The Simulation of Single Phase Induction Motor (SPIM) Operation Using Insulated-Gate-Bipolar Transistors (IGBT) AC/DC/AC Converter

Fazarudin bin A.Wahab
Bachelor of Electrical Engineering (Hons)
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email: fazarudinwahab@yahoo.com

Abstract – **This paper describes a generalized simulation model of a single-phase induction motor (SPIM) using SIMULINK software package of MATLAB. An analysis of SPIM performance using power electronics application is studied. The installation of power electronics can save energy consumption of electrical apparatus with more efficient use of electricity. Insulated-Gate Bipolar Transistor (IGBT) was used as a switching device for both rectifier and inverter part. The IGBT has low switching times as well as low power losses and thus can make better performance. Sinusoidal Pulse Width Modulation (SPWM) technique was used to switch on or off the IGBTs in both converter circuits. The switching frequency in the PWM generator for IGBTs was adjusted and determined. Speed performance of the SPIM using AC/DC/AC converter and directly connected to AC supply was observed. The percentages of Total Harmonic Distortion (THD) of the input and output current that comply with IEEE 519-1982 were obtained after adjusting filter value and the switching frequency.**

Keywords – single-phase induction motor (SPIM), Insulated-Gate-Bipolar Transistors (IGBT), Pulse Width Modulation (PWM) Technique, Matlab Simulink application.

I. INTRODUCTION

Single-phase induction motors are widely used in fractional and sub-fractional horsepower applications, usually in locations where only single-phase energy supply is available. These types of motors typically have a main and auxiliary stator winding displaced 90 electrical degree apart from each other. Since the main winding and the auxiliary winding do not have the same number of turns it can be consider a two-phase asymmetric motor if the startup and running capacitors are removed [1]. Adjustable speed drivers can be used to achieve variable-frequency operation.

In order to have better performance of SPIM, power electronics circuit was employed and connected between AC supply and SPIM. Unfortunately, power electronics installed will be produce the harmonic spectrum thus increasing the percentage of Total Harmonic Distortion (THD) [2]. In order to overcome this problem which is to reduce the THD percentage, the filter at the input and output was added. The lower the percentage of THD, the better signal will get. The power electronics application that has been applied in this project was rectifier and inverter. The rectifier is connected from AC supply and then connected with inverter. It is then connected to the output load which is SPIM.

The main purpose of this project is to enhance the operation of SPIM in terms of its speed and torque performance after the implementation of power electronic devices. Moreover, the objective of this study is to investigate the value of THD for input and output current after adjusting the value of the filter and the switching frequency for PWM used in the circuit.

II. IGBT

Until recently, power bipolar transistors and MOSFET'S have been commonly used for inverters driving ac motors. As a third possible alternative, insulated-gate-bipolar transistors (IGBT's) have emerged recently. IGBT's offer low on resistance and require very little gate drive power [2].

In this project, IGBT was used as the switching device for both rectifier and inverter circuit. The IGBT is the combination between the simple gate-drive characteristics of the MOSFETs with the high-current and low saturation voltage capability of bipolar transistors. The IGBT has the output switching and conduction characteristics of a bipolar transistor but is voltage-controlled like a MOSFET. In general, this means it has the advantages of high-current handling capability of a bipolar with the ease of control of a MOSFET. However, the IGBT still has the disadvantages of a comparatively large current tail and didn't have body drain diode [3].

IGBT's control terminals are the gate and emitter. The device turns-on when a voltage V_{GE} greater than gate-emitter threshold voltage V_{GEth} is applied between the gate and emitter [1]. To turn-off the device a resistance R_{GE} must be connected between gate and emitter, which provides a discharge path for the gate-to emitter capacitance [1].

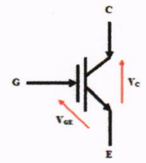


Fig. 1 IGBT's symbol.

III. METHODOLOGY

Fig. 2 shows the flow chart for the methodology used along the way to complete this project. The research of this project is to investigate the operation of the load, SPIM which use IGBT full-bridge rectifier with IGBT full-bridge inverter. The circuit topology is shown in Fig.3 below.

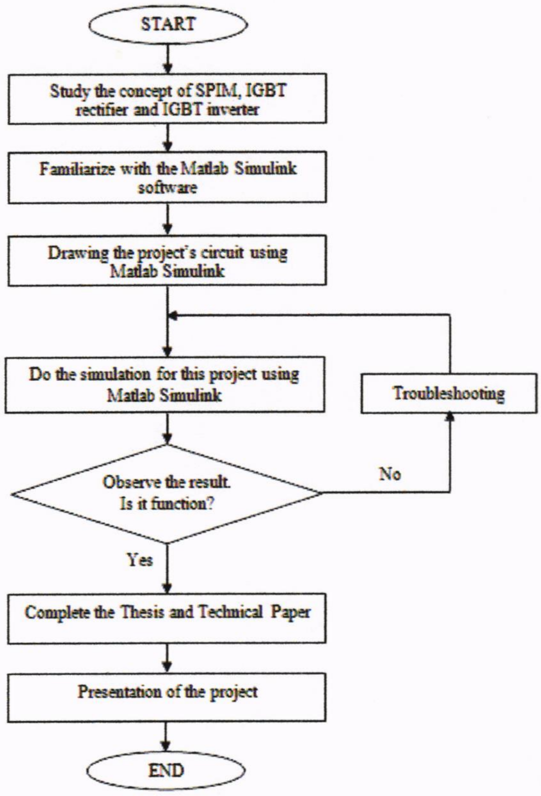


Fig. 2 Flow chart of project's process.

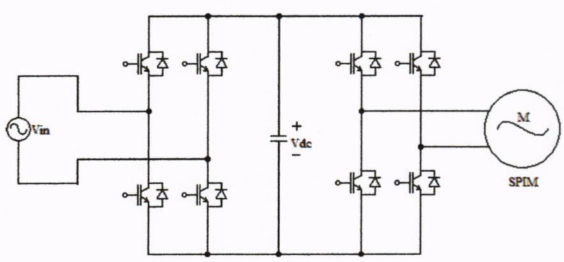


Fig. 3 Circuit topology.

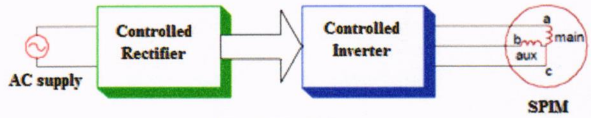
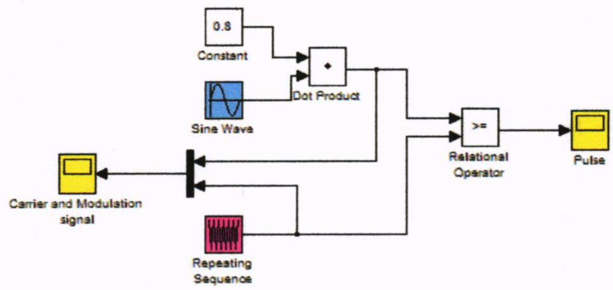


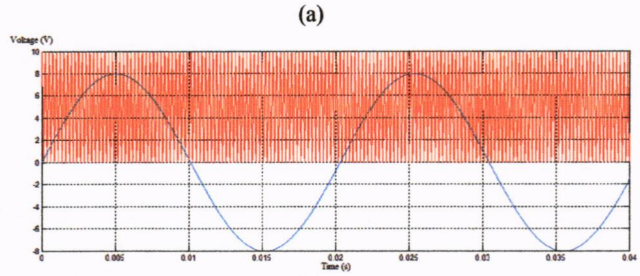
Fig. 4 Block diagram.

Fig.4 shows the block diagram for this project. The rectifier will convert the AC supply voltage to DC voltage and then convert back to AC by using inverter. Theoretically, the process of converting AC/DC/AC will give better performance for SPIM by comparing with SPIM that directly connected from AC supply. The performance has been observed through rotor speed and torque waveform. Besides that, the THD of input and output current has also been observed in order to see the effect of using power electronics device. In order to turn on the IGBTs used in the circuit, Sinusoidal Pulse Width Modulation (SPWM) technique was implemented.

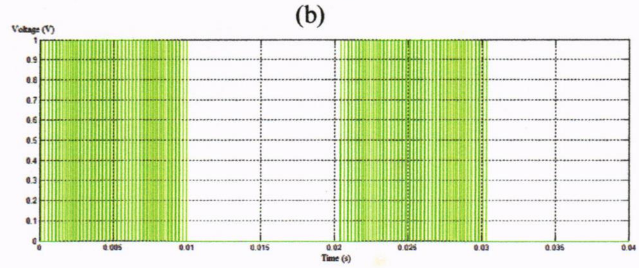
SPWM technique is a technique used for this project for the purpose of controlling the IGBTs. PWM generator injects pulse at the IGBT's gate in order to turn on and off the IGBT. There are two types of PWM technique which are unipolar PWM and bipolar PWM. For this project unipolar PWM was used and the carrier signal is in a triangular form. The block diagram and the output simulation for the PWM generation with switching frequency 500Hz is shown in Fig. 5.



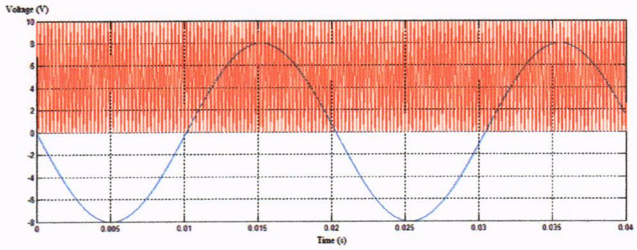
(a)



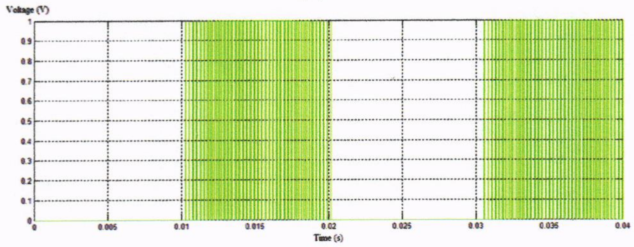
(b)



(c)



(d)



(e)

Fig. 5 (a) PWM generator. (b) Carrier signal and modulation signal during positive cycle. (c) Pulse during positive cycle. d) Carrier signal and modulation signal during negative cycle. (e) Pulse during negative cycle.

In the most straightforward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high frequency triangular carrier signal as depicted schematically in Fig.6. When the amplitude of the modulation signal is higher than the amplitude of the carrier signal, the positive dc bus voltage is applied at the output and vice versa [3]. By controlling the magnitude and frequency of the modulated sinusoidal signal, the output voltage magnitude and frequency of the PWM inverter are controlled accordingly [2].

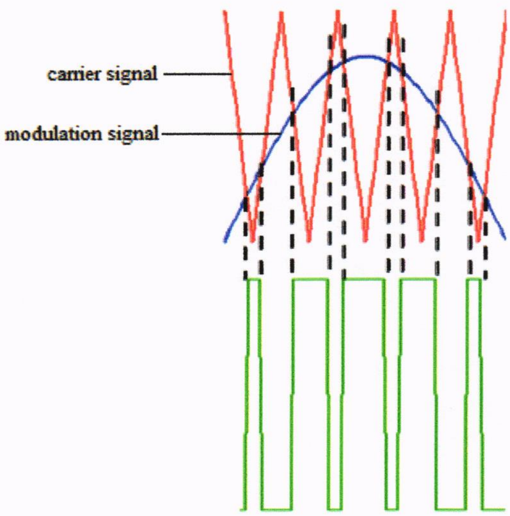


Fig.6 Principal of Pulse Width Modulation.

IV. RESULTS AND DISCUSSION

The simulation of the circuit was executed using MATLAB Simulink. This result of the project was focused on the THD of the input and output current, the rotor speed and output torque.

In order to analyze the output, SPWM switching technique circuit has been successfully developed. By referring to Fig. 5(a) to 5(e), the switching frequency used is 500 Hz in order to make the triangular form to be seen clearly. As known, the lower value of switching frequency, f will give higher number of period, T according to T = 1/f formula. So, each cycles of the carrier signal can be seen clearly. However, for both rectifier and inverter project's circuit, the optimum switching frequency used is 4 kHz. After adjusting the variable switching frequency from 500 Hz to 5 kHz, the optimum switching frequency that will give better performance of the speed and torque is 4 kHz.

Even though it gave better performance to SPIM, but the THD for input and output current is slightly higher than the lower switching frequency. Thus, the filters have been adjusted by increasing their value to ensure that the THD will less than 5%.

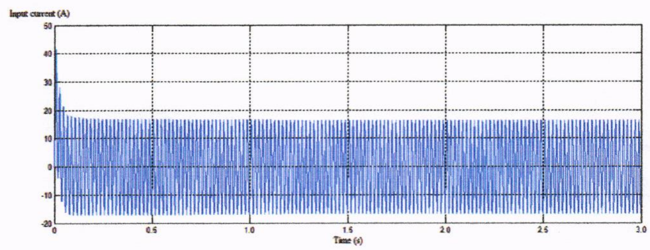


Fig. 7 Input current waveform.

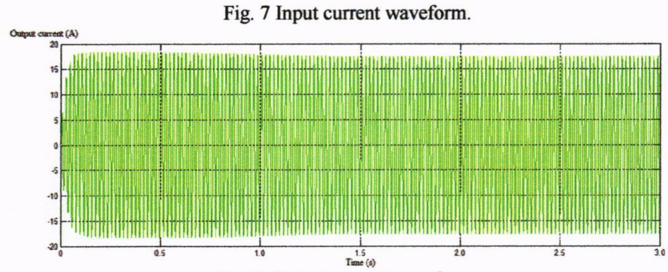


Fig. 8 Output current waveform.

Waveforms of the input current and the output current are shown in Fig. 7 and Fig. 8 respectively. Both waveforms show that they are most likely the same in term of the amplitude of the current but the difference is at the starting current. In Fig. 7, it can be seen that the starting current for the input is high which is 41 A and it is unstable. After about 0.1 seconds, it starts to stabilize to 17 A. Compared to the output current as shown in Fig. 8, the starting current is low which is 6 A. After about 0.1 seconds, it starts to stabilize to 17 A.

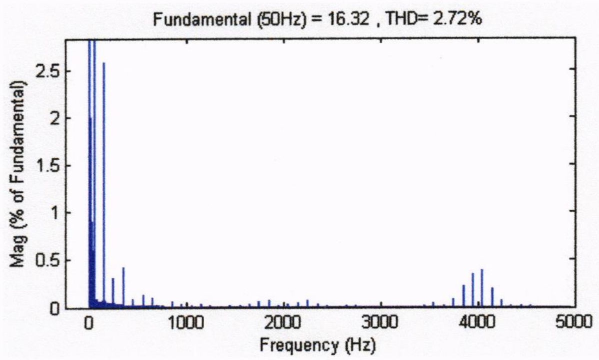


Fig.9 THD for input current.

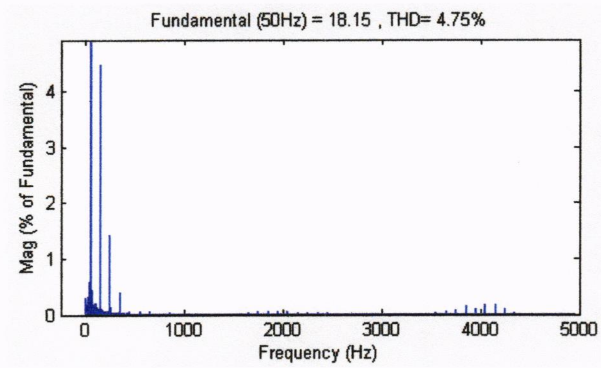


Fig.10 THD for Output current.

The THD percentages of the input current and the output current are shown in Fig.9 and Fig. 10 correspondingly. It can be seen that THD percentages for the output current is higher than THD percentages for the input current. Based on the circuit which connected directly to AC supply, the THD is 0.10%. Theoretically, the ideal THD according to IEEE 519 – 1982 for current should be less than 5% to show that the output is good enough and give better signal [3]. So, the THD percentages for both input and output current are complied with IEEE 519 – 1982.

As shown in both Fig. 9 and Fig. 10, the THD for input current is 2.72% while the THD for output current is 4.75%. To have low THD, the switching frequency must be low as well but the worst effect will goes to the speed of the motor. The speed will drop to negative value after less than 0.5 seconds. This means that the motor is rotated counter-clockwise. As the frequency increased, the speed curve is getting better but the THD value will increase. To overcome this problem, the filter value needs to be adjusted. When adjusting the value of inductive and capacitive filters, the rotor speed curve become well however, the time where the speed reach steady-state become longer but it is still better than the SPIM directly connected.

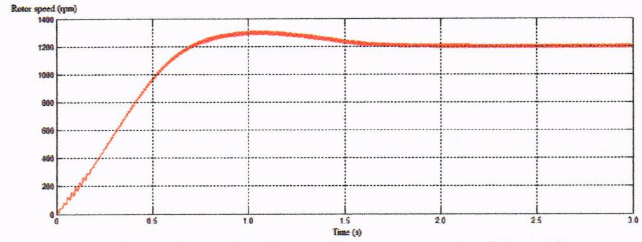


Fig.11 Speed for SPIM without converter implementation

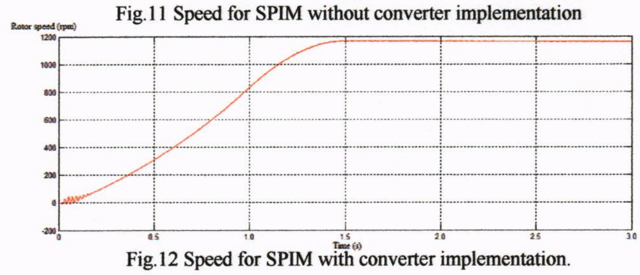


Fig.12 Speed for SPIM with converter implementation.

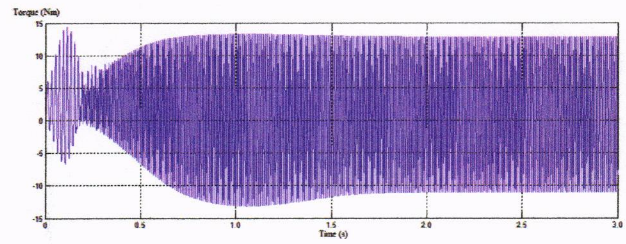


Fig.13 Torque for SPIM without converter implementation.

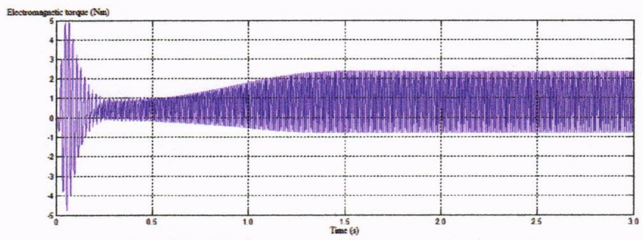


Fig.14 Torque for SPIM with converter implementation.

Analysis on SPIM load connected directly to AC supply voltage has been done and the results are presented in Fig. 11 and Fig. 13. While the results of analysis on SPIM load connected to AC supply using power electronic devices have been shown in Fig. 12 and Fig. 14.

Based on the SPIM connected without converter implementation, the time for rotor speed of SPIM to starts reach steady-state is at 1.7 seconds as shown in Fig. 11. However, the waveform is seen to have ripple signal and not run smoothly. It is also swelling at certain time before it became stable. Theoretically, the rotor speed should be less than the synchronous speed which is 1500 rpm as calculated in equation (1). This is because in order to produce torque, the rotor must rotate at the speed slower or faster than the synchronous speed. For this case, the rotor rotates at slower speed than synchronous speed [4]. Thus, the condition is met since the revolution per minute for this circuit is 1200 rpm.

$$\text{Synchronous speed, } N_s = \frac{120f}{\text{poles}} \quad (1)$$

$$= \frac{120 \times 50}{2}$$

$$= 1500 \text{ rpm}$$

Fig. 12 shows that the time for rotor speed starts to reach steady-state are at 1.4 seconds for the circuit of the SPIM connected with converter implementation. The waveform seemed to have less ripple signal and smoothly run compared to the direct SPIM connected. It is constant speed at steady-state. For this circuit, the speed is about 1400 rpm which is less than the synchronous speed and thus complied with the theoretical expectation. This proved that the implementation of AC/DC/AC converter will give better outcomes to the application in term of rotor speed.

Comparisons of torque signal for both circuits are shown in Fig. 13 and Fig. 14. The signals have proven that the SPIM connected with power electronics application gave enhanced starting torque as compared to the SPIM directly circuit. As presented in Fig. 13, the fluctuation of electromagnetic torque at the starting is much smoother than the fluctuation of electromagnetic torque in Fig.12 which is directly connected SPIM. The implementation of power electronics devices in SPIM application has proved that it will improve the performance of the electromagnetic torque.

The use of controlled power electronics switches which are IGBTs, at both rectifier and inverter part has made the circuit more complex and difficult to control in order to get the best results. This could be solved by improving the filters which have been used in this project.

V. CONCLUSION

The research on the operation of SPIM using IGBT AC/DC/AC converter has been successfully experimented and analyzed. The analysis of rotor speed and torque signal has been proved that the use of power electronics switches could improve SPIM performance. As it is well known, power electronic converters are generators of harmonics [4]. This study has proved that the percentage of THD for the input current is complied with IEEE 519 – 1982 which is less than 5%. The filters have been adjusted over and over again to achieve the IEEE compliance.

VI. FUTURE DEVELOPMENT

For future development, this project may apply the other types of filters in order to reduce the THD of input current such as active filters. Besides that, variety switching techniques can also be used to observe the performance of the rotor and torque for SPIM. There are a lot of switching techniques that can be applied to the circuit, for instance bipolar SPWM, sawtooth SPWM, uniform PWM and space vector PWM.

AKNOWLEDGEMENT

The author would like to express his deep and sincere gratitude to his supervisor, Miss Nor Farahaida Binti Abd. Rahman for her detailed and constructive comments and also her important support throughout this project is very helpful. Her understanding, encouraging and personal guidance have provided a good basis for this study. During this project, the author has collaborated with many colleagues for whom the author has great regard. The author likes to extend the warmest thanks to all those who have helped in completing this project.

REFERENCES

[1] Thiyagarajah K., V. T. Ranganathan and B. S. Ramakrishna Iyengar, et al. (October 1991). "A High Switching Frequency IGBT PWM Rectified/Inverter System for AC Motor Drives Operating from Single Phase Supply". Vol.6

[2] Gamal M. Hashem, A.DeyaaEI-Koshariy, et al. 2006. "Investigation of Induction Motor Performance Fed from PWM Inverter"

[3] Kumsuwan, Y., W. Srirattanawichaikul, et al. 2009. "Analysis of a Two-Phase Induction Motor Using Dynamic Model Based on Matlab/Simulink"

[4] M. T. Outeiro, E. S. Saraiva. "Harmonics on the Electromagnetic Torque of a Slip Energy Recovery System with Two Thyristor Bridges and no DC Coil"

[5] Ali S. Ba-thunya, Rahul Khopkar, Kexin Wei, and Hamid A. Toliyat, et al. 2001. "Single Phase Induction Motor Drives - A Literature Survey". IEEE

[6] Jawad Faiz, A, Keyhani, et al. March 1999. "PSPICE Simulation of single-phase Induction Motors". IEEE Transactions on Energy Conversion, Vol. 14, No. 1

[7] Senan M. Bashi, I. Aris and S.H. Hamad, et al. 2005. "Development of Single Phase Induction Motor Adjustable Speed Control Using M68HC11E-9 Microcontroller". Journal of Applied Sciences 5 (2): 249-252, 2005.

[8] G. Pandian and S. Rama Reddy, et al. 2009. "Simulation and analysis of multilevel inverter fed induction motor drive". Indian Journal of Science and Technology, Vol.2 No 2 (Feb. 2009) ISSN: 0974- 6846.

[9] K. Vinoth Kumar, Prawin Angel Michael, Joseph P. John and Dr. S. Suresh Kumar, et al. 2010. "Simulation and Comparison of SPWM and SVPWM Control for Three Phase Inverter". Vol. 5, No. 7(July 2010) ISSN:1819-6608.

[10] K. L. Shi, T. F. Chan and Y. K. Wong, et al. 1997. "Modelling of the three-phase Induction Motor using SIMULINK".

APPENDICES

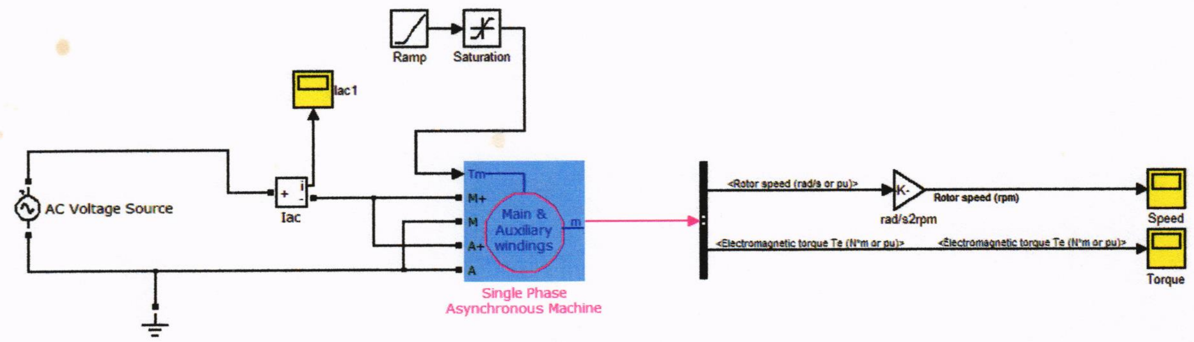


Fig. 14 SPIM circuit without AC/DC/AC converter implementation.

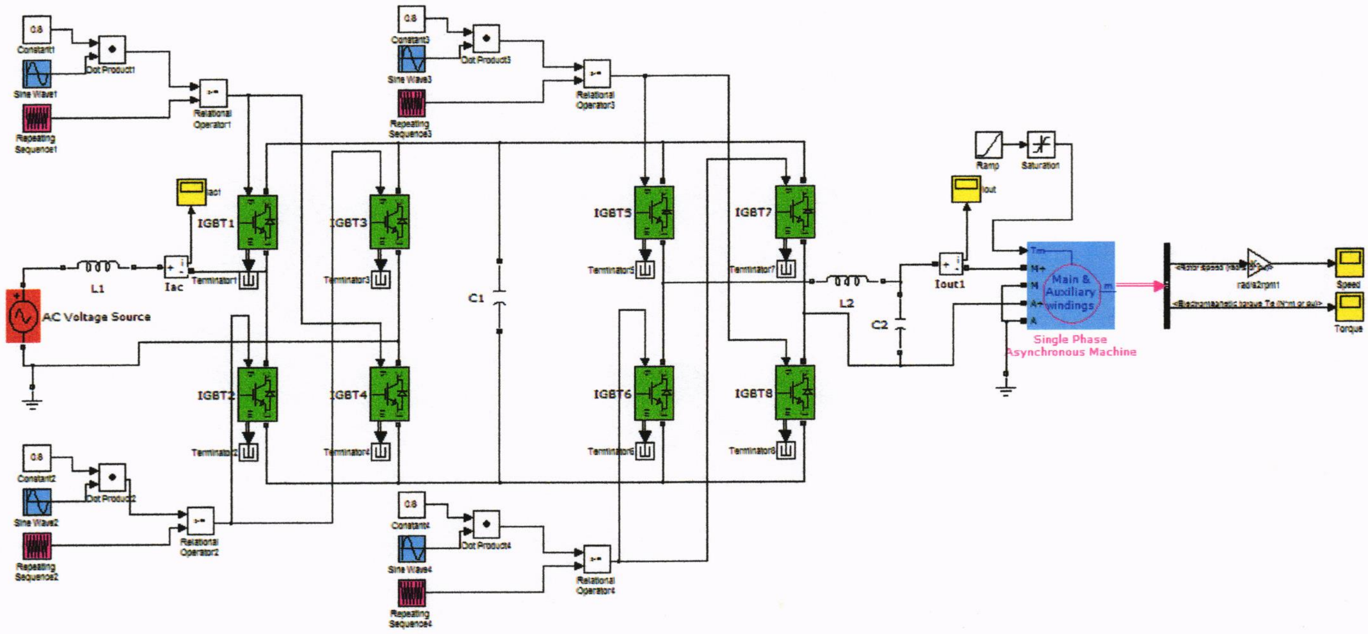


Fig. 15 SPIM circuit with AC/DC/AC converter implementation.