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Design and Implementation of Voltage Source Inverter Using Sinusoidal Pulse Width Modulation Technique to Drive A Single-Phase Induction Motor

Salam Waley Shneen [a,1,*], Zainab B. Abdullah [b,2], Hashmia S. Dakheel [b,3]

[a] Energy and Renewable Energies Technology Center, University of Technology, Iraq
[b] Department of Electromechanical Engineering, University of Technology, Iraq
[1] salam_waley73@yahoo.com; [2] Zainab.B.Abdullah@uotechnology.edu.iq; [3] Hashmia.S.Dakheel@uotechnology.edu.iq
* Corresponding Author

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ABSTRACT

A study is underway under the title, Design and implementation of voltage source inverter using sinusoidal pulse width modulation technique to drive a single-phase induction motor. The objectives of the study can be achieved by building a simulation model for a single-phase full-wave inverter consisting of four IGBT transistors. The inverter converts a direct voltage of 220 volts from the power source connected to the inverter input to an alternating voltage of 220 volts RMS. A 10-ohm resistive load is fed to the inverter output. In the first test, a square wave is generated as a result of operating the inverter in the first mode, as a result of activating two electronic switches that give the value of the voltage wave to the load, while the second mode gives the negative voltage with an interval of ten milliseconds for each mode, i.e., at a frequency of 50 Hz for twenty milliseconds for the square wave generated at the inverter output. The other model uses sinusoidal pulse width modulation technique to remove harmonics and control the inverter output by opening and closing electronic switches, which leads to removing some harmonics. The third model depends on adding a filter to obtain the basic wave and get rid of the rest of the harmonics, which results in generating a sine wave. After obtaining an inverter model that converts 220 volts direct voltage to 220 volts alternating voltage RMS as a first stage, the second stage is to feed a single-phase induction motor and operate it under test conditions that include a no-load condition, i.e., zero torque, a constant load condition, i.e., 1 Newton-meter torque, and finally a variable load condition, which is similar to many applications such as a fan, pump, etc. From the simulation results, we can say that the system is effective in operating the induction motor at the specified speed (1430 rpm) after providing the specified electrical quantities, a frequency of 50 Hz, and a voltage of 220 volts alternating voltage RMS.

1. Introduction

The importance of electronic power devices in the construction of electronic converters, including the inverter, is highlighted in many uses and in many fields. The inverter is of single-phase, three-phase, half-wave and full-wave types. The single-phase, full-wave inverter consists of four electronic power devices such as transistors and thyristors. Converters, including the inverter, operate according to the opening and closing periods of these switches, and determining them is based on the required output of the converter [1]-[3]. We can generate the trigger pulses for the switches using different techniques, including the pulse width modulation technique for a sine wave, which relies on using a reference sine wave and a triangular wave to cut the wave and generate a trigger pulse [4]-[6]. For example, generating a trigger pulse from a reference sine wave with a frequency of 50 Hz with a triangle wave with a frequency of 5000 Hz, the duration of one sine wave is twenty milliseconds, while in this time 50 triangle waves can be observed. When they are entered into a comparator, the trigger wave is generated for one electronic switch. To generate another wave that works opposite to that wave, a notch gate is added to obtain a second trigger pulse [7]-[9]. To operate the four switches, a second reference wave with a phase difference of 180 degrees is used to generate a third pulse, and by adding a notch gate, the fourth wave is obtained. When designing the model, it must be ensured that the technology operates the switches in the correct sequence to provide the required output [10]-[12]. To operate the model, testing requires determining the available input voltage and the voltage required to supply the load, which requires connecting loads to study different cases, including connecting a resistance as a single-phase alternating load. Connecting a single-phase induction motor in operation at zero torque and a constant torque of 1 Newton-meter or more and a variable torque linked to the motor speed, taking the square of the speed in the torque divided by the speed squared [13]-[15].

Single-phase induction motors (SPIMs) are used in many applications, including industrial applications, such as water or fuel pumps. Renewable energy sources such as solar energy or photovoltaic power can be power sources for single-phase induction motors in areas far from the national grid [16], [17]. A single-phase induction motor requires an AC power source. The importance of using inverter-type voltage source converters (VSI) comes when the DC power source is converted into AC. In order to provide the specified voltage to obtain the specified speed and suitable behavior for all operating conditions, sinusoidal pulse width modulation (SPWM) type technique is used to regulate the inverter output and represent the specified motor input voltage [18]-[20]. In this study, the researchers propose to simulate a system that represents the operation of a motor with a torque that represents the operation of a pump. In this study, the researchers propose to simulate a system that represents the operation of a single-phase induction motor driven by a DC power source using pulse width modulation technique and a voltage inverter. The results show that the motor can be operated within the specified speed when fed with the specified voltage value.

The current research deals with building and designing simulation models to identify the work of the inverter in feeding the induction motor and providing the appropriate output voltage for the motor to rotate at the required speed. Identifying the design and construction of the pulse width modulation technique and verifying the possibility of controlling the inverter output. Verifying the possibility of operating the induction motor with the appropriate electrical quantities, a voltage of 220 RMS, an alternating voltage with a frequency of 50 Hz, to rotate at the specified speed of 1430 rpm.

2. Single Phase Induction Motor and Single-Phase Inverter

2.1. Single Phase Induction Motor

In home and daily applications, it is preferable to use a single-phase induction motor. Therefore, in this article we will present its components, how it works, its types and its various applications. Building a single-phase induction motor, the single-phase induction motor consists of two main parts, the stator and the rotor shown in Fig. 1. The stator, it is the fixed section of the motor, and consists of three main parts, which are the outer frame, it means the outer body of the motor to support the core and windings of the stator. The stator core, it consists of thin sheets, usually 0.3 to 0.5 mm thick. The stator core carries the alternating flux which results in eddy current and hysteresis loss [21]-[23]. The stator winding, there are two coils in the stator core, an auxiliary coil (starting coil) and a primary coil (running coil) connected to a single phase alternating current source that produces a rotating magnetic field. Rotor (rotating part), Tthe moving part contains aluminum or copper rods that are shorted at both the start and end ends through short rings. The working principle of single-phase induction motor. Note, we know that to operate any electric motor whether it is an AC or DC motor, we need two fluxes because the interaction between these two fluxes produces the required torque. When we apply a single-phase AC current to the stator coil of a single-phase induction motor, the alternating current starts flowing through the stator or the primary coil. This alternating current produces an alternating flux called the primary flux. The primary magnetic flux penetrates the air gap between the stator and the rotor to intersect with the rotor coil [24]-[26].

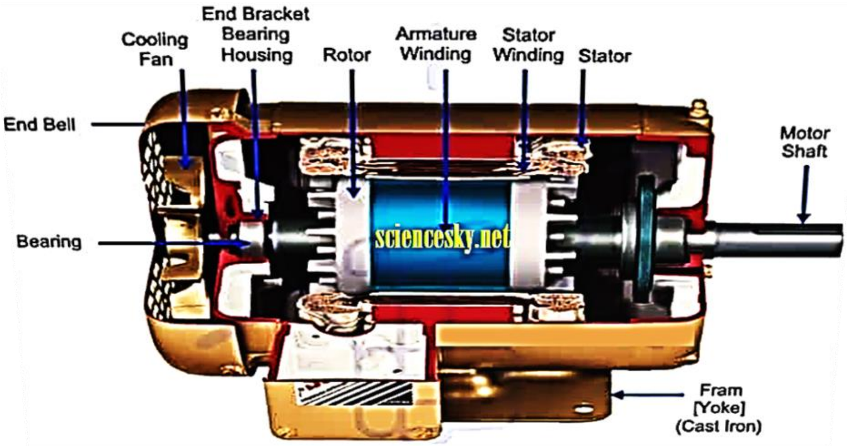


Fig. 1. Construction of single-phase induction motor

Working principle of single-phase induction motor, note: We know that to operate any electric motor whether AC or DC, we need two fluxes because the interaction between these two fluxes produces the required torque. When we apply a single-phase AC current to the stator coil of a single-phase induction motor, the AC current starts flowing through the stator or primary coil. This AC current produces an alternating flux called the primary flux. The primary magnetic flux penetrates the air gap between the stator and the rotor to intersect with the rotor coil. According to Faraday's law of electromagnetic induction, an electromagnetic force (EMF) is induced in the rotor [27]-[29]. This force produces a current in the conductors of the rotor coil because the rotor coil is limited to itself. The induced current will produce an electromagnetic force consisting of two parts, a negative part and a positive part, and the two parts are equal in value and opposite in direction, and thus the resultant force will be equal to zero. In this case, the circuit will vibrate and will not have the ability to rotate, i.e., it will not have a self-starting torque. To solve this problem, an auxiliary coil (starting coil) and a capacitor (capacitance) are added in series with it, in addition to the main coil, and the purpose of this coil (auxiliary) is to produce an additional magnetic field (auxiliary) that differs in its angle from the primary magnetic flux by an angle of 90 electrical degrees. Therefore, the auxiliary flux will give additional torque in one direction and form the torque for the engine during start-up [30]-[32].

Advantages and disadvantages of single-phase induction motor, its design structure is easy. Low cost. Suitable for most home applications where there is often no three-phase source. As for its disadvantages, its efficiency is low compared to a three-phase motor. It does not have a starting torque without an auxiliary coil and a starting capacitor. If the starting capacitor is damaged, the motor will fail to start, and if it is not disconnected from the power supply, its temperature will rise and its coils may burn. More failure cases than the three-phase motor [33], [34].

2.2. Single Phase Inverter

Electronic power converters, including the inverter, are characterized by their ability to increase and improve efficiency by regulating load requirements and reducing losses during the energy conversion process, which provides reduced energy consumption and reduced repairs and maintenance [35]-[37]. They also have high reliability by keeping their components from damage due to constant conversion, which reduces excess quantities such as voltage, current and temperatures, which provides safety from risks. The inverter provides improved control, which allows for precise regulation of power levels. The inverter is widely used in many applications, including electric vehicles, renewable energy systems, pumping systems, and others. It is also characterized by being a compact, small and lightweight system. It is considered a future device that enters into many directions as a result of the continuous development in the field of energy, including a bright future for electronic converters [38]-[40].

The inverter converts the input voltage to alternating current at its output, which is compatible with the requirements of the conversion process. Electronic filters are connected to the inverter output to smooth the wave and eliminate harmonics and create a pure sine wave to feed the alternating loads or to feed the grid, which ensures the safety of electrical equipment from any possible damage and for the electrical equipment to operate properly. The inverter can be designed to produce the wave at a suitable frequency and voltage as determined by alternating current sources [41], [42]. DC/AC converter inverter shown in Fig. 2.

The inverter is either a modified square wave generator (MSW) or a sine wave generator (PSW). The modified square wave (MSW) is less expensive than the other and is limited in use for some electrical appliances, including household appliances. The sine wave generator (PSW) is more powerful, more efficient, and similar to main power sources, but its prices are high and are used for high-consumption industrial equipment such as sound systems, satellites, compressors, refrigerators, and others [43], [44].

Fig. 2. DC/AC converter inverter

The inverter is a converter that converts direct voltage to alternating voltage. It is an electronic module with a direct voltage input and multiple switches inside it. These switches may be single-phase or three-phase with a control signal. The inverter output is alternating voltage and may contain impurities called harmonics and in it are components of alternating waves or may be without harmonics, only the basic wave [45], [46]. The inverter is characterized by the ability to choose the output frequency according to the request and voltage through the design of the inverter. In this type of converter (inverter), a new concept appears called the operating system (Switching Pattern), where there are circuits called control scans (control signal) and there is no scanner (firing signal) in it [47], [48].

The single-phase full wave voltage source inverter consists of four switches (transistors) as shown in the Fig. 3 [49]-[51]. If the two transistors (the first and the second) are connected at the same time, the current passes through the load and the output voltage are equal to the wave source voltage (+VS). In the second part, the (third and fourth switches) are connected and then the current passes to the load and the negative source voltage (-VS) comes to the inverter output. Fig. 3 shows the inverter circuit and Fig. 4 shows the output signals [52]-[54].

3. Modeling and Simulation

The current paragraph includes two stages, the first is simulating the resistive load and the second is the inductive load.

3.1. Simulating the Resistive Load

In this section there are two parts, first part single-phase inverter to generate square wave. Second part, single-phase inverter to generate sine wave:

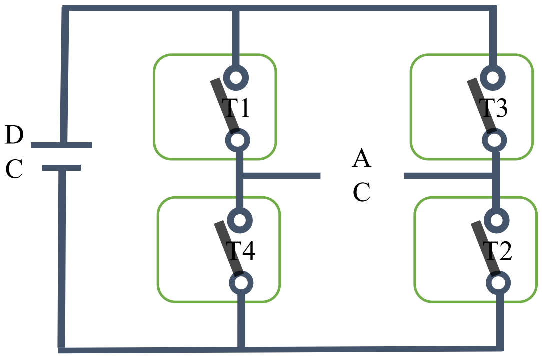


Fig. 3. single-phase full wave voltage source inverter

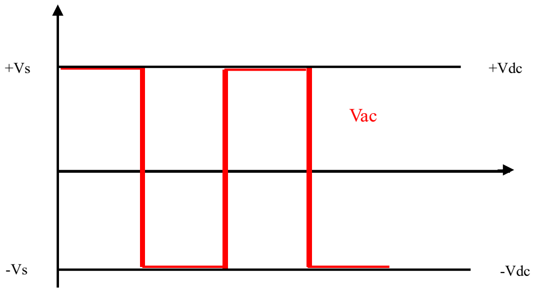


Fig. 4. The output signals

3.1.1. Simulation Model of Single-Phase Inverter to Generate Square Wave by Matlab

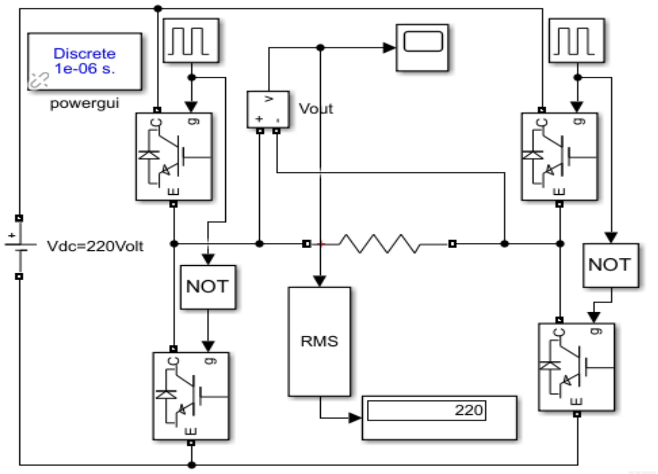
In this section the present test aims to convert 220 V DC to 220 RMS AC to supply a single-phase resistive AC load that by using the model of single-phase inverter as show in Fig. 5:

3.1.2. Simulation Model of Single-Phase Inverter to Generate Sine Wave by Matlab

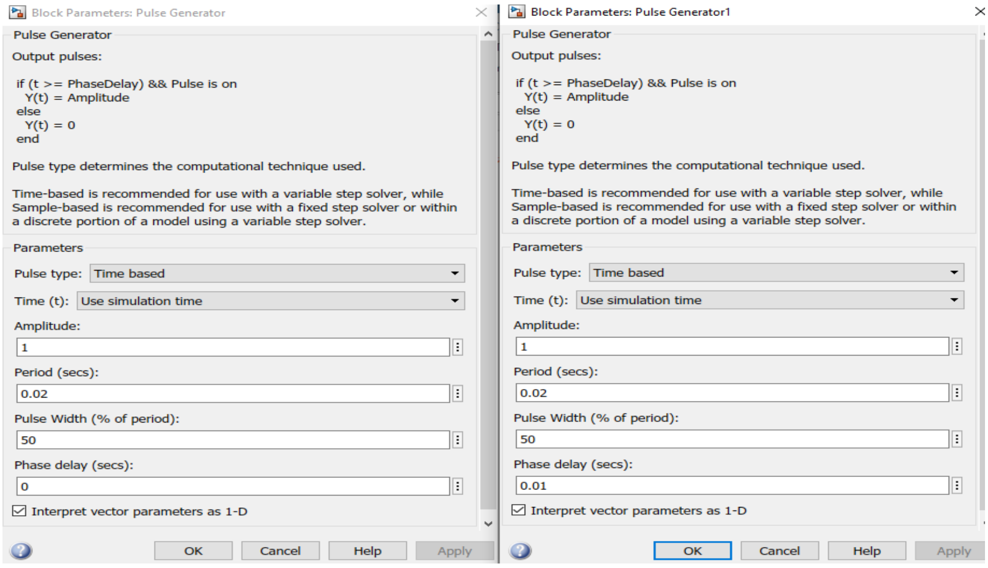
In this part there are three tests, first test by using modeling of SPWM technology for two switches also using modeling of SPWM technology for four switches. Second test by using SPWM to delete some of the harmonics. third test by using LC filter to delete all the harmonics and to find the fundamental wave (generate sine wave).

A. SPWM modeling and simulation

In this test there are two states, first state by using modeling of SPWM technology for two switches that show in Fig. 6. Second state by using modeling of SPWM technology for four switches that show in Fig. 7.

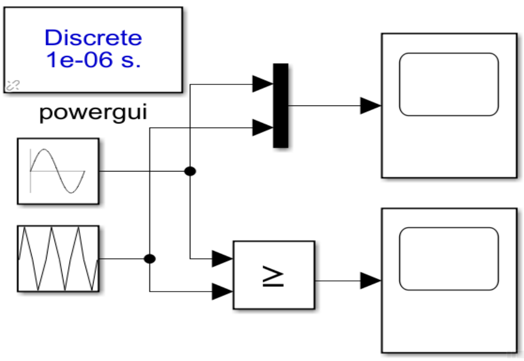


a. VSI without and R-Load

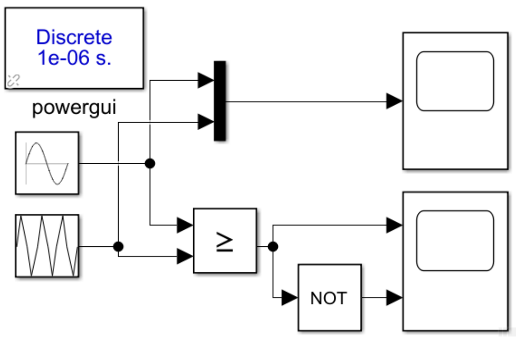


b. Parameters pulsus generator

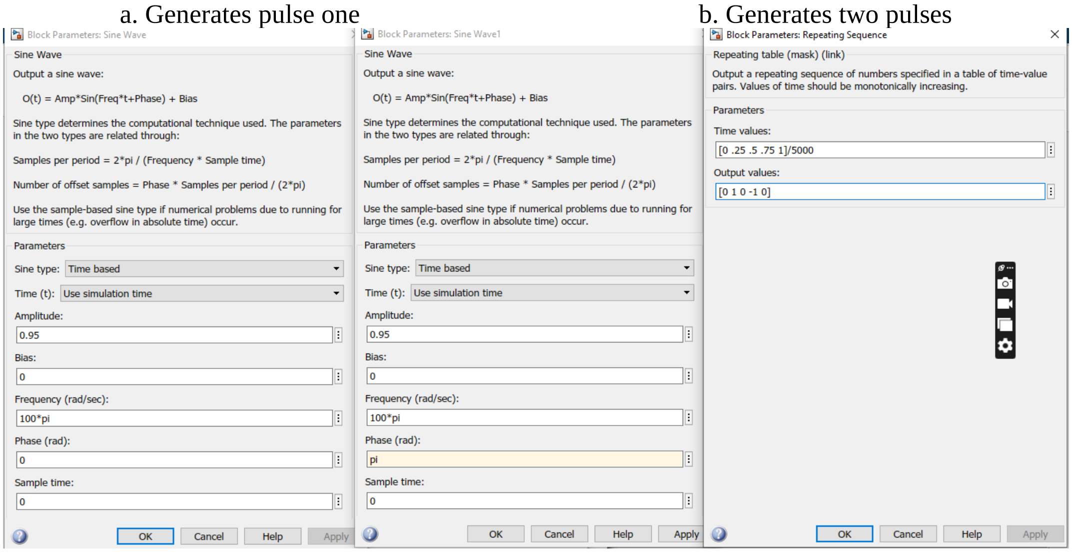
Fig. 5. Simulation model of Single-phase inverter (convert 220 V DC to 220 RMS AC) by MATLAB



a. Generates pulse one



b. Generates two pulses



c. Parameters pulsus generator (SPWM)

Fig. 6. SPWM technology for one and two switches

The simulation includes a prototype of a sine wave pulse width modulation technique that turns on and off an electronic switch through a transistor gate with an on and off pulse. By adding a not gate, another switch can be operated in reverse of the first switch as in the two models Fig. 2 and Fig. 3 show the simulation models for turning on and off the switches.

B. Modeling and simulation of VSI-SPWM

In this test there are three states, first state by using VSI – SPWM without LC filter and R-Load that show in Fig. 8. Second state by using VSI – SPWM with R-Load that show in Fig. 9. Third state by using VSI – SPWM with LC filter and R-Load that show in Fig. 10.

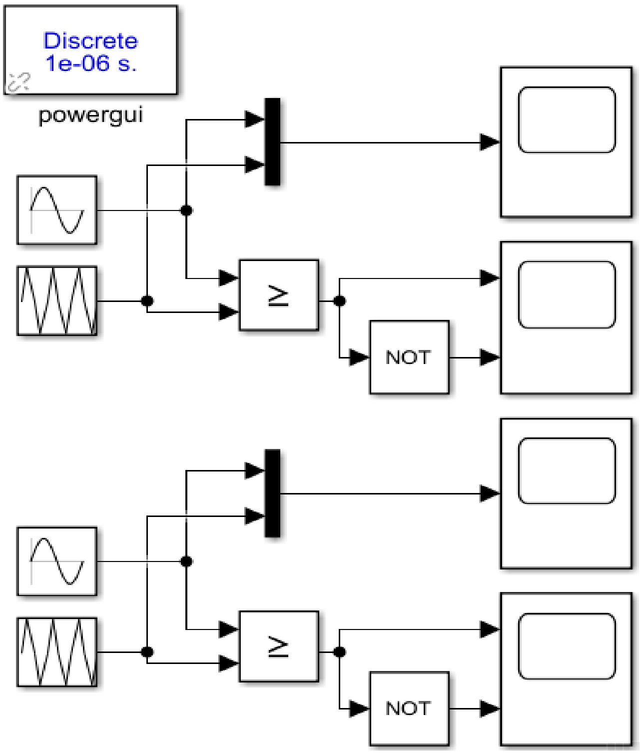


Fig. 7. SPWM technology for four switches

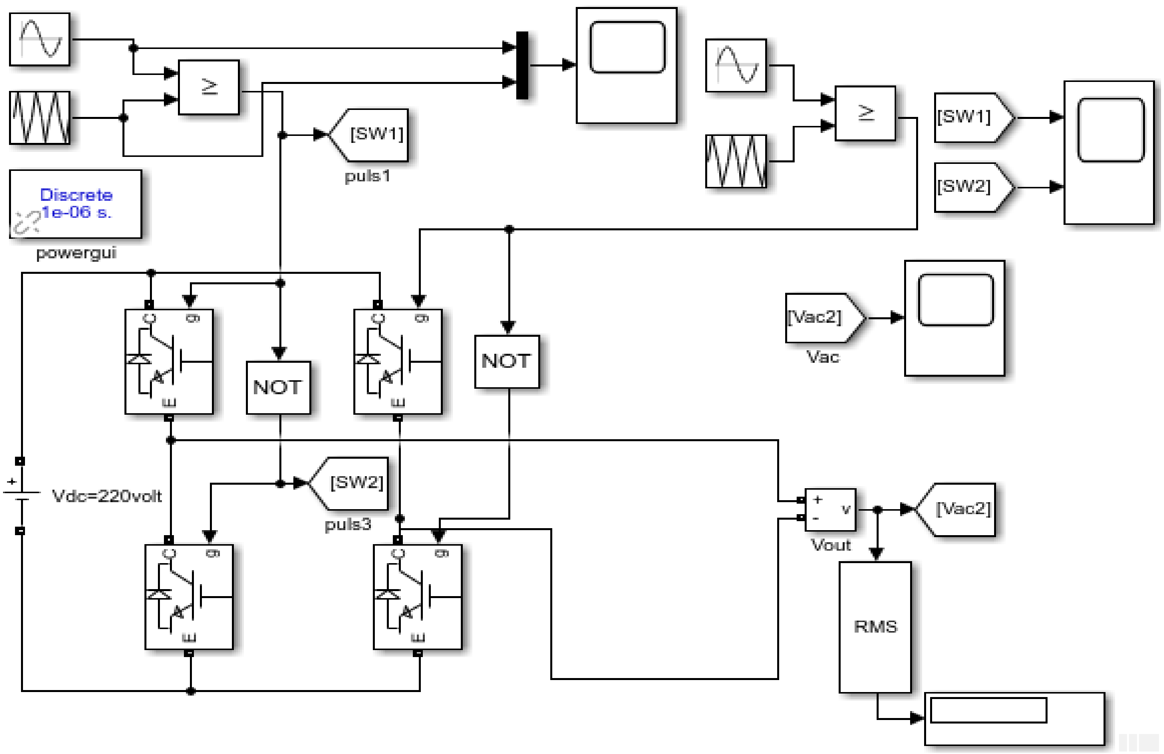


Fig. 8. VSI – SPWM without LC filter and R-load

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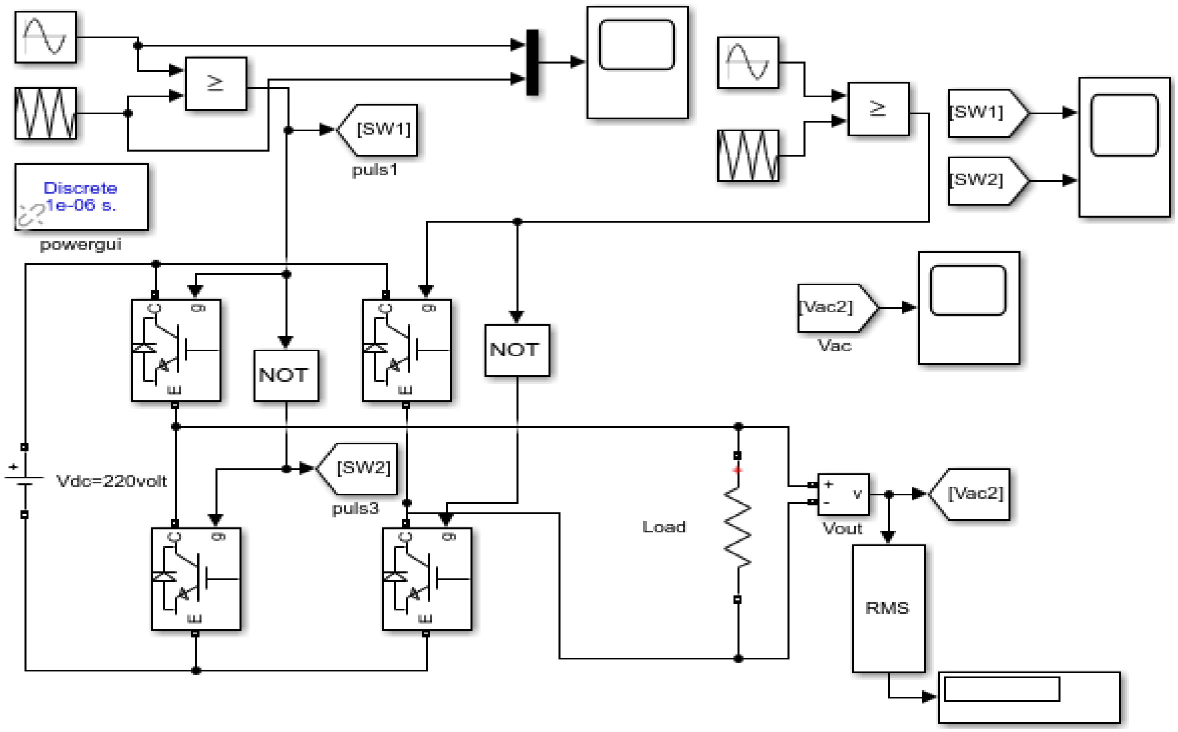


Fig. 9. VSI – SPWM with R-load

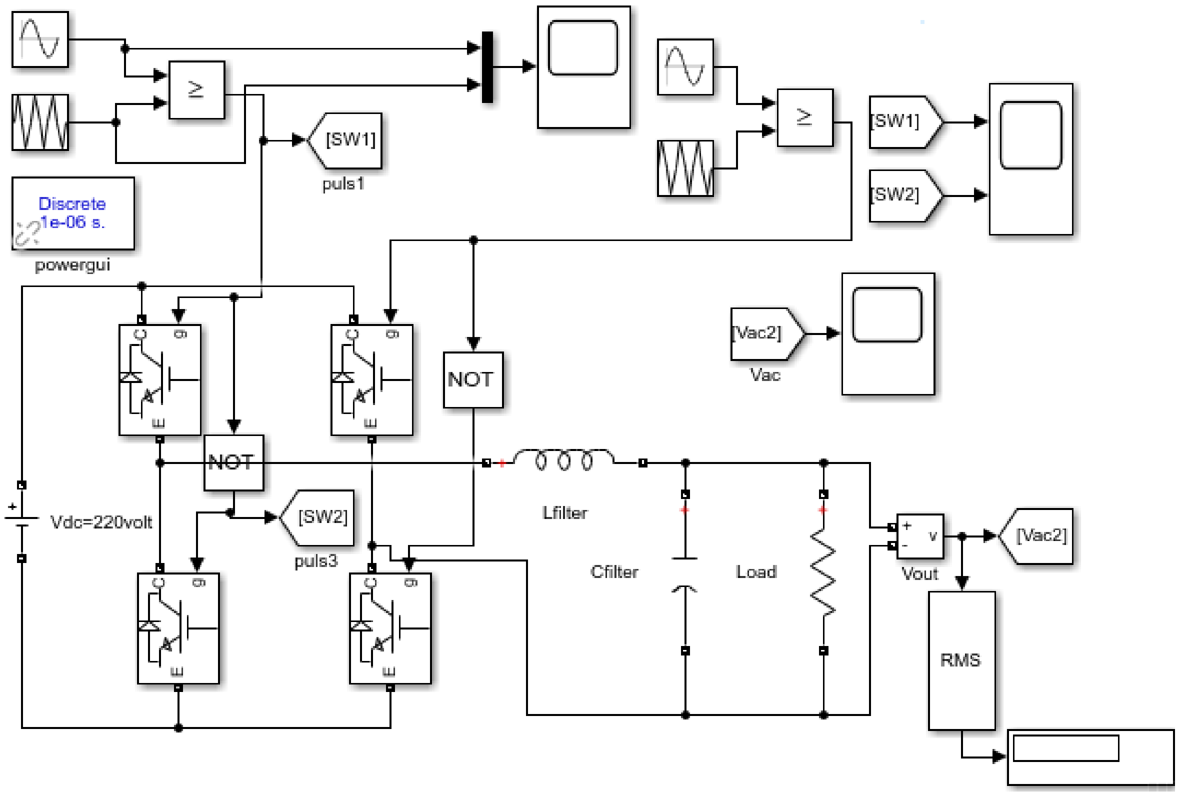


Fig. 10. VSI – SPWM with LC filter and R-load

3.2. Modeling and Simulation of SPWM-VSI for I.M.

In this section there are three tests for SPWM-VSI for I.M, first test the I.M at no load. Second test, the I.M at constant load. Finally, with variable load.

3.2.1. Modeling and Simulation of SPWM-VSI for I.M. at No Load

The Fig. 11 show the Modeling and simulation of SPWM-VSI for I.M. at No Load. In this test the value of rated voltage dc volt equal 325 volt that connected to input of inverter. The single-phase induction motor rotates at rated speed 1340 r.p.m when the fed rated frequency 50 Hz and rms rated AC voltage 220volt that the output voltage for inverter connected to I.M.

3.2.2. Modeling and Simulation of SPWM-VSI for I.M. at Constant Load

Fig. 12 shows the SPWM-VSI modeling and simulation of I.M. under constant load condition. In this test, a test value of 1 Nm is taken. The output signals of motor speed and torque are plotted and compared with the first case at no load, i.e. at zero torque.

3.2.3. Modeling and Simulation of SPWM-VSI for I.M. at Variable Load

Fig. 13 shows the SPWM-VSI modeling and simulation of I.M. under variable load condition. In this test, a test value is taken as the square of the rotor speed times the torque divided by the speed squared. The output signals of the motor speed and torque are plotted and compared to the first and second cases at no load i.e. zero torque and variable load.

$$220\ \text{volt}, 50\ \text{Hz}, \text{wrated} = 157\text{rad/sec}, \text{ws} = 1500\text{r.p.m}$$

$$\text{w} = \text{wrated} * 30/\text{pi} = \text{wr.p.m}$$

$$(3)/(\text{wrated} * \text{wrated}) = \text{Tm}$$

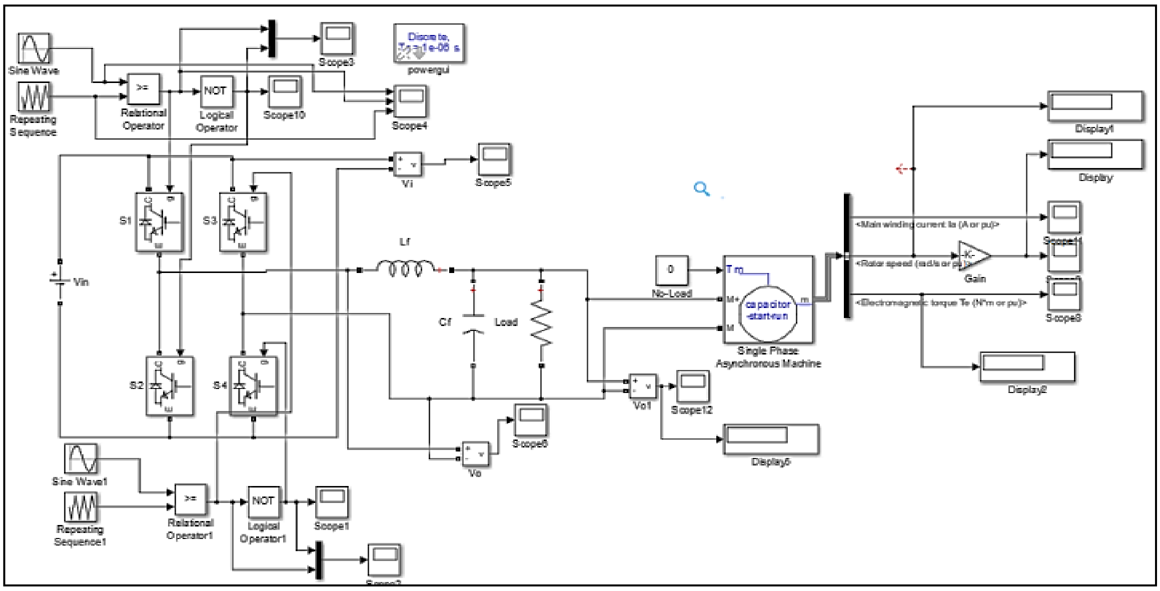


Fig. 11. Modeling and simulation of I.M. with no-load

4. Results and Discussion

The current section includes the results of two stages, the first is the result of simulating the single- phase resistive load and the second is the single-phase induction motor load.

4.1. Resistive Load Simulation Results

This section contains two parts, the first part is the results of a single-phase inverter to generate a square wave. The second part is the results of a single-phase inverter to generate a sine wave:

4.1.1. Results of A Single-Phase Inverter Simulation Model to Generate a Square Wave Using Matlab

In this section, the current test aims to show the results of converting 220 V DC to 220 RMS AC to supply a single-phase resistive AC load using the single-phase inverter model. The simulation results are shown the pulses as show in Fig. 14 and output of the single-phase inverter is in the form of a square wave as shown in the Fig. 15:

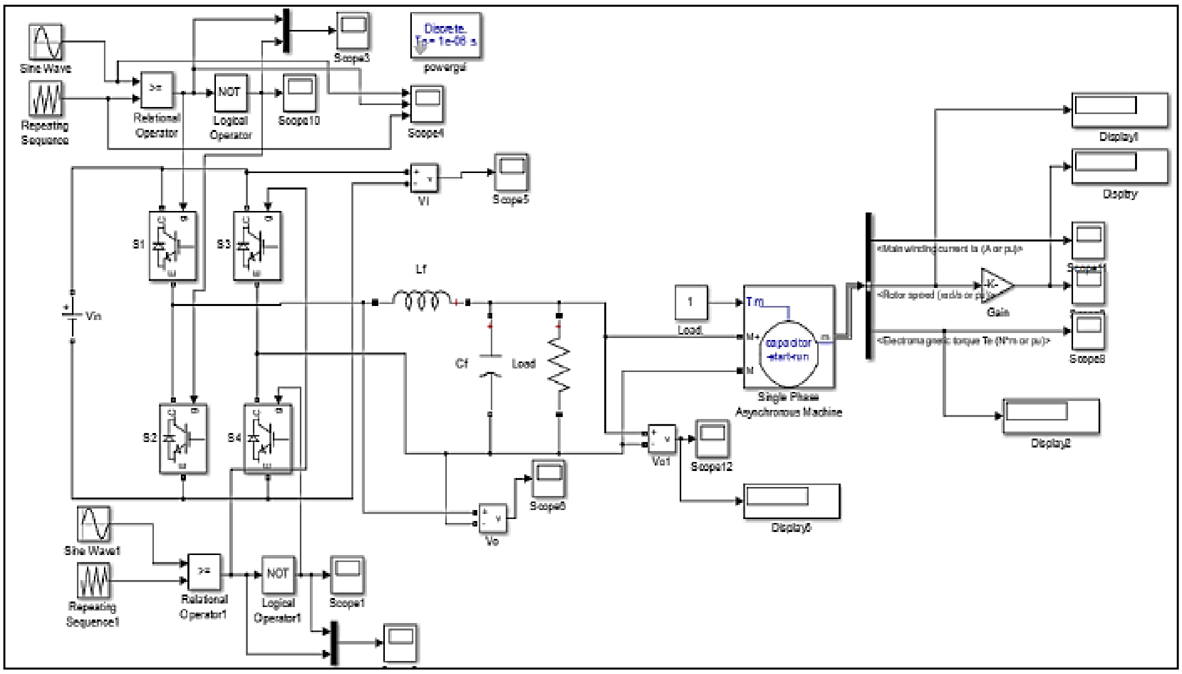


Fig. 12. Modeling and simulation of I.M. with load

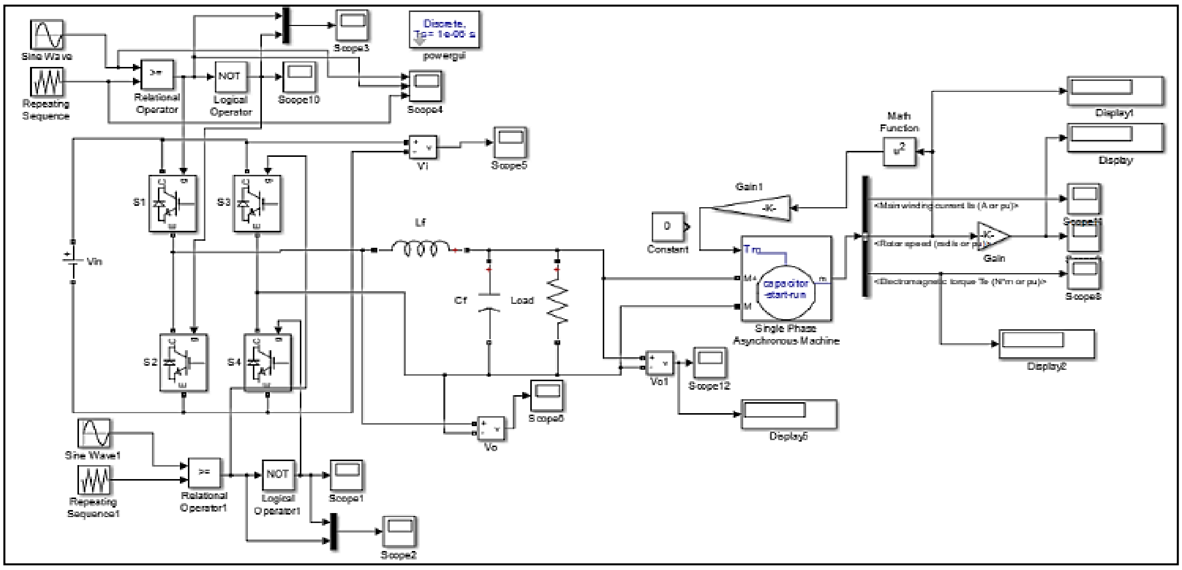


Fig. 13. Modeling and simulation of pump

Four electronic switches of the type of IGBT Transistor are used to build the inverter model, operating according to the first mode in which two switches are closed and two are open for a period of ten milliseconds, and in another period in which the opposite period is also ten milliseconds, to generate a wave with a frequency of 50 Hz. The first period gives a positive half of the value of the continuous voltage connected to the load by the two switches according to the first mode for a period of ten milliseconds, and in the same way the second mode works, giving the negative half by connecting the negative voltage source with the other two switches and the load. The output waveform of the inverter, which is fed to the load, can be observed as a sine wave of 220 volts and a frequency of 50 Hz.

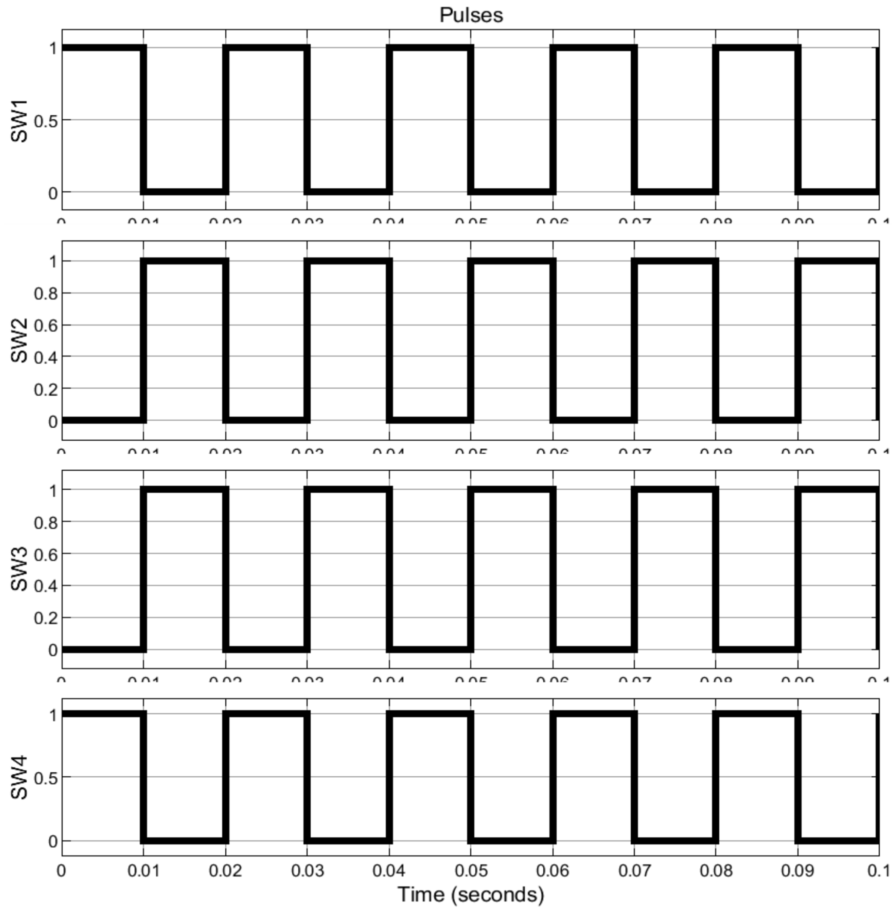


Fig. 14. Pulses for SW1, SW2, SW3 and SW4

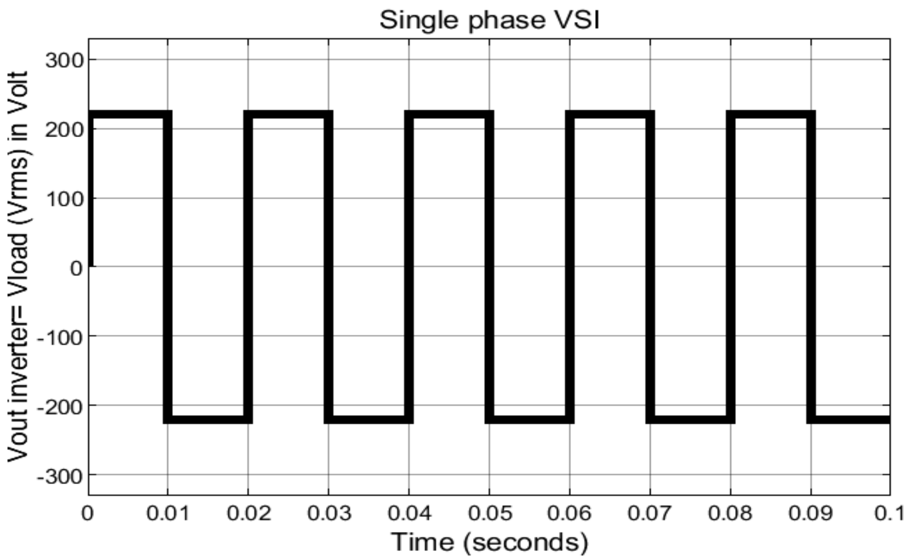
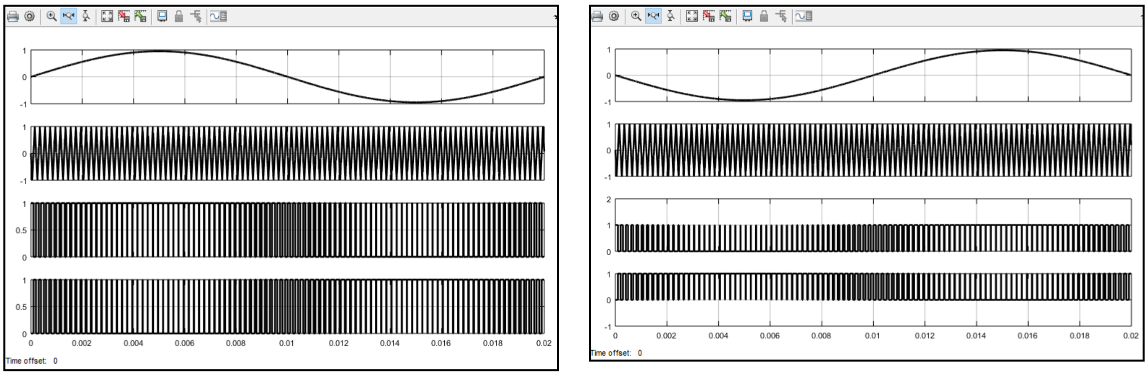


Fig. 15. Simulation result of Single-phase inverter (convert 220 V DC to 220 RMS AC) by Matlab

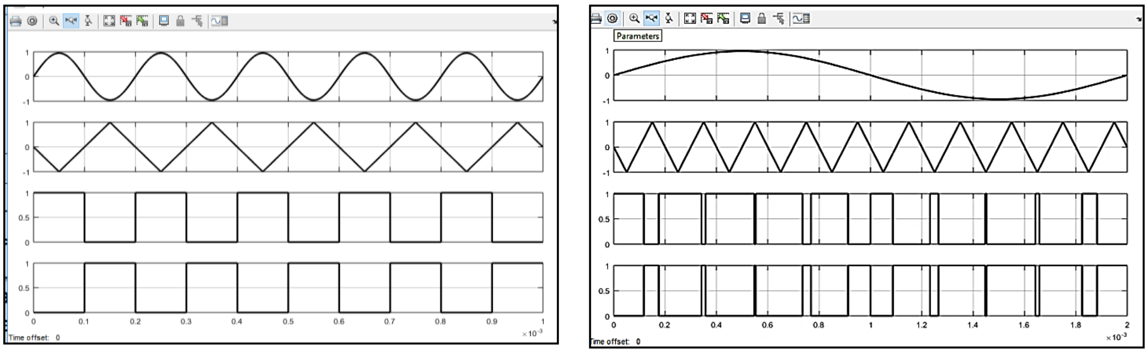
4.2. SPWM Simulation Results

Using the two models shown in Fig. 6 and Fig. 7, it is possible to know the signals of the pulse width modulation technology model, which represent the pulses that open and close electronic switches. It includes the operation of two switches, as well as the operation of four electronic switches, as in Fig. 16, Fig. 17, Fig. 18, Fig. 19.



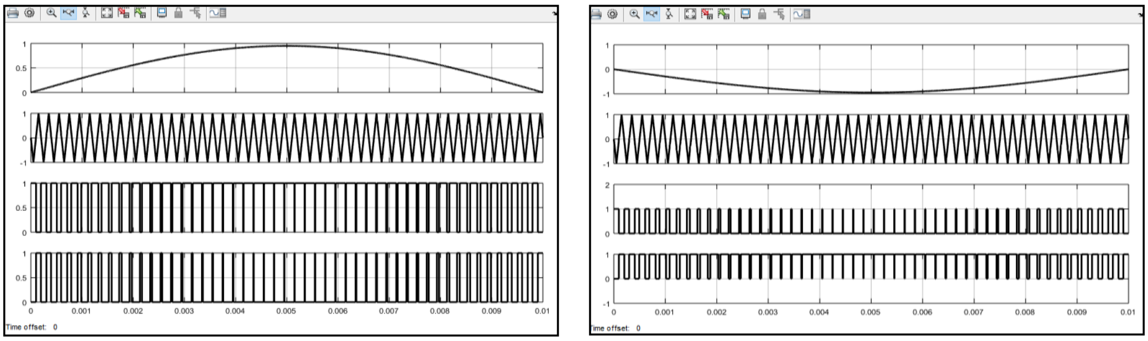
a. SPWM1 for SW1&SW2 at T=0.02sec b. SPWM2 for SW3&SW4 at T=0.02sec with phase shift 180o

Fig. 16. Response for SPWM1&SPWM2 with different phase shift at T=0.02sec



a. SPWM1 for SW1 & SW2 at Trun = 0.001sec b. SPWM1 for SW1&SW2 at Trun = 0.002sec

Fig. 17. Response for SPWM1&SPWM2 with different frequency



a. SPWM1 for SW1&SW2 at T=0.01sec b. SPWM2 for SW3&SW4 at T=0.01sec with phase shift 180o

Fig. 18. Response for SPWM1&SPWM2 with different phase shift at T = 0.01 sec

4.3. Simulation Results for VSI

This paragraph represents the use of the simulation models shown in Fig. 8, Fig. 9, Fig. 10, which represent models of a single-phase full-wave inverter composed of four electronic switches using pulse width technology. The simulation included operating the inverter in the first cases without a filter or load for the model, as in Fig. 8 and the results are in Fig. 20. The second is with a load and without a filter for the model, as in Fig. 9. The results are in Fig. 21. The third is the presence of the filter and load for the model as in Fig. 10 and the results in Fig. 22.

4.4. Simulation Results of LM

In this paragraph, the simulation models shown in Fig. 11, Fig. 12, Fig. 13 are used to study, analyze and know the behavior of the system in the case of running instant messaging without loading the model in Fig. 11 and its results as in Fig. 23, as well as the case of loading the model in Fig. 12 and its results are as in Fig. 24, in addition to the operation of the I.M. as a pump for the model in Fig. 13, and its results in Fig. 25 which represent the operation of the muscle as a pump.

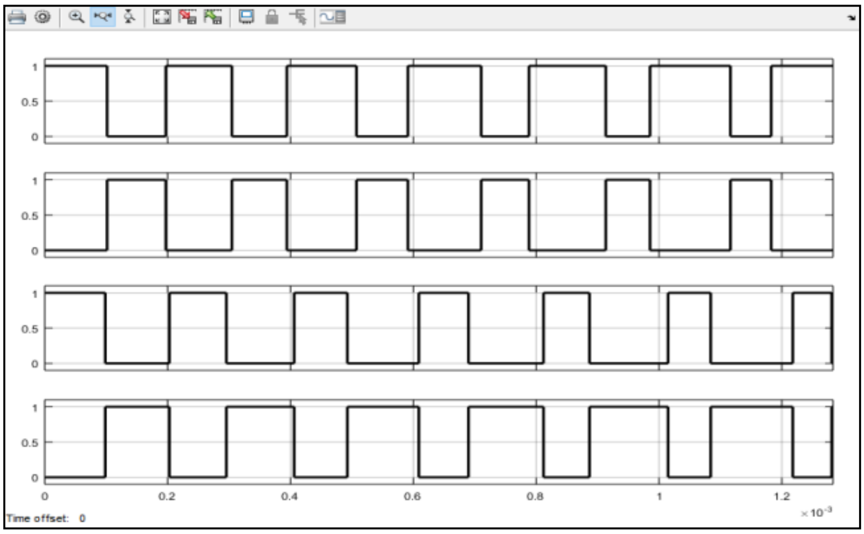
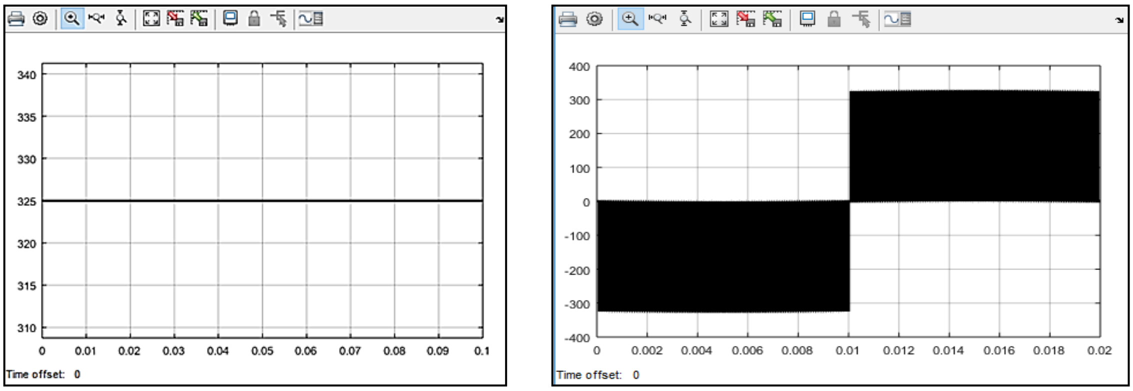


Fig. 19. Pulses for Sw1, Sw2, Sw3, Sw4



a. Input voltage of VSI b. Output voltage of SVI

Fig. 20. Results of VSI at No-Load

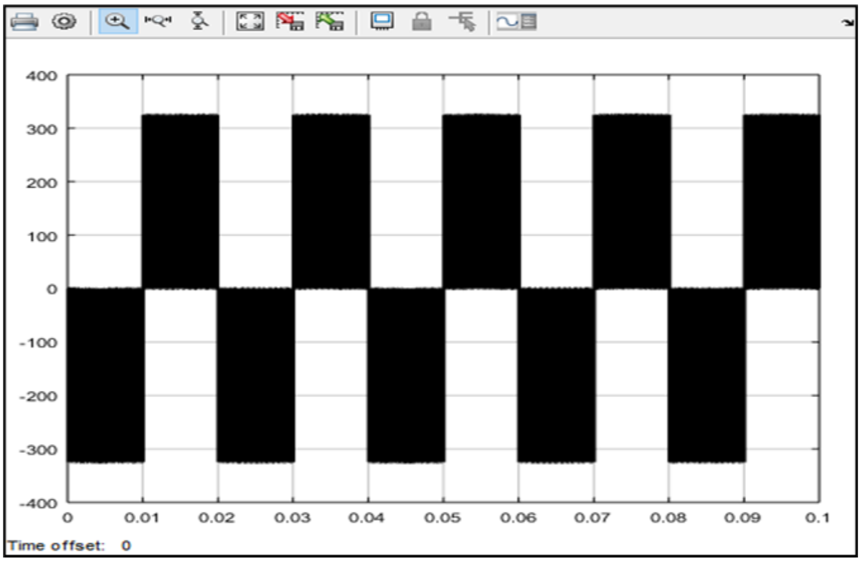


Fig. 21. Results of output voltage for VSI at R-load

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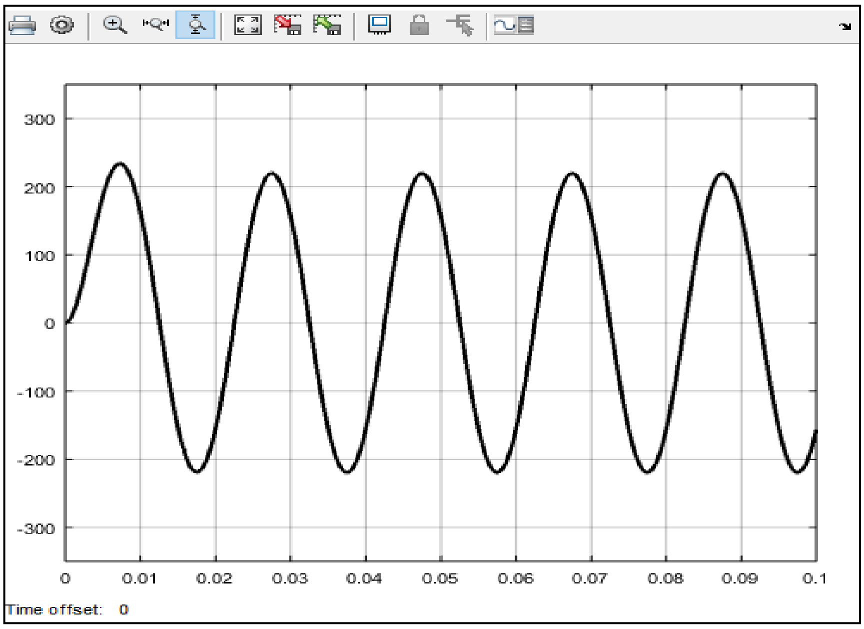
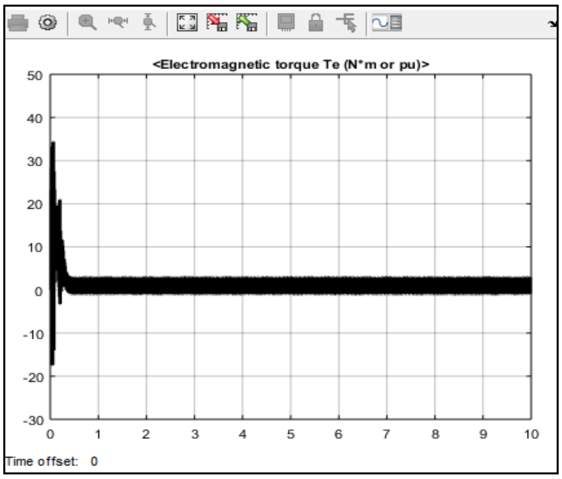
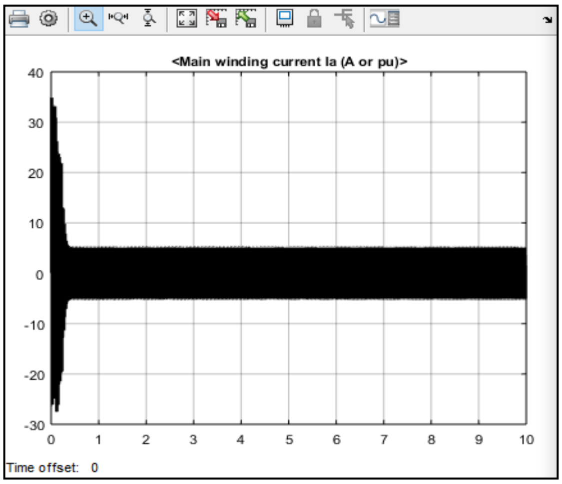


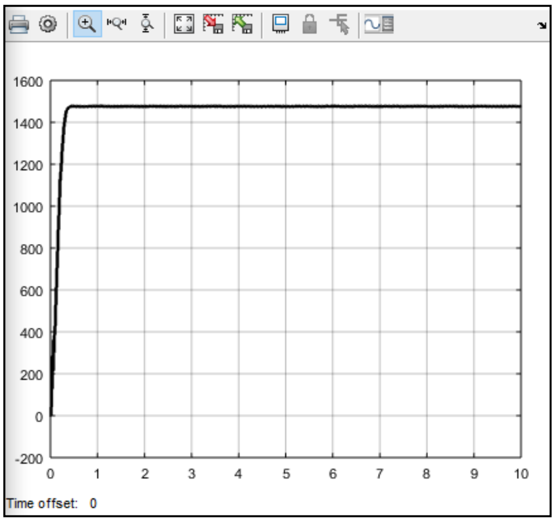
Fig. 22. Results of output voltage for VSI with the filter and R-load



a. Torque of I.M

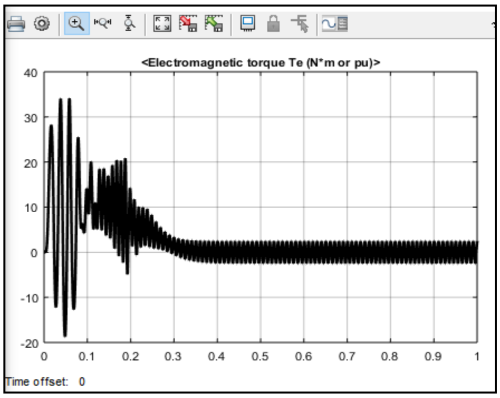


b. Current of I.M.

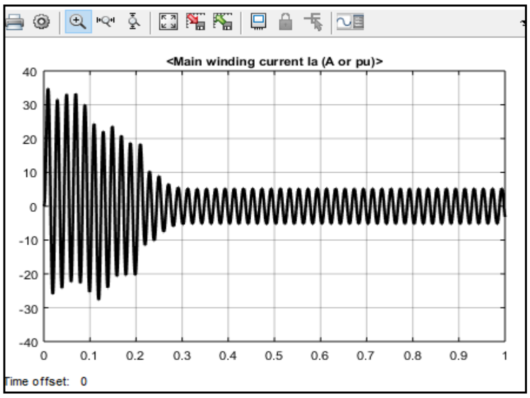


c. Speed (r.p.m)

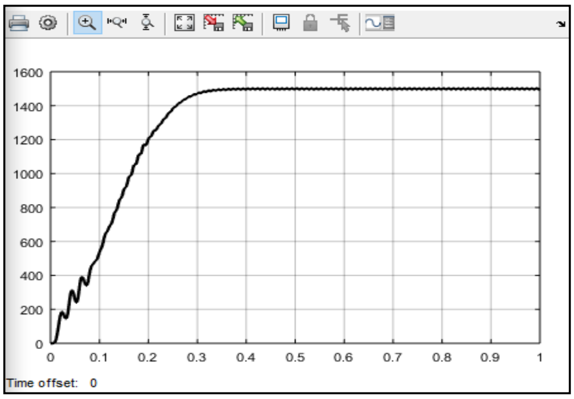
Fig. 23. Results of I.M. at No-Load



a. Torque of I.M

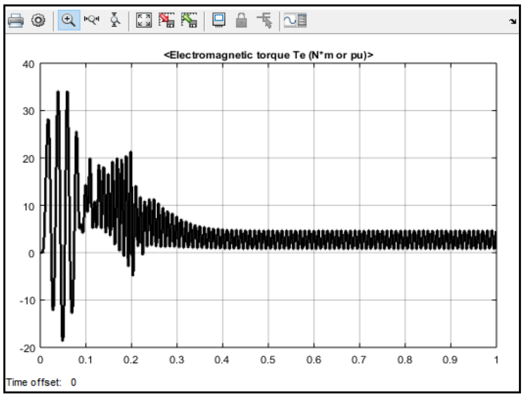


b. Current of I.M.

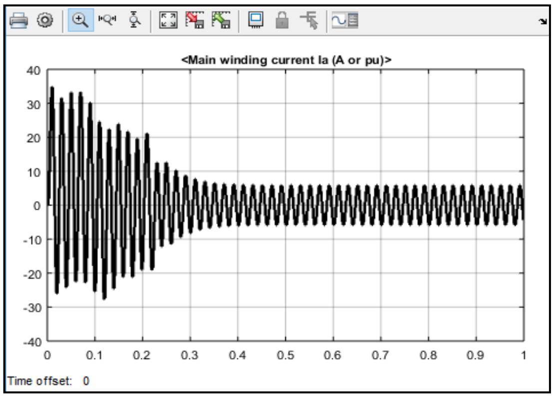


c. speed (r.p.m)

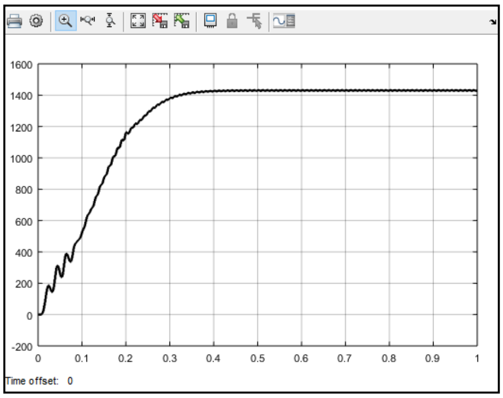
Fig. 24. Results of I.M at load



a. Torque of I.M



b. Current of I.M.



c. Speed (r.p.m)

Fig. 25. Results of I.M. for Pump

5. Conclusion

Simulation models were built to achieve two sets of objectives, one for the inverter performance and the other for the induction motor performance. The simulation was conducted to verify the possibility of using the inverter to generate square waves and sine waves after being fed from a DC voltage source. The system tests also verified the possibility of eliminating the harmonics contained in the square wave and generating a pure sine wave. The possibility of using pulse width modulation technology to control the required inverter output was verified by operating the electronic switches in the correct sequence. The possibility of generating an alternating current wave with a specific frequency that can be changed as required was verified with the possibility of determining the required inverter output voltage. On the other hand, the simulation was conducted to verify the possibility of operating the motor at the specified speed when connected to the inverter output and operating it at no load, constant load and variable load conditions. The models proved the effectiveness of the system and the possibility of using it for many future applications, including the closed loop system and the use of various control systems, as well as for applications such as operating the motor as a fan and another as a pump to explore more information about the system features.

It is worth noting that the engine can run at the specified speed when fed with the specified voltage. The possibility of building and designing a simulation model that includes all operating conditions has been verified. It is also possible to work in the future to address the starting current using different control methods, including controlling the voltage, frequency, or voltage-to-current ratio, with different control systems such as the traditional, expert, and smart controller.

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