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Enhancing Power Quality in PV Inverters Using Hysteresis Current Control (HCC) Technique

Atikah Razi[1*], Syahar Azalia Ab Shukor[1], Nur Asmiza Selamat[2], Hismawati Ahmad[3]

[1]EV-PRODRIVES, Centre of Robotics and Automation (CeRIA), Fakulti Teknologi dan Kejuruteraan Elektrik (FTKE), Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia
[2]REAT, Centre of Robotics and Automation (CeRIA), Fakulti Teknologi dan Kejuruteraan Elektrik (FTKE), Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia
[3]Tenaga Nasional Berhad (TNB), Kawasan Perindustrian Miel Pasir Gudang, Pasir Gudang, Malaysia
Email: *atikah@utem.edu.my

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Abstract

This manuscript proposed three closed-loop strategies using Hysteresis Current Control (HCC) for PV-inverter application. A string-PV arrangement of parallel and series-PV connection ($Np = 6$ and $Ns = 10$) aims for target input voltage of ±400 V, intended for Off-grid PV (OGPV) system. The PV-system design is tested under Standard Test Condition (STC) where the irradiance and temperature are kept constant at 1000 W/m^2 and 25˚C, respectively. Full-bridge inverter is chosen as the PV-inverter since it is commonly used inverter for unfolding purposes in the PV application. The proposed PV-inverter with HCC strategy was designed and compared with the PV-inverter using conventional Bipolar Pulse Width Modulation (PWM). These proposed blocks were designed and simulated using MATLAB/Simulink software. Performance improvement of the power quality was measured in terms of current and voltage harmonic percentage, where the PV-inverter with HCC produced slightly lower current harmonic percentage of THDi = 25.45% compared to THDi = 29.19% from the conventional strategy. The proposed HCC technique resulted in a 3.74% improvement in power quality. When combined with an additional *LC*-filter, the power quality was further enhanced, achieving improvements of 74% in voltage and 82% in current harmonic reduction, respectively.

Keywords

Solar PV, PV Inverter, Hysteresis Current Control, PWM, PV System

1. Introduction

Control switching techniques in green energy sources are essential to ensure efficient energy conversion and maintain optimal performance under varying operational conditions. Photovoltaic (PV) inverters are responsible for converting direct current (DC) from PV modules into alternating current (AC) for use in homes, businesses, or feeding into the electrical grid. The switch operation of the PV-inverters during the conversion process can greatly impact on the overall stability, efficiency, and quality of the power output. Among these techniques, open-loop and closed-loop control switching methods are the two primary control mechanisms [1] used in PV-inverters, each suited to specific conditions and applications. Understanding these techniques, their advantages and disadvantages, and their impact on PV inverter performance is key to selecting the right control method.

Control switching techniques have a significant impact on the efficiency, reliability, and quality of power output from PV-inverters. Different control switching strategies directly affect important parameters like Total Harmonic Distortion (THD), which measures the deviation of the output waveform from an ideal sine wave, power efficiency, which affects the overall energy output and conservation, and response to load changes, which is crucial for maintaining stable operation in varied environmental conditions.

For PV systems connected to the grid, maintaining a low THD [2] is essential to comply with power quality standards and avoid interference with other grid-connected devices. Closed-loop control techniques help achieve this by continuously adjusting the PV-inverter's output to minimize distortions and align closely with grid requirements. On the other hand, open-loop systems, lacking feedback, often exhibit higher THD levels, making them more suitable for standalone applications where power quality demands are less stringent.

In the context of solar PV applications, the choice between open-loop and closed-loop control significantly depends on the specific requirements of the system. Open-loop control is an effective choice for small-scale or Off-Grid PV (OGPV) systems [3], where simplicity, cost savings, and ease of implementation are important. Its low complexity and reduced need for maintenance make it ideal in environments with stable conditions. Open-loop control systems are often employed in rural or remote locations with standalone PV systems, where cost constraints outweigh the need for high power quality.

However, closed-loop control is necessary for Grid-Connected PV (GCPV) or dynamic PV systems, where power quality and adaptability are essential [4]. Closed-loop control systems offer substantial advantages in maintaining consistent output, reducing harmonic distortion, and responding to load changes, making them suitable for residential, commercial, and utility-scale PV systems that require compliance with grid standards. In these applications, the ability to maintain constant voltage and current levels despite external fluctuations is critical for ensuring efficient power distribution and minimal interference with the grid.

This manuscript's main contributions are summarized as follows:

1) Reviewed the control switching techniques for the PV-inverter in OGPV system.

2) Provided the model development of the closed-loop control strategy using Hysteresis Current Control (HCC).

3) Provided the performance analysis for the PV-inverter in the OGPV system in terms of the power quality output using FFT-analysis consists of harmonic percentage of output current and voltage.

In line with the above contributions, the paper is organized as follows: Section I: Introduction provides background information related to the topic discussed and significant contribution for the manuscript. Section II discussed the literature on the control techniques in PV-inverters. Section III highlights the proposed methods toward the closed-loop strategy using HCC technique. Section IV discusses the results and analysis of the implementation of closed-loop strategy using HCC block and *LC*-filter to the conventional Full-bridge PV-inverter. Section IV concludes the performance improvement of the harmonic percentage for both open-loop and closed-loop control technique of the PV-Inverter.

2. Open & Closed Loop Control Technique

The choice between open-loop and closed-loop control also influences the efficiency of the PV system. Since closed-loop control systems can adapt to real-time changes in input conditions, they are able to operate closer to optimal efficiency, ensuring maximum energy extraction from PV panels under varying sunlight conditions. In contrast, open-loop control systems cannot adjust to changes, which can lead to energy losses during periods of fluctuating input or load. For instance, on a partially cloudy day, a closed-loop PV-inverter can quickly adapt to changes in solar irradiance, adjusting its output to match the new conditions, while an open-loop PV-inverter may continue operating at a non-optimal level.

The open-loop control switching technique operates based on a set of predefined switching commands without utilizing feedback from the output parameters as shown in the open-loop control block diagram in **Figure 1**. This means that the PV-converter and PV-inverter follows a fixed pattern of switching, regardless of changes in load or input conditions. The lack of feedback makes open-loop control systems simpler and more cost-effective, as they require fewer components and less complex circuitry [5]. Open-loop systems are often preferred in applications where the cost is a primary consideration, and dynamic adjustments to output are not necessary. Such applications are typically found in standalone or OGPV systems [6] [7] in regions with relatively stable sunlight and load conditions. For example, remote areas with smaller-scale PV installations can effectively utilize open-loop PV-inverters to supply a constant load, where minor fluctuations in output quality have a minimal impact.

Open-loop systems are designed with basic pulse-width modulation (PWM) or other simple control techniques that regulate the switching sequence without accounting for real-time output. Since no monitor occurred at the output changes, these systems cannot respond to sudden shifts in voltage or current caused by load changes, shading on PV panels, or other environmental factors. This characteristic makes open-loop control less ideal for Grid-Connected PV (GCPV) systems, where maintaining power quality and consistency is paramount. Despite these limitations, open-loop control has the advantage of low implementation costs and reduced complexity, making it easier to design and deploy. It is a practical choice for smaller PV systems or in locations where reliability of sunlight is consistent, and output fluctuations are minimal.

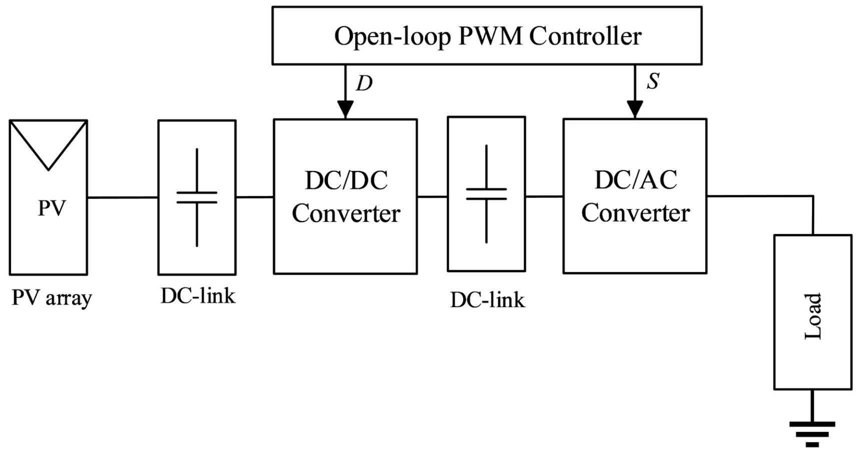

Figure 1. Block diagram of open-loop control PV system.

However, open-loop systems have several disadvantages, particularly regarding accuracy and adaptability. Since there is no feedback, open-loop inverters were not able to adjust output to account for variations in the input or load. This limitation often leads to higher Total Harmonic Distortion (THD), reduced efficiency, and possible instability under variable conditions. Furthermore, open-loop systems are sensitive to input parameter changes, meaning that they may produce inconsistent output under dynamic conditions, such as shifting sunlight or temperature variations that affect the PV panel's efficiency. As a result, open-loop PV-inverters may struggle to meet the power quality standards required for sensitive electrical loads or grid-connected applications.

On the other hand, there are two fundamental closed-loop control switching techniques that utilize feedback from the output of PV-panels and PV-inverter, which can be illustrated in **Figure 2** and **Figure 3**, respectively. Feedback values in terms of PV-current and voltage, I_{PV} and V_{PV} allows to regulate duty cycle, D for the first stage energy conversion block which is PV-converter switches. However, feedback values in terms of output current and voltage, I_{OUT} and V_{OUT} allows to regulate the switching signal for the second stage energy conversion block which is PV-inverter switches. These feedback values allow the adjustment of switching sequence in real-time. This feedback loop allows PV-converter and PV-inverter to maintain a set of desired output values, such as voltage or current levels, by dynamically modifying the duty cycle, D and switching signals, S. By constantly monitoring output parameters, closed-loop systems can respond to fluctuations in load, input variations, or external disturbances, making them much more adaptable than open-loop systems. This adaptability is particularly beneficial for GCPV systems, where maintaining stable and high-quality power output is essential.

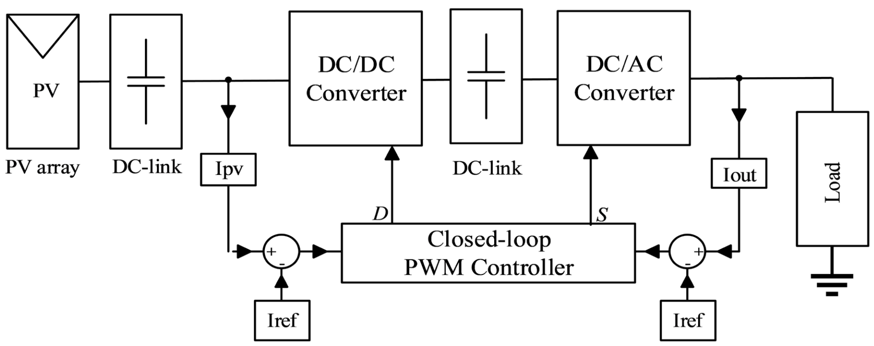

Figure 2. Block diagram of closed-loop current control PV system.

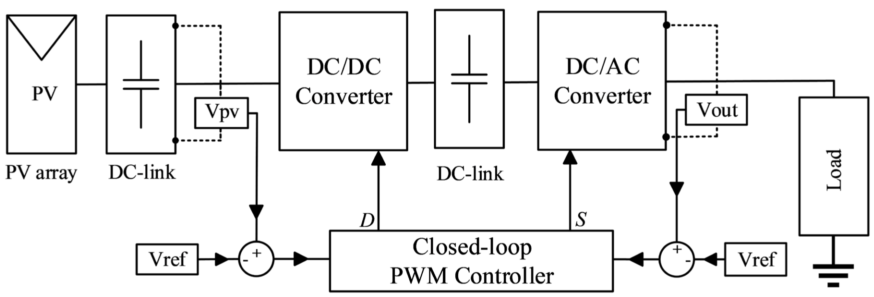

Figure 3. Block diagram of closed-loop voltage control PV system.

2.1. Open-Loop Pulse Width Modulation Control

The PWM open-loop control technique is a basic and widely used method for regulating power inverters, particularly in applications where feedback mechanisms are not required. In an open-loop system, PWM operates by creating a fixed switching pattern without responding to changes in the output parameters such as voltage, current, or load. This approach is straightforward, where switching commands are predefined and implemented through the PWM modulator, typically following a sinusoidal reference wave to approximate an AC output waveform from a DC source, such as in PV inverter systems.

PWM open-loop control technique used in PV-inverters, typically used in H-Bridge PV-inverter [8]-[13] with a target to regulate the power delivered to devices by adjusting the width of gate pulses for the PV-inverter switch. The basic principle behind PWM is to control the average voltage and power delivered by varying the "ON" and "OFF" times within each cycle. For instance, a gate pulse with "1" value indicates "ON", while gate pulse with "0" value indicates "OFF". **Figure 4** illustrates the gate pulse or known as duty cycle, D for switching strategy for energy conversion circuit either for PV-converter or PV-inverter switches, resulting from the PWM open-loop control configuration. Referring to **Figure 4**, this process produces 50% of duty cycle, D of width pulses, consequently producing continuous PWM gate pulses towards the switches of the PV-Converter of PV-inverters.

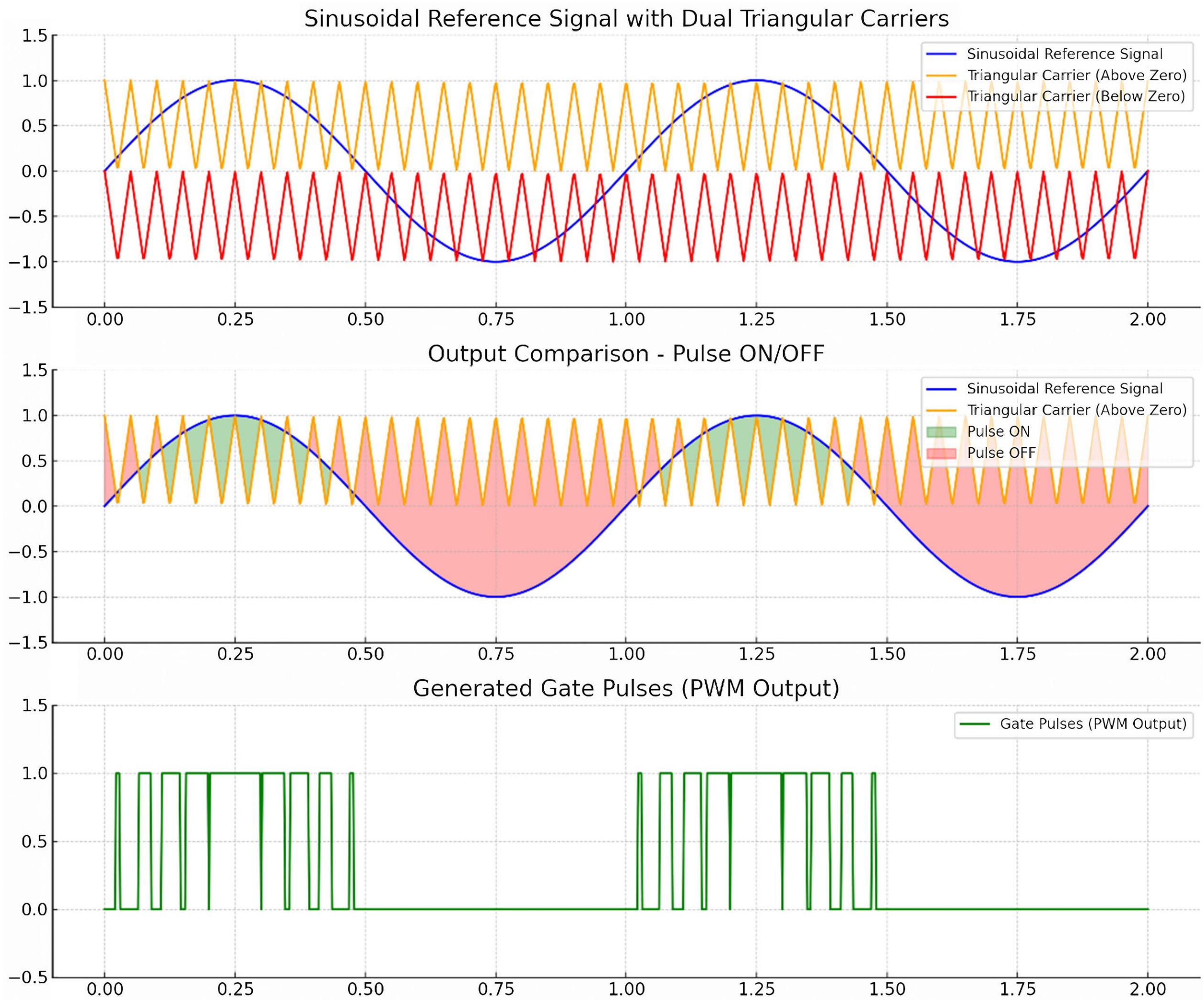

Figure 4. PWM Open-loop control switching gate operation.

The PWM process relies on the interaction of two primary signals named as a reference signal (usually a sinusoidal signal) and a carrier signal (usually triangular signal). In PV-inverter applications, the reference signal is a low-frequency sinusoidal waveform that represents the desired output waveform, typically for creating an AC output from a solar DC-source. This sinusoidal signal dictates the shape and frequency of the output. The reference signal is then compared with a high-frequency triangular or sawtooth waveform known as the carrier signal, which has a much higher frequency than the reference signal, often in the range of tens of kilohertz. This high-frequency carrier wave is essential for rapid switching control, allowing the PWM to generate precise, short-duration pulses that accurately replicate the reference waveform.

2.2. Closed-Loop Current Control

Closed-loop current control is a method used in PV-inverters, aims to maintain a stable current output by continuously adjusting to fluctuations in load or input conditions. This technique involves a feedback loop that monitors the output current and compares it to a desired reference value, typically set based on the system's power requirements. The core process begins with the feedback system measuring the actual output current, which is then compared to the reference signal. Any difference, or "error," between the actual and desired current prompts an adjustment in the inverter's switching pattern to bring the output current back in line with the target. This feedback loop is essential in applications such as GCPV, where consistent current output is crucial for synchronizing with the grid and meeting power quality standards.

The closed-loop current control process uses several key signals. The reference signal, often a low-frequency sinusoidal waveform, represents the ideal current output that the system aims to maintain. Alongside this, the actual current signal is fed back from the PV-inverter output and compared with the reference in real time. The error signal, which represents the difference between the actual and reference currents, is processed by a controller. Controller for PV inverter integrating with Proportional-Integral (PI) controller [14]-[19], or Hysteresis Current Controller (HCC) [20]-[23]. Recently, the HCC control strategies were improved by combining with other methods such as Space Vector PWM [24] or Scalar Hysteresis Control [25] aim for improving the switching behavior, and minimizing the current error compared to existing direct current controllers. Apart from that, there are more sophisticated control techniques to mitigate ground leakage current by adopting Proportional Resonant (PR) [26] or circulating leaking current attenuation in PV station by applying min-max synchronous pulse width modulation of Phased-Locked Loop (PLL) [27].

The hybrid of two common techniques became popular, such combination of PI-PSO [14] PSO-ANFIS [14] and PI-MPPT [4], where these controllers worked in adjusting the PWM switching pattern in response to error thus ensuring the current output closely follows the reference signal, even in the presence of load or input fluctuations. This continuous feedback allows closed-loop current control to dynamically adapt to changing conditions, maintaining a low current harmonic, THDi and ensuring stability. The use of real-time current measurement and adjustment components makes this technique complex, but it is highly effective in environments with variable loads or input conditions, providing reliable current control and efficient, high-quality power output.

2.3. Closed-Loop Voltage Control

Closed-loop voltage control is a feedback-based method used to maintain a stable output voltage in PV-inverter systems, particularly valuable for applications where the load varies or where consistent voltage is essential. The closed-loop voltage control process begins with measuring the actual output voltage of the PV-inverter and comparing it to a predefined reference voltage, which represents the desired output level. This reference signal typically matches the target voltage needed for downstream devices. Any discrepancy between the measured output voltage and the reference voltage generates an error signal, which is processed by a control system that adjusts the inverter's switching pattern to correct the voltage output.

This error signal is managed by a controller, commonly a KI-controller [28] or PSO controller [4] or even more sophisticated methods like Fuzzy logic [29] and Sliding Mode Controller [30] [31], which adjusts the PWM switching signals in response to voltage deviations. For example, if the output voltage dips below the reference, the controller increases the duty cycle, effectively delivering more power to raise the voltage. Conversely, if the output voltage is higher than desired, the controller reduces the duty cycle, decreasing power output to maintain voltage stability. By dynamically adjusting the switching in this way, the closed-loop voltage control system can maintain a consistent output even when input conditions fluctuate, such as during changes in sunlight in solar PV applications.

The process of real-time monitoring and correction makes closed-loop voltage control effective in maintaining low ripple and stable output, which is especially useful in standalone systems with sensitive electronic equipment or in GCPV system where power quality is essential. Through continuous adjustment and correction, closed-loop voltage control ensures that the PV-inverter provides a steady and reliable voltage output, meeting the demands of complex or variable loads.

2.4. Control Technique Summary

Figure 5 shows the diagram for the control technique classification for PV-inverters, while **Table 1** summarizes the characteristics, application, pros and cons of both open-loop control and closed-loop current and voltage control configurations for PV-inverters. Open-loop PWM control is a basic method used in PV-inverters where the switching pattern is predefined and not adjusted based on output feedback. However, since there's no feedback mechanism, open-loop PWM is limited in its ability to handle changes in load or input conditions, which can result in higher THD and less precise output control. This approach is generally best for small-scale OGPV setups where power quality is less critical.

Closed-loop current control typically employs controllers like PI or HCC uses real-time feedback to regulate the output current, making it highly adaptive to load and input fluctuations. This method continuously monitors the output current and adjusts the PV-inverter's switching pattern to match a reference value, which is essential in GCPV systems requiring synchronization with the grid.

Closed-loop voltage control employs Sliding Mode Control or Fuzzy controllers, which are designed to maintain a stable output voltage despite variations in load. By comparing the actual output voltage to a reference and adjusting the switching pattern accordingly, this method ensures a consistent voltage supply to sensitive equipment, making it ideal for standalone systems with variable loads.

As a summary, closed-loop current controller hybrid with PWM switching is the best choice for PV-inverters as it precisely regulates current output, resulting in lower current harmonic, THDi consequently providing high-quality output current. Therefore, it extends the lifespan of the PV-inverter. Additionally, this control method enables PV-inverters to meet the IEC 61727 standard, which requires THDi to remain below 5%.

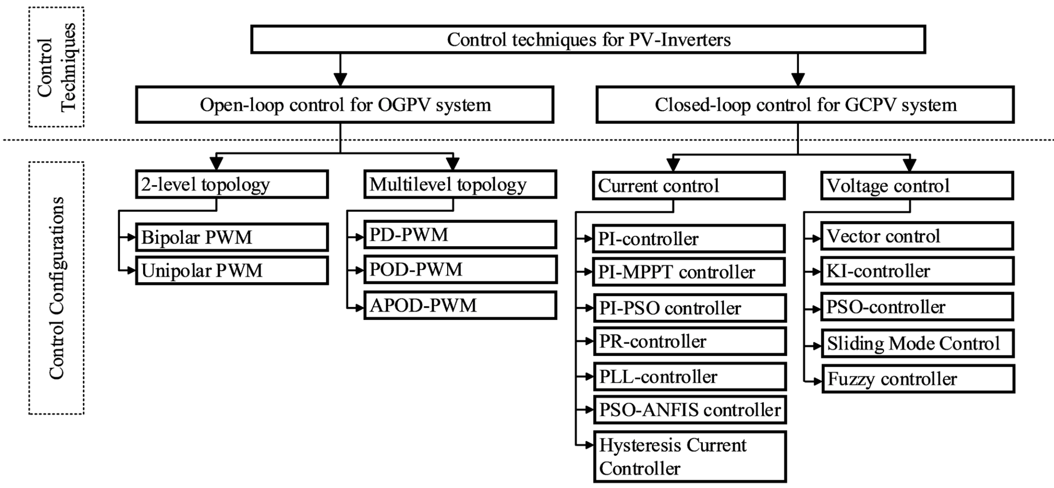

Figure 5. Diagram of the control techniques classification for PV inverters.

Table 1. Summary of the open-loop control versus closed-loop control for PV inverters.

Control technique	Open-loop PWM control	Closed-loop Current control	Closed-loop voltage control
Characteristics	No feedback mechanism Fixed switching pattern	Feedback based on output current Adjusts switching to maintain target current	Feedback based on output voltage Regulates voltage to ensure stable output
Applications	OGPV system Stable PV setups	OGPV system GCPV system	OGPV system with variable loads GCPV system
Merits	Simple and cost-effective Low component count	Reduced THD Quick response to load variations Improved stability	Stable output voltage Ideal for variable load conditions
Limitations	High harmonic distortion (THD) Limited adaptability to load/input changes	Higher implementation complexity Increased cost	Limited control over current Higher system complexity

3. Proposed HCC for PV Inverter

The PV module type of 144-Cell Half-Cut Mono Perc Solar Module by Panasonic utilized with power rating 450 W per module. The total number of parallel PV-string, *Np* and series-PV per string, *Ns* are *Np* = 6 and *Ns* = 10, to add up for roughly ±400 Vpeak. The PV-Inverter system is conducted under Standard Test Conditions (STC), where the irradiance and temperature of the cell are fixed at 1000 W/m^2 and 25˚C, respectively. The conventional Full-Bridge PV-Inverter will serve as a benchmark study with bipolar PWM open-loop control technique. Therefore, Table 2 and Table 3 show the description of PV array parameters setting and inverter parameters used in the MATLAB/Simulink, respectively.

Table 2. Description of PV-array parameters utilized in MATLAB simulink.

Parameters	Values
Number of parallel strings, *Np*	6
Number of series-connected modules per string, *Ns*	10
Standard Test Conditions (STC), Irradiance & Temperature	1000 W/m^2 @ 25˚C
No. of cell per module, N_{cell}	144
Open circuit voltage, V_{oc}	49.2 V
Short circuit current, I_{sc}	11.61 A
Voltage at max power point, V_{mp}	41.4 V
Current at max power point, I_{mp}	10.87 A
Temperature coefficient of V_{oc}	−0.304%/˚C
Temperature coefficient of I_{sc}	0.050%/˚C

Table 3. Description of PV-inverter parameters utilized in MATLAB simulink.

Parameters	Values
RL load, RL_{load}	100 Ω + 5 mH
Carrier signal frequency, f_{sine}	50 Hz
Carrier signal voltage, Vm_{sine}	1 V
Reference signal frequency, f_{tri}	15k Hz
Reference signal voltage, Vm_{tri}	1 V
FET resistance, R_{on}	0.1 Ω
Internal diode resistance, R_d	0.01 Ω
Snubber resistance, R_s	1e5 Ω

The conventional full-bridge PV inverter is employed as an unfolding circuit and tested using a closed-loop control strategy based on Hysteresis Current Control (HCC). Three proposed variants of the closed-loop HCC strategy, referred to as HCC-I, HCC-II, and HCC-III, are developed and integrated within the inverter model. The full-bridge inverter, incorporating both bipolar PWM and the HCC techniques for PV applications, is modeled and simulated using MATLAB/Simulink, as illustrated in Figure 6 and Figure 7.

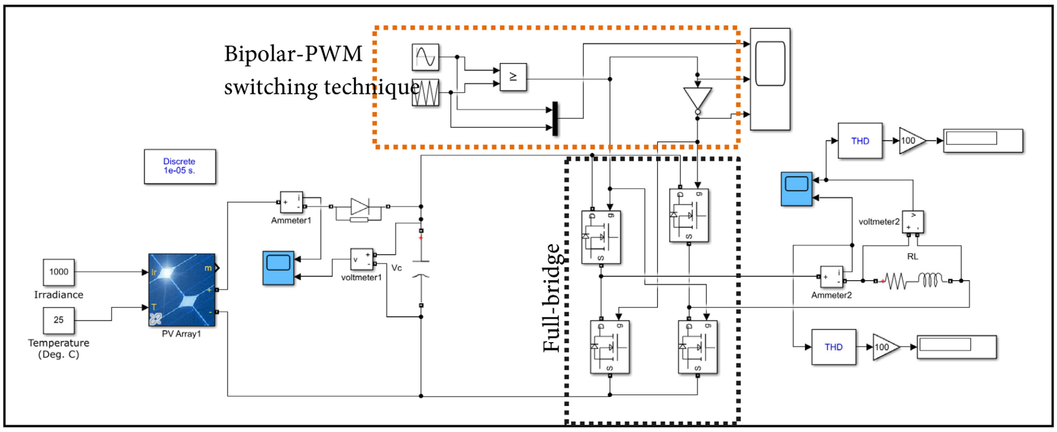

Figure 6. Model of full-bridge PV inverter with Bipolar-PWM switching technique.

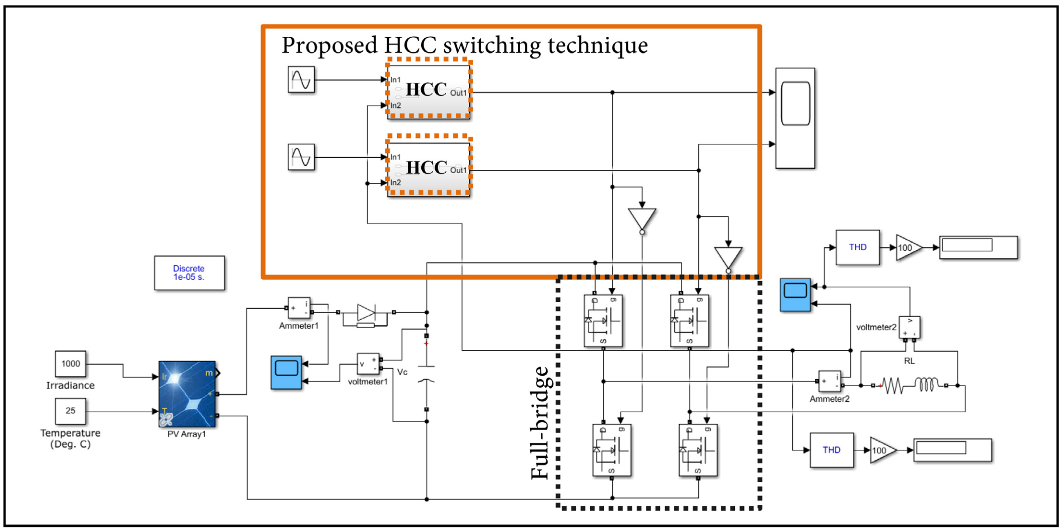

Figure 7. Model of full-bridge PV inverter with Hysteresis Current Control (HCC) technique.

The methodology for modeling the proposed full-bridge PV inverter system focuses on injecting a control current into the gate signal, which has a significant impact on reducing the current harmonic distortion (THDi) compared to the voltage harmonic distortion (THDv). As shown in Figure 7, the proposed inverter model consists of two symmetrical subsystem blocks, identified as the upper and lower sections, which generate gate signals for switching during the positive and negative half-cycles of the AC output, respectively. Each subsystem includes the proposed HCC control blocks named HCC-I, HCC-II, and HCC-III. These blocks are designed to minimize the total harmonic distortion in the output current.

The HCC models are implemented in MATLAB/Simulink, and their performance is evaluated using Fast Fourier Transform (FFT) analysis to measure total harmonic distortion. The internal configurations of the proposed HCC Block I, Block II, and Block III are shown in Figures 8-10, respectively. As illustrated in Figure 7, each HCC block receives a sinusoidal reference signal and a feedback signal from the current output, which are connected to Input-1 and Input-2 of the

HCC block, respectively, to enable real-time current regulation and improve power quality.

3.1. Proposed HCC Block I

In the subsystem model of the HCC Block I, the input-1 of subsystem is connected to the input sign "+" of the sum block while the input-2 is connected to the input sign "−" of the sum block. Both output from the sum block will enter the relay switch block. The relay will turn on when it reaches the switch on point value and remains on until it reaches the switch off point value parameter. Then, the output from relay block will go to out signal output port into the simulation circuit.

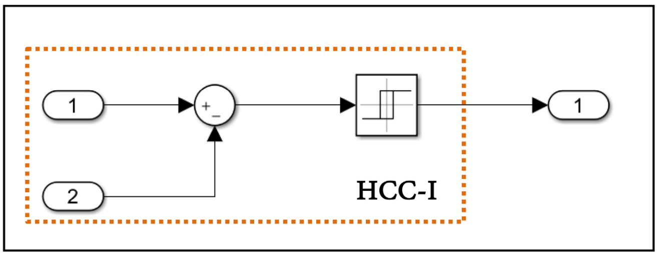

Figure 8. Proposed subsystem model of the HCC block I.

3.2. Proposed HCC Block II

Now, the relational operator block and repeating sequence block has been added into the subsystem model of the HCC Block II. The input-1 of the subsystem connected with the input sign "+" of the sum block while the input-2 was connected with the input sign "−" of the sum block. The relational operator sign is used to perform the specific operation to determine the block accepts one or more input signals. The output of added repeating sequence block connected to relational operator block that produces the waveform according to the set value parameters. Then, the output from relational operator block entered the relay block and serves as the signal output port.

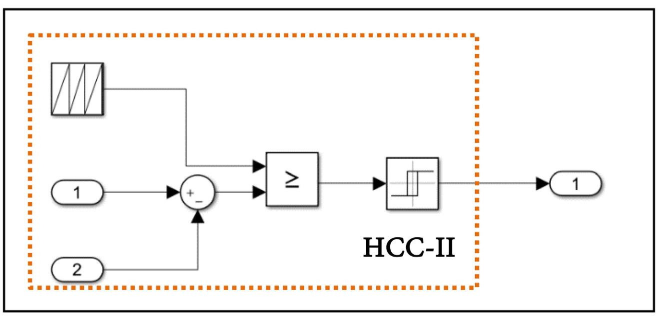

Figure 9. Proposed subsystem model of the HCC block II.

The hypothesis here was that modulating the hysteresis band in real-time can result in a more adaptive current regulation, especially under transient conditions or varying irradiance. The dynamic band helps prevent excessive switching when the current is within acceptable limits, thereby reducing switching frequency and limiting losses, while still maintaining acceptable THDi performance.

3.3. Proposed HCC Block III

In this proposed model HCC Block III, the constant block is set at 0.4 value to generate a constant signal input directly entering the relational operator block. The connection between input-1 and input-2 with sum block have remained the same as the proposed HCC block before. Then, the output from relational operator block entered relay block and serves as the signal output port into the circuit. The intent here was to offer a simpler and more stable implementation of HCC, suitable for conditions where dynamic band adaptation is not necessary. This design emphasizes ease of implementation and predictable switching behavior, which is expected to produce a moderate reduction in THDi while keeping the system response and computational load straightforward.

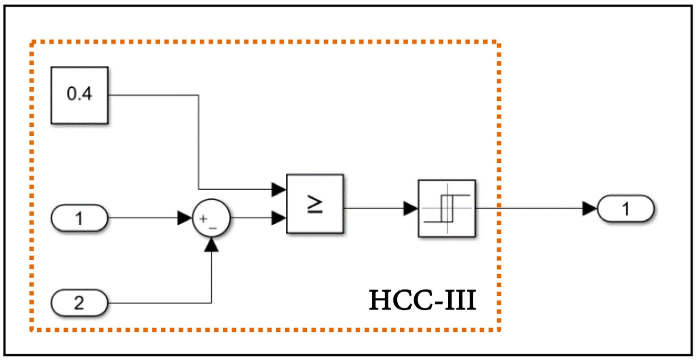

Figure 10. Proposed subsystem model of the HCC block III.

4. Results and Comparative Analysis

In this section, output performance of the Full-bridge PV-Inverter each with conventional Bipolar PWM control technique and proposed HCC control techniques will be compared and analyzed in terms of voltage and current harmonics, THDv and THDi, respectively. Next, the proposed Full-bridge PV-inverter with HCC block is simulated and analyzed with the additional filter, aiming to smooth out the output waveforms. The inductor and capacitor have been added in the circuit where it acts as the filter.

4.1. PV Inverter with Open-Loop Bipolar PWM Control

The gate signals during positive cycle were given by the gate signals of S1 and S4 while the gate signals during negative cycle were given by the gate signals of S2 and S3. Gate signals, voltage and current outputs for PV-inverter using open-loop Bipolar PWM control technique are presented in Figure 11 and Figure 12, respectively. From the simulation model, the output voltage and current are 487.5 V and 4.875 A, respectively, while the voltage and current harmonic presented are, THDv = 99.41% and THDi = 29.19%, respectively.

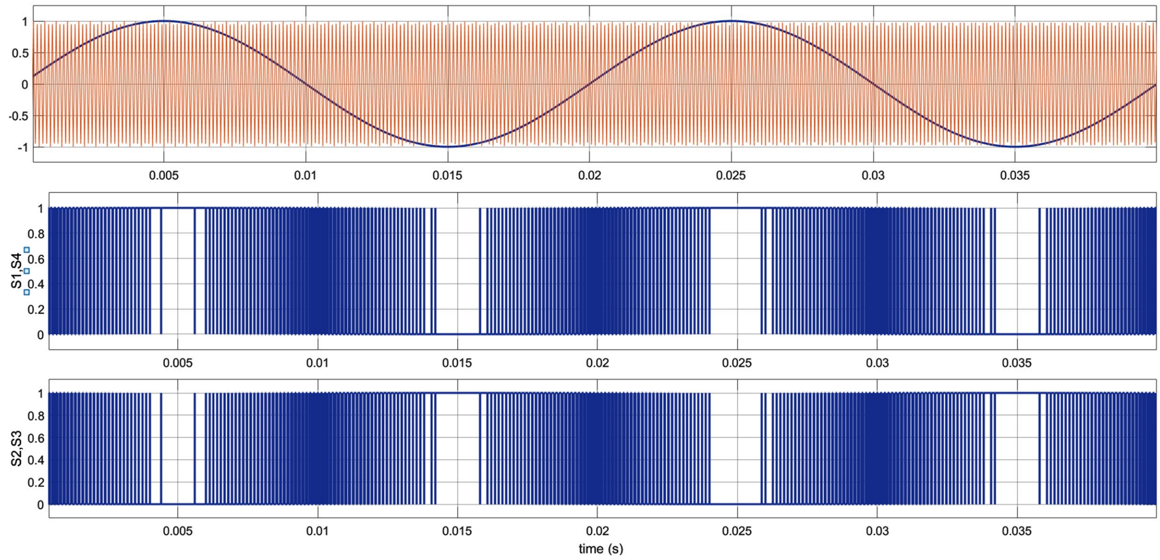

Figure 11. Gate signal for full bridge inverter using open-loop bipolar PWM control.

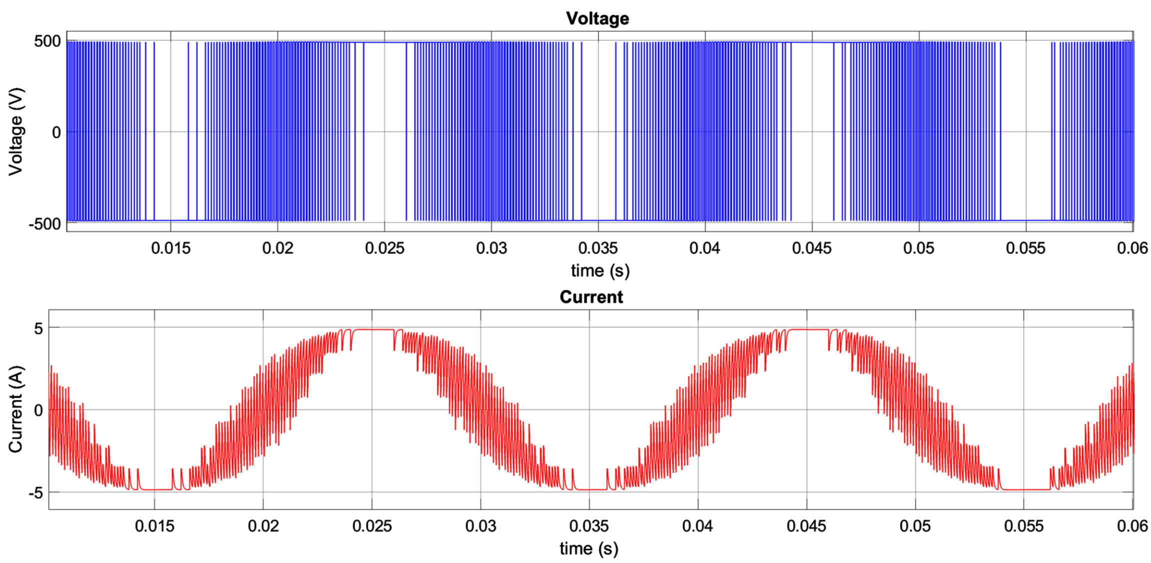

Figure 12. Voltage and current output waveform using open-loop bipolar PWM switching.

4.2. PV Inverter with Proposed Closed-Loop HCC Control

For the proposed HCC techniques, current harmonics have been observed and analyzed using the FFT Analyzer. Figures 13-15 illustrate the current harmonic, THDi, each representing the output performance from the proposed HCC Block I, HCC Block II, and HCC Block III, respectively. By comparing the THDi percentage among the proposed HCC blocks, the proposed HCC Block I provide greater improvement with THDi = 25.45%, hence suitable to apply as the gate signals sources towards the PV-Inverter. The proposed HCC Block II and HCC Block III produce slightly higher THDi which are 50.39% and 28.28%, respectively. Table 4 summarized the THD percentages for PV-Inverter using Bipolar PWM and proposed HCC Blocks.

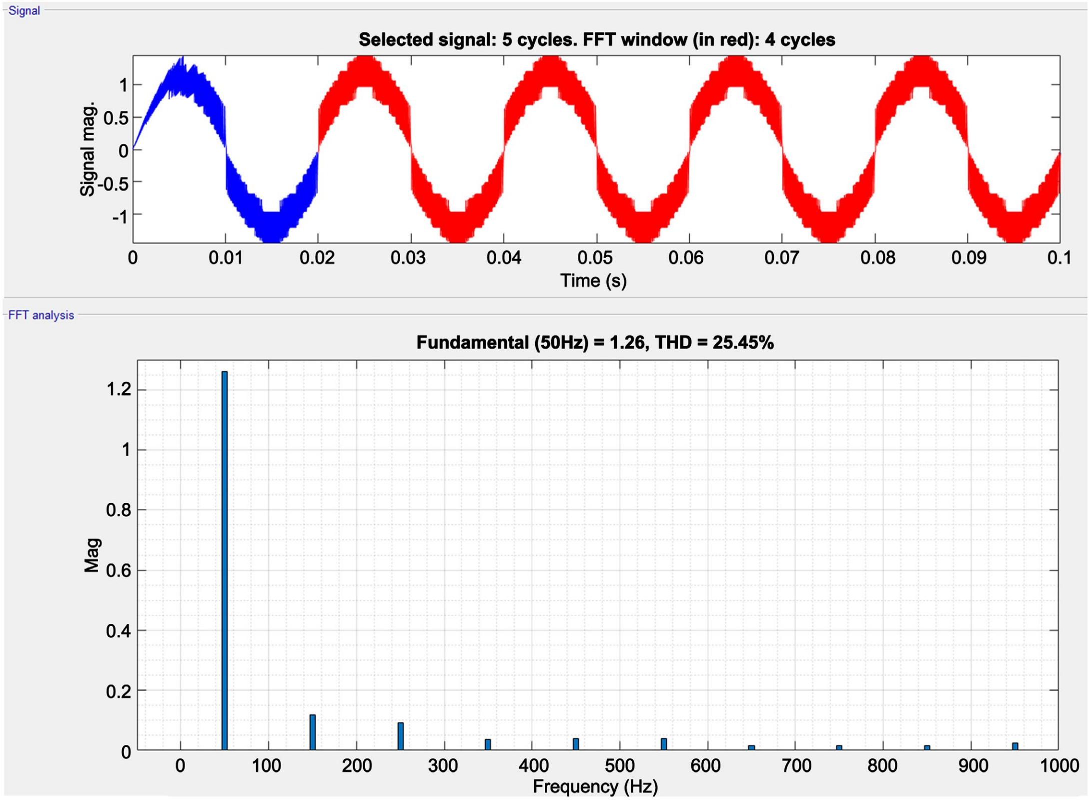

Figure 13. Analysis of THD current output by using proposed HCC block I.

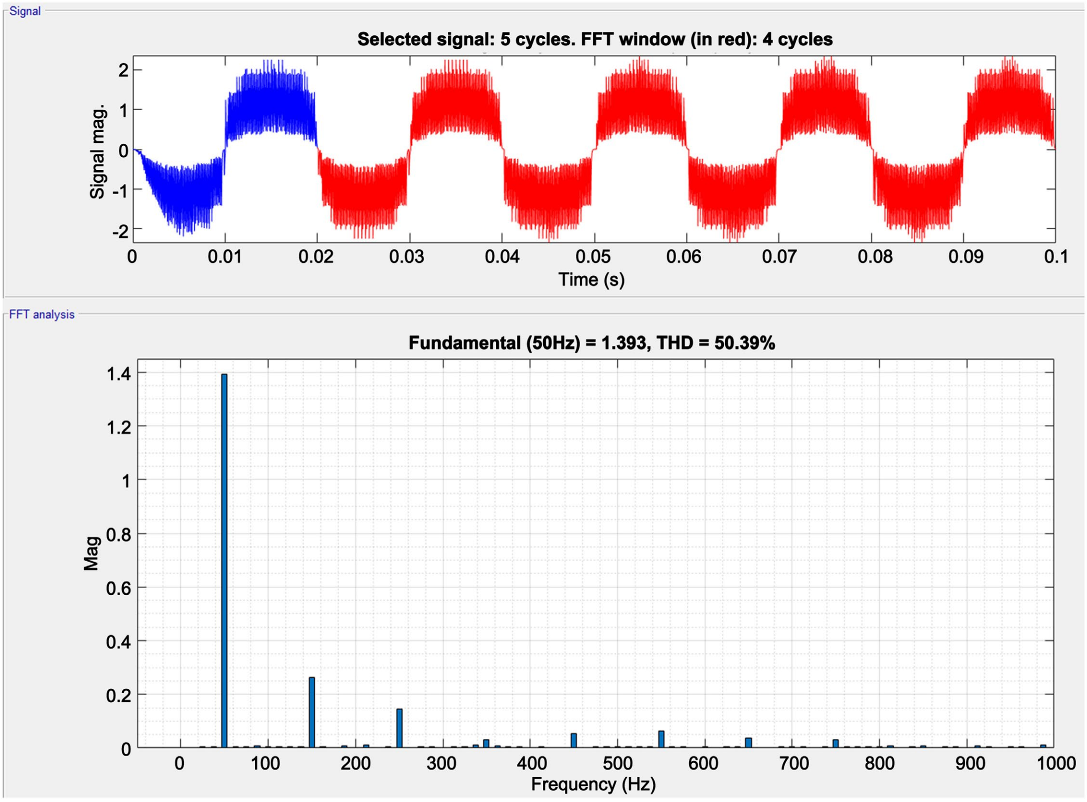

Figure 14. Analysis of THD current output by using proposed HCC block II.

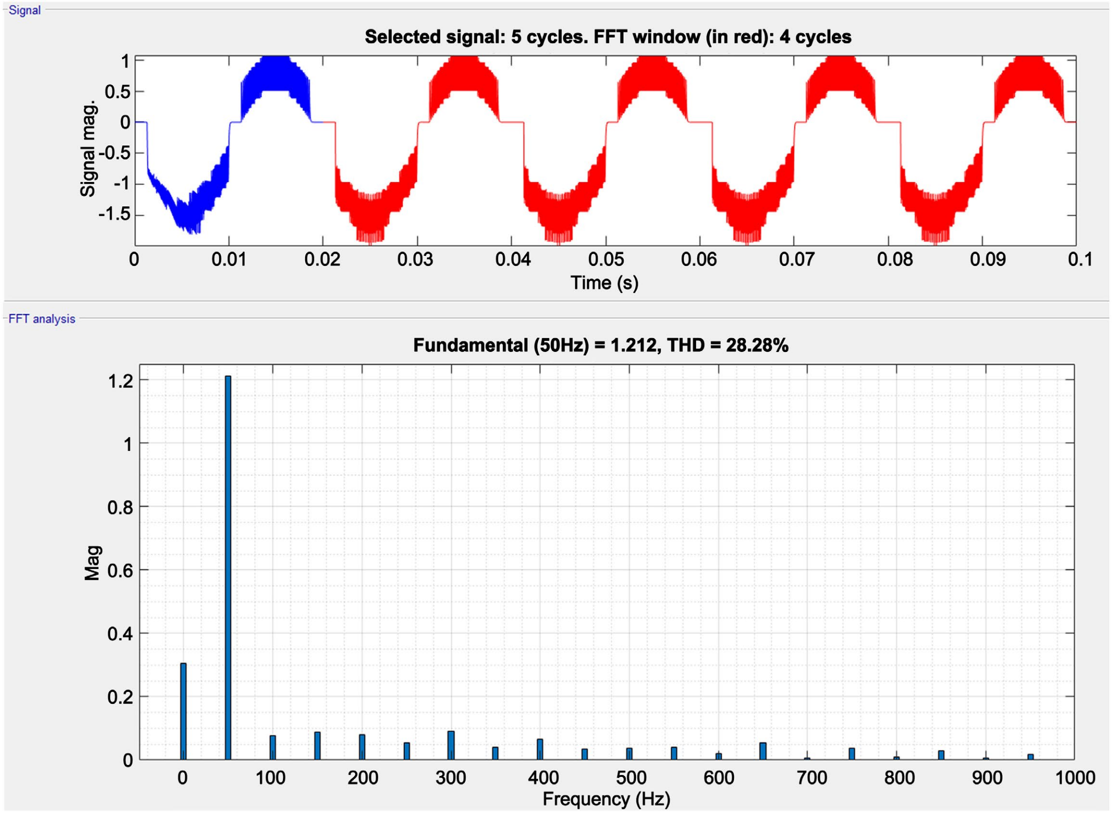

Figure 15. Analysis of THD current output by using proposed HCC block III.

Table 4. Description of PV-inverter parameters utilized in MATLAB simulink.

Controller	THDi (%)	THDv (%)
Bipolar PWM	29.19	99.41
Proposed HCC block I	25.45	203.95
Proposed HCC block II	50.39	196.13
Proposed HCC block III	28.28	198.74

4.3. PV Inverter with Proposed Closed-Loop HCC Control and *LC*-Filter

Next, a series of *LC*-filter combinations acts as filtering component for PV-Inverter output utilizing HCC Block I. The inductor filter values shown in Table 5 varies from 5 mH until 25 mH, while the capacitor filter value has remained the same at 1 μF. Figure 16 illustrates the output waveforms produced from the PV-Inverters with HCC Block I before and after the utilization of *LC*-filter. By comparing the THDi and THDv percentage among the variations value of *LC*-filter, the proposed HCC BlockIwith *LC*-filter of 25 mH + 1 μF provide greater THDi improvement from 25.45% to 7.52% and THDv improvement from 203.95% to 5.23%. The results indicate that the proposed HCC method, when integrated with an additional passive filter, effectively improves power quality by 70% and 97% for current and voltage performance, respectively.

Table 5. Comparison of THD performance using different parameter values of *LC*-filter.

Inductor filter, L_f (H)	Capacitor filter, C_f (F)	THDi (%)	THDv (%)
-	-	25.45	203.95
5m	1μ	29.84	19.59
10m	1μ	17.88	12.43
15m	1μ	12.51	8.79
20m	1μ	9.33	6.49
25m	1μ	7.52	5.23

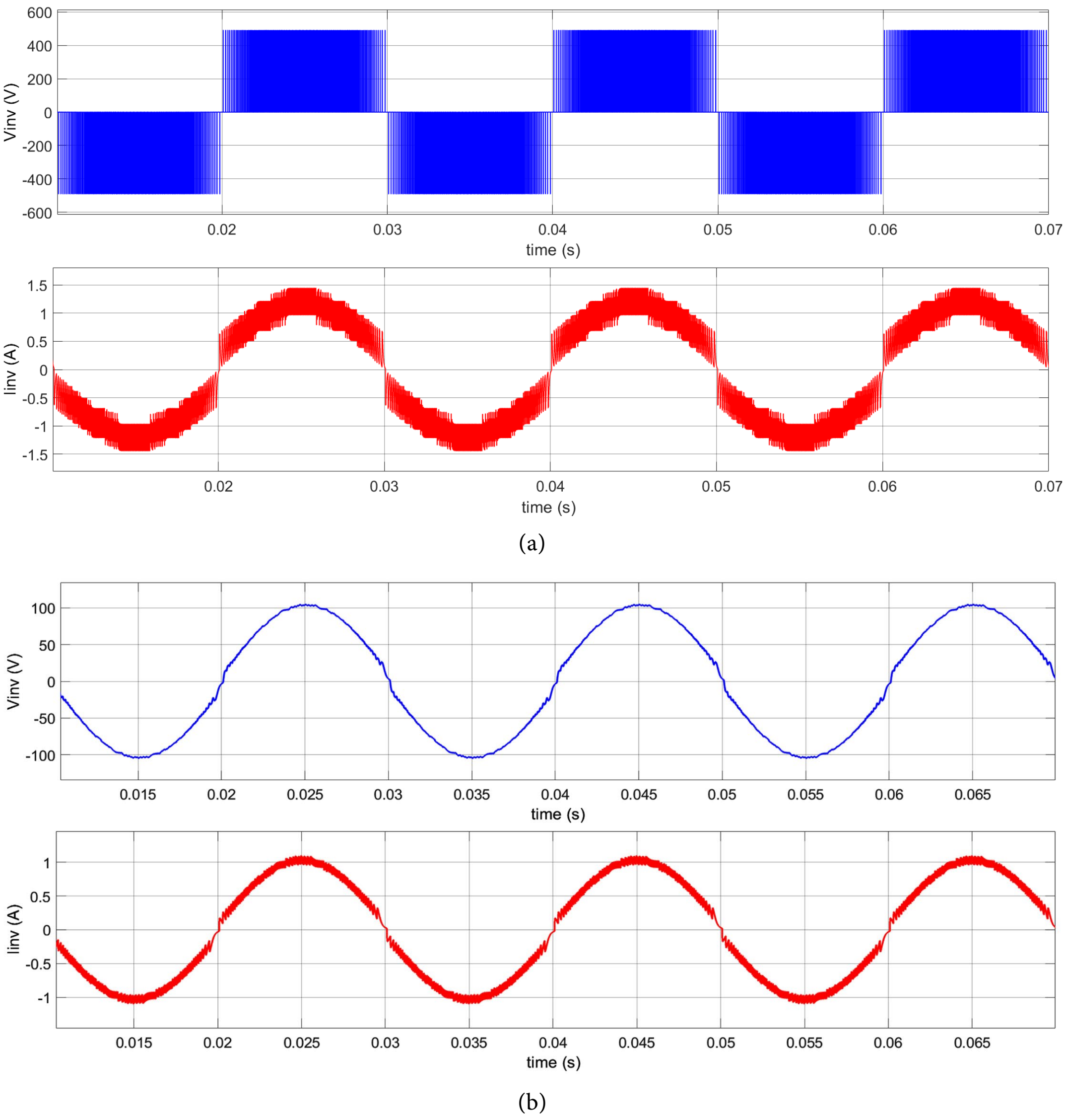

Figure 16. Hysteresis current control output waveform before and after *LC*-filtering. (a) Before filter; (b) After filter.

5. Conclusion

In conclusion, this manuscript has provided the methodology needed in analysis performance of the PV-Inverter with proposed Hysteresis Current Control (HCC) for string-PV application. The model of isolated inverter for PV application has been designed successfully in the MATLAB/Simulink software. By using several PV modules connected in array arrangement (Np = 6, Ns = 10), it can produce more than ±400 V which is the target input supply for this project. The irradiance and temperature are tested in Standard Test Conditions (STC) of 1000 W/m2 and 25˚C, respectively. The open-loop control of Bipolar-PWM technique is then compared with closed-loop control of HCC. There are three closed-loop control blocks proposed in the manuscript named HCC Block I, HCC Block II and HCC Block III, where all these proposed blocks were designed and simulated using MATLAB/Simulink software. The output performances in terms of harmonic percentage have been recorded and verified. The results showed that the proposed PV inverter incorporating HCC Block I produced a slightly lower current harmonic distortion, with THDi = 25.45%, and a higher voltage harmonic distortion, with THDv = 203.95%, compared to the conventional PV inverter using Bipolar PWM, which yielded THDi = 29.19% and THDv = 99.41%. However, the implementation of HCC Block I combined with an LC-filter significantly enhanced the power quality of the PV inverter, reducing harmonic distortion in the current and voltage outputs by approximately 70% and 97%, respectively. While the implementation of an LC-filter contributes notably to reducing harmonic distortion and improving power quality, it is important to note that it may also introduce trade-offs in terms of increased system cost, physical size, and weight. These practical considerations must be weighed in real world applications, particularly for residential or space-constrained PV installations. Therefore, implementing an advanced control strategy like Hysteresis Current Control with passive filtering not only strengthens the technical performance of the PV system but also delivers practical and long-term value to end users.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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