# Simulation and Prototyping of a Two-Phase Inverter to Drive an Asymmetrical Single-Phase Induction Motor

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**Abstract:** Nowadays, a single-phase induction motor can be found in almost all electronic devices, especially for applications that use low power. This motor has one speed. A certain application requires this motor to have a speed variable generally uses mechanical techniques such as gears or sometimes electrical grouping windings. However, true variable speed will not be obtained, consuming more energy. The most precise way to control the speed of this motor is to use an inverter where the output voltage and frequency are variable. As it is known that a single-phase of the induction motor is a motor consisting of two windings. Alternating current flowing into each winding must have a phase difference of $90^0$. This paper discusses the research of a two-phase inverter with a simulation in MATLAB and prototyping. The driver circuit of the inverter used the three-legged method. Two legs were used as alternating voltage outputs, with a phase difference of $90^0$. One leg was used as common. Each leg consisted of a pair of IGBT with input in the form of SPWM voltage generated from signal modulation. From the inverter prototype that has been made, the inverter has driven the motor to rotate. Many harmonic signals in the current flowing to the motor were still found due to non-ideal component factors. Further research will be better to reduce the harmonic signals in the current windings to produce better rotation.

**Keywords:** single-phase motor, two-phase inverter, SPWM

## 1 Introduction

Single-phase induction motors are widely found in electronic devices that require low power, such as electronic devices for households. In addition, this motor is also used for medium power, where a three-phase electricity network is not available in that place [1]. This motor consists of two asymmetrical windings, where each winding requires a different phase current for this motor to rotate. This motor uses a single-phase source. To get a different phase current in each winding, use a capacitor in series with one of the windings. Since these motors use capacitors to make the current flowing into each winding different in phase, these motors are often referred to as permanently separated capacitor motors (PSCM)[2]. This motor rotates at one speed. This

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motor can rotate with variable speed through mechanical gears, grouping windings. However, this speed is not continuous. The use of an inverter can adjust the frequency needed to create continuous speed because the speed of this motor depends on the frequency of the voltage source [3].

For a single-phase motor to be powered and speed controlled using an inverter, it must be viewed as a two-phase motor. Each winding gets a different phase voltage source from the inverter. So the inverter needed here is a two-phase inverter. The two-phase inverter is an inverter that can produce two voltage sources with different phases. The advantage of using this inverter is that no mechanical device is needed to get a motor that rotates at a variable speed. In addition, the motor speed can also be adjusted continuously. The thing that needs to be considered in controlling the speed of this motor is operating at low frequencies because it can cause an overheat to the winding. Frequency adjustment in motor operation can reduce torque ripple and noise. Many methods have been proposed for manufacturing inverters to control the speed of single-phase motors. The price of power electronics components, which continue to decline, makes it possible to implement the methods that have been proposed in the manufacture of inverters for single-phase variable speed motors [4].

There are several studies related to controlling the continuous speed of single-phase motors. One of them is by using a single-phase converter. The main winding was still connected to the AC power grid source, while the auxiliary winding was connected to the inverter. The workings of this single-phase inverter were done by controlling the phase angle of the voltage coming out of the inverter. The phase angle of the frequency created from this inverter will adjust to the frequency of the AC power grid source. This process resulted in a phase difference between the two windings. The speed of the motor can be made variable because the frequency of the auxiliary winding is made variable. However, the modified phase angle decreases the motor's ability, causing ripples in the torque. It caused the motor to vibrate and generate noise[5].

In research [6], it was discussed that one way to make a continuously variable speed on a single-phase motor was to change a single-phase power source into a DC voltage source. Then, this DC source was converted into a three-phase voltage. Three-phase sources have variable frequency and amplitude. This three-phase source was then used to supply a single-phase motor by utilizing two-phases to each winding of the single-phase motor. It reduces torque pulses and lessens the noise.

The application of single-phase motors with variable speed depends on the needs. Three-phase motors cannot be used for various reasons, such as cost, mechanical structure, and space. A two-phase motor is a single-phase motor that has two unbalanced windings. However, there are also single-phase motors whose two windings are balanced. A two-phase inverter can be used for both conditions of a single-phase motor.

This paper discusses the research that has been done. This study performed a simulation in MATLAB to drive a single-phase induction motor with a voltage source using an inverter with a three-leg model. This simulated inverter produces three outputs in the SPWM waveform. Two outputs function to supply electrical power to the main and auxiliary windings, while the other functions as common or neutral. The current, motor speed, and torque were observed when the voltage and frequency in the inverter were changed. The subsequent discussion carried out in this paper is testing the inverter prototype that has been made in the study. This inverter prototype is based on the design and simulation carried out in MATLAB. Testing the inverter output using an oscilloscope is presented in this paper. In addition, the use of this inverter prototype to supply induction motors with motor data is also shown.

## 2 A single-phase induction motor model

**Figure 1** illustrates permanent-split capacitor motors (PSCs) commonly found in household devices, such as AC compressors, refrigerator compressors, washing machines, and fans. This motor has two windings: the main winding and the auxiliary winding. These two windings are installed at a position of $90^0$ to each other. These two windings are asymmetrical. A larger current will flow to the main winding, supplied by a single-phase power source. The electric current flows into the two windings with a phase difference of $90^0$, a capacitor is added in series to the auxiliary winding. The current flowing into the auxiliary winding will lead $90^0$ to the current flowing into the main winding. With the current phase difference flowing into each winding, there will be an unbalanced magnetic field in both windings. It will cause the motor to have the torque to rotate even from a stationary position. The circuit replacement for an induction motor is shown in Figure 2[7].

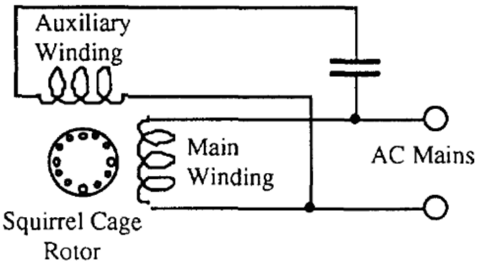

**Fig. 1.** Single-Phase Capacitor-Run Induction Motor

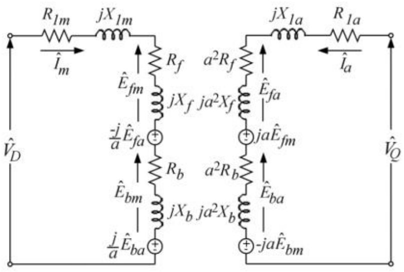

**Fig. 2.** The equivalent circuit of an asymmetric two-phase induction motor

Single-phase induction motors usually use capacitors in two ways. Firstly, the capacitor is used permanently, often referred to as the Running Capacitor. Otherwise, it is only used temporarily when the motor is turned on, often referred to as the Starting Capacitor. The difference between these two models is that the Running Capacitor establishes a phase difference between the main and auxiliary windings continuously while the motor is running. This auxiliary winding will work to provide power to the motor. While the Starting Capacitor is used when driving the motor from rest.

A rotating magnetic force (MMF) can be generated if a phase current difference occurs between the two windings. MMF becomes maximum if this difference is in the quadrant. The capacitor connected in series with the auxiliary winding will be a resonance reservoir. The result is an increase in the voltage across the auxiliary winding. To overcome this, the resistance in the auxiliary winding is greater than the main winding. When selecting capacitors, it is essential to pay attention to the impedance, which is a combination of the resistance of the auxiliary winding and the internal resistance of the capacitor. The winding ratio between the main and auxiliary can be formulated as follows.

$$\alpha = \frac{V_{aux}}{V_{main}} \tag{1}$$

The auxiliary winding is very sensitive to changes in frequency. The auxiliary winding in series with the capacitor has a slight chance of changing its frequency value because this will significantly affect the current passing through the winding. Incorrect frequency will cause the motor to fail because the current in the two windings is not in phase difference that forms a quadrant. In addition, it can also cause a large current to flow into the auxiliary winding so that the winding becomes burned. To find out the ratio of turns, coil size, and frequency can use the Veinott technique, [8] with reference to Figure 2. Changing the frequency value on the motor must be accompanied by changing the voltage value with a constant value required by the motor is volts/hertz. To prevent motor saturation, the frequency range given to the motor is $\frac{f_{rated}}{a} \leq f < f_{rated}$ [9].

## 3 Two-phase inverter model

Several studies have used solid-state switches to adjust the capacitor value by making several capacitor combination circuits. It was done to increase the torque of the motor. Keeping the phase angle of the current of the two windings maintained at $90^0$ increased the speed of the motor for maximum torque reasons. Thus, there is a little slip on the motor. However, this is not a way of making a single-phase motor have a variable speed.

Several studies have also proposed replacing the capacitor in series with the auxiliary winding with an inverter. The inverter was functioned to adjust the frequency of the auxiliary winding. Thus, it had a phase difference from the main winding. This phase difference varied according to the phase angle of the voltage frequency coming out of the inverter. It made the resulting speed control have pulsating torque, increased noise, and increased motor heat. It was a poor solution.

To obtain continuous variable speed control in a single-phase motor, the auxiliary and main windings must be supplied with voltage from two different sources. Each of these sources must have a variable frequency, amplitude, and phase angle. Hence, the current flowing in each winding can be arranged to keep it in the quadrant at all times. The way that can be used is to use an H bridge circuit in each winding and provide pulse width modulation (PWM) in the circuit. Each bridge requires four power electronics switches for eight switches.

A more effective way is to use six switches. There are three terminals of a single-phase motor. The first terminal is for the current flowing into the auxiliary winding. The second terminal is for the current flowing into the main winding, while the third terminal is for common flows. Each terminal requires two electronic switches. The switch for the common terminal must have twice the size of the other switches because the current flowing into the auxiliary winding and the current flowing into the main winding will meet at the common terminal. This series of drivers are packaged in one module and widely sold with a power of less than 1KW.

A modulation strategy is needed to produce a voltage output in the inverter, where this voltage can make the current flowing in both windings of the motor in quadrants. The frequency variation generated by the inverter to get a continuously variable motor speed must still produce a current phase difference of $90^0$[10]. The most important thing about the output voltage is the shift with a $90^0$ angular difference. The principle of producing a balanced two-phase PWM output voltage was based on comparing a two-phase modulated sine signal with a $90^0$ phase shift compared to a triangular waveform[11], known as a sinusoidal pulse width modulation (SPWM). Inverter with a two-legged model with two outputs of the same voltage has the following modulation function:

$$\begin{cases} v_a = V_m sin(\omega_r t) \\ v_b = V_m \sin(\omega_r t - 90^0) \end{cases} \quad (2)$$

By changing the amplitude and frequency of the reference sine wave signal, the output of the inverter was also changed. The phase voltage outputs of this inverter can be changed independently without being affected by one another. **Figure 3** shows a proposed three-legged VSI called a full-bridge PWM inverter for a two-phase motor drive system[12]. A third modulation function for the third leg was required compared to a conventional two-leg half-bridge inverter, as given in the equation below.

The two winding voltages are always squared w

$$\begin{aligned} v_a &= V_m \sin(\omega_r t) \\ v_b &= V_m \sin(\omega_r t - 90°) \\ v_c &= V_m \sin(\omega_r t - 180°) \end{aligned} \quad (3)$$

ith this modulation function for a balanced output voltage. Unfortunately, unbalanced output voltages with a phase difference of $90^0$ do not occur with the independent control of these modulating function signals[12].

In this paper, the modulation method was made to find the difference between leg A and leg C for the main winding and leg B and leg C for the auxiliary winding. As noted earlier in **Figure 3**, it is essential that the main and auxiliary winding currents were maintained at a phase of $90^0$. If the winding impedance is assumed to have the same ratio of resistance to reactance, the winding current will have the same relationship as the winding voltage. First, the cases where these assumptions were tested, and then the results were modified to handle cases where these assumptions are not valid.

$$\begin{aligned} V_a &= V_{ma} \sin(\omega t) \\ V_c &= V_{mc} \sin(\omega t - 90^0) \\ V_b &= V_a + V_c \\ V_b &= V_{ma} \sin(\omega t) + V_{mc} \sin(\omega t - 90^0) \end{aligned} \quad (4)$$

This equation explains the SWPM modulation that comes out of each leg. Voltage $V_B$ serves as a common point for voltage $V_A$ and voltage $V_C$. If we look for an analogy to a DC circuit, then in this inverter circuit, Voltage $V_B$ is analogous to a ground point. Since the two main winding terminals of the $V_D$ motor were connected to pins A and B, while the two auxiliary winding terminals of the $V_Q$ motor were connected to pins B and C, the equation for the voltage across each winding can be formulated as follows.

$$
\begin{aligned}
V_D &= V_{ba} = V_b - V_a \\
V_D &= (V_{ma}\sin(\omega t) + V_{mc}\sin(\omega t - 90^0)) - V_{ma}\sin(\omega t) \\
V_D &= V_{mc}\sin(\omega t - 90^0) \\
V_Q &= V_{bc} = V_b - V_c \\
V_Q &= (V_{ma}\sin(\omega t) + V_{mc}\sin(\omega t - 90^0)) - V_{mc}\sin(\omega t - 90^0) \\
V_Q &= V_{ma}\sin(\omega t)
\end{aligned}
\tag{5}
$$

In this formula, the voltage across the main and auxiliary windings differed in phase by $90^0$. The advantage of the modulation made in this study is that the voltage passed through the winding wire can be determined independently by determining the amplitude.

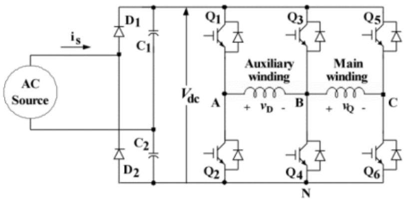

**Fig. 3.** The driver circuit of a two-phase inverter with a 3-leg model.

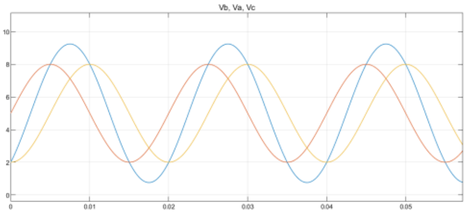

**Fig. 4.** Three-phase sine signal.

## 4 Inverter design and simulation

**Figure 5** shows the inverter circuit diagram proposed in this paper and simulated in MATLAB. This inverter consisted of a DC voltage source, two filter capacitors in series, three pairs of power transistors, and three pairs of rectifier diodes. One terminal of the main winding was connected to the midpoint of the power transistor pair on pin A, and the other was connected to pin B. Furthermore, one terminal was connected to pin C for the auxiliary winding. In contrast, the other was connected to pin B so that it became one with one of the terminals of the main winding so that pin B became the common terminals of the two motor windings. The reverse current from these two windings was fed back to pin B. The use of additional capacitors and transistors was aimed to assist the rotation of the current supply. The sine voltage generated from the SPWM control will produce an ideal sine if it can meet the current needs of the load. If not, then the source voltage drop will occur. The voltage drop that occurred rhythmically was called harmonic voltage. This harmonic voltage produced a torque pulse that interfered with the work of the motor. The addition of an auxiliary transistor for each leg, supplied by the capacitor, helped prevent harmonic voltages.

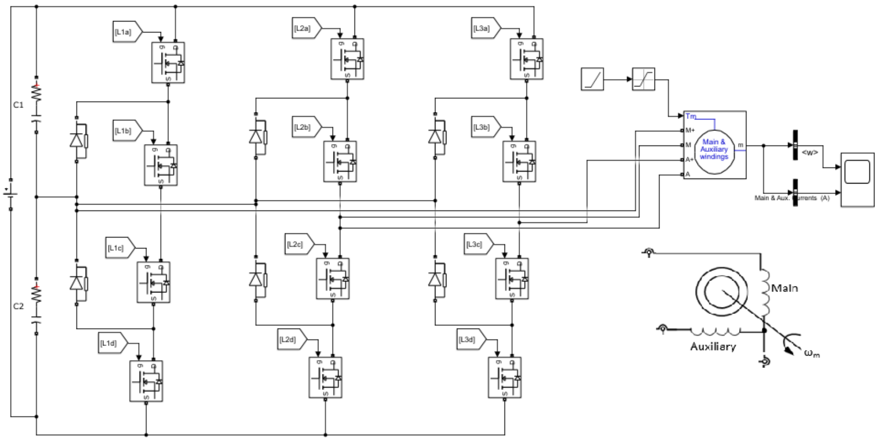

**Figure 5.** Circuit of a two-phase inverter for supplying a single-phase induction motor.

The control input of a two-phase inverter circuit with a 3-leg system is shown in Figure 6. The two modulated signals, Sas(t) and Scs(t), were made to have a phase difference of 900. Then the SPWM voltage was made based on these two signals using Tr(t) carrier wave. The two generated SPWM voltages are Sas(t) and Scs(t). This voltage was then used to control the inverter circuit to supply the motor. The input source of this inverter circuit was a DC voltage of 100 V. This DC voltage was generated from a converter that can be supplied by a battery or solar panel. The capacitance value of C1 = C2 = C = 2000uF. The inverter circuit used a constant V/f control strategy and SPWM. Two-phase modulated signals were generated by separately comparing two sine waves (Sas(t) and Scs(t)), with a phase difference of $90^0$, for a triangular Tr(t) carrier wave. At a certain instant, when Sqs(t) was greater than Tr(t), Q1 was ON, and Q2 was OFF in **Figure 6**.

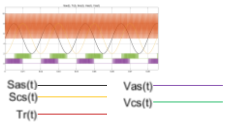

**Fig. 6.** SPWM technique waveforms from Sas, Scs, Tr, L1a, and L3a.

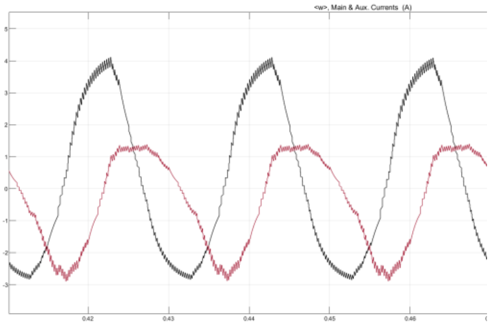

**Fig. 7.** Current in the main winding and current in the auxiliary winding.

The most important thing to know in this simulation is whether the current flowing in the two windings already had a phase difference of $90^0$. This requirement has been met from the measurement results in the simulation of the currents of the $I_{main}$ main winding and the $I_{aux}$ auxiliary winding, as shown in Figure 7. In this part, the current in the main winding was greater than the current in the auxiliary winding. The two sine waves created had the same amplitude and frequency. So that when connected to the motor, the current flowing to the main winding will be greater because the winding characteristics of the motor are different, where the number of turns in the main winding was less, or the resistance was smaller.

Furthermore, the measurements of the terminal voltages on each of the two motor windings were also carried out. Figure 8 shows the voltage across the main winding. This voltage is SPWM and, in terms of shape, slightly changed with the resulting SPWM voltage to control the inverter circuit because of the influence of the inductive nature caused by the winding of the motor against the source voltage.

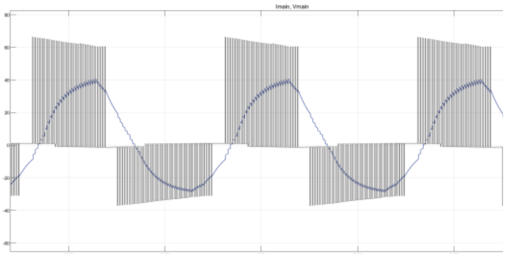

**Fig. 8.** Voltage in the main winding and current in the main winding.

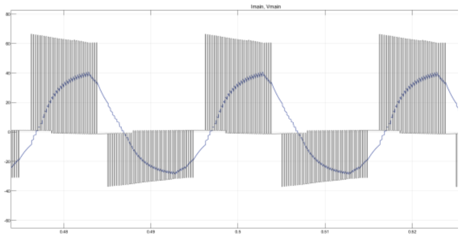

**Fig. 9.** Voltage in auxiliary winding and current in auxiliary winding.

## 5 Prototyping

The operation of a single-phase induction motor under the proposed variable speed control strategy was tested both in simulation and prototype using a two-pole (3000 rpm), 220, 25 W, capacitor-run motor. Experiments to realize the simulation of a two-phase inverter for a single-phase induction motor has been made on a prototype scale. This relation used Arduino Microprocessor to generate SPWM signal. The modulation techniques that have been simulated in the MATLAB software were then coded in the Arduino programming language. Furthermore, a three-leg inverter driver circuit was made using 1 KVA IGBT. The DC voltage source used to supply this inverter power was from a power supply of 100V.

Experiments have been carried out with 1 KVA IGBT, which was directly switched with an Arduino microprocessor. The program algorithm was specifically written using Arduino IDE software to create a two-phase modulated waveform with each phase voltage's variable absolute and relative magnitude, which moves from zero Hz to the desired frequency with a fixed V/Hz. The simulation was verified by selecting several operating points and comparing the simulated and experimental currents. In all cases, the similarity was very close, in which the software model was validated, and with the concept of variable control.

**Fig. 10.** Two-phase inverter prototype and its test with an oscilloscope.

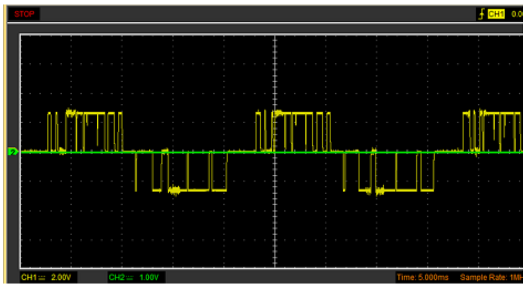

**Fig. 11.** The results of testing the output voltage of a two-phase inverter prototype with an oscilloscope.

Some of the generated constraints are in the form of signals that were still not exactly the same as simulated due to the quality factor of the IGBT. It was caused by the switching speed factor that did not reach the target. Nevertheless, this inverter system can make the motor rotate at a variable speed.

## 6 Conclusion

This study has carried out simulations and prototypes of a two-phase inverter to power a single-phase induction motor. This two-phase inverter circuit was made using a 3-leg system. Two legs were used to supply power to the main and auxiliary windings. In contrast, the other leg was used as the common of these two supplied windings. Two parameters are critical in this inverter. The first was that the phase difference of the current flowing in each winding must be $90^0$ because this will cause the motor to start from rest and have a stronger torque. The second is the comparison between the frequency and the output voltage. The current entering the winding was even more significant when the frequency was lowered. It is typical of the motor's inductive load; hence, decreases in frequency must be accompanied by a decrease in the voltage from the inverter. The simulation using Simulink Matlab resulted in the ability of this inverter to drive and regulate the speed of a single-phase motor. When made into a prototype, this inverter could drive a single-phase motor, but the motor rotation still pulsed because the IGBT transistor factor was still not ideal. For further research, eliminating pulses in motor rotation by adding new modulation techniques is highly recommended as a research topic.

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