DC-AC Inverter 220-230 VAC for Home Scale Photovoltaic Systems

Faizal Arya Samman
Department of Electrical Engineering
Universitas Hasanuddin
Makassar, Indonesia
e-mail: faizalas@unhas.ac.id

Muhammad Aswan
Department of Electrical Engineering
Universitas Hasanuddin
Makassar, Indonesia
e-mail: aswanm16d@student.unhas.ac.id

Andi Ejah Umraeni Salam
Department of Electrical Engineering
Universitas Hasanuddin
Makassar, Indonesia
e-mail: ejah@unhas.ac.id

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Abstract— **This paper presents a DC-AC inverter for home-scale solar-based electrical system applications that providing 220-230 VAC. The inverter is designed according to standardized Total Harmonic Distortion (THD) value. Two pulse waveforms to switch power MOSFET are evaluated for comparative studies, i.e. Square Wave Pulse (SWP) and Sinusoidal Pulse Width Modulation. 36V DC voltage is used to supply the inverter. A microcontroller is used to generate pulse signals. Low Passive Filters and dampers are used to reduce voltage harmonics caused by the switching process and produce a pure sine signal. By comparing the simulation and experimental results between SWP and SPWM, a lower THD percentage was obtained by using the SPWM switching technique.**

Keywords—DC-AC inverter, renewable energy, photovoltaic systems, harmonic analysis.

I. INTRODUCTION

The need for of electrical energy is increasing day by day, while the primary energy used as fuel for power generation is generally from non-renewable energies. The increasing dependence and price of fossil fuels is the driving factor for the need for new and renewable energy sources. One of these alternative energy sources is a Solar-based Power Plant, which is then synchronized so that it can be used with the grid in a hybrid system [1].

Household electrical appliances generally use an alternating current (AC) power source. An alternative to generating AC voltage for electrical equipment at home, especially for lighting in a simple home, can be utilizing solar energy. In converting this energy into the required electrical energy, several electrical circuits are needed. However, the resulting voltage is mostly still in the form of DC voltage (Direct Current) so that a converter is needed that can convert DC voltage into AC voltage.

Inverter is an electronic equipment that is able to convert a direct voltage source (DC) into an alternating voltage source (AC) with the desired magnitude and frequency. The output waveform generated from the inverter can generally be divided into 3 types, namely rectangular (square wave), modified sine signal (modified sine wave), and pure sine wave (pure sine wave).

The technique used to obtain AC waves from DC wave conversion is to modulate the width of the DC wave pulse signal. The techniques used in general are SWP (Square Wave Pulse) and SPWM (Sinusoidal Pulse Width Modulation). As for obtaining a pure sinusoidal signal is to use a filter, where the AC wave size is expected to reduce harmonics, especially low-order harmonics to below 10% [2].

This THD value is in accordance with the IEEE standard: 519-1992 which states that the permissible THD value for dedicated system applications is 10%, while in the IEEE standard: 519-2014 it is 8% [3, 4]. If the THD value is still above the standard value, then the electronic equipment is classified as still having a fairly high THD value.

Therefore, in this paper, a single-phase full bridge inverter controlled with a microcontroller-based switching control will be designed with a voltage of 220-230 VAC following the expected the standardized THD value, where the inverter is supplied from a DC voltage source.

This paper contributes to the comparative study for the inverter circuit evaluation by using different switching scheme with deep assessment on the load and no-load conditions.

II. SYSTEM DESCRIPTIONS

A. System Design

The block diagram of the home scale photovoltaic systems is presented in Fig. 1. DC-AC inveter is one of the most important parts in home scale photovoltaic sytems. DC-AC inverter is a power electronic equipment that functions as a converter of direct current (DC) input source into alternating current (AC) output whose voltage amplitude and frequency can be adjusted [5]. The power semiconductor device performs the switching action, and the desired output is obtained by varying the turn-on and turn-off times. Power semiconductor devices must have controllable turn-on and turn-off characteristics. Usually the devices used are BJT, MOSFET, IGBT, GTO, MCT, and force-commutated thyristor [6].

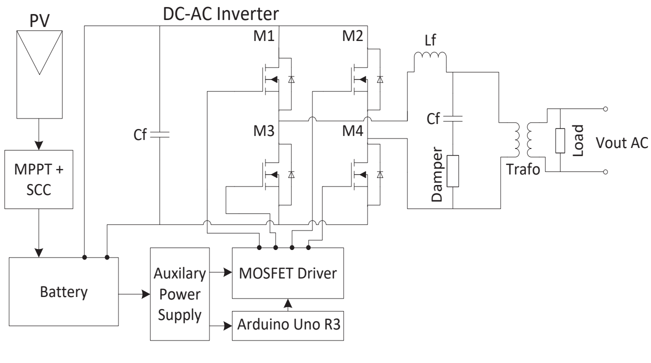

Fig. 1. A single phase DC-AC Inverter circuit schematic.

In this paper, the type of inverter used is a single-phase DC-AC inverter circuit with a full-bridge power switch configuration that uses MOSFET IRFP460N as the switching devices. A microcontroller (Arduino Uno R3 kit) is used as the main device to generate Square Wave Pulse (SWP) and Sine Pulse Width Modulation (SPWM) signals. The output voltage harmonics will be reduced by the filter and damper which will then be fed to the transformer to increase the voltage to 220-230 VAC and can be used for loads.

The circuit schematic of the single-phase DC-AC Inverter is shown in Figure 1. The specification of the inverter circuit is shown in Table I.

TABLE I. INVERTER AND FILTER PARAMETERS

Parameters	Value
Switching voltage for MOSFET	24 V
Inverter's DC Input voltage	36 V
Output voltage	230 V
Switching frequency	10 kHz
Output voltage frequency	50 Hz
Modulation index	0.9
Filter inductor	125 μH
Filter capacitor	300 μF
Filter damper resistor	10 Ω

B. Switching Techniques

The switching inverter technique uses two techniques, namely Square Wave Pulse (SWP) and Sinusoidal Pulse Width Modulation (SPWM). Square Wave Pulse (SWP) is a switching technique by changing the pulse width with a fixed amplitude and frequency value. In SWP control, the conduction angle of a power semiconductor device is generated by comparing the reference signal with the carrier signal. The pulse width can be varied by changing the carrier voltage. The modulation index is determined by Eq.(1).

$$M = \frac{V_c}{V_r} \quad (1)$$

Where A_r is the peak value of the reference signal and A_c is the peak value of the carrier signal [6]. The frequency of the modulating signal determines the fundamental frequency of the output waveform, while the frequency of the carrier signal determines the switching frequency of the inverter-controlled switch [7].

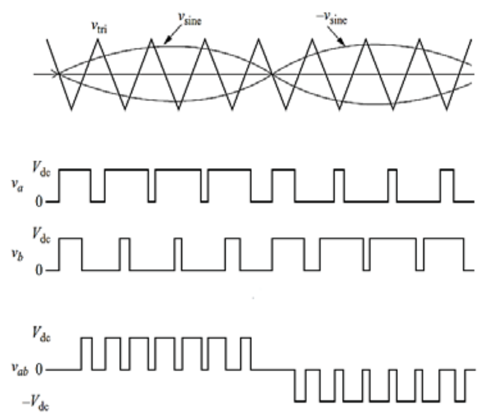

Fig. 2. The concept of the SPWM technique.

Sinusoidal Pulse Width Modulation (SPWM) is a switching technique by comparing a triangular wave and a sine wave, where the triangular wave is the carrier and the sine wave is the modulated wave. In SPWM, each pulse has a constant amplitude but neither the duty cycle nor the width of each pulse are changed in proportion to the amplitude of the sine wave evaluated in the middle of the same pulse [8]. To produce a full-wave AC output voltage or current in Figure 2, SPWM technique is needed to adjust the semiconductor component as a power switch on the inverter. The SPWM technique generates an output pulse by comparing the voltage on the reference signal or sinusoidal V_{sine} and the carrier signal or triangular signal V_{tri} where $V_c > V_\Delta = S_1+, S_2-$ ON. The amplitude modulation ratio is determined by the modulation index m_a with the condition $m_a \leq 1$ [6, 9].

$$m_a = \frac{V_c}{V_\Delta} \quad (2)$$

The modulation index affects the total pulses generated in a wave period and on the harmonics of the switching process.

C. Low Pass Filter and Damper Element

Low Pass Filter (LPF) is a circuit that forwards signals that have a frequency below the transition frequency and attenuates signals with a frequency above. It is used to eliminate all unfavorable harmonics from the output signal, where the LPF will select the required frequency and eliminate frequencies higher than the cut-off frequency.

There are three types of LPF circuits with each order level, namely L filters, LC filters, and LCL filters that can be connected between the inverter and the grid [10]. LC filter is proposed for better attenuation, reducing losses and costs. This filter is a second order filter where the inductor is connected in series with the capacitor [10, 11]. This filter is used to reduce harmonics and make the signal sinusoidal which will then be fed to a step-up transformer to be amplified.

LC filters are prone to oscillations and will amplify the frequency around their cut-off frequency. The easiest way to dampen them is to add a damping resistor. Attenuation of the LC filter can be obtained by placing resistors in different places on the inductor side or in series or parallel with the capacitor [12]. By connecting the resistor variant in series with the capacitor as shown in Figure 3, the resistor's attenuation value can be calculated by Eq.(3).

$$R_{damper} = \frac{1}{3\omega_{res}C_f} \quad (3)$$

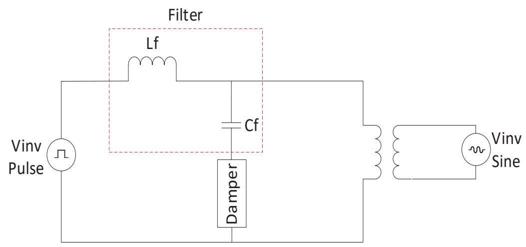

Fig. 3. LC filter circuit with damper element and transformer.

D. Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) is defined as the percentage of the total harmonic component to the fundamental component (the component can be either a voltage or a current). THD is written as

$$THD = \frac{[\sum_{n=2}^{k} V_n]^{\frac{1}{2}} \times 100\%}{V_1} \quad (4)$$

Where,
V_n : harmonic component
n : order of harmonics
V_1 : fundamental component
k : maximum harmonic component observed

III. Simulation Results

A. *Simulation Results with SWP control*

This simulation is carried out to see the output waveform on a single phase inverter with SWP control under the following conditions:

1. Before installing the passive filter and damper.
2. After installing the passive filter and damper.

Condition 1 shows the inverter output signal before it is filtered with filter and damper. The resulting output voltage amplitude is 27.41 V in the form of a pulse signal with a fairy high THD value of 48.51%. Condition 2 shows the inverter output signal whose harmonics have been reduced by passive filter and damper. The output signal is sinusoidal and has a fairly low THD value of 2.84%. The resulting output voltage amplitude is 24.54 V.

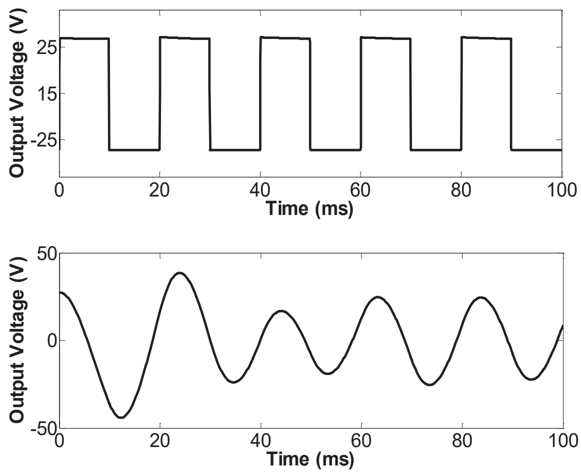

Fig. 4. The inverter output voltage using SWP control respectively without and with filter and damper.

B. *Simulation Results with SPWM control*

This simulation is carried out to see the output waveform on a single phase inverter with SPWM control under the following conditions:

1. Before installing the passive filter and damper.
2. After installing the passive filter and damper.

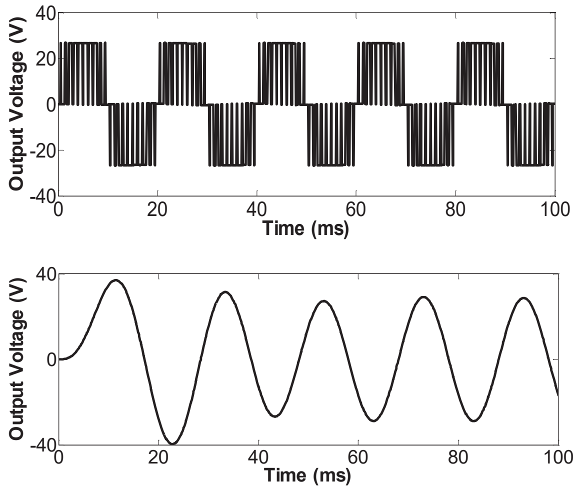

Fig. 5. The inverter output voltage using SPWM control with filter and damper element.

Condition 1 shows the inverter output signal before it is filtered with filter and damper. The resulting output voltage amplitude is 27.41 V in the form of a pulse signal from the results of SPWM modulation with a fairy high THD value of 36.48%. Condition 2 shows the inverter output signal whose harmonics have been reduced by passive filter and damper. The output signal is sinusoidal and has a fairly low THD value of 2.51%. The resulting output voltage amplitude is 24.66 V.

TABLE II. The Comparison of The Output Voltage and THD Measurement for The SWP and SPWM Control.

Condition	Switching method	Output Voltage (V)	THD (%)
Without filter and damper	SWP	27.41	48.51
	SPWM	26.48	36.48
With filter and damper	SWP	24.54	2.84
	SPWM	24.66	2.51

IV. Experimental Results

In Figure 6, the results of the single phase inverter design are shown. The DC input is obtained from a DC power supply source, while the inverter output which is connected to the LC filter and damper is connected to the transformer to increase the output voltage to 220-230 VAC which is then connected to the load. The process of controlling the MOSFET IRFP460N is done by amplifying the signal from Arduino using TLP250 and IC IR2110 as a MOSFET driver or MOSFET controller.

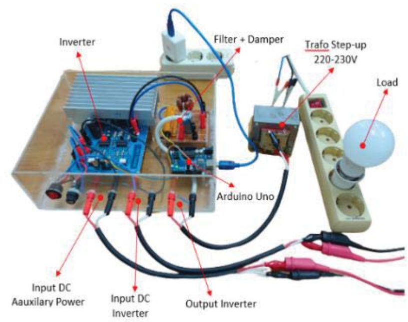

Fig. 6. The real hardware implementation of the inverter circuit .

Figure 7 shows the experimental setup of the whole experimental prototype of a single phase inverter. The main electronic control unit in the system is a microcontroller. In this case, we use Arduino Uno Board as shown in the figure. In this experiment, a LED lamp used as the load. The inverter output voltage is increased to reach 220 VAC using a step-up transformer.

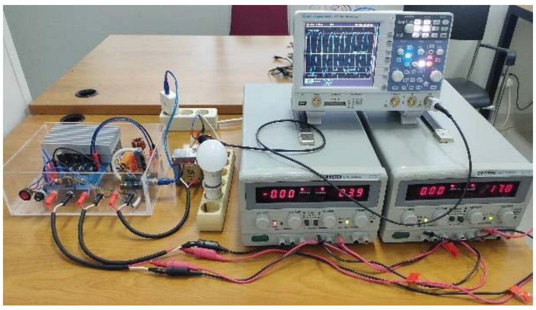

Fig. 7. The real hardware implementation of the inverter circuit.

A. Experiment with SWP Switching Control

This experiment was conducted to see the output waveform on a single phase inverter with SWP control under the following conditions:

1. Before installing the passive filter and damper.
2. After installing the passive filter and damper.
3. After the voltage is increased to 220-230 VAC.
4. After being given a 5W lamp load.

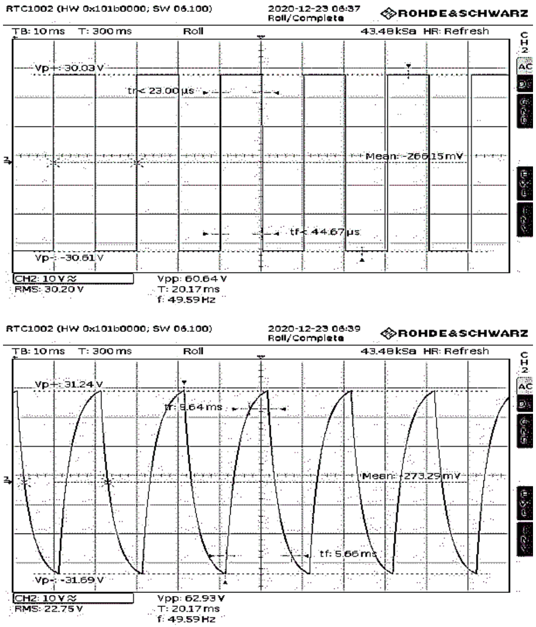

Fig. 8. The inverter output voltage using SWP control respectively without and with filter-damper.

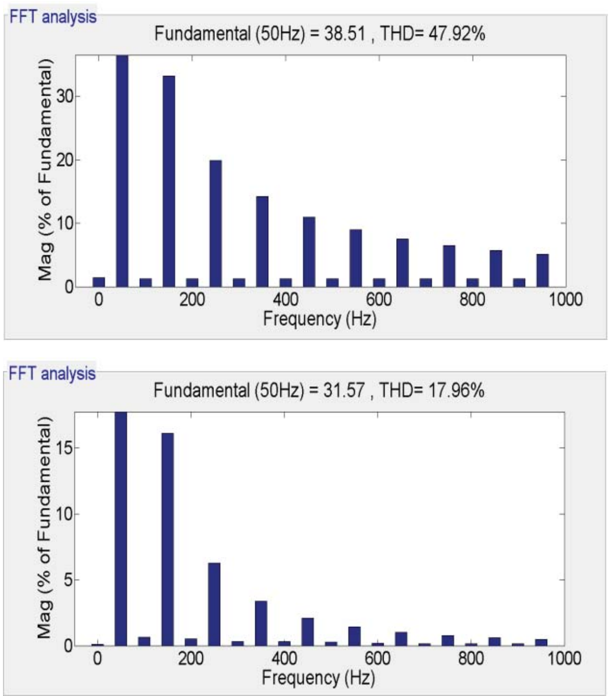

Fig. 9. Harmonic spectrum of the inverter output using SWP control respectively without and with filter-damper.

Condition 1 shows the inverter output signal before it is filtered with filter and damper. The resulting output voltage amplitude is 30.20 V in the form of a pulse signal with a fairy high THD value of 47.92%. Condition 2 shows the inverter output signal whose harmonics have been reduced by passive filter and damper. The output signal is sinusoidal and has a fairly low THD value of 17.96%. The resulting output voltage amplitude is 22.75 V.

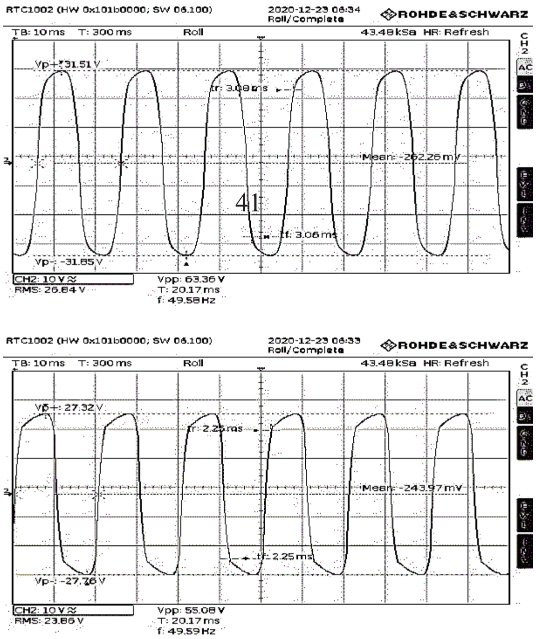

Fig. 10. The inverter output voltage using SWP control with filter, damper and transformer without and with load respectively.

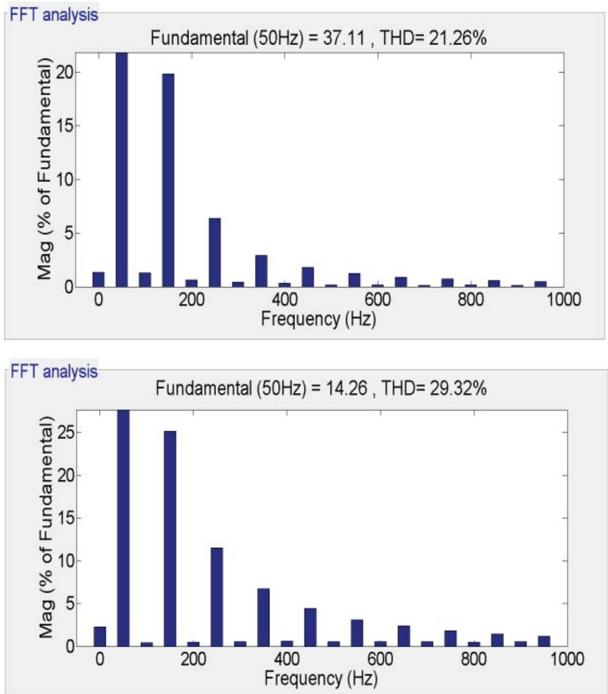

Fig. 11. Harmonic spectrum of the inverter output using SWP control with filter, damper and transformer without and with load respectively.

Condition 3 shows the output signal from the inverter after the voltage is increased through the transformer without loads resulting in a voltage of 223.7 V and a THD value of 21.26%. While condition 4 shows a single-phase inverter output signal after the voltage is increased and a 5W lamp load is given. The output voltage amplitude decreased to 207.7 V and the THD value increased to 29.32%.

B. Experiment with SPWM Switching Control

This experiment was conducted to see the output waveform on a single phase inverter with SPWM control under the following conditions:

1. Before installing the passive filter and damper.
2. After installing the passive filter and damper.
3. After the voltage is increased to 220-230 VAC.
4. After being given a 5W lamp load.

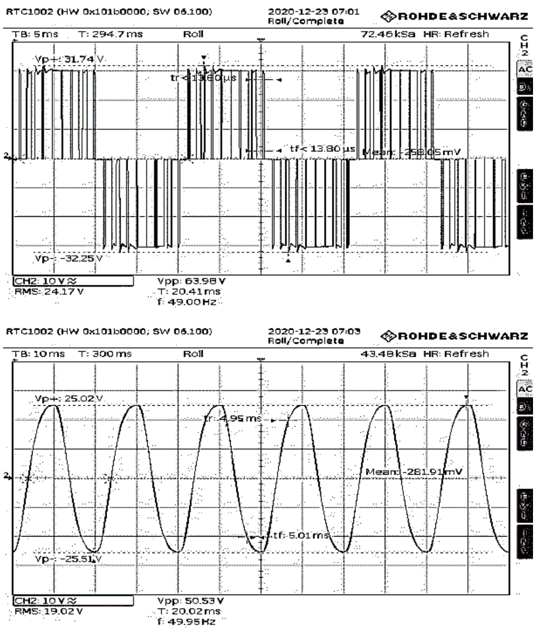

Fig. 12. The inverter output voltage using SPWM control with filter, damper and transformer without and with load respectively

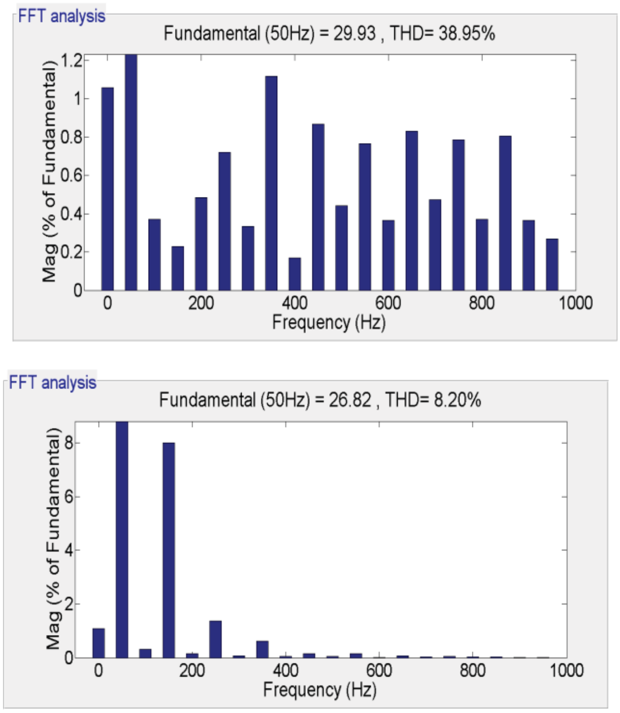

Fig. 11. Harmonic spectrum of the inverter output using SPWM control with filter, damper and transformer without and with load respectively.

Condition 1 shows the inverter output signal before it is filtered with filter and damper. The resulting output voltage amplitude is 24.17 V in the form of a pulse signal with a fairy high THD value of 38.95%. Condition 2 shows the inverter output signal whose harmonics have been reduced by passive filter and damper. The output signal is sinusoidal and has a fairly low THD value of 8.20%. The resulting output voltage amplitude is 19.20 V.

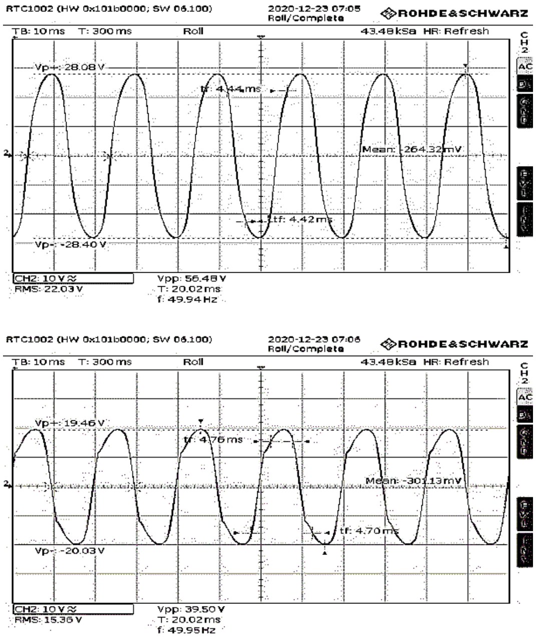

Fig. 13. The inverter output voltage using SPWM control with filter, damper element and transformer and respectively with and without load.

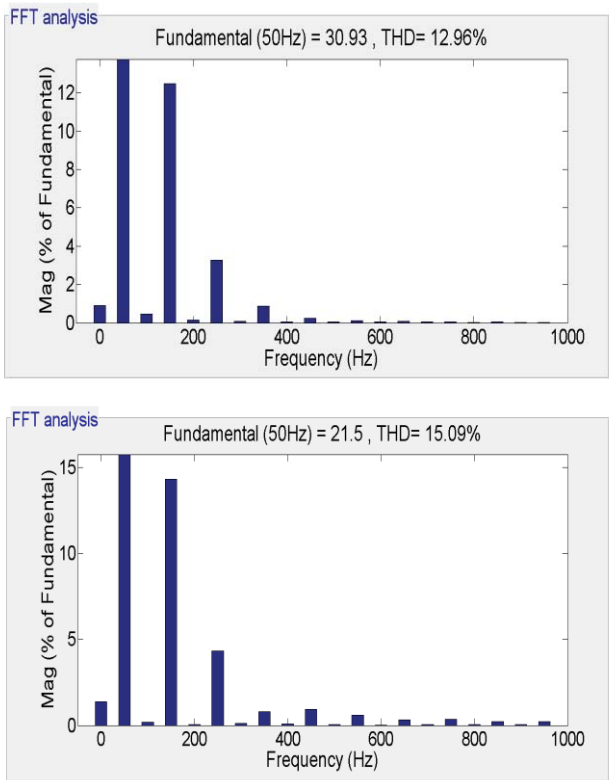

Fig. 14. Harmonic spectrum of the inverter output using SPWM control with filter, damper and transformer without and with load respectively

Condition 3 shows the output signal from the inverter after the voltage is increased through the transformer without loads resulting in a voltage of 231 V and a THD value of 12.96%. While condition 4 shows a single-phase inverter output signal after the voltage is increased and a 5W lamp load is given. The output voltage amplitude decreased to 226 V and the THD value increased to 15.09%. Table III presents the comparative data of the experiment presented in this section.

TABLE III. INVERTER OUTPUT VOLTAGE AND THD MEASUREMENTS FOR DIFFERENT SWITCHING METHODS AND TEST CONDITION

Condition	**Switching Method**	**Output Voltage (V)**	**THD (%)**
Without filter and damper	SWP	30.20	47.92
	SPWM	24.17	38.95
With filter and damper	SWP	22.75	17.96
	SPWM	19.20	8.20
Without load	SWP	223.70	21.26
	SPWM	231.00	12.96
With load	SWP	207.70	29.32
	SPWM	226.00	15.09

Table IV presents the measurements of the inverter output voltage and THD obtained from simulation and real hardware test or experiment. It seems that there are deviations between the simulation and real measurements. This deviation is due to the different parameters or parameter drift in the experiments. The deviation of the filter and damper parameters is very significant to changes in the value of the output voltage and the percentage of THD so that it can be seen that the variation in the value of the output voltage and THD is different between simulations and experiments.

TABLE IV. INVERTER OUTPUT VOLTAGE AND THD MEASUREMENTS FOR SIMULATION AND REAL HARDWARE TEST

Test Condition and the used switching method		Output Voltage (V)		THD (%)	
		SPICE Simula -tion	Real Hard-ware Test	SPICE Simula -tion	Real Hard-ware Test
Without filter and damper	SWP	27.41	30.20	48.51	47.92
	SPWM	26.48	24.17	36.48	38.95
With filter and damper	SWP	24.54	22.75	2.84	17.96
	SPWM	24.66	19.20	2.51	8.20

V. CONCLUSIONS

Based on the simulation results, testing and analysis, it can be concluded the inverter that has been designed can convert 36 VDC voltage into 220-230 VAC voltage so that it can be used for home-scale electrical purposes. The designed inverter produces THD output in the range of 17.96% with SWP switching technique and 8.20% with SPWM switching technique from standard values of IEEE: 519-1992 and IEEE: 519-2014. The SPWM technique presents better performance than the SWP technique in producing output voltage and THD percentage.

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