

PERFORMANCE ANALYSIS OF VARIOUS INVERTERS FOR SOLAR PHOTOVOLTAIC ARRAY

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Abstract - For Solar PV systems to achieve high-quality, efficient energy conversion, multilevel inverter integration has become more crucial. The main goal of this project is to model and simulate the operation of a solar PV array. Multilevel inverters attract a lot of attention due to their easy control and flexible design when connected in a solar PV array. These inverters operate exceptionally well since they generate an output voltage that closely a sine wave. A MATLAB Simulink model is simulated for a sine wave, 3-level, and 5-level inverter, and the corresponding output is analyzed. FFT Analysis is also done to examine the total harmonic distortion (THD) in all three cases.

Key Words: Solar PV Array, Multilevel Inverter, THD, FFT Analysis, Boost Converter, MATLAB Simulink.

1. INTRODUCTION

Life on Earth is supported by solar energy, it is also an endless and sustainable supply of electricity. Many studies have been carried out to investigate different design elements and performance traits of photovoltaic (PV) cells over the last 50 years. Creating fully integrated PV modules that are capable of effectively competing with conventional energy sources have been the ultimate goal. Because solar energy is expected to play a crucial role in future smart grids as a distributed renewable energy source, there is an increasing trend towards using solar cells in both industrial and residential applications. A grid-connected solar photovoltaic system uses a DC/AC inverter and a DC-DC boost converter to provide electricity to the utility grid. The PV cell model that is used in this system is simple and The PV cell model used in this system is simple and accurate since it takes solar radiation and ambient temperature into account. Recently, interest in adopting renewable energy has surged due to sustainable energy alternatives. sources. Solar power production, in particular, stands out due to its wide availability and eco-friendly features. This energy source helps reduce reliance on fossil fuels and lowers carbon emissions. As a result, more people are using solar energy in their homes. The objective is to create a detailed model and simulation framework for a solar power production system connected to the electrical grid. Fossil fuels, primarily coal, supply most of the world's energy. Yet, the traditional method of generating electricity poses challenges, as it

contributes to greenhouse gas emissions. In addition, as the population grows, fossil fuels and all other non-renewable resources used to produce electricity are running out and offering potential alternatives to these issues since they are thought to be long-lasting and pure sources. In order to solve these issues, renewable resources—such as solar photovoltaic, wind, tidal, wave, and biomass—are currently being used as alternative methods of producing electricity. Due to its low maintenance needs, low noise level, and lack of pollutants, solar photovoltaic energy has become one of the main renewable energy sources in recent decades. Together, solar PV panels and power converters efficiently supply electricity. A photovoltaic system is thus produced. There are numerous configurations for PV systems. Among these, stand-alone and grid-connected are the two most important system configurations. Renewable energy sources have accounted for 15–20% of global energy consumption in the last ten years. The energy generated by photovoltaic (PV) arrays is one of the many renewable energy sources and is growing in importance every day. Solar energy is widely used because it is inexpensive, readily available, and abundant. One of the numerous renewable energy sources is the energy produced by photovoltaic (PV) arrays, is becoming increasingly significant every Day. Due to its abundance, ease of availability, and low cost, solar energy is very popular. worldwide. PV arrays generate DC electricity directly, with no emissions or negative effects on the environment. DC/DC converters or inverters can then convert DC electricity to AC energy or raise the DC level of energy using a DC/DC converter. During the day, solar energy can be used to generate electricity. It is perfect for energy at intermediate and high temperatures. use. However, erratic and abrupt variations in the weather or the temperature at which cells operate can have an impact on solar energy. PV systems typically have a few components, such as a PV array, energy storage devices, and either DC or AC power. load and converter. For nine months of the year, experiences roughly ten hours of sunshine on average. Therefore, the fact that the PV array generates electricity is advantageous. However, this electricity needs to be modified for computing devices and electronics such as personal computers, lighting and heating controls, and uninterruptible power supply, among others. Consequently, a low-cost, high-efficiency DC/DC converter with voltage

feedback is typically constructed for the system in order to modify the power output of the PV array.

1.1 Objectives

1) To design and model a solar photovoltaic (PV) system integrated with a DC-DC boost converter and multilevel inverter using MATLAB/Simulink.

2) To analyze the performance of different inverter topologies — namely 2-level (sine wave), 3-level, and 5-level inverters — for solar PV power conversion.

3) To evaluate the Total Harmonic Distortion (THD) of inverter output waveforms and compare harmonic reduction among different configurations.

4) To investigate the effect of increasing inverter levels on output voltage waveform quality and system efficiency.

5) To validate that multilevel inverter technology improves power quality and minimizes the need for bulky filters in grid-connected solar PV systems

1.2 System Design and Methodology

The proposed system consists of a PV array, DC-DC boost converter, and a multilevel inverter. The PV array converts solar irradiation into DC voltage. The boost converter elevates the voltage to a stable DC level suitable for inversion. Three inverter configurations—sine wave, 3-level, and 5-level—are modeled in MATLAB/Simulink. The multilevel inverter employs cascaded H-bridge topology with Pulse Width Modulation (PWM) control to generate near-sinusoidal output voltage. FFT analysis is performed to assess harmonic distortion in each case.

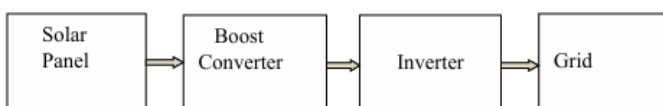


Fig 1: Block diagram of Solar power generation.

Solar power generation involves capturing sunlight and converting it into usable electricity, primarily through photovoltaic (PV) cells. PV systems use of solar panels, which directly transform sunlight into direct current (DC) electricity. This DC is then boosted by a DC-DC Boost Converter. This Boosted DC is then converted to alternating current (5 level) by an inverter, the converted AC is connected to the Grid, from the grid, electricity is used for home appliances. Minimization of THD by a 5 Level inverter.

1) Solar Panel (PV Array)

a) The photovoltaic (PV) panel absorbs solar radiation and converts it directly into direct current (DC) electricity.

b) Solar irradiation, temperature, and load conditions all affect the output voltage and current. It is necessary to do additional processing because this output is typically poor and unregulated.

2) Boost Converter (DC-DC Stage)

a) The boost converter raises the low DC voltage from the PV panel to a higher, stable DC level suitable for the inverter.

b) Example: A PV module giving 40 V can be stepped up to around 350–400 V DC.

3) Inverter (DC-AC Stage)

a) The inverter converts the regulated DC into alternating current (AC).

b) A sinusoidal AC voltage is produced by the inverter using methods such as Pulse Width Modulation (PWM).

c) In order to achieve correct synchronization, the inverter also makes sure that its output voltage, frequency, and phase match those of the grid.

4) Grid Connection

a) The AC output of the inverter is fed into the utility grid.

b) When the PV system generates more than the local demand, surplus energy is exported to the grid. On the other hand, the grid provides the load with the necessary energy when solar power is insufficient.

1.3 SOLAR PV ARRAY MODULE DATA:

Parameters	Values
Solar Modula	1Soltech 1STH-230-P
Voltage at maximum power	29.9V
Current at maximum power	7.65A
Open circuit voltage	37.1V
Short circuit voltage	8.18A
Open circuit voltage Temp Co-efficient (% deg.C)	-0.361
Short circuit voltage Temp Co-efficient (%/deg.C)	-0.102
Number of cells	32
Number of cells in series	8
Number of cells in parallel	4
Total Power generated	7.296kW

2.1 MODELLING OF BOOST CONVERTER CONNECTED TO PV ARRAY USING MATLAB/SIMULINK.

From solar PV array block parameters 1Soltech 1STH-230-P

The module is selected that is available in the module section of the PV array block in MATLAB/Simulink.

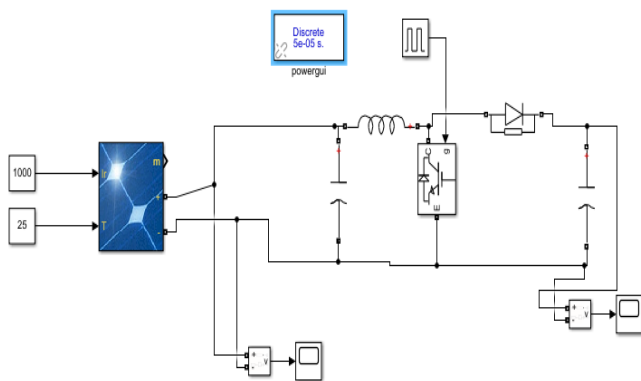


Fig 2: PV array model in MATLAB/Simulink.

Solar photovoltaic (PV) systems generate direct current (DC) power when exposed to sunlight. However, the raw voltage output from PV modules is usually low and not consistent enough for real-world uses. To make it suitable for further use, such as feeding an inverter or connecting to the grid, a boost converter is employed. The boost converter increases the PV voltage to the desired level while regulating the output.

The simulation demonstrates the effective operation of a PV system with a boost converter. Here, the PV array is connected to a DC-DC Boost Converter in this simulation. Solar irradiance of 1000w/m² and temperature 25 °C gives 113V of voltage, which is boosted to 228V by using a DC-DC Boost converter. When the switch is ON, current flows through the inductor, and energy is stored in its magnetic field. When the switch is OFF, the inductor releases stored energy, which adds to the PV voltage, resulting in a higher output voltage. The output of the boost converter in this model is approximately 423V DC.

CALCULATIONS:

1) Duty Cycle $D = 1 - \frac{V_{in}}{V_{out}} = 1 - \frac{113}{228} = 0.50$.

$V_{out} = 228$

2) Inductor L

Choose ripple $\Delta I_L = 0.3 I_{in}$

Inductance $L = \frac{(V_{in} * D)}{(F_s * \Delta I_L)} = 1.34 \text{ mH}$

$(F_s * \Delta I_L)$

3) Capacitor

For boost, with small ripple approximation:

Capacitor $C = \frac{I_{out} \max * D}{(F_s * V_{out})} = 2.95 \mu\text{F}$.

$(F_s * V_{out})$

2.2 MODELLING OF PV Array Connected boost converter and sine wave inverter using MATLAB/SIMULINK.

Here, the PV array is connected to a DC-DC Boost Converter and a sine wave inverter(2-level) in this simulation. Solar irradiance of 1000 w/m² and temperature 25 °C gives 113V of voltage, which is boosted to 228V by using a DC-DC Boost converter. Fig. 4.2 shows the boosted output waveform. we can see the boost converter output using a

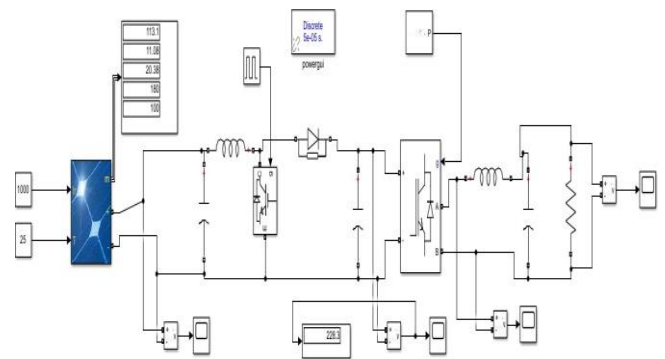


Fig 3:PV array connected to a Boost converter and sine wave inverter.

2.3 PV Array Connected boost converter and 3-level inverter Simulink model.

The 3-level inverter produces an output that steps through positive, zero, and negative voltages, making the waveform smoother and closer to a sine wave compared to a 2-level inverter.

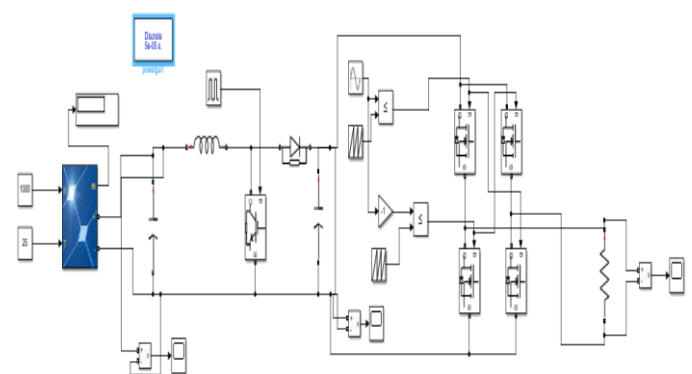


Fig 3:PV array connected to a Boost converter and 3-level inverter.

2.4 PV Array Connected boost converter and 5-level inverter Simulink model.

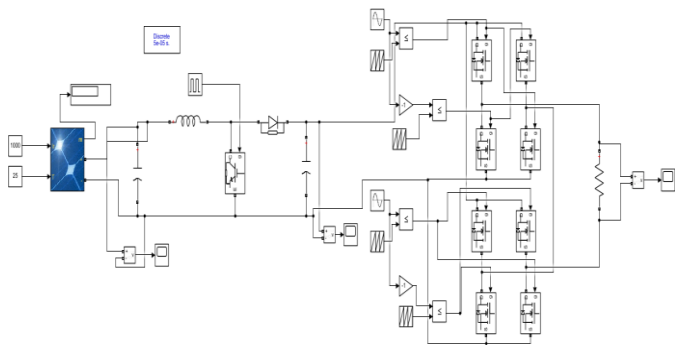


Fig 4: PV array connected to a Boost converter and a 5-level inverter.

An above 5-level inverter creates a staircase waveform with five voltage steps in each half cycle. The higher number of steps makes the output much closer to a sine wave, reduces distortion, and improves overall power quality compared to a 2-level or 3-level inverter.

3.1 Simulation Result:

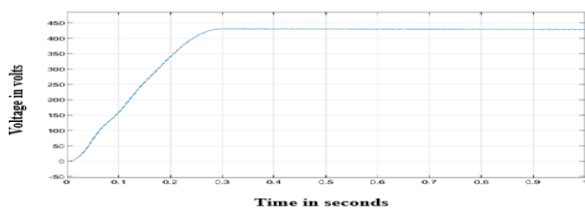


Fig 5 : output waveform of boost converter connected to PV array.

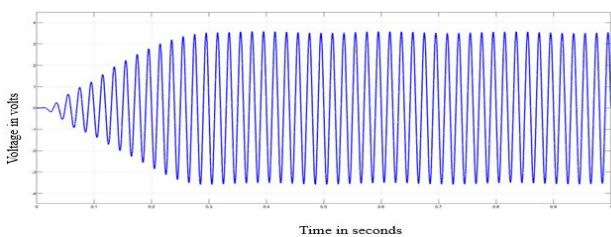


Fig 6: output waveform of PV array connected to a Boost converter and sine wave inverter.

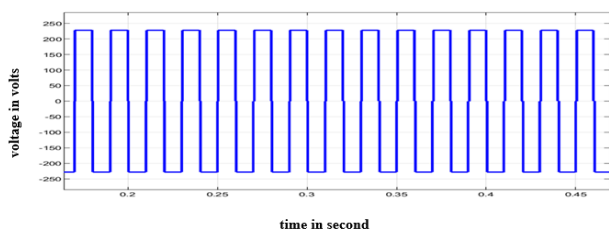


Fig 7: output waveform of PV array connected to a Boost converter and 3-level inverter.

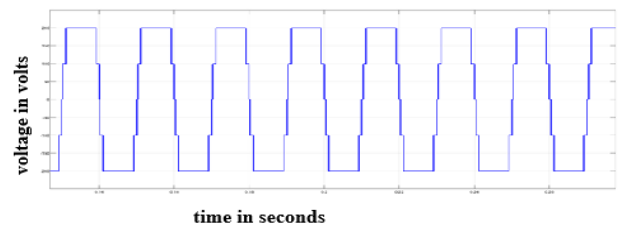


Fig 8 : output waveform of PV Array Connected boost converter and 5-level inverter Simulink model.

A 3-level inverter produces an output that steps through positive, zero, and negative voltages, making the waveform smoother and closer to a sine wave compared to a 2-level inverter. The 5-level inverter creates a staircase waveform with five voltage steps in each half cycle. The higher number of steps makes the output much closer to a sine wave, reduces distortion, and improves overall power quality compared to a 2-level or 3-level inverter.

3.2 FFT Analysis to calculate THD of various inverters:

A time-domain voltage or current waveform is broken down into its frequency components using FFT (Fast Fourier Transform) analysis. For power-electronics outputs (inverter/boost converter), FFT is used to:

- 1) Identify the fundamental frequency and harmonic content.
- 2) Calculate THD (Total Harmonic Distortion).
- 3) Evaluate filtering or modulation effectiveness.

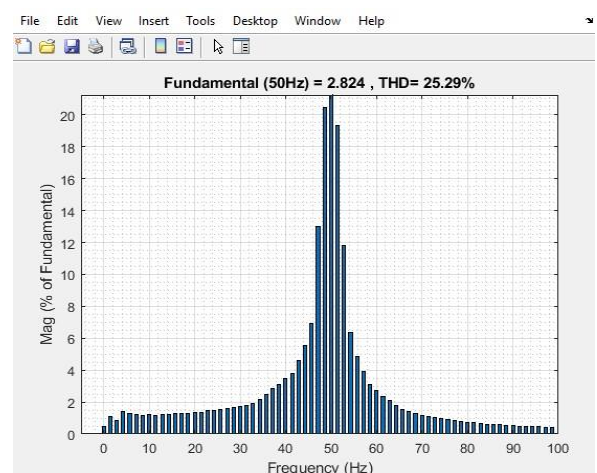


Fig 9 : FFT Analysis of sine wave Inverter.

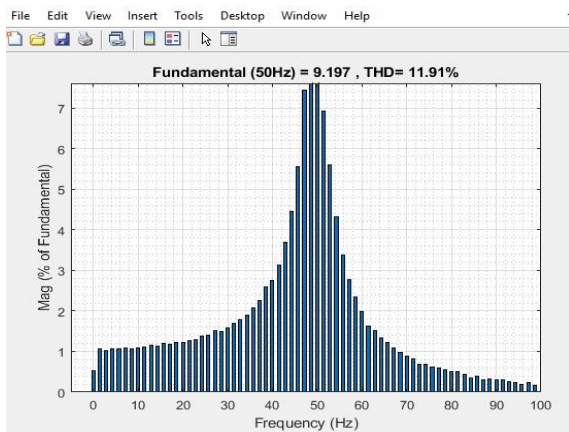


Fig 10: FFT Analysis of 3-level inverter.

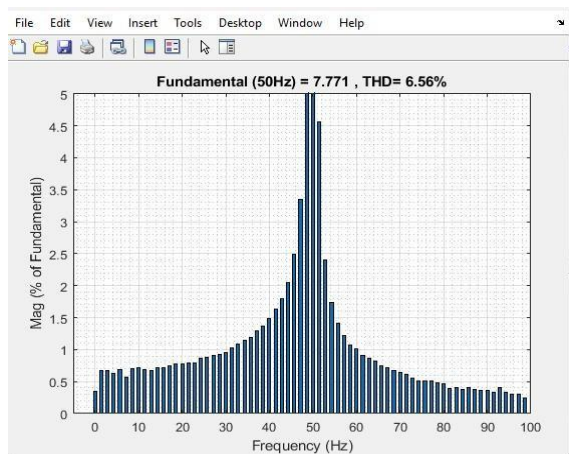


Fig 10: FFT Analysis of 5-level inverter.

The FFT analysis of the 5-level inverter shows a fundamental frequency at 50 Hz with a magnitude of 7.77 and a THD of 6.85%, which is good. The waveform contains very few harmonics, indicating it is very close to a pure sine wave. To further improve, you need better filtering or advanced inverter modulation techniques (like SPWM or multilevel inverter design). Figure 4.10 shows the FFT Analysis of a 5-level inverter. According to IEEE Standards, THD of Voltage and Current should be below or Equal to 5% and 4%.

4.1 RESULT:

Inverter Type	Output Waveform Quality	THD	Remarks
Sine Wave Inverter (2-level)	Stepped waveform, far from pure sine	25.29 %	High harmonic distortion needs a bulky filter
3-Level Inverter	Closer to sine wave, smaller voltage steps	11.91 %	Moderate THD, reduced filter size
5-Level Inverter	Very close to pure sine wave, smoother steps	6.56%	Low THD, better efficiency

CONCLUSION:

A multilevel inverter's output waveform approaches a pure sine wave as the number of levels rises, and THD sharply falls. Therefore, in terms of power quality and harmonic reduction, 5-level inverters perform better than 3-level and traditional sine wave (2-level) inverters. In this paper, MATLAB Simulink is used to simulate a solar PV array consisting of sinewave, 3-level, and 5-level inverters. Total Harmonic Distortion (THD) is calculated in each case the value of THD decreases as the level of the inverter increases.

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