load. The positive current (I_L) flows through D_2- D_3 and returns energy to the DC source. The negative current ($-I_L$) flows through M_2-M_3 and draws energy from the supply.
- M_1-M_3 ON: Applies zero volts across the load. The positive current's path is M_1-M_3 and the negative current's path is D_1-T_3.
- M_2-M_4 ON: Applies zero volts across the load. The positive current's path is through D_2-D_4 and the negative current's path is M_2-M_4.

Fig 12 showed the AC voltage has been generated from simulation of PSpice. The output of the H-bridge inverter was used to run the SPIM. The speed of the induction motor is directly proportional to the supply frequency and the number of poles. Basically, the number of poles is fixed by design and the best ways to control the speed is by varying the frequency.

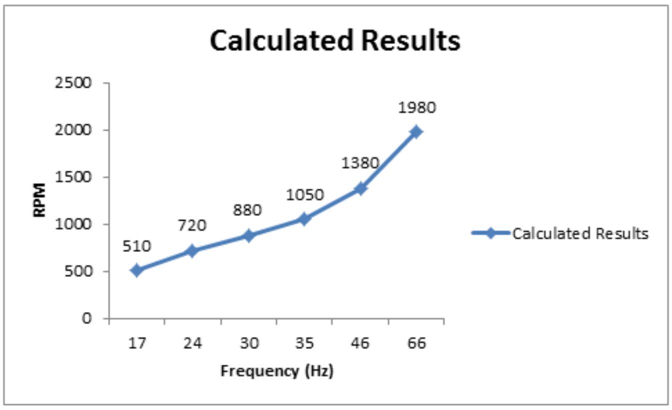

Figure 13. Calculated results of variable speed drive

Fig 13 showed the calculated results of the variable speed drive circuit at different frequency. The result can be calculated by referred to the equation (2). Fig.14 shown the test results of SPIM when it was running at different frequency. In the experiment, the lowest frequency is 16 Hz at 480 rpm while the highest frequency is 56 Hz at 1680 rpm.

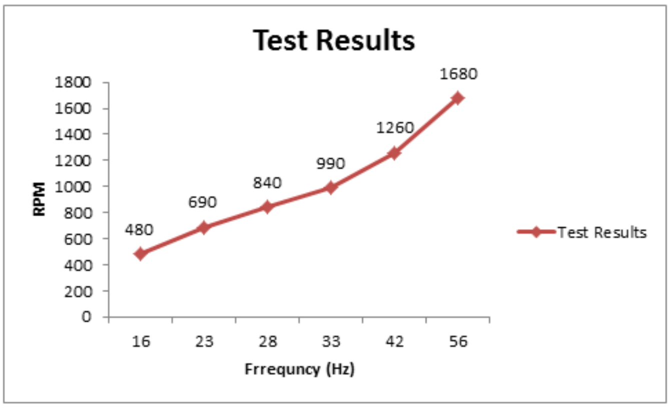

Figure 14. Test results of variable speed drive

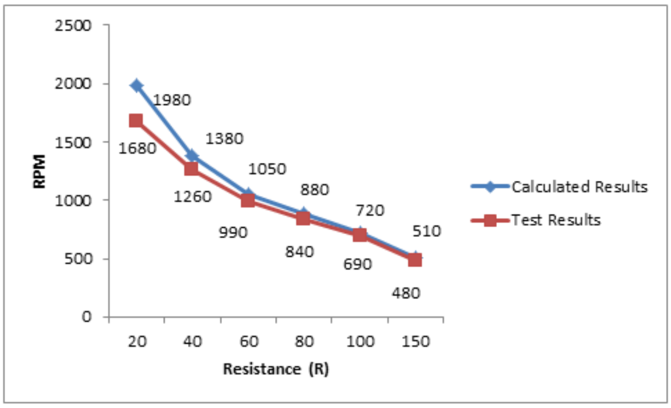

Figure 15. Comparison between the calculated results and test results at different resistance

The development of variable speed drives has been tested at desired speed by changing the frequency using the variable resistance. Fig. 15 showed the comparison between the calculated results and tested results at different level of resistance. At low resistance, the frequency will be higher and the speed of SPIM will be increased or vice versa.

V. CONCLUSION

In this paper, the development of the speed control system using frequency control has been designed by combinations of PWM control circuit, driver circuit and H-Bridge inverter. The most important parts in this research is to make a simple, robust and compact open-loop PWM controller circuit to control the SPIM. The experimental results show that the SPIM can be successfully driven to a variable frequency and speed. The frequency range of the designed variable drive circuit is 16 Hz up to 56 Hz at a constant voltage to control the SPIM speed. While the speed is limited to 480 rpm up to 1680 rpm if 50 Hz single phase AC motors are used.

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