

# Hybrid Cascaded Inverter-Based Integrated Hybrid Power Supply Using Nonconventional Energy Sources

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## Abstract

In this research, a hybrid integrated topology that would work very well for applications involving distribution generation has been suggested. The Photovoltaic and Fuel Cell source are used to power the hybrid integrated topology's power supply. Photovoltaic source is utilized as the main power and runs very near to its Maximum Power Point, while the fuel cell section serves merely as a DC supply and feeds just the power that is needed to make up the difference. The integrated approach improves the overall power level that is supplied because of the presence of the fuel cell in parallel with the photovoltaic source. This may be achieved by smoothing out the voltage stress that are brought by the photovoltaic system's output. Another important characteristic is that the load may be fuelled by photovoltaic energy in any quantity, even if that quantity is relatively low. This is a feasible regardless of the size of the photovoltaic system. In addition, excess power may be sent to the electrolysis load, which results in the source of energy being used in the most effective manner possible. When converting voltages, a Hybrid Cascaded Multilevel Inverter (HCMI) topology is preferred over a conventional three phase inverter because it has the advantages of a gradual decrease in switching losses, a low total harmonic distortion, and a minimum power loss. This in comparison to the conventional three phase inverter, has none of these advantages. In addition to that, the voltages might be converted in a more effective way using this design. The suggested system has a number of desirable qualities, and the most notable are its low operational costs, its user-friendly layout, and its high level of durability.

**Keywords:** Hybrid Cascade Multilevel Inverter (HCMI), distributed generation, Photovoltaic (PV), Fuel Cell (FC)

## 1. Introduction

Local energy generation was formerly preferred. Power generating systems were placed distant from highly populated cities, near fuel sources. The technique had minimized transportation costs and urban emissions. Despite Ohmic losses, power quality and voltage control concerns, and extension limits, such techniques were widespread until recently. Rising power demand has taxed these clustered power producing facilities. "Local" energy production and consumption has led to distributed generation of power system networks. Understanding the need of a sustainable environment and the limited availability of fossil resources has encouraged the idea of local power production employing Non-Conventional Energy (NCE) sources. Most non-polluting raw resources are plentiful and are dangerous. PV is unavailable at night or in bad weather. Wind energy may or may not be accessible. Fuel cells might be more dependable, but they're expensive. Stable, low-cost electricity requires two or more NCE sources.

For hybrid distributed generation systems, it was suggested that combining photovoltaic sources and fuel cells makes for a powerful pair with potential benefits [1-6]. To overcome fuel cell discrepancies, an ultra-capacitor or a battery must be used [4]. After that, there is a quick look back at the survey on hybrid distributed generation systems.

The author of [5] suggested the hybrid distribution generation systems configuration seen in Figure 1 in their earlier work (a). It is composed of two parallel inverters, the outputs of which are linked to a single multilinking step-up transformer that connects to the grid. The disadvantage of this otherwise sophisticated scheme is that it does not make use of the available sources and does not enforce full power point monitoring.

Paper [6] later expanded on the method by using a two-loop controller with maximum power point tracking, the combination of rectifiers, inverters and magnetic coupling. The article [8-12] suggested a bidirectional, multi-input DC-DC converter design configuration. Galvanic isolation and high boosting power were provided by this configuration. It really does, however, have several power processing stages as well as a DC/AC converter for powering alternating current loads. As a result, there is a high need for a vast number of devices.

Another hybrid distributed generation system design with photovoltaic cells, fuel cells and battery power sources. Paper [13] proposed a collaboration method which can satisfy the distinct demands and requirements from the load end point of view. For proper load sharing among the numerous sources, the authors proposed an updated Euler style moving average prediction model. For the use as a stand-alone or utility device with high power, the proposed device is a reasonable fit. The paper [14] suggested a proposed device in hybrid method that uses the surplus electricity provided by renewable sources to produce hydrogen. The paper [15] suggested a useful framework for space applications that uses photovoltaic and fuel cell sources. The device maximized the use of solar energy by diverting excess power to hydrogen production through electrolysis. Valenciaga et al., [7] discussed a wind turbine, photovoltaic cell, and battery that provides charging solutions that not only protect the interests but also the battery. Blaabjerg, F. et al., [16], gave an in-depth analysis of the control strategies and grid synchronisation in hybrid power generating systems. Many useful hybrid power configurations based on above techniques with the help of wind as a source along with photo voltaic and fuel cells were recorded as well.

A hybrid topology with the photocells and fuel cells methodology had been proposed in [17], which used an individual dc–dc boost converter for two sources, with a standard grid inverter point. The DC-DC converter enhanced the power of low voltage solar systems and fuel cells. The maximum power point was also treated with the light source side variable. To minimise inefficient operation, the photovoltaic DC–DC converter must be deactivated during low insolation [20]. As a result, generation from the PV source is underutilized at low power levels. This may be appropriate in high power systems, but may be problematic in domestic or personalized power installations [21]. If the DC-DC photovoltaic side converter is paired with the reversing point, low solar radiation power may be utilised. Optimizing hybrid power supply with classic inverter architecture had been studied in [22].

For grid interfacing, most Hybrid Distribution Generation Systems setups use an inverter topology of H-Bridge type, which requires the use of a heavy-duty transformer at the line frequency in the output level or at input level a large connection of DC voltage to the inverter [18-19]. This article suggests the integrated hybrid power supply in energy delivery applications that have been driven by non-conventional renewable resources Hybrid Cascaded Multilevel Inverter (HCMI). The suggested design, which includes Photovoltaic (PV), Fuel Cell (FC), and electrolysis loads, uses a HCMI to reduce overall harmonic distortion while also reducing the amount of switching devices and power loss. The following

sections explain the proposed configuration, other characteristics, operating theory, simulation, and experimental performance.

## 2. Proposed Methodology

The architecture of the proposed design is based on an inverter topology that is suitable of inverting (DC–AC), boosting and bucking the voltage, and tracking the maximum power level. The essential principle that supports the integrated arrangement has been presented in Figure 1 (a). Figure 1(b) offers a more in-depth analysis of the information shown in Figure 1(a), as well as an example of one of the many potential applications (electrolysis). The design receives its power from a diverse range of sources, including both photovoltaic and fuel cell in equal measure. This photovoltaic source supplies the inverter perhaps through a temporary storage capacitor,  $C_{PV}$ , while the fuel cell supply is linked to a DC–DC converter. This allows the FC source to have a higher output voltage than the photovoltaic source. As a result, the FC source is able to have a voltage that is greater than the PV source. In order to redirect the excess power that is being generated by the PV source, an extra block has been installed across CPV. The goal of the system that is now under consideration is to satiate a minimum required demand of power ( $P_{req}$ ) from the grid side. PV is the principal source, and changes are performed on a regular basis to ensure that it adheres to the Maximum Power Point (MPP) even while it supplies the grid with the necessary quantity of electricity. A current may be drawn from the FC source in the same way that it can be drawn from the PV source. This function is carried out by a particular kind of converter known to be a buck boost converter. When there is inadequate or no sunshine, its only function is to provide a complement to the PV source of energy. As a direct consequence of this, the only kind of power that can be contributed to the grid by FC is termed to be back up power.

On the other side, any excess power by the PV output is conditioned and delivered to an auxiliary application like as electrolysis, which makes hydrogen for FC usage. This allows for the maximum amount of energy to be harvested from the PV source. This enables the source of the PV energy to provide the greatest quantity of energy that can be captured. Because of this, the available resources are used to the greatest extent, which results in a system that is exceptionally efficient in terms of cost [14, 25, 26]. As a direct consequence of this, the proposed method has three kinds of operation as follows:

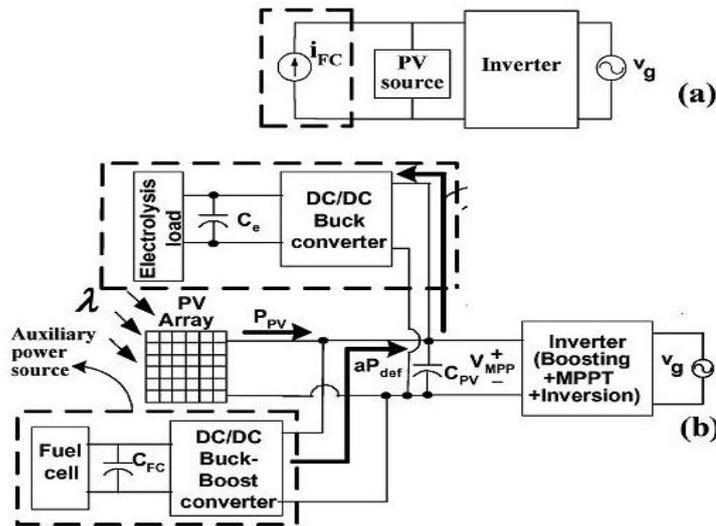
- First mode is the PV mode only

- Second mode is the Hybrid Operation (PV and FC)
- Third mode is the only FC mode accessible

The power converter modes are summarized in Table 1

**Table 1.** Active Power Converter Operating Mode

Operating Mode	Condition	Active Sources	Power Converters
I	$P_{ex} = P_{PV} - P_{req}$	PV	Buck * (for $P_{ex} > 0$ )
II	$P_{def} = P_{req} - P_{PV} > 0$	PV + FC	Buck + boost
III	$P_{PV} = 0$	FC	Buck + boost



**Figure 1.** Proposed Methodology (a) Block diagram (b) Detailed view of (a) with an application [4]

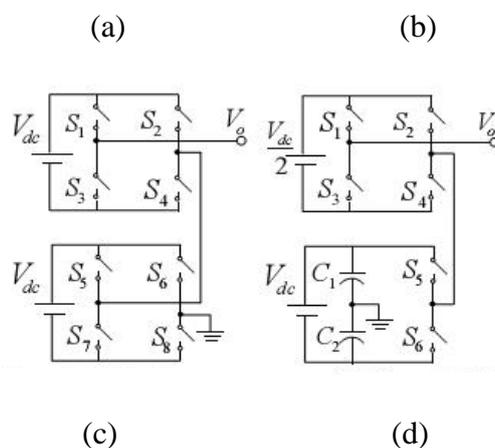
The unique features of hybrid integrated nature include,

- Hybrid integrated structure removes the boost converter to condition photovoltaic electricity.
- Only one of the capacitors either  $C_{dc}$  or  $C_{PV}$  is required.
- Parallel FC decreases PV voltage fluctuations caused by changing circumstances. So, power fluctuations are decreased.
- Voltage dips and surges might boost maximum power point tracking speed.

- Two-stage systems monitor the PV array and  $C_{dc}$  voltages for power control. In the proposed system, the  $C_{dc}$  emerges across the PV terminals removing the boost step, and for that one sensor is sufficient.
- It lowers the need for additional communication and coordination gear [23, 24] to develop and maximize energy.
- The PV and FC sources' architectural style makes the FC section a DC supply independent of output voltage. PV is connected to FC. This makes it simple to manage PV voltage for maximum output.
- The suggested arrangement is dependable, cost-effective, and ideal for renewable energy applications.

### 3. Hybrid Multilevel Inverter

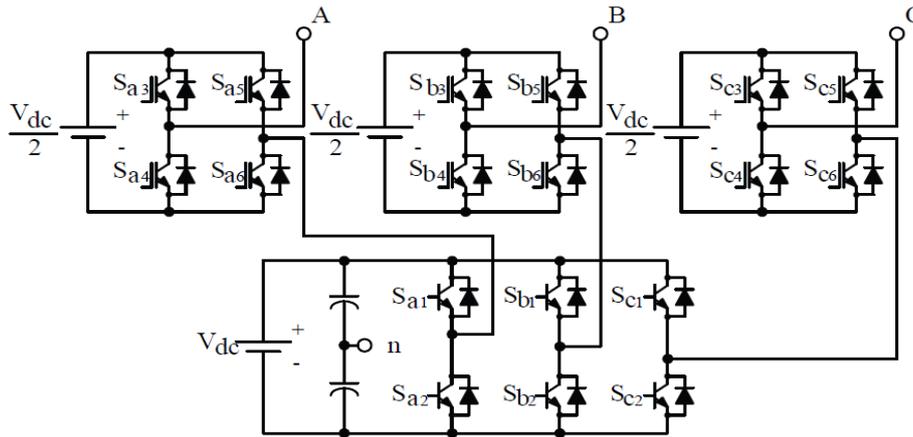
Multilevel inverters convert DC to AC. DC voltages are the same since they're all batteries, solar cells, capacitors, etc. Inverters convert DC to AC. Multilevel inverters are popular because of their lower switching loss, significantly larger voltage capability, hence less harmonics.



**Figure 2.** Single phase. (a) Diode type. (b) Capacitor type. (c) Bridge Type. (d) Hybrid Type[4, 5]

Diode-clamped, flying capacitance, and cascading H-bridge are multilevel inverter designs. Several multilayered inverter topologies have been proposed. Most multilevel converter topologies are hybrids. Multilevel inverters employ subharmonic and optimal PWM, subdividing both categories MC-SFO PWM (Multicarrier Switching Frequency

Optimal PWM). MC-SH PWM (Multicarrier Sub Harmonic PWM) cascaded multilayer inverter reduced harmonic distortion and increased output voltage. Increased levels lower Total Harmonic Distortion (THD). Low THD output voltage is ideal, but adding levels needs more circuitry and makes control more complicated. It balances cost, weight, complexity, and output voltage with minimal THD. Figure 2 shows a single-phase diode-clamped circuit, flying capacitor, cascaded H-bridge, and hybrid multilevel inverter.



**Figure 3.** Topology of 5 level 3 phase Hybrid cascaded inverter [18]

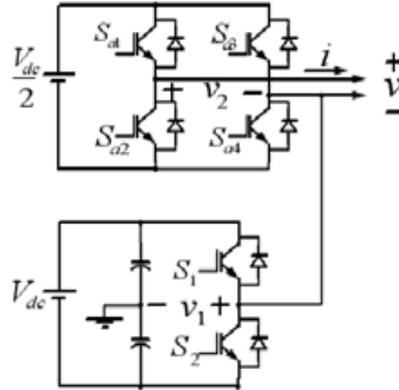
Table II illustrates this topology's number of switches, diodes, and capacitors (a 5-level multilevel inverter)

**Table 2.** Components of One Phase of A-5 Level Inverter

Inverter Types	Switch Components	Diode Component	Capacitor components
Diode	8	12	4
Capacitor	8	-	10
Bridge Type	8	-	-
Hybrid Type	6	-	2

Figure 3 shows 5 level 3 phase hybrid multi-level cascaded inverter structure. Figure 4 shows the single-phase hybrid multilevel inverter. The image displays a hybrid in series with each standard inverter using a distinct DC power source ( $V_{dc}/2$ ) at the top and one leg of a traditional three-leg inverter using  $V_{dc}$  at the bottom.  $v_1$  may be  $+V_{dc}/2$  or  $-V_{dc}/2$  depending on whether switch is closed ( $S_1$  or  $S_2$ ). When switch  $S_1$  is closed,  $v_1$ 's output voltage is either  $+V_{dc}/2$  or  $-V_{dc}/2$ . When coupled in series with a full H-bridge inverter, this

leg's output voltage is  $+V_{dc}/2$  when  $sa1, sa4$  are closed, 0 when  $sa1, sa3$  or  $sa2, sa4$  are closed, or  $-V_{dc}/2$  when  $sa2, sa3$  are closed. Closed  $sa2, sa3$  reduces the H-output bridge's voltage. Figure 5 shows the possible waveforms from this setup.



**Figure 4.** Single phase hybrid type [13]

The operation and working of a hybrid multilevel cascaded inverter have been discussed thus far, and the implementation is as follows. The following wave functions can be used to implement pulse generation, and the equation can be used to define the AC voltage ( $v$ ) as a function of time.

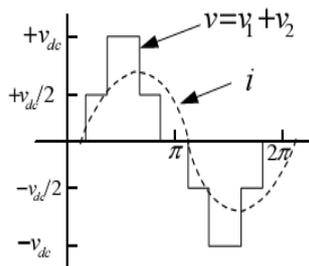
$$v_a(t) = m_a \cdot \sin(\omega t) \tag{1}$$

$$\frac{T_p}{T_c} = \begin{cases} 2 \left( v_a(t) - \frac{1}{2} \right); & \frac{1}{2} \leq v_a(t) \leq 1 \\ 2 \left( \frac{1}{2} - v_a(t) \right); & 0 \leq v_a(t) \leq \frac{1}{2} \end{cases} \tag{2}$$

$$A_1 = \begin{cases} 1; & v_a(t) \geq 0 \\ 0; & v_a(t) < 0 \end{cases} \tag{3}$$

$$A_2 = \begin{cases} 1; & |v_a(t)| > \frac{1}{2} \\ 0; & |v_a(t)| < \frac{1}{2} \end{cases} \tag{4}$$

$$A = \pi r^2 \tag{5}$$

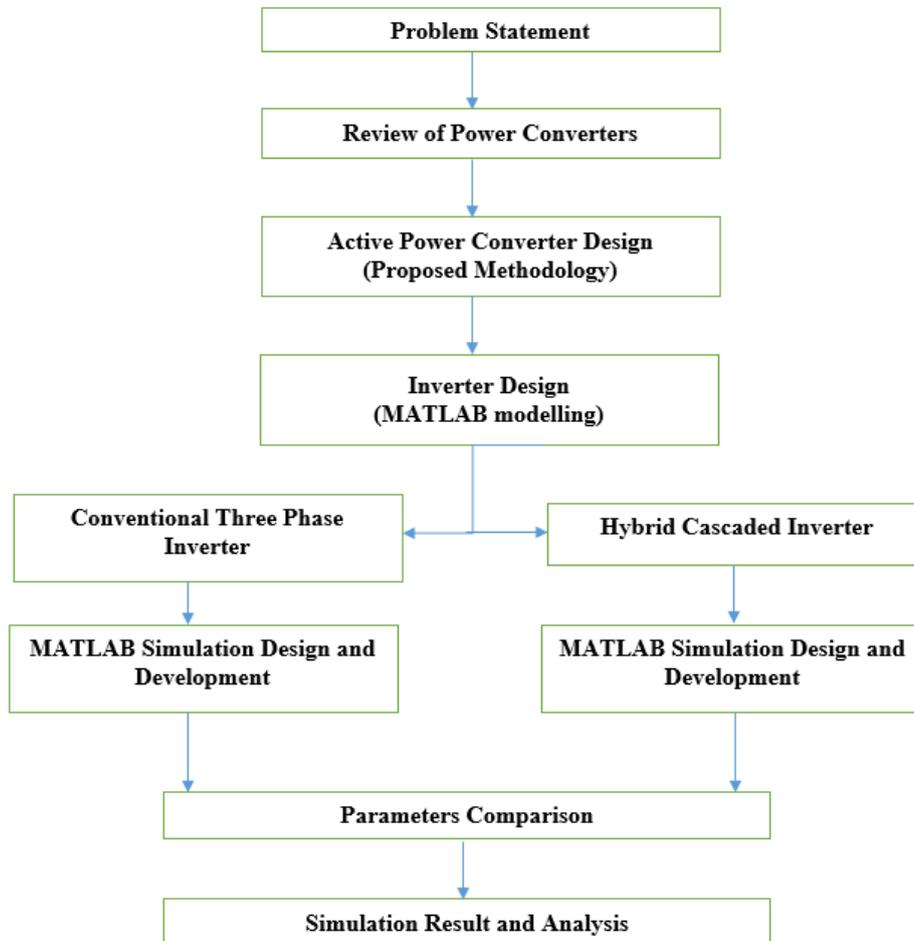


**Figure 5.** Output

As a result, fabricated pulse width modulated signal for hybrid cascaded multi-level inverter can be obtained. Consequently, the pulse width modulated signal generated for the hybrid cascaded multi-level inverter may be implemented by the logic architecture shown in table 3.

**Table 3.** PWM signal for hybrid cascaded multilevel inverter

Switch ( $H_{wn}$ )	PWM ( $H_{pw} - PWM$ )
$H_{wa1}$	$s_1$
$H_{wa2}$	$\bar{s}_1$
$H_{wa3}$	$H_{pw} + ((s_2 \cdot s_1) + (\bar{s}_2 \cdot \bar{s}_1))$
$H_{wa4}$	$\overline{H_{pw} + ((s_2 \cdot s_1) + (\bar{s}_2 \cdot \bar{s}_1))}$
$H_{wa5}$	$\overline{H_{pw}} \cdot ((s_2 \cdot s_1) + (\bar{s}_2 \cdot \bar{s}_1))$
$H_{wa6}$	$\overline{H_{pw}} + ((s_2 \cdot s_1) + (\bar{s}_2 \cdot \bar{s}_1))$

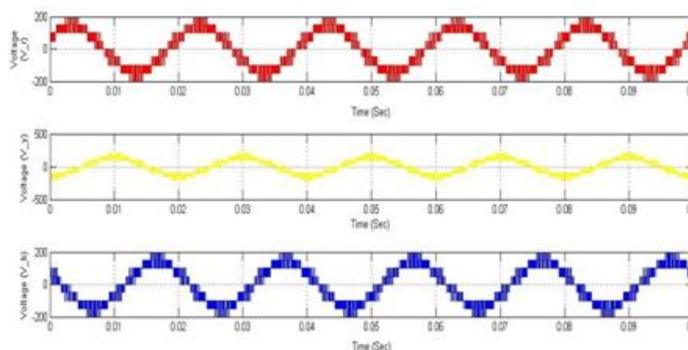


**Figure 6.** Research workflow and structure

The structure and scope of this research study are shown in the flowchart that can be found in Figure 6.

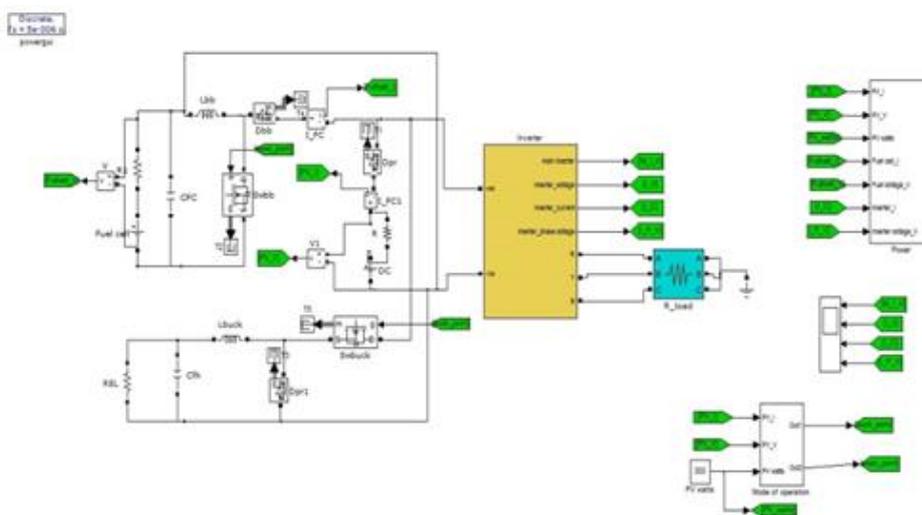
#### 4. Results and Discussion

Simulation depicts the voltage signal at the hybrid cascaded multi-level inverter's output. The output describes the schematic of a hybrid cascaded multi-level inverter, its use in three distinct modes of operation, the power used by each mode, the overall harmonic distortion, and a comparison with a conventional inverter. The results of this research are being simulated using MATLAB simpower tool box, with the solver input parameter to ode 15, and the step size is at 1 second. Figure 7 depicts the HCMI's voltage waveform as follows.



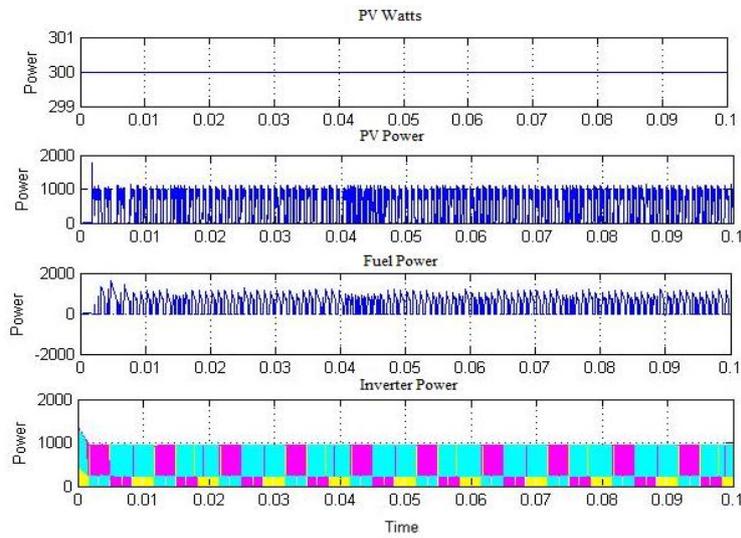
**Figure 7.** Output voltage wave form of the HCMI Inverter

Figure 8 depicts model for three modes of operation using a hybrid cascaded multilevel inverter.



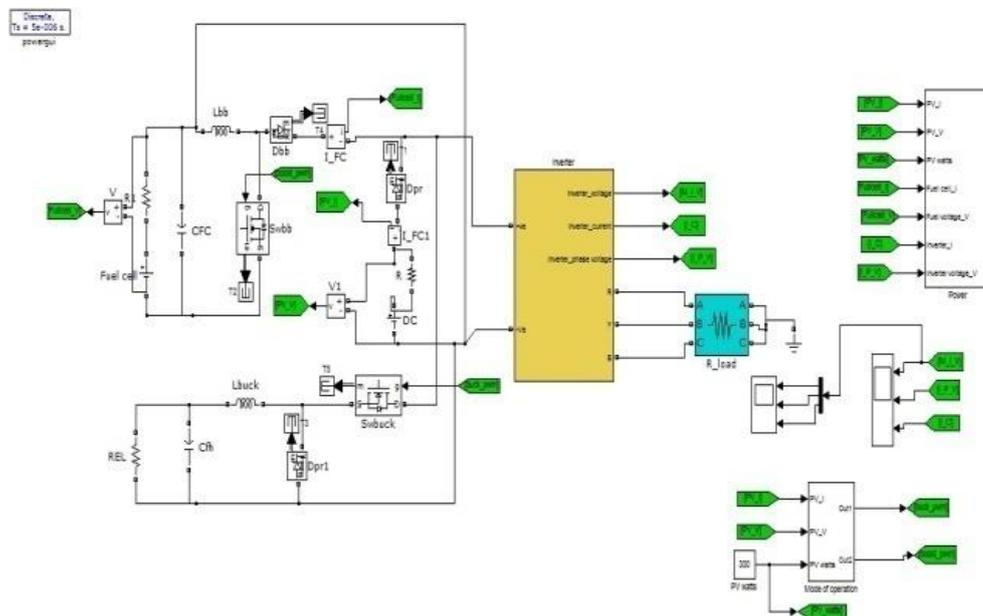
**Figure 8.** Design of 3 modes of operation using hybrid cascade multilevel inverter

Figure 9 depicts the power consumption using three modes of operation using a hybrid cascade inverter.



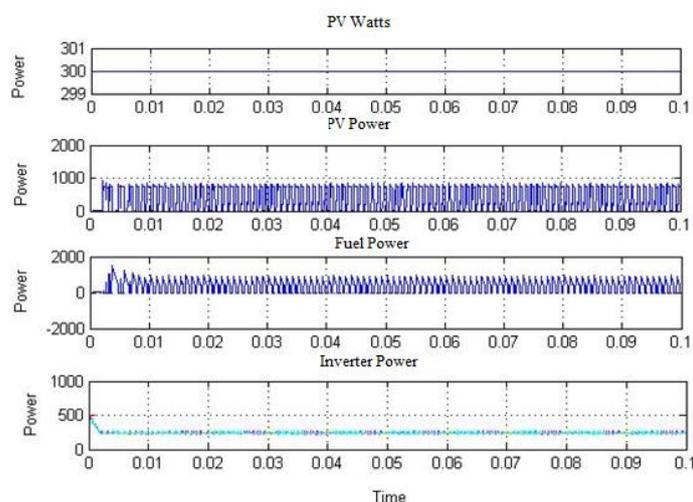
**Figure 9.** Simulink diagram for Power utilization using hybrid cascaded multilevel inverter

Figure 10 depicts the configuration of three modes of operation using a traditional three-phase inverter.



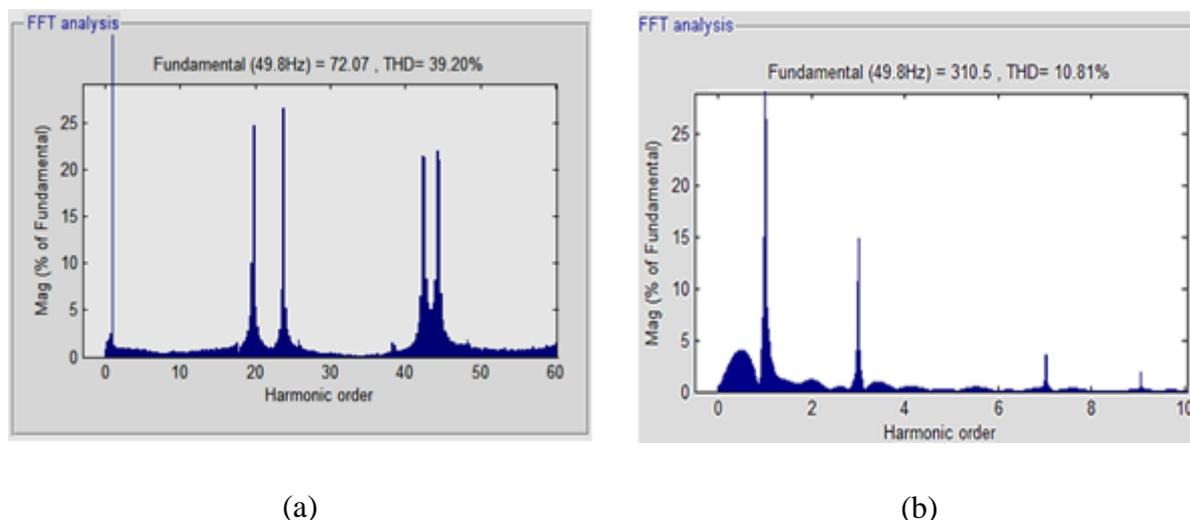
**Figure 10.** Design of 3 modes of operation using Conventional 3 phase inverter

Figure 11 depicts power consumption using three operating modes using a three-phase traditional inverter.



**Figure 11.** Simulink diagram for Power utilization using 3 phase conventional inverter

Figure 12 compares the Total Harmonic Distortion (THD) for traditional and hybrid cascaded multilevel inverters.



**Figure 12.** Comparison of THD for both conventional and HCM inverter

(a) THD for conventional 3 phase inverter, (b) THD for HCM I

## 5. Conclusion

According to the previous research, the modes of operation of this proposed methodology help to maximize the use of power, reduce the overall harmonic distortion, and require fewer switching devices when compared to the traditional inverters. The proposed design for this methodological approach is one that has a low cost, a form factor, and a high degree of efficiency. Implementing an intelligent or MPC controller to share the total power

produced by photovoltaic, fuel cell, and electrolysis load is one way to increase the power utilization and bring it closer to its maximum potential.

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