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Article

Power Factor Correction on 500W Inverter Microcontroller-Base Using Particle Swarm Optimization Method

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Abstract: This research explores the design and evaluation of an inverter system incorporating the Particle Swarm Optimization (PSO) method to enhance power factor efficiency. The study investigates the inverter's performance across resistive loads (40W and 100W lamps), inductive loads (40W fan and 200W blenders), and a combination of resistive-inductive loads, both with and without PSO-based Power Factor Correction (PFC). By optimizing the phase difference between voltage and current, the PSO algorithm aims to maintain a power factor close to the industry standard of 0.85 or higher. The findings indicate that resistive loads consistently sustain a power factor of 1.00, while inductive loads benefit significantly from PSO implementation. The 40W inductive fan, initially operating at 0.55, improved to 0.57 – 0.60, whereas the 200W inductive blender increased from 0.90 to 0.98. Similarly, mixed resistive-inductive loads showed an enhancement from 0.89 to 0.99, emphasizing PSO's role in improving power efficiency. The study recorded a total power factor improvement of 0.36, with an average increase of 0.0144 per test case, confirming PSO's effectiveness in reducing reactive power losses and optimizing energy conversion. These results highlight the potential of PSO-based control strategies in enhancing power quality, stabilizing inverter performance, and improving energy efficiency, particularly in applications where inductive loads are predominant. The research contributes to the development of intelligent inverter systems that offer greater reliability, cost-effectiveness, and energy savings for residential and industrial power applications.

Keywords: Inverter; Power Factor Correction; Particle Swarm Optimization;

1. Introduction

The use of electrical energy currently plays an important role in everyday life, both on a large scale (industry) and small scale (homes). Residential houses need electrical energy as the main source to operate every electrical load. Residential houses usually have two types of loads, namely inductive and resistive loads. One of the supporting equipment that can protect various electrical loads from interference is an inverter, this tool functions as a stabilizer against interference and a backup power source [1]. Inverters play a very important role as one of the electricity supply devices at home as emergency power when the electricity goes out [2][3]. Inverters can be used with unidirectional power sources such as batteries, solar panel batteries, and other unidirectional power sources. Inverters that produce sinusoidal waves have a positive impact on power factor [5]. In addition, it can help optimize energy use, power losses, and improve power efficiency [6-9].

Power efficiency issues related to AC power in the form of voltage, current, and frequency can result in wasted energy and shorten battery/accu life [10-12]. The minimum value standard for the power factor or power factor set by PLN based on SPLN 70-1 regulations is > 0.85[13]. A power factor of less than 0.85 is an indication of low power efficiency at the inverter output. Low power efficiency at the inverter output is caused when the electrical load power is close to the inverter capacity. This is due to the absence of Power Factor Correction (PFC) to improve power efficiency in various power efficiency problems in AC loads.

PFC can be used to optimize inductive, resistive and capacitive loads. The PFC system is made using inductive and resistive load simulations, referring to the accumulation of residential load characteristics. It takes a PFC that is able to provide capacitive and inductive compensation that can work to optimize the power factor under inductive and capacitive load conditions [14]. As for the advantages of using PFC, namely PFC as a power factor improvement tool and can also improve the voltage of the electrical system in residential homes.

Based on the problems from the background, the author intends to make a research entitled: 'Implementation of Power Factor Correction on Microcontroller-Based 500W Inverter Using Particle Swarm Optimization Method'. The planning of making an inverter circuit with PFC is to increase the power efficiency of the inverter output [15]. The PSO method is used to optimize the inverter output when using the accumulator/accu voltage input [16]. The results of this research are expected to be used as emergency power in residential homes [17].

2. Materials and Methods

2.1. Block Diagram

The research concept is used as a reference or foundation for the author to complete his research. The focus in this research is the implementation of PFC on a 500W inverter to improve the power factor value to approach the standard 0.85 or 1 The block diagram can be seen on Figure 1. The source used to test the inverter with power factor correction is accu /aki. Accu/aki is used in the hope that this research can be applied to residential homes as emergency power.

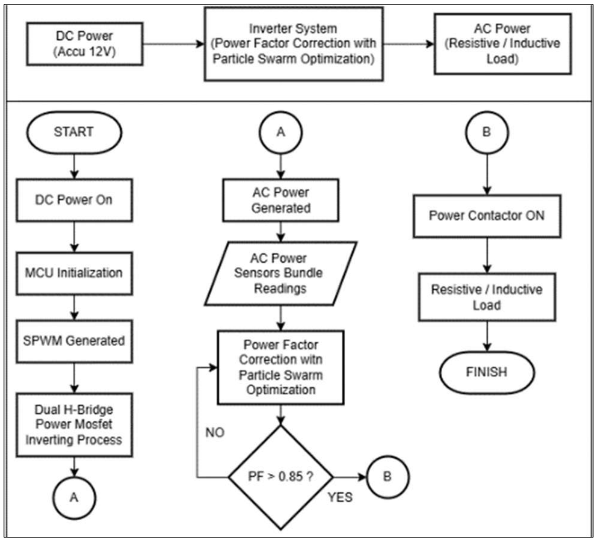
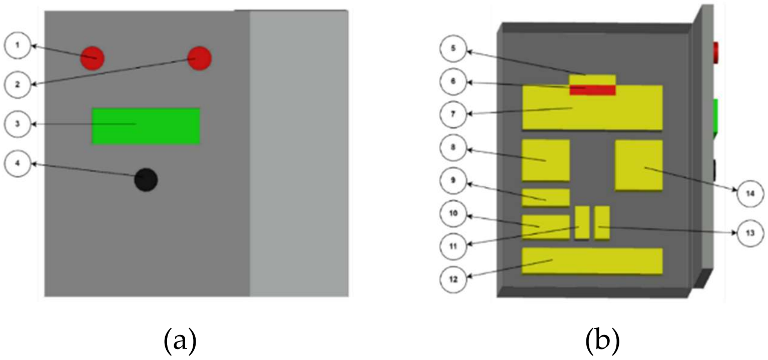


Figure 1. Inverter System Block Diagram.

2.2. Inverter System Hardware Planning

Hardware planning is made with the aim of knowing the layout of the components to be used and preparing the equipment needed in conducting this research. In addition, the planning of this inverter system is based on a block diagram Figure 1.

Figure 2(a) and Figure 2(b) are the design plans of the inverter system that will be built in this study. The panel box as the inverter cover is 40cm x 50cm x 20cm. The panel box has a selector switch that functions as a switch to run and turn off the inverter system. The panel box is also equipped with 2 green indicator lights when the inverter system is running and a red light when the inverter has a disturbance. In addition, the inverter system panel box is also equipped with an LCD display to view the parameter values generated by the inverter system such as input voltage, input current, input power, MOSFET temperature, output voltage, output current, output power, frequency, and power factor. Based on the block diagram and design planning of the inverter system, the following is the electrical hardware design planning illustrated. The descriptions for Figure 2(a) and Figure 2(b) are outlined in Table 1 below:



(a) (b)

Figure 2. (a) Box Panel Hardware Planning External View, (b) Box Panel Hardware Planning Inside View

Table 1. Box Panel Numbering Description.

Instruction Number	Description
1	Indicator lamp
2	Indicator lamp
3	LCD display
4	Selector switch
5	Cooling fan
6	Temperature Sensor
7	Dual H-Bridge Power Mosfet
8	Microcontroller Unit Board
9	Voltage DC sensor
10	Voltage DC Regulator
11	Power Contactor
12	Terminal block
13	AC Sensors Bundle
14	Transformer step-up

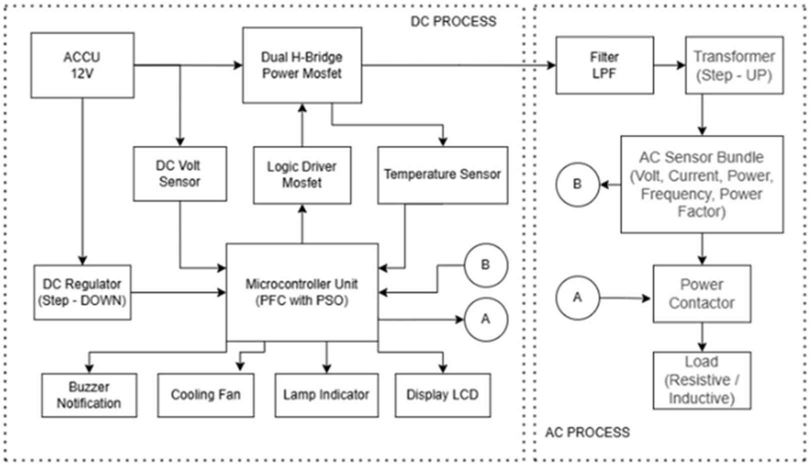


Figure 3. Inverter System Electrical Hardware Planning.

Figure 3 is the electrical hardware planning of the inverter system that will be made in this study. A 12VDC capacity battery is used as a DC voltage input for the inverter system which will be read by a DC voltage sensor to determine the voltage value generated by the battery and the sensor reading data will be sent to the ESP32 microcontroller for processing. ESP32 gets DC voltage input from the battery whose voltage value is reduced using a DC voltage regulator to 3.3VDC. ESP32 is used as data processing from the data sent by each sensor. In addition, ESP32 is used as a PWM signal generator for the MOSFET switching process assisted by an IR2110 driver. To find out the temperature value of the MOSFET, a temperature sensor is used to read and send the value to ESP32. The results of the inverter circuit switching process in the form of RMS voltage will be filtered using a Low Pass Filter (LPF) circuit with the aim of smoothing the signal results and can be a pure sinusoidal wave. After that, the voltage from the LPF circuit will be increased to AC 220V voltage using a step-up transformer. The result of the 220V AC voltage is used to supply voltage to resistive, inductive, and capacitive loads which will later be evaluated for its power factor value to remain stable according to the standard, which is> 0.85.

2.3. SPWM Signal Generation Planning

The generation of SPWM signals using ESP32 aims to generate PWM signals that can be used to control the inverter output voltage and frequency. Here are some steps for SPWM signal generation:

- Determine the frequency and period of the desired reference (sine) wave. This research uses a modulation frequency of 50Hz.

$$T_r = \frac{1}{f_r} = \frac{1}{50} = 0{,}02s \ or \ 20ms \tag{1}$$

- Determine the frequency and period of the carrier wave. This research uses a carrier frequency of 20kHz.

$$T_c = \frac{1}{f_c} = \frac{1}{20000} = 0{,}00005s \ or \ 0{,}05ms \ or \ 50\mu s \tag{2}$$

- Determines the number of pulses by comparing the period values of the reference signal and the carrier signal.

$$M_T = \frac{T_r}{T_c} = \frac{20ms}{0{,}05ms} = 400 \ squence \tag{3}$$

- Determining the sinusoidal value of each cycle, known modulation period ($\boldsymbol{T_m}$) in radians is equal to 2π.

$$\begin{gathered} M_T = \frac{T_m}{T_s} \rightarrow 400 = \frac{2\pi}{T_s} \\ T_s = \frac{2 \times 3{,}14}{400} = \frac{6{,}28}{400} = 0{,}0157\ rad/squence \end{gathered} \tag{4}$$

- Determines the nth pulse width (duty cycle) (n = cycle value 0-399), for example the amplitude ($\boldsymbol{\alpha}$) is 100 and the figure shown in Figure 4.

$$\begin{gathered} V_n = \alpha \times \sin\,(0{,}0157 \ \times \mathrm{n}) \\ V_0 = 100 \times \sin(0{,}0157 \ \times 0) = 0 \\ V_1 = 100 \times \sin(0{,}0157 \ \times 1) = 1{,}57 \\ V_2 = 100 \times \sin(0{,}0157 \ \times 2) = 3{,}14 \\ V_3 = 100 \times \sin(0{,}0157 \ \times 3) = 4{,}71 \\ V_4 = 100 \times \sin(0{,}0157 \ \times 4) = 6{,}28 \\ V_5 = 100 \times \sin(0{,}0157 \ \times 5) = 7{,}84 \\ V_{100} = 100 \times \sin(0{,}0157 \ \times 100) = 99{,}99 \\ V_{200} = 100 \times \sin(0{,}0157 \ \times 200) = 0 \\ V_{250} = 100 \times \sin(0{,}0157 \ \times 250) = -6{,}02 \\ V_{300} = 100 \times \sin(0{,}0157 \ \times 300) = -99{,}99 \\ V_{399} = 100 \times \sin(0{,}0157 \ \times 399) = -1{,}88 \end{gathered} \tag{5}$$

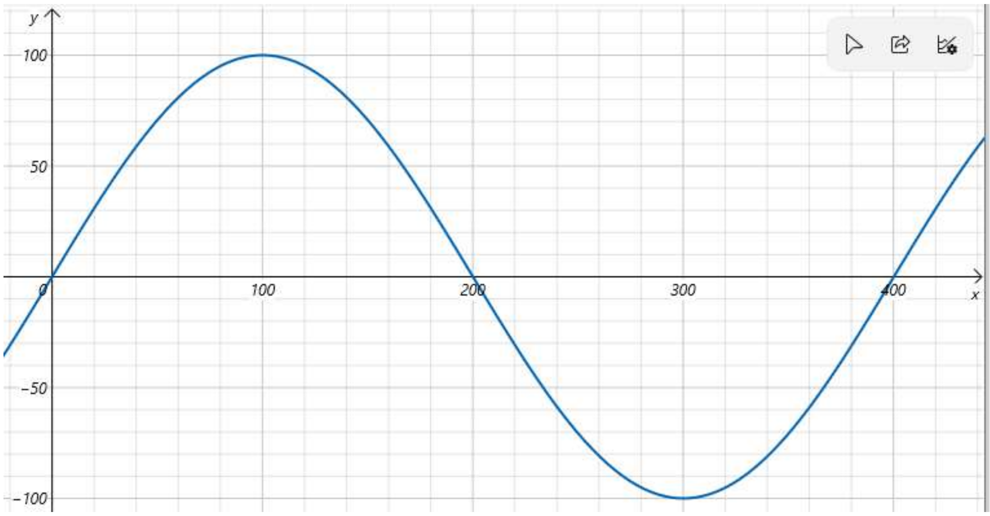


Figure 4. Amplitude Simulation Based on SPWM.

The results of the formula for finding the pulse width (duty cycle) of each cycle will be used in the ESP32 microcontroller programme to generate SPWM signals. In addition, the selection of the carrier frequency value was chosen because it is more optimal and with a frequency of 20kHz it is sufficient to achieve the purpose of planning the generation of SPWM signals in the inverter.

2.4. Power Factor Correction Planning

This plan aims to apply power factor correction to the inverter without using additional components such as capacitor banks, but through programming and PWM signal settings. The first step in using PFC is to measure the power factor value using the AC Sensor Bundle (PZEM004T sensor) integrated with the inverter system. The equation used to be implemented into the ESP32 programs.

$$pf = \frac{P}{\sqrt{P^2 - Q^2}} \tag{6}$$

$$ps = \cos^{-1}(pf) \tag{7}$$

The function uses the measured PZEM004T power factor value (pf) and returns as a phase shift in radians using the $\cos^{-1}$ function.

$$\text{If measured } pf = 0{,}8 \text{ then the phase shift value } ps = \cos^{-1}(0{,}8) = 0.6435 \tag{8}$$

The result of that phase shift (0.6435) is implemented in PWM signal modulation to regulate the inverter output signal.

$$P_{pwm} = 350 \text{ x} \sin(2\pi \times 50 \times \frac{1}{20000} + 0{,}6435) \tag{9}$$

2.5. Particle Swarm Optimisation Plannin

Particle Swarm Optimization is a method or algorithm used to optimize the phase difference between voltage (V) and current (I) at the inverter output. The purpose of optimizing the phase difference between voltage and current is to keep the power factor value close to 1 or equal to 1 when given different types of loads. This is very important so that the inverter can function more efficiently with various types of loads (resistive, inductive, and capacitive). The PSO flowchart starts the process by setting the parameters W (inertia weight), C_1 (cognitive constant), and C_2 (social constant) that govern the speed (V_i^t) and direction position of the particles (P_i^t). Once the parameters are set, the particles are randomly generated (U_1^t and U_2^t) to form an initial population which is then evaluated for its fitness value which reflects how well it optimizes the phase difference.

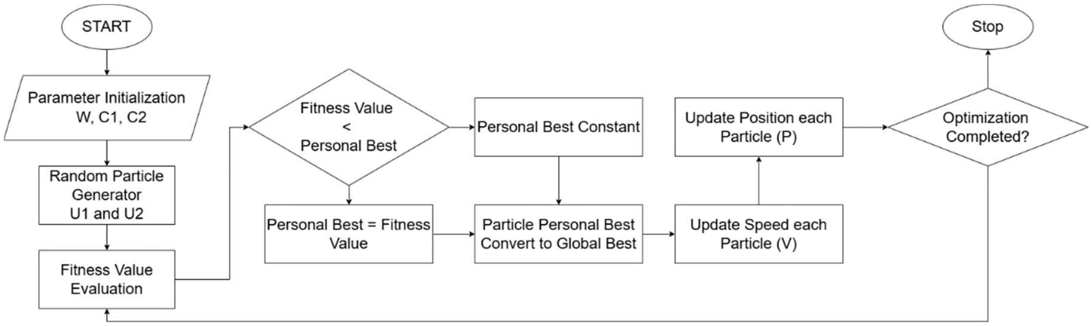


Figure 5. Flowchart Particle Swarm Optimization Method.

$$V_i^{t+1} = \mathrm{W}.V_i^t + C_1.U_1^t\left(P_{b_1}^t - P_i^t\right) + C_2.U_2^t\left(g_i^t - P_i^t\right) \tag{10}$$

$$P_i^{t+1} = P_i^t + V_i^{t+1} \tag{11}$$

After evaluating the fitness value, the next step is to compare the fitness value of each particle with $P_{b_1}^t$ (Personal Best). The comparison is done to find out the best position ever achieved by the particle. If the particle fitness value is better than $P_{b_1}^t$ then $P_{b_1}^t$ will be updated. The best $P_{b_1}^t$ of all particles will become the g_i^t (global best), which is the best particle position globally or overall. The velocity of each particle is updated based on the g_i^t and $P_{b_1}^t$ results respectively using a formula that considers inertia, cognitive (C_1), and social (C_2) factors. The particle speed (V_i^{t+1}) and particle positions (P_i^{t+1}) are also updated and this process repeats in desired iterations to find the optimal solution.

Table 2. Particle Swarm Optimization Initialization Variable

Variable	Value
W	0,5
C_1	1,5
C_2	1,5
t_{max}	100
i_{max}	30
U_1^t	$rand(0 \leq U_1^t \leq 1)$
U_2^t	$rand(0 \leq U_2^t \leq 1)$

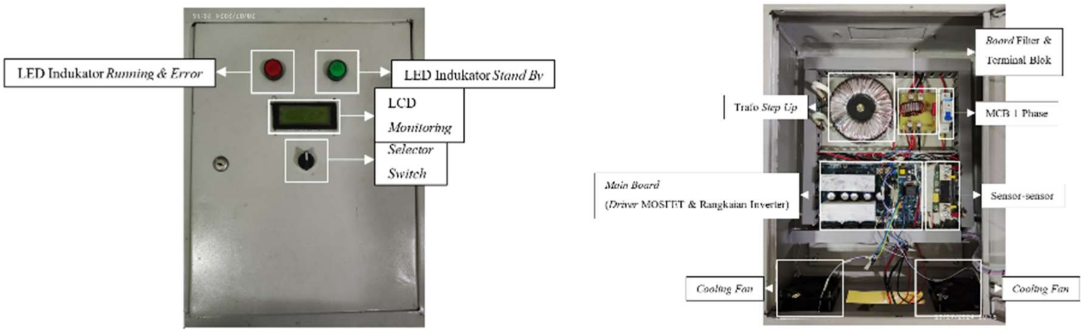
This iteration process continues until it reaches the desired optimization condition ($P_i^{t+1}\ eq\ Optimal$), which is an updated particle position or power factor (P_i^{t+1}) value close to 1 or equal to 1. The inverter can adapt to changes in load type and maintain high efficiency using the PSO method. In addition to optimizing the power factor, this method can also help reduce power losses and improve the operational stability of the electrical system in the inverter. This optimization is particularly useful in practical applications where inverters are used with different types of loads and ensure consistent performance. The workflow of the PSO method that will be used to support power factor improvement is described in the Figure 5.

3. Results

Based on the planning that has been done in the previous chapter and applied to this research. Then the results and discussion of power factor correction research on the inverter will be obtained. In chapter three will be described about the tests that have been carried out and will be discussed as detailed as possible. As well as comparisons will be made when research using the method and when research without using additional methods.

3.1. Inverter System Panel Box Design Results

The design of the inverter system panel box is an important stage in ensuring proper and safe installation of this research. Wiring the correct panel box will optimize the performance of the inverter system and ensure the safety of the user and the components used. The panel box functions as a provider of an organized place to arrange all electrical connections between the required components including power input, power output, and the required control system. The panel box used in this Final Project has a length x width x height of 40cm x 50cm x 20cm.



(a) (b)

Figure 6. (a) Front View of Box Panel, (b) Results of the Inside View of the Panel Box

Figure 6(a) shows some of the control components and indicators that are useful for monitoring and operating the inverter system. The top of the panel has red and green indicator LEDs. The red LED indicates the condition of the inverter system is working or can already produce 220V AC voltage and the indicator can function as an error indicator in the inverter system. The green LED indicates that the inverter system is in standby condition with the 12V DC voltage already connected. In the middle of the panel there is an I2C LCD which functions as monitoring data readings from sensors in real time. At the bottom of the LCD there is a selector switch that functions as a control to switch on and off the inverter system. If the selector switch is rotated clockwise, the inverter system will turn on or be in running condition.

Figurer 6(b) shows the inside view of the inverter system panel box which consists of various components such as a step up transformer to increase the output voltage to 220V, a board filter to filter sinusoidal wave noise and the bottom of the filter board there is a terminal block as an auxiliary terminal for 220V voltage output, as well as a 1 phase MCB section as overcurrent protection. The sensors section functions as data collection for monitoring and control of the inverter system. In addition, the main board consists of a MOSFET driver PCB and an inverter circuit PCB that converts DC current into AC. Finally, 2 cooling fans at the bottom aim to maintain the panel box temperature to remain optimal. The arrangement of the components in the panel box is designed for ease of maintenance and operational efficiency.

3.2. PWM Signal Generation Test Results

Figure 7(a) shows the measurement results of the PWM signal that will be used to control the IR2110 driver in controlling the MOSFET in the inverter system. This PWM signal has a frequency of 50Hz which shows how fast the PWM cycle is in one second. The right frequency is very important to ensure a fast and efficient response from the MOSFET. The resulting Duty Cycle is a constant 50% which means the signal is at its highest level for half a period in one cycle period. This Duty Cycle is generally used for symmetrical switching operations, ensuring that the MOSFET can be switched on and off with balanced switching. The ESP32 output pin under test is pin 27 which is connected to the first 1LIN pin of IR2110.

The resulting $\boldsymbol{V_{pp}}$voltage is 3.52V, indicating the voltage difference between the highest and lowest levels of the PWM signal which must match the input specifications of the IR2110 driver. The average voltage ($\boldsymbol{V_{avg}}$) shows a result of 1.63V which means it gives an indication of the DC effect of the PWM signal which can affect the switching characteristics of the MOSFET. The RMS voltage ($\boldsymbol{V_{rms}}$) shows a value of 2.30V which is important for determining the effective energy delivered by the PWM signal to the load. The maximum voltage ($\boldsymbol{V_{max}}$) of the signal is 3.39V and the minimum voltage ($\boldsymbol{V_{min}}$) is 0.13V. This is important to ensure that the PWM signal reaches the logic levels required to properly switch the MOSFETs on and off.

(a) (b)

Figure 7. (a) PWM Pin 27 Output Testing Results, (b) PWM Pin 26 Output Testing Results

(a) (b)

Figure 8. (a) PWM Output Testing Results Pin 18, (b) PWM Pin 19 Output Testing Results

Figure 7(b) shows the results of testing the PWM signal output pin 26 of the ESP32 connected to pin 1HIN of the first IR2110 driver. This signal has a frequency of 50Hz and a duty cycle of 50% with a constant or invariable value. This aims to ensure symmetrical switching of the MOSFETs for stable and efficient operation. The peak-to-peak voltage ($\boldsymbol{V_{pp}}$) shows a result of 3.56V, an average voltage ($\boldsymbol{V_{avg}}$) of 1.63V, and an RMS voltage ($\boldsymbol{V_{rms}}$) of 2.37V. In addition, the maximum voltage ($\boldsymbol{V_{max}}$) and minimum voltage ($\boldsymbol{V_{min}}$) yielded values of 3.44V and 0.12V, respectively. This ensures that the signal reaches the logic level required to switch the MOSFET on and off.

3.3. Step Up Transformer Testing Results

Figure 9 shows the results of testing the output of the step up transformer after the filtration process using LPF. Based on Figure 4.29, the peak-to-peak voltage ($\boldsymbol{V_{pp}}$) can reach 617.00V with a maximum voltage of 307.00V and a minimum voltage of -310.00V. The resulting signal frequency is still fixed at 50Hz, but the duty cycle results sometimes drop at 48% and sometimes back at 50%. The average voltage ($\boldsymbol{V_{avg}}$) generated is around -3.00V to -4.00V. In addition, the resulting RMS voltage ($\boldsymbol{V_{rms}}$) of 220.40V gives an indication of an effective value and is in line with expectations for residential electrical loads.

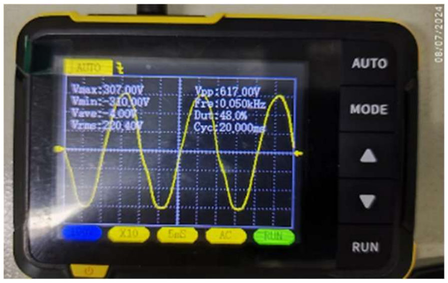


Figure 9. Step Up Transformer Testing Results.

The results of this test show that the toroidal type step up transformer has successfully increased the output voltage after filtration. It also shows that the AC voltage of the sinusoidal wave is in accordance with the needs of residential electrical loads. In addition, this measurement shows that the toroidal type step up transformer works efficiently, producing a stable and symmetrical output voltage close to 0V which is important for maintaining signal quality and ensuring reliable operation of the electrical load to be connected to the inverter system.

4. Discussion

4.1. Test Results of Inverter System Without Method

Tests were carried out using resisitive and inductive loads. The electrical loads used are 40W incandescent lamps, 100W incandescent lamps, 40W fans, and 200W blenders. Tests are carried out alternately to determine changes in the power factor value of each load tested. The following are the results of the tests that have been carried out. The results of testing the inverter system without the method show stable results according to the type of load used. including resistive, inductive, and mixed resistive-inductive loads. The resistive loads, specifically 40W and 100W lamps, maintain a stable power factor (PF) of 1.00, indicating that these loads exhibit purely active power consumption with no reactive component.

Table 3. Inverter System Testing Results Without PSO Method

NO.	TYPE LOADS	OUTPUT PARAMETERS				
		V (V)	I (A)	P (W)	F (Hz)	PF
1	Res. 40W	215,30	0,18	37,68	50,00	1,00
2		215,29	0,18	38,75	50,00	1,00
3		214,70	0,17	36,50	50,00	1,00
4		215,10	0,18	38,72	50,00	1,00
5		215,10	0,18	38,73	50,00	1,00
6	Res. 100W	186,10	0,40	74,07	50,00	1,00
7		185,00	0,38	70,30	50,00	1,00
8		186,10	0,40	74,44	50,00	1,00
9		186,10	0,40	74,44	50,00	1,00
10		186,30	0,39	72,66	50,00	1,00
11	Induc. 40W	214,60	0,18	37,56	50,00	0,55
12		205,90	0,18	36,44	50,00	0,55
13		211,90	0,18	37,93	50,00	0,55
14		212,20	0,18	37,77	50,00	0,55
15		210,10	0,18	36,77	50,00	0,55
16	Induc. 200W	129,70	0,72	93,38	50,00	0,99
17		129,00	0,74	94,94	50,00	0,93
18		128,70	0,73	93,69	50,00	0,99
19		128,50	0,74	94,45	50,00	0,98
20		129,00	0,74	94,82	50,00	0,98
21	Res. & Indc.	183,90	0,29	53,33	50,00	0,90
22		183,90	0,29	53,33	50,00	0,90
23		199,90	0,29	57,97	50,00	0,90
24		200,10	0,29	58,03	50,00	0,89
25		200,03	0,29	58,01	50,00	0,90

The recorded voltage for these loads ranges from 185V to 215V, with corresponding current values between 0.17A and 0.40A, leading to power outputs between 36.50W and 74.44W. This expected behavior confirms that resistive loads do not introduce phase shifts between voltage and current, resulting in maximum power efficiency. However, the inductive loads, such as 40W fans and 200W blenders, exhibit a significant drop in power factor due to the presence of reactive power. The 40W fan load shows a power factor of 0.55, implying that nearly 45% of the apparent power is reactive, causing inefficiencies. The power readings for this load range from 36.44W to 37.77W, with a steady current of 0.18A, demonstrating that inductive components cause phase delays between voltage and current. For 200W inductive loads (blenders), the power factor improves to 0.90, indicating partial compensation for reactive power, likely due to the nature of the load or internal correction mechanisms. The power consumption in this category fluctuates between 93.38W and 94.94W, with current values of 0.72A to 0.74A, signifying that while inductive effects still exist, they are less pronounced compared to smaller inductive loads. When examining resistive and inductive loads combined, the power factor falls between 0.89 and 0.90, showing a balance between active and reactive power. The total power consumption in this scenario ranges from 53.33W to 58.01W, with voltage values between 183.90V and 200.03V, while the current stabilizes around 0.29A.

4.2. Inverter System Testing Results With Methods

This electrical load testing aims to optimise the performance of the inverter using the Particle Swarm Optimisation (PSO) method. Various types of loads, both resistive and inductive, are tested individually and in combination to analyse their effect on the power value and power factor. The use of PSO is expected to find the best inverter configuration capable of producing optimal power and improving power factor, especially on inductive loads. Tests were conducted using a 12VDC battery as an energy source.

Based on Table 4 the test results of the power factor value on a 100W incandescent lamp load get a value of 1.00 as well as an incandescent lamp with a capacity of 40W. This is a very efficient value because in resistive loads there is no reactive power component so that the voltage and current waves are in phase. The resistive loads, represented by 40W and 100W lamps, continue to exhibit an optimal power factor (PF) of 1.00 or close to 0.99, confirming that these loads remain purely active with minimal or no reactive power losses. The recorded voltage levels range from 198V to 215V for 40W lamps and 169V for 100W lamps, with current values between 0.17A and 0.40A, resulting in power values from 34.67W to 67.38W. This behavior is consistent with expectations for resistive loads, where the voltage and current remain in phase, ensuring maximum power conversion efficiency. The impact of the PSO method becomes particularly evident in inductive loads, such as 40W fans and 200W blenders, where the power factor has notably improved compared to results from the non-PSO method in Table 3. The 40W fan load, which previously had a power factor of 0.55, now exhibits an increased power factor ranging from 0.57 to 0.60, demonstrating a reduction in the phase shift between voltage and current. The corresponding power consumption varies between 34.20W and 36.54W, with a steady current of 0.17A, suggesting that PSO optimizes the inverter's response to inductive characteristics, mitigating some reactive power losses. A more pronounced improvement is observed in 200W inductive loads (blenders), where the power factor remains consistently high, reaching 0.98, compared to 0.90 in the previous test without PSO. The power output fluctuates between 95.63W and 99.33W, with current values around 0.71A to 0.73A, indicating that PSO significantly enhances power conversion efficiency for larger inductive loads by optimizing control parameters to minimize energy losses. When analyzing mixed resistive and inductive loads, the power factor has also seen a notable increase, reaching values between 0.91 and 0.99, compared to the 0.89 - 0.90 range in the non-PSO test. The total power consumption varies from 55.85W to 60.05W, with voltage levels between 201V and 203V, while the current stabilizes around 0.28A to 0.30A.

Table 4. Inverter System Testing Results Using the PSO Method

NO.	TYPE LOADS	OUTPUT PARAMETERS				
		V (V)	I (A)	P (W)	F (Hz)	PF
1	Res. 40W	215,30	0,17	36,17	50,00	0,99
2		206,30	0,17	35,28	50,00	0,99
3		215,30	0,18	37,68	50,00	1,00
4		198,10	0,18	34,67	50,00	1,00
5		215,30	0,17	36,39	50,00	1,00
6	Res. 100W	169,30	0,40	67,38	50,00	0,99
7		169,10	0,40	67,30	50,00	1,00
8		169,10	0,39	65,44	50,00	1,00
9		169,00	0,39	65,07	50,00	1,00
10		169,00	0,39	66,25	50,00	1,00
11	Induc. 40W	207,30	0,17	34,20	50,00	0,58
12		209,50	0,17	35,20	50,00	0,60
13		207,70	0,17	34,48	50,00	0,57
14		217,70	0,17	36,14	50,00	0,59
15		217,50	0,17	36,54	50,00	0,60
16	Induc. 200W	138,50	0,71	98,06	50,00	0,98
17		135,70	0,73	99,33	50,00	0,99
18		129,90	0,73	95,09	50,00	0,99
19		131,00	0,73	95,63	50,00	0,99
20		135,00	0,73	98,55	50,00	0,99
21	Res. & Indc.	203,10	0,28	55,85	50,00	0,91
22		201,10	0,29	58,92	50,00	0,90
23		200,80	0,27	54,42	50,00	0,91
24		202,20	0,30	60,05	50,00	0,91
25		203,30	0,28	56,31	50,00	0,99

4.3. Comparison Power Factor Correction Result

Specifically, this research wants to know the extent to which the PSO method can improve inverter efficiency under various load conditions. Through the analysis of the data obtained, it is expected to gain a deeper understanding of the factors that affect inverter performance. The results of this research are expected to contribute to the development of a more efficient and reliable inverter system, and become a reference for further research in the field of power system optimisation.

The comparison between PF Without Methods and PF With Methods reveals that, in most cases, the application of the method leads to an increase in the power factor. For resistive loads, the power factor remains unchanged at 1.00, indicating that resistive loads naturally exhibit unity power factor with or without additional optimization. However, the impact of the applied method becomes evident in inductive loads, where the power factor improves noticeably.

Table 5. Comparison Power Factor Results with and without the PSO Method

NO.	TYPE LOADS	PF Without Methods	PF With Methods	Difference Value Result	Total Difference	Average
1	Res. 40W	1,00	0,99	-0,01	0,36	0,0144
2		1,00	0,99	-0,01		
3		1,00	1,00	0		
4		1,00	1,00	0		
5		1,00	1,00	0		
6	Res. 100W	1,00	0,99	-0,01		
7		1,00	1,00	0		
8		1,00	1,00	0		
9		1,00	1,00	0		
10		1,00	1,00	0		
11	Induc. 40W	0,55	0,58	0,03		
12		0,55	0,60	0,05		
13		0,55	0,57	0,02		
14		0,55	0,59	0,04		
15		0,55	0,60	0,05		
16	Induc. 100W	0,99	0,98	-0,01		
17		0,93	0,99	0,06		
18		0,99	0,99	0		
19		0,98	0,99	0,01		
20		0,98	0,99	0,01		
21	Res. & Indc.	0,90	0,91	0,01		
22		0,90	0,90	0		
23		0,90	0,91	0,01		
24		0,89	0,91	0,02		
25		0,90	0,99	0,09		

The Table 5 of Comparison Power Factor Results with and without the PSO Method provides an in-depth analysis of how Particle Swarm Optimization (PSO) enhances power factor (PF) across different types of electrical loads, including resistive, inductive, and mixed resistive-inductive loads. The results indicate that resistive loads consistently maintain a PF of 1.00, with minimal variations due to PSO. However, the greatest impact of PSO is observed in inductive and mixed loads, where noticeable improvements in power factor are recorded. For the 40W inductive load, the power factor increases from 0.55 to values between 0.57 and 0.60, with improvements ranging from 0.02 to 0.05, illustrating PSO's effectiveness in mitigating phase shifts caused by inductive elements. Similarly, in the case of 100W inductive loads, the power factor remains stable or improves slightly, reaching up to 0.99, indicating that PSO helps maintain high energy efficiency by optimizing reactive power management. The most substantial improvements occur in mixed resistive-inductive loads, where the power factor rises from 0.89 to 0.99, with some instances showing a 0.09 increase, highlighting PSO's role in optimizing inverter performance and minimizing energy losses. Overall, the total improvement across all tested conditions amounts to 0.36, with an average increase of 0.0144 per measurement, demonstrating PSO's consistent contribution to power quality enhancement.

5. Conclusions

This research successfully demonstrates the development and testing of an inverter design with and without the implementation of the Particle Swarm Optimization (PSO) method. The inverter was tested using various types of electrical loads, including resistive loads (40W and 100W lamps), inductive loads (40W fan and 200W blenders), and a combination of resistive and inductive loads. The results indicate that resistive loads inherently maintain a near-unity power factor (PF ≈ 1.00) with minimal variation, as they do not introduce reactive power. However, for inductive loads, the power factor significantly improves with the implementation of PSO, demonstrating that the optimization technique effectively compensates for reactive power and minimizes phase shifts between voltage and current. The 40W inductive fan, which initially exhibited a PF of 0.55 without PSO, improved to values between 0.57 and 0.60 with PSO, while the 200W inductive blender load saw its power factor increase up to 0.98. Furthermore, in mixed resistive-inductive loads, the power factor increased from 0.89 to as high as 0.99, highlighting PSO's capability in optimizing overall system performance. The total recorded power factor improvement across all tested scenarios amounted to 0.36, with an average increase of 0.0144 per case, reinforcing the benefits of PSO in real-world inverter applications. From these findings, it is evident that the PSO method plays a crucial role in improving power quality, reducing reactive power losses, and enhancing the efficiency of inverter-based systems, particularly in environments where inductive loads dominate.

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