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Parallel Session Schedule

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Table

Inverter Design with Selective Harmonic Elimination Pulse Width Modulation (SHE PWM) Method For Agricultural Irrigation Pump

Bambang Sujanarko
Department of Electrical Engineering
University of Jember
Jember, Indonesia
sujanarko.teknik@unej.ac.id

Achmad Danil Endrico
Department of Electrical Engineering
University of Jember
Jember, Indonesia
danilrico13@gmail.com

Wahyu Muldayani
Department of Electrical Engineering
University of Jember
Jember, Indonesia
wahyumuldayani.teknik@unej.ac.id

Dedy Kurnia Setiawan
Department of Electrical Engineering
University of Jember
Jember, Indonesia
dedy.kurnia@unej.ac.id

Abstract— Global warming is a result of the use of fossil fuels. To overcome this problem, renewable energy sources need to be encouraged. Among the renewable energy sources that are currently the most effective are Photovoltaic (PV), which convert sunlight into electrical energy. However, PV can only produce electrical energy from morning to evening and in the form of Direct Current (DC) power. Therefore, batteries are needed as energy storage and inverters. This research discusses inverters with low harmonics through the Selective Harmonic Elimination Pulse Width Modulation (SHEPWM) technique to increase the utility of an integrated PV-battery system. The whole system then be implemented for agricultural irrigation pumps.

Keywords– global warming, photovoltaic, inverter, selective harmonic elimination, pulse width modulation, irrigation pump.

I. Introduction

Nowadays, the amount of fuel oil is getting scarce and the price is getting more expensive. In addition, fuel oil also produces considerable pollution. As a result, many power plants have switched to using renewable energy. One example is PV. Many companies have started using solar panels as their power source. However, there are quite a lot of obstacles because there are several systems that cause decrease of the quality of electric power. It's crucial problem because power quality is very important in modern industrial systems [1].

The majority of the population in Indonesia has a livelihood as farmers, so one implementation of PV is as a water pump for irrigation in agricultural areas. An electric motor used for it purpose. Electric motor is an electric machine that convert electrical energy into mechanical energy, where the mechanical energy is in the form of rotation of the motor. One of motor type most used is Alternating Current (AC) motor, because the AC pump motor has an affordable price and is relatively easy to obtain.

Using PV-batteries integration for AC motors for irrigation requires an inverter that convert DC to AC power [2]. On inverter DC convert to a sinusoidal AC voltage in certain magnitude and frequency. But the output voltage waveform of a discretely activated inverter contains harmonics. Harmonics is some distortions in the current and voltage waves, so that the resulting wave is not pure sine. This distortion should be as close as possible to the sinusoidal waveform [1].

Therefore an appropriate method is needed to generate a sinusoidal wave. The SHEPWM technique is one of the switching strategies introduced in 1974 by H. S. Patel and R. G. Holt [3]. The SHEPWM strategy is implemented by first solving non-linear equations using numerical methods such as Newton-Raphson, Resultant Theory, Genetic Algorithm and Pattern Search Methods to get the right switching angle from the inverter [4-6].

II. Method

A. *Schematic design*

The schematic design of the inverter circuit is shown in Fig. 1. In this schematic consist of four MOSFET in the bridge formula, driver MOSFET, Arduino microprocecor, etc. This schematic has been simulated with Proteus.

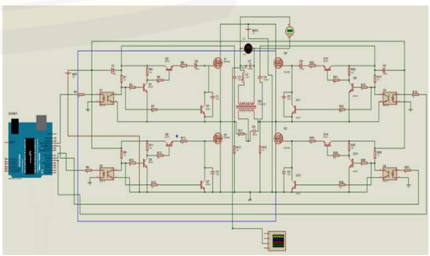

Fig. 1 Inverter Circuit Schematic with Proteus

B. Switching Angle Calculation

Second step of SHEPWM design is calculation the switching angles. In this research, it's done by Fourier transform and Newton-Raphson and by using MATLAB software.

B.1 Fourier Transform

The general formula for calculating the switching angle of inverter are in (1) that derived from Fourier series.

$$\begin{aligned} &\mathrm{Cos}(\alpha_1) - \mathrm{Cos}(\alpha_2) + \cdots \pm \mathrm{Cos}(\alpha_N) = \frac{\pi}{4}M \\ &\mathrm{Cos}(3\alpha_1) - \mathrm{Cos}(3\alpha_2) + \cdots \pm \mathrm{Cos}(3\alpha_N) = \frac{3\pi}{4E}h_3 \\ &\mathrm{Cos}(5\alpha_1) - \mathrm{Cos}(5\alpha_2) + \cdots \pm \mathrm{Cos}(5\alpha_N) = \frac{5\pi}{4E}h_5 \\ &\mathrm{Cos}(N\alpha_1) - \mathrm{Cos}(N\alpha_2) + \cdots \pm \mathrm{Cos}(N\alpha_N) = \frac{N\pi}{4E}h_N \end{aligned} \tag{1}$$

Where M is the modulation index and M=h1/E. The cosine terms of N are negative for an even number N. While N is positive for odd numbers N. According to the nonlinear system above, the surplus harmonic N-1 can be removed from the output waveform by setting the equation to zero, then the calculation is as follows:

$$\begin{aligned} &\mathrm{Cos}(3\alpha_1) - \mathrm{Cos}(3\alpha_2) + \cdots \pm \mathrm{Cos}(3\alpha_N) = 0 \\ &\mathrm{Cos}(5\alpha_1) - \mathrm{Cos}(5\alpha_2) + \cdots \pm \mathrm{Cos}(5\alpha_N) = 0 \\ &\mathrm{Cos}(N\alpha_1) - \mathrm{Cos}(N\alpha_2) + \cdots \pm \mathrm{Cos}(N\alpha_N) = 0 \end{aligned} \tag{2}$$

B.2 Newton Raphson Calculation

The lowest odd harmonic component needs to be removed from the single-phase system while the lowest non-triple harmonic component needs to be removed in the three-phase system. In general, all triple harmonics in the line-to-line voltage will be eliminated with a characteristic phase shift of 120 degrees. There are several steps to calculating the angle using Newton-Raphson. The first step is to create a switching angle matrix as (3).

$$\alpha^j = [\alpha_1^j, \alpha_2^j, \alpha_3^j, \ldots, \alpha_N^j] \tag{3}$$

The second step is to create a nonlinear system of equations matrix as (4) then (5).

$$F^j = \begin{matrix} Cos(\alpha_1^j) - Cos(\alpha_2^j) + \cdots \pm Cos(\alpha_N^j) \\ Cos(3\alpha_1^j) - Cos(3\alpha_2^j) + \cdots \pm Cos(3\alpha_N^j) \\ Cos(N\alpha_1^j) - Cos(N\alpha_2^j) + \cdots \pm Cos(N\alpha_N^j) \end{matrix} \tag{4}$$

$$\left[\frac{\partial f}{\partial \alpha}\right]^j = \begin{matrix} -Sin(\alpha_1^j) + Sin(\alpha_2^j) - \cdots \pm Sin(\alpha_N^j) \\ -3Sin(3\alpha_1^j) + 3Sin(3\alpha_2^j) - \cdots \pm 3Sin(3\alpha_N^j) \\ -Sin(N\alpha_1^j) + Sin(N\alpha_2^j) - \cdots \pm NSin(N\alpha_N^j) \end{matrix} \tag{5}$$

Where,

$$\alpha_1 < \alpha_2 < \cdots < \alpha_n < \frac{\pi}{2} \tag{6}$$

For the graph of the calculation results using the Fourier and Newton-Raphson series, it is obtained as shown in the Fig.2. Where is the blue for the 1st harmonic, red for the 3rd harmonic, black for the 5th harmonic, yellow for the 7th harmonic, and green for the 9th-harmonic. For the modulation index (M) using a value of 1, which is obtained from (7). Final result of switching angle is shown in Table I. Switching angle then insert in the Arduino microprocessor.

$$M = \frac{V_{out}}{V_{dc}} \tag{7}$$

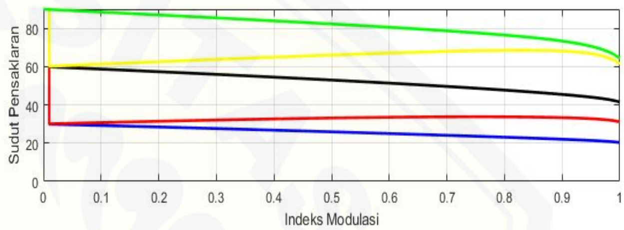

Fig. 2 Switching Angles of SHEPWM

TABLE I. SWITCHING ANGLES

Orde	Switching Angles
1	20,3477°
3	31,1314°
5	41,5082°
7	61,5130°
9	64,4130°

C. Photovoltaic Specification

Solar panels are made of semiconductor materials that have weakly bonded electrons or what is called the valence band. When the energy exceeds a certain limit then the remaining energy is applied to the valence electrons first. The inverter in the schematic has an important role.

The inverter converts the 100 volt DC voltage from the solar panel into 200 volt AC. So that electricity from generating sources can be used at home loads. The modified sine wave inverter is an inverter that is suitable for use in household electronic equipment that has an induction load such as an electric motor. In the research the solar panel input is considered stable at a voltage of 100 volts as shown in Table II.

TABLE II. PHOTOVOLTAIC SPECIFICATIONS

Voltage	100 VDC
Current	5 A
Capacity	500 Wp

In this study using a solar panel with the type of polycrystalline. Polycrystalline is usually blue in colour and is produced by melting raw silicon, which is a faster and less expensive process than that used for monocrystalline cells. Polycrystalline has a lower efficiency of about 15%.

D. Motor Pumps Specification

In An induction motor (also known as an asynchronous motor) is a commonly used AC electric motor. In an induction motor, the electric current in the rotor required to produce torque is obtained through electromagnetic induction from the rotating magnetic field in the stator winding. The induction motor rotor can be either a squirrel cage rotor or a wound type rotor.

Induction motors are referred to as 'asynchronous motors' because they operate at speeds less than their synchronous speed. The induction motor is the simplest electric machine from a construction point of view. Induction motors work on the principle of induction in which an electromagnetic field is induced into the rotor when the rotating magnetic field of the stator cuts the stationary rotor. Induction machines are by far the most common type of motor used in industrial, commercial, or residential settings.

For the working principle of AC motor, we need to provide double excitation to make the DC motor rotate. But in induction motors, we only provide one supply, so it is interesting to know how induction motors work. In the research the motor pump is considered stable at a capacity of 125 watt as shown in Table III.

TABLE III. MOTOR PUMP SPECIFICATIONS

Voltage	220 VAC
Current	0,58 A
Capacity	125 W
Frequency	50/60 Hz

Therefore, for the implementation of the inverter design, it takes test data from the output voltage and current from the inverter to the motor pump and tests the output voltage and current waves from the inverter using an oscilloscope. After the data from the output voltage and current is obtained, it is continued with the calculation of the THD value to determine whether the inverter with the SHE PWM method has low harmonic distortion in the output voltage and current. For no-load testing, namely testing the voltage and current output directly from the inverter using an Avometer and an oscilloscope. As for testing with a motor load, the inverter is connected to a step up transformer first because the pump motor requires a voltage of 220 V.

E. THD Calculation

Total Harmonic Distortion, or THD, is one way to measure the quality of a power supply. THD shows how many harmonic components are contained in the voltage and current waveform, and it serves as an indicator of the extent of distortion of the waveform caused as a result. In addition to power waveforms, THD is used to analyse vibration and audio waveforms.

The harmonic or frequency harmonic of a periodic voltage or current is a frequency component in a signal that is at an integer multiple of the main signal frequency. This is the basic result shown by Fourier analysis of a periodic signal. Harmonic distortion is signal distortion due to these harmonics. A pure sinusoidal voltage or current has no harmonic distortion because it is a signal consisting of one frequency. A voltage or current that is periodic but not purely sinusoidal will have a higher frequency component in it which contributes to the harmonic distortion of the signal. In general, the less a periodic signal looks like a sine wave, the stronger its harmonic component and the more harmonic distortion it has.

So, a pure sinusoidal signal has no distortion whereas a square wave, which is periodic but doesn't look sinusoidal at all, will have a lot of harmonic distortion. In the real world, of course, sinusoidal voltages and currents are not perfectly sinusoidal; some amount of harmonic distortion will be present. That is, the calorific value of the harmonic potential is relative to the fundamental. This index can be calculated for voltage or current. The THD of Voltage is obtained using (8).

$$THD_V = \frac{\sqrt{\sum_{h>1}^{\infty} V_h^2}}{V_1} X100\% \quad (8)$$

This test is done by directly analyzing the THD value on the oscilloscope. On the oscilloscope display selected on the math menu then the THD spectrum will appear. After the math menu appears, you can read the THD value. This test is carried out with an inductive load in the form of a pump motor with a power of 125 Watt. The value of total harmonic distortion (THD) is obtained by reading the FFT oscilloscope spectrum. From this spectrum, it can be calculated the value of voltage THD.

F. Inverter 1 Phase

Single phase inverter is used to convert DC electricity from solar panels into AC electricity. Then after the inverter is directly channelled to the load. Making an H-bridge inverter using PWM as a sine wave generator has various advantages. Making this Inverter using MOSFET IRFP450LC.

This MOSFET was chosen because it adjusts the maximum solar panel voltage up to 100 volts and the current reaches 5 amperes. The IRFP450LC MOSFET has a VDS of up to 500 volts and an ID of up to 14 amperes. The MOSFET arrangement is placed on the side so that it is easy to combine with the heat sink. For the inverter with the SHE PWM method, four triggers are used, namely S1, S2, S3, and S4. The configuration as shown on Fig. 3.

The PCB circuit uses four MOSFET drivers with a BC847 optocoupler which functions as a safety for the MOSFET. In addition, there is also a diode that functions as a safety so that the voltage and current of the DC source do not short with the source of the MOSFET trigger. For the voltage required for the GATE to open is 15 VDC.

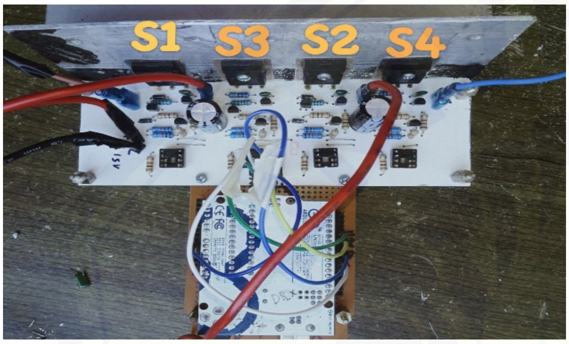

Fig. 3 Inverter Circuit

The input to the inverter has two inputs consisting of a VDC input which will be converted into VAC and an input for MOSFET of 15VDC. For triggers, the Arduino has four triggers and one ground which is connected to the Arduino Uno microcontroller. To trigger the Arduino Uno, initialize PWM pins 5, 6, 9, and 10. These pins will later become triggers for MOSFETs S1, S2, S3, and S4.

After determining the components in the inverter, the parameter values in the design can be determined as shown in Table IV.

III. Result and Discussion

A. Inverter Test

The first test of the inverter with the SHE PWM method is to use a variable voltage to determine the efficiency of the inverter. The source voltage variation on the inverter uses a power supply with variations between 0 VDC to 12 VDC. The scheme is to connect Arduino Uno to a laptop or 9 VDC battery as a PWM trigger to the MOSFET. Then, connect 15 VDC from the power supply to the MOSFET driver. After that, the source of the power supply with a voltage starting from 0-12 VDC is connected to an inverter to be converted to 0-12 VAC with a switching circuit in the form of an IRFP450LC MOSFET. The 12 VAC output is then connected to a fixed load in the form of a 5 Watt capacitor with a resistance of 470 ohms.

TABLE III. INVERTER PARAMETERS

Output Voltage	100 VAC
Input Voltage	100 VDC
Output Current Max	12 A
Switching Frequency	52,37 Hz
Power MOSFET	IRFP450LC
Octocoupler	BC847
Microcontroller	Arduino Uno

With the average efficiency value of the voltage variation of 80%, the inverter with the SHE PWM method can be tested to the next stage, namely implementation with lamp loads and motor loads. For the current value at the inverter output has an average of 0.019 A. So the power generated at the inverter output also has a small average as well. This is influenced by the magnitude of the resistance value on the resistor of 470 ohm.

B. Load Test

The implementation of the inverter with the SHE PWM method uses a voltage directly from the solar panel of 100 VDC. The solar panels used consist of 5 solar panels. For the capacity of one solar panel itself is 20 WP with a voltage of 20 VDC and a current of 1 A. The five solar panels are connected in series to get a voltage value of 100 VDC.

For the implementation scheme, namely connecting Arduino Uno to a laptop or 9 VDC battery as a PWM trigger to the MOSFET. Then, connect 15 VDC from the power supply to the MOSFET driver. After that, the source from the solar panel with a voltage of 100 VDC is connected to an inverter to be converted to 100 VAC with a switching circuit in the form of an IRFP450LC MOSFET. The 100 VAC output is then increased to 220 VAC using a slide transformer and connected to a low pass filter and an AC motor pump with an active power of 125 Watt. From the results of the implementation, the data obtained Table V.

TABLE IV. INVERTER TEST RESULTS WITH SHE PWM METHOD USING WATER PUMP MOTOR LOAD

Parameter	Input	Output
Voltage	101 VDC	216 VAC
Current	3,76 A	1,71 A
Capacity	379,76 W	371,52 W

In Table V it can be observed that the input voltage value from the solar panel is 101 VDC with a current of 3.76 A. This is because the time of data collection was carried out at 9.50 WIB in the morning with cloudy sunny conditions, so the voltage at the input reached 100 VDC. .

As for the output power generated for powering that is equal to 379.76 Watt. This is influenced by the amount of current from the solar panel which has a capacity of 5 A, while the active power required by the motor itself is quite large, namely 125 Watt. The data also shows that a large enough current is required from the source in order to power the motor optimally. For the waveform generated during testing with a pump motor load, it is obtained as shown in Fig. 4.

Fig. 4 shows that the value of the wave frequency when using a pump motor load is 53.88 Hz. This frequency value is influenced by the absence of a low pass filter. The frequency value that exceeds this also causes the pump motor to sound because the frequency that should enter the pump motor is 50/60 Hz. To reduce the ripple of the wave, it is necessary to have a suitable filter so that the ripple of the wave is reduced.

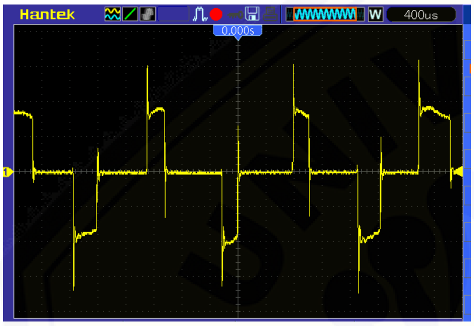

Fig. 4 SHEPWM Inverter Waveform Using Water Pump Motor

C. Testing Inverter THD Value With SHE PWM Method When Implemented With Pump Motor.

This test is carried out with an inductive load in the form of a pump motor with a power of 125 Watt. The value of total harmonic distortion (THD) is obtained by reading the FFT oscilloscope spectrum. From the spectrum, it can be calculated the value of THD with an inductive load.

It is obtained that the THD voltage on the inverter with the SHE PWM method is 61.476%. This THD value is quite large because the pump motor load is inductive which has active power and reactive power which also affects the magnitude of the THD voltage. To minimize the THD value which is quite large, it is necessary to have a filter that can affect the wave ripple.

IV. Conclusion

Based on the research that has been done on "Inverter Design with Selective Harmonic Elimination Pulse Width Modulation Method for Agricultural Irrigation Pumps" obtained several conclusions as follow.

1. The average power efficiency of the inverter with the SHE PWM method is 80%. This is because the inverter still has a voltage ripple and the resulting wave is not yet in the form of a pure sine wave which can reduce efficiency.

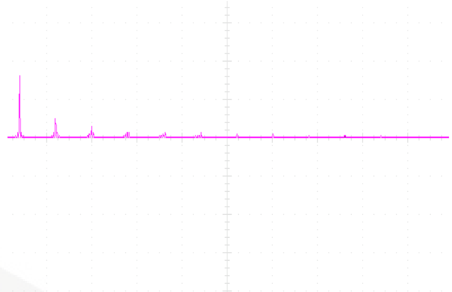

Fig. 5 FFT Spectrum THD of Inverter

2. The power of the pump motor when implemented with an inverter and solar panels is 371.52 Watt. This is because the source that comes from solar panels has a power capacity of 500 Wp, so it is very good to be implemented in pump motors. In addition, changing weather conditions can also affect the input power of the inverter when it is implemented.
3. The THD value of the voltage on the pump motor is 61.476%. This is because the inductive load of the pump motor used to pump water requires greater torque, so that it can increase the ripple on the inverter output wave and the absence of a filter from the inverter can also increase the THD value of the voltage. In addition, the magnitude of the ripple wave can also affect the THD value of the voltage.

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