

# Comparative Performance Analysis of Bipolar and Unipolar Pseudo-based Inverter for Off-Grid Photovoltaic Application

A. Razi, M.Nabil Hidayat and S. A. A Shukor

**Abstract**— In this paper, a comparative performance analysis of two-switch Pseudo-inverter and Full-bridge inverter for Off-Grid Photovoltaic (OGPV) system is presented using single 250W-PV module. The performance of Pseudo-inverter and conventional Full-bridge inverter in terms of total harmonic distortion of the output voltage and current are compared based on the internal control of the inverter (open loop control) using Bipolar and Unipolar Sinusoidal Pulse-Width Modulation (SPWM). The total harmonic distortion (THD) of the conventional Full-bridge inverter and Pseudo-inverter, before and after implementation of filtering components also being analyzed. The results show that the Unipolar Pseudo-inverter with filter significantly provide lowest THD which are (5.01% and 5.35%) compared to conventional Unipolar Full-bridge inverter (13.9% and 35.55%), for current harmonic and voltage harmonic, THD<sub>i</sub> and THD<sub>v</sub>, respectively. All the analytical work was performed using MATLAB Simulink software.

**Index Terms**—Pseudo dc-link, inverter, Full-bridge, Microinverter, Voltage source inverter, Off-Grid Photovoltaic, Bipolar, Unipolar, PWM modulation.

## I. INTRODUCTION

TREND of Photovoltaic (PV) installation in Malaysia is promising and the determination to drive the PV systems comes from the inverter technologies. Conventional Full-bridge inverter basically were used as unfolding circuit or integrated circuit in the AC Module topologies, either in dual-stage topologies [1–4], single-stage topologies [5–9] or pseudo dc-link topologies [10–13] as shown in Fig. 1. Energy from PV installed at small-scale rooftop is channelled to the household AC-powered appliance such as water pump. However, some power electronic components were required in between enabling the energy flows from PV to the household load. These power electronics role as power conversions (DC to DC, or DC to AC) and smooth the AC output (filter) before supplied to the AC-powered load.

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DC-DC converter may have several topologies [3-4,6-8] to choose from based on the purposed served. Conventional boost converter or buck converter could be used for stabilizing and the same time increasing or decreasing the value of DC input respectively. Then, an inverter will be connected to transform

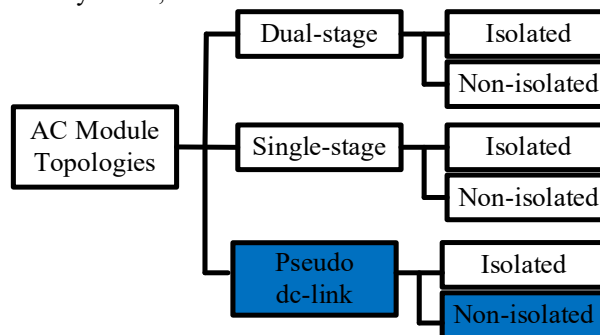


Fig. 1. Classification of the AC Module Topologies. Highlighted block is the focus inverter for this paper.

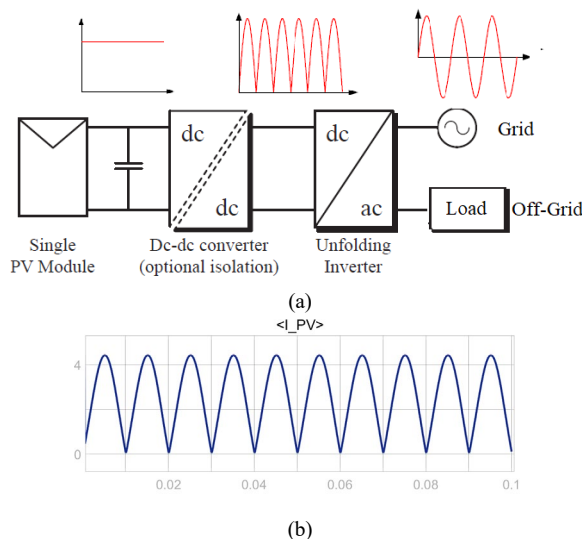


Fig. 2. Block diagram of the AC Module implementation towards the grid or off-grid application: a) Pseudo-based input inverter and b) Input current of the proposed Pseudo-Inverter.

the DC signal to AC signal with the help of power switches arrangement. Power switches arrangements may developed numerous inverter topologies [1], [5], [17–24] depending on the circuit requirements. Conventional inverter with four power switches constructed in two-leg bridges is known as Full-bridge inverter. Inverter may generated pure AC sine-wave,

square-wave AC or modified AC sine-wave [18-19].

There are two types of load when dealing with PV module; either can be connected to grid or specified load, also known as Grid-Connected PV (GCPV) or Off-Grid PV (OGPV) [27–31] respectively.

This study proposed to use single power switch during positive AC cycle and another power switch for negative AC cycle, transforming pseudo-wave DC input into AC output without the present of transformer. Higher number of power switches converting into more switching losses involve in the inverter conversion. Hence, this study with Pseudo-inverter comprise of total of two power switches is proposed. Different kinds of SPWM techniques (Bipolar and Unipolar) and the impact of the filtering components of the non-isolated Pseudo-inverter for OGPV application were being analyzed and compared to the conventional Full-bridge inverter. Finally the simulation results for a single-phase Pseudo-inverter using Bipolar and Unipolar SPWM techniques with and without filter components described are presented.

## II. CONVENTIONAL FULL-BRIDGE INVERTER

General block diagram for GCPV or OGPV system can be illustrated as Fig. 2a, involving a PV-input, followed by DC-DC Converter, DC-AC Converter, and output.

Referring to Fig. 1a, input PV can be arranged in different configurations depending on the size of input voltage requirement; which known as central PV, string PV, multistring PV or micro PV (AC module) [14], [15], [32-33]. DC input from PV can be classified based on the waveform generated; a) direct-DC, b) pulsating-DC, or c) pseudo-DC [5-6] Fig. 2b illustrates the pseudo-waveform from the input PV current of the proposed Pseudo-inverter. The DC input can be increased or decreased with the connection of DC-DC converter.

The flaw from the conventional Full-bridge inverter yields square-wave AC (before filter) and modified AC sine-wave (after filter) with the presence of four power switches (two power switches during each conduction mode). Therefore, based on the hypothesis, that only one power switch active during each conduction mode (one switch active during positive cycle and another one power switch active during negative cycle), able to produce AC waveform from the pseudo-DC waveform, thus generates pure AC sine-wave after inverter and filter components. Pure AC sine-wave aims for lower harmonic content before entering the off-grid load, consequently reducing the harmness that could occur to the load itself.

Inverter output voltage generally can be controlled by these various methods [10], [13], [35–41]: a) external control of AC output voltage (Known as closed loop control or voltage feedback control), b) external control of DC input voltage, usually for Current-Source Inverter (CSI), and c) internal control of the inverter (open loop control).

## III. PROPOSED TWO-SWITCH PSEUDO-INVERTER

Block diagram of the OGPV system as shown in Fig. 3, consisting single PV module, DC-link capacitor, proposed Pseudo-inverter, LC filter and RL load representation as off-grid load. Fig. 4 shows the proposed Pseudo-inverter which was

used in this work, consisting only two power switches, S1 and S2, each of the switch operates during the conduction mode (either positive cycle or negative cycle). One of the power switch was placed for allowing the current to pass through the positive RL load, hence creating the positive output cycle. While another power switch was placed for allowing the current to pass through the negative RL load, hence creating negative output cycle. This proposed topology allow only one power switch conducted during the conduction mode, hence ideologically reduced the conduction loss from the conventional Full-bridge inverter that requires two active power switches during each conduction mode. Small R were placed to prevent from the short-circuited simulation.

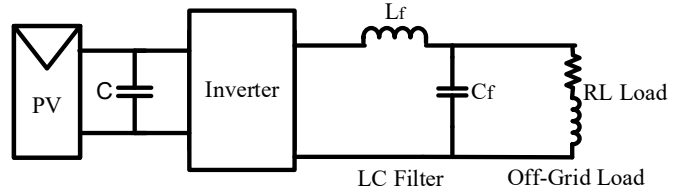


Fig. 3. Block diagram of the proposed OGPV system.

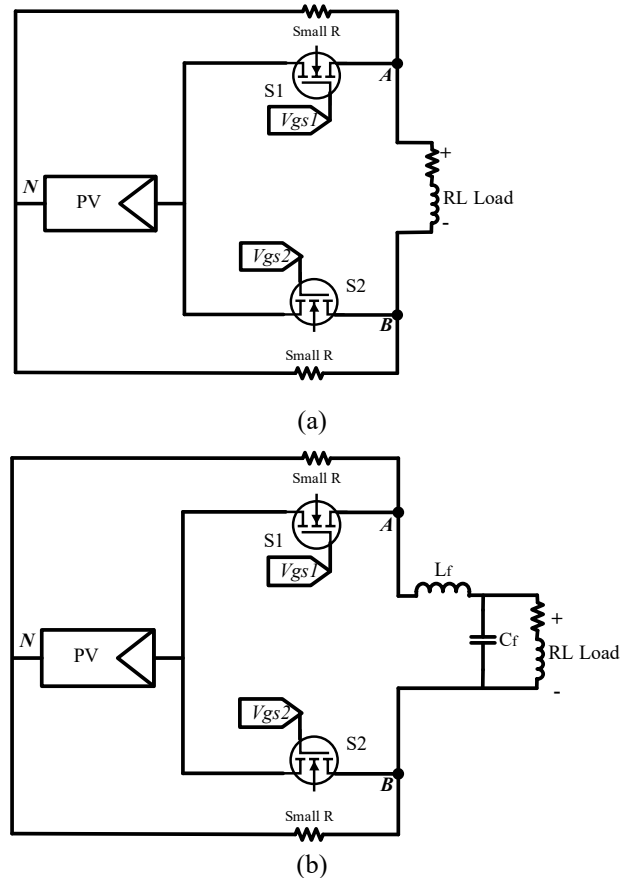


Fig. 4. Block diagram of the proposed Pseudo-inverter for OGPV system; a) without LCL filter and b) with LCL filter.

Based on Fig. 4, proposed inverter with and without LC filter were represented for off-grid PV application. Duty cycle of the power switches each will be turn on for 50%. During positive half cycle, as power switch S1 turns on, the current flow from PV module to the positive RL load and complete the cycle to the negative PV module terminal through small resistance, R. For negative half cycle, as power switch S2 turns on, the current

flow from PV module to the negative RL load and complete the circuit to the positive PV module terminal through small resistance,  $R$ . Hence generating AC waveform measured at the RL load. LC filter were added to smooth-out the AC output voltage, consequently reducing the harmonic content at the RL load.

#### IV. SINUSOIDAL PULSE WIDTH MODULATION (SPWM) TECHNIQUE

Specified duty cycle of the SPWM signal generating voltage signal or gate pulses across the power switches allowing the switch to be turns on and off based on the specified duty cycle. SPWM were comparing two modulating signal; carrier signal (triangle) and reference signal (sinusoidal), thus generating gate pulses to the power switches. The frequency of the reference signal was set at 50Hz which determines the proposed Pseudo-inverter output frequency, while the amplitude of the reference signal controls the modulation index and the RMS value of the inverter output voltage. SPWM technique were chosen in this paper because of the simple implementation using analogue components or digital microcontroller.

##### A. Bipolar SPWM

The gate pulses from the Bipolar SPWM technique requires one reference signal, one carrier signal. The carrier signal is triangulate between 1, -1 and back to 1, while reference signal is sinusoidal wave with amplitude equal to 1. These two signal were compared generating one gate pulse, named as  $V_{gs1}$  for turning on and off the power switch, S1. Analogue NOT component was required to generate gate pulse for the power switch, S2. Fig. 5a shows Bipolar SPWM block diagram of Simulink Model and aggregated gate signal for power switches,  $V_{gs1}$  and  $V_{gs2}$ , respectively. Based on the Fig. 5a, at time zero, the power switch, S2 already being turn on and generate output simultaneously. Bipolar SPWM caused both power switches, S1 and S2 will be turn on and off during both positive and negative cycle. It means, the power switches will always operate through out the time period, thus increase the stress on the power switches consequently reduce lifespan of the power switches for a long operation.

##### B. Unipolar SPWM

The gate pulses from the Unipolar SPWM technique requires two sinusoidal modulating waveform as reference signal and one carrier signal. The carrier signal is triangulate between 1 and 0 while both of the sinusoidal waveforms with same amplitude of 1, but  $180^\circ$  out of phase. These two sinusoidal signal were compared with a triangular signal, generating two gate pulses, named as  $V_{gs1}$  and  $V_{gs2}$  for turning on and off the power switches, S1 and S2 respectively, without additional analogue component. Fig. 5b SPWM block diagram of Simulink Model and aggregated gate signal for power switches,  $V_{gs1}$  and  $V_{gs2}$ , respectively. Based on the Fig. 5b, both of power switches, S1 and S2 were off few seconds before start to be

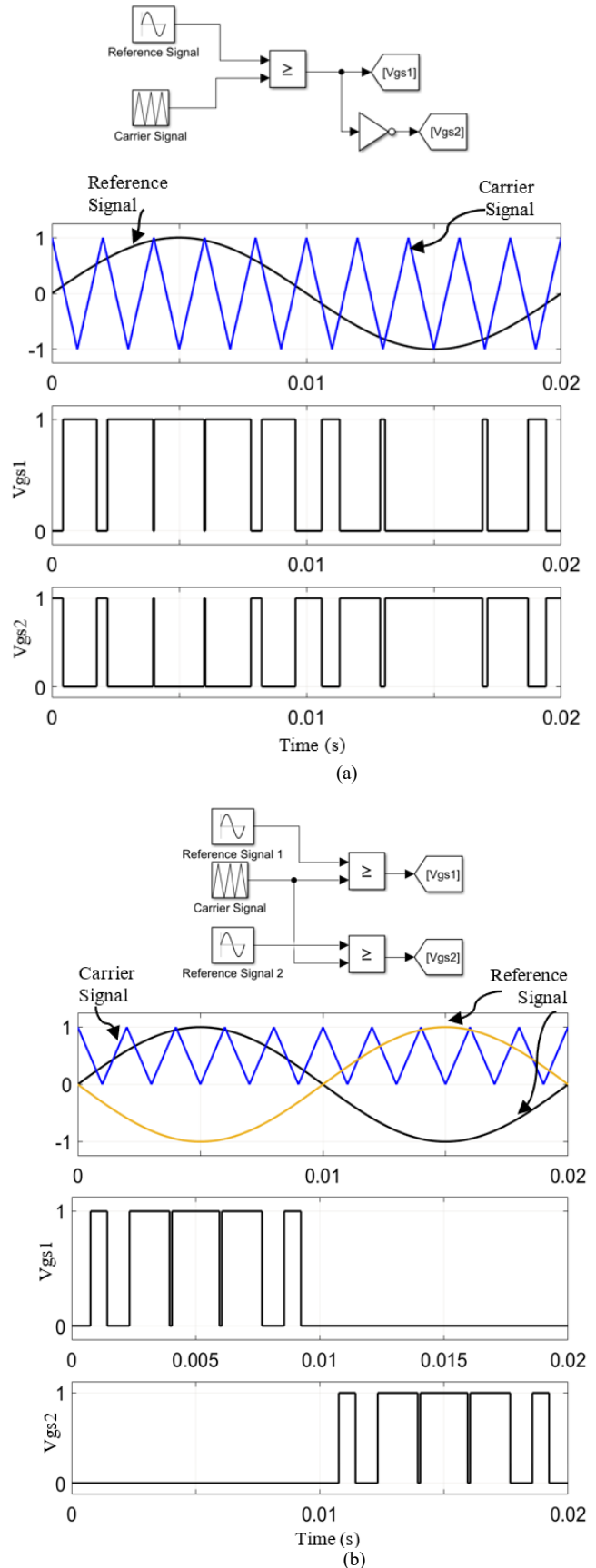


Fig. 5. Block diagram of the SPWM; a) Bipolar and b) Unipolar.

operated. Unipolar SPWM caused only one power switch to be turn on during half of the cycle, hence reducing the stress on the respective power switch consequently improve the lifespan of the power switches for a long operation. Vast advantage of using Unipolar SPWM which provide the balncking time or known as dead-time,

V. PROPOSED PSEUDO-INVERTER FOR OGPV SYSTEM WITH SPWM TECHNIQUE

The proposed topology converting the pseudo-based DC input into AC output, where the proposed Pseudo-inverter has been modulated using both Bipolar and Unipolar SPWM. Parameters used for the Simulink Model were tabulated in the Table 1. Power switches, S1 and S2 had the same duty cycle at 50%, carrier signal was set at 20kHz with modulation index, ma = 1. DC-link voltage was set in parallel to the PV module to provide constant DC voltage to the inverter as well as treating the inverter as voltage-source inverter (VSI). Proposed Pseudo-inverter and conventional Full-bridge inverter circuit were tested at irradiation, G=1000 W/m<sup>2</sup>, with real environment at T =65°C. The off-grid load is represented by using RL load and will be tested with and without low-pass filter, L<sub>f</sub>C<sub>f</sub> using Eq. 1. The proposed topology as shown in Fig. 6 will be compared to the conventional Full-bridge inverter in Fig. 7, both using Bipolar and Unipolar SPWM.

$$L_f = \frac{1}{(2\pi f_o)^2 C_f} \tag{1}$$

Where  $f_o$  is the resonant frequency, which normally set to 10% of the  $F_s$ .

TABLE I  
PARAMETERS FOR BIPOLAR AND UNIPOLAR OF THE PROPOSED INVERTER FOR OFF-GRID PV

Variable	Parrameter	Value
PV Module	LUMOS LS250-60M	250W
	Paralel string, N <sub>pv-parallel</sub>	1
	Series string, N <sub>pv-series</sub>	1
V <sub>c</sub>	DC-link capacitor	100μF
V <sub>mpp</sub>	PV voltage at MPP	30.1V
V <sub>oc</sub>	PV voltage at Open Circuit	37.3V
I <sub>mp</sub>	PV current at MPP	8.31A
L <sub>filter</sub>	L <sub>f</sub>	3.165mH
C <sub>filter</sub>	C <sub>f</sub>	2μF
RL	RL load	10Ω 5mH
R	Small R	5Ω

TABLE II  
THD ANALYSIS OF CONVENTIONAL FULL-BRIDGE INVERTER AND PROPOSED PSEUDO-INVERTER USING BIPOLAR AND UNIPOLAR SPWM

SPWM	Inverter Topology	Filte r	THDi (%)	THDv (%)	Fig.
Bipolar	Full-Bridge	-	1.93	104.2	8a
		LC	1.08	1.45	8b
	Proposed inverter	-	2.672	202.1	8c
		LC	0.68	1.754	8d
Unipolar	Full-Bridge	-	33.2	137.9	9a
		LC	29.08	33.4	9b
	Proposed inverter	-	5.68	141.6	9c
		LC	5.095	5.685	9d

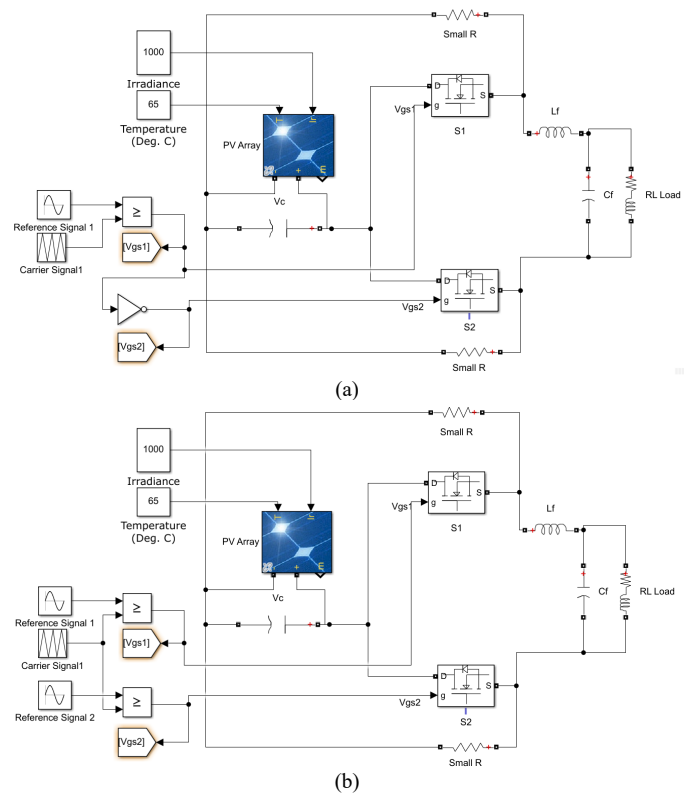


Fig. 6. Simulink Model of the proposed Pseudo-Inverter for Off-Grid PV system using; a) Bipolar SPWM and b) Unipolar SPWM.

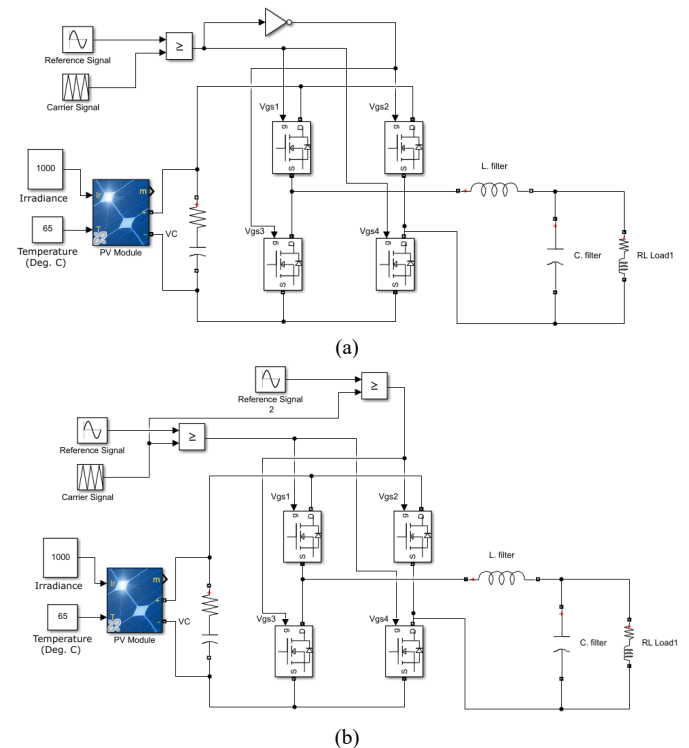


Fig.7. Simulink Model of the conventional Full-bridge Inverter for OGPV system using; a) Bipolar SPWM and b) Unipolar SPWM.

## VI. RESULTS AND DISCUSSION

The proposed Pseudo-inverter with Bipolar and Unipolar SPWM are simulated using MATLAB Simulink with parameters as tabulated in Table I. Fig. 1b shows the desired DC current from the PV module in pseudo-wave shape pattern used in this work. The values of inverter output voltage and current have been set to make comparison for their performance. Output current and voltage waveform of both conventional Full-bridge inverter and proposed Pseudo-inverter with different modulation techniques and with or without filter connection which are depicted in Fig. 8 and Fig. 9 respectively.

Table II summarizes the FFT analysis on the total harmonic distortion of the Bipolar and Unipolar SPWM for conventional Full-bridge inverter as well as the proposed Pseudo-inverter, with and without LC-filter component. The FFT analysis setting are: fundamental frequency equal to 50Hz, while the maximum frequency was set at 20kHz along across a time of period,  $T=0.1s$  and the FFT analysis start time at 0.02s, to give time for the system to settle down, as shown in Figure 10.

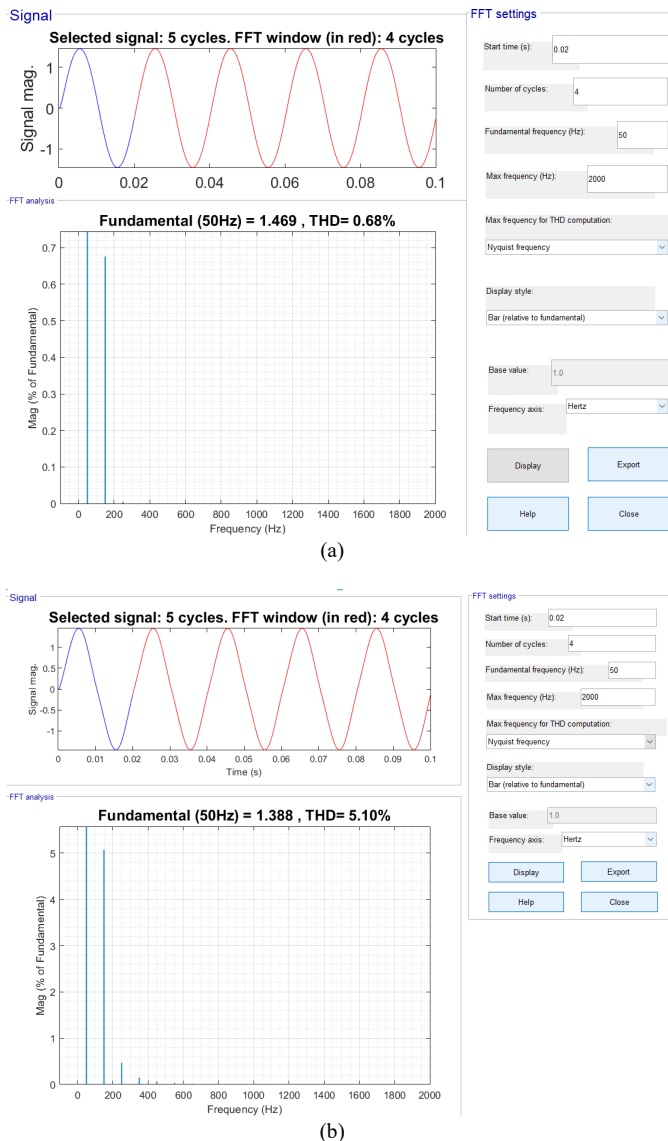


Figure 10: Harmonic setting on the FFT Analysis for proposed Pseudo-inverter using a) Bipolar SPWM and b) Unipolar SPWM.

Referring to Fig. 8a and Fig. 8c, Bipolar SPWM technique produce inverter output voltage between  $-V$  and  $+V$  along the time period. It shows that by using Bipolar SPWM, the switching and operation mode of both power switches, S1 and S2 will be taken place in turns during both positive and negative cycle. Full-bridge inverter and Pseudo-inverter using Bipolar SPWM producing quite low THD<sub>i</sub> which are 1.93% and 2.672% respectively. However, Bipolar SPWM producing two-level output voltage ( $+V$  and  $-V$ ), does generating higher THD<sub>v</sub> in proposed Pseudo-inverter and conventional Full-bridge inverter which are 104.2% and 202.1% respectively.

Previously in Fig. 5b, Unipolar SPWM allowing only one power switch to be operated during half cycle, while the other power switch is off, and vice versa. Hence, Unipolar SPWM producing three-level output voltage ( $+V$ ,  $0V$  and  $-V$ ) due to the dead-time occurred from the carrier signal's setting; which triangulate between  $[1,0,1]$  consequently producing output waveform near to the sinusoidal shape and reducing the THD<sub>v</sub>. This can be seen in Table II, where the proposed Unipolar Pseudo-inverter shown in Fig. 9c producing lower THD<sub>v</sub> compared to Bipolar Pseudo-inverter shown in Fig. 8c, where the THD<sub>v</sub> drop from 202.1% to 141.6% respectively. By comparing Unipolar of the inverters shown in Fig. 9c and Fig. 9a from Table II, the proposed Pseudo-inverter producing lower THD<sub>i</sub> which equal to 5.7% compared to the conventional Full-bridge inverter with THD<sub>i</sub> equal to 33.19%.

Low-pass filter was connected parallel to the off-grid load of both inverters. Referring to Fig. 8d and Fig. 8b from Table II, the proposed Bipolar Pseudo-inverter with LC-filter successfully producing AC waveform with THD<sub>i</sub> equal to 0.68% which are lower compared to conventional Bipolar Full-bridge inverter with THD<sub>i</sub> equal to 1.08%. However, Bipolar Pseudo-inverter with LC filter does have slightly higher THD<sub>v</sub> but still in the acceptable values at 1.76%, compared to the conventional Full-bridge inverter at 1.45%.

The impact of the LC-filter on the Unipolar SPWM can be illustrated in Fig. 9d and Fig. 9b, where the proposed Unipolar Pseudo-inverter with LC filter successfully producing AC waveform with lowest THD<sub>i</sub> and THD<sub>v</sub> which are 5.1% and 5.69% respectively, comparing to the Unipolar Full-bridge inverter which are 29.08% and 33.4% respectively.

Last, based on Table II, the proposed Pseudo-inverter producing better THD performances by using Bipolar or Unipolar SPWM as shown in Fig. 8d and Fig. 9d compared to the conventional Full-bridge inverter as shown in Fig. 8b and Fig. 9b respectively.

These findings suggested that internal control of the inverter (open loop control) for this paper through Bipolar and Unipolar SPWM plus additional filter component able to generate inverter AC output, eventhough generates very low voltage range due to the single PV-input. The proposed Pseudo-inverter was planned for off-grid application where the output required is low. Hence, anything received by the PV input will be transformed into AC by the proposed Pseudo-inverter and transferred to the load directly, without storage unit nor connected to the national grid. However, more higher voltage range could be generated by inserting DC-DC converter as the

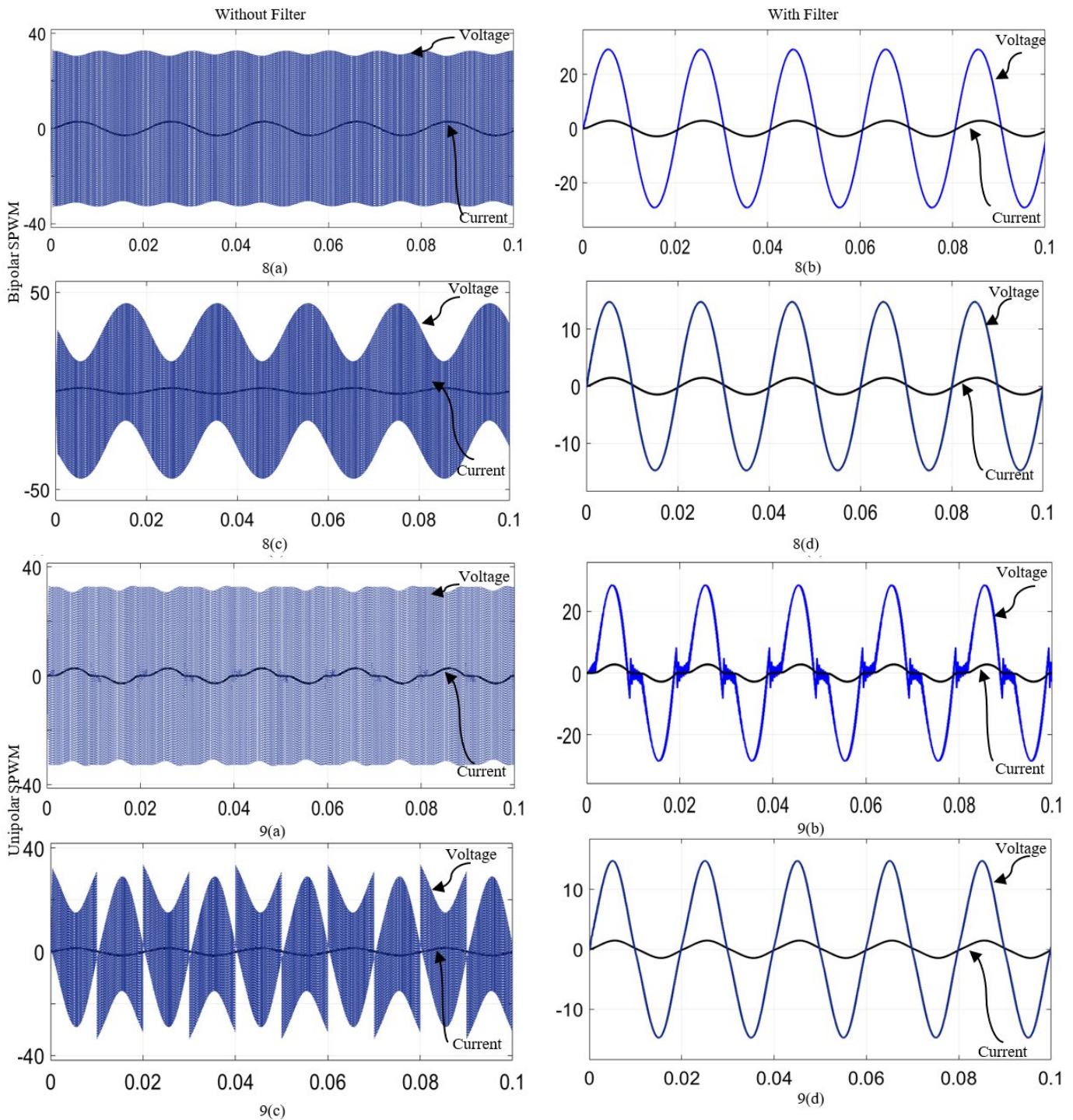


Fig 8. Inverter Voltage and Current Output using Bipolar SPWM; a) Full-bridge Inverter without filter, b) Full-bridge Inverter with filter, c) Proposed Pseudo-Inverter without filter and d) Proposed Pseudo- Inverter with filter.

Fig. 9. Inverter Voltage and Current Output using Unipolar SPWM; a) Full-bridge Inverter without filter, b) Full-bridge Inverter with filter, c) Proposed Pseudo-Inverter without filter and d) Proposed Pseudo- Inverter with filter.

boosting effect or using PV arrays at the input.

These results and discussions provide further support for the hypothesis earlier that only one power switch active during each conduction mode (one power switch active during half of the positive cycle and another one power switch active during half of the negative cycle), through open loop control of the Bipolar

and Unipolar SPWM Pseudo-based inverter which able to transform DC waveform into AC waveform, moreover produce AC sine wave output with lowest  $THD_i$  and  $THD_v$ .

## VII. CONCLUSION

The purpose of the study was to determine the whether only one power switch can be activated during each conduction mode (where one power switch active 50% during the positive cycle, while another power switch active 50% during the negative cycle), thus transforming DC input into AC output through Pseudo-based inverter. The research has shown that controlling the proposed Pseudo-inverter through open-loop control using Bipolar SPWM successfully generating two-level voltage output (+V and -V) with 0.68% and 1.76% of THDi and THDv respectively. Additional, three-level voltage output (+V, 0V, and -V) was successfully generated by using open-loop control using Unipolar SPWM with 5.1% and 5.69% of THDi and THDv respectively. Based on the analysis conducted, it can clearly concluded that the proposed Pseudo-inverter with open loop control using Bipolar and Unipolar SPWM and installation of low-pass filter generating better THDv and THDi comparing to the conventional Full-bridge inverter.

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