

A Review Asymmetrical Multi-level DC-link Inverter for PV Energy System Based Voltage Regulator

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Abstract: In this paper an independent photovoltaic generating system with a multi-level inverter is suggested in this study. In order to achieve steady DC voltage and maximum power extraction, it is operated utilizing the innovative MPPT approach. An MLDCL inverter with 31 levels of asymmetrical switch-diode is suggested to include a capacitor compensator circuit and a “perturb and observe based voltage regulator the use of “MLDCL in a freestanding photovoltaic (PV) system necessitates consistent DC voltages from the PV panels. To control this voltage and ensure maximum power output at full load, the POVR method is employed. The panels and the inverter in a POVR system communicate with one another using boost DC-DC converters.

Keywords: Multi-level inverter, photovoltaic (PV) system, maximum power point, voltage regulator, capacitor compensator (CC), P&O MPPT, Incremental Conductance Method.

1. Introduction

The rapid advancement of photovoltaic (PV) technology has been a game-changer in the field of renewable energy. As the world seeks sustainable and clean energy sources, PV systems have emerged as a leading solution due to their ability to convert sunlight directly into electricity. These systems are not only eco-friendly but also help in reducing dependence on fossil fuels, making them crucial in the fight against climate change [1].

At the heart of PV energy systems lies the DC-link inverter, a critical component that converts the “direct current (DC) generated by the solar panels into alternating current (AC)”, which is compatible with the electrical grid. However, despite their importance, traditional inverters often face challenges related to efficiency, performance, and reliability. These issues can lead to suboptimal energy conversion, affecting the overall effectiveness of the PV system.

The concept of multi-level inverters represents a significant advancement in inverter technology. Multi-level inverters can produce a more refined output waveform compared to traditional inverters, reducing harmonic distortion and improving efficiency. Among these, asymmetrical multi-level inverters offer additional

advantages by balancing the voltage levels across different stages, which enhances performance and reliability [2].

One of the critical aspects of optimizing PV systems is voltage regulation. Proper voltage management ensures that the system operates efficiently and safely, preventing potential damage to components and improving overall performance. Traditional methods of voltage regulation can be complex and often require sophisticated control systems. To address these challenges, the “Perturb and Observe (P&O) algorithm” has gained prominence. This method adjusts the operating point of the PV system based on real-time feedback to maintain optimal voltage levels.

1.1 Grid connected systems

It is mostly used at work places or homes, basically making it useful in traditional electrical systems. By bringing them in use in conjunction or alteration with the power grid, end-users’ energy requirements can be fulfilled.

Standalone systems are equipped with batteries to provide the user with the access to the energy during the night or when the solar irradiation is not sufficiently available. It is built as to complete the application of an PV energy system. Solar panels, which are really “photovoltaic (PV) cells”, work is of collecting the sunlight and convert into electrical power. A module is constructed by stringing

together individual cells consisting of an energy-transmitting semiconductor, such as silicon. There are usually 30 modules in a solar panel for a rooftop. Photovoltaic panels use semiconductors to absorb sunlight, which releases “electrons (the building blocks of electricity)” and allows them to flow through the panels. This charge imbalance between the front and rear surfaces of the cell is caused by the movement of these dislodged electrons, which have a negative charge each, across the cell. Similar to the positive and negative ends of a battery, photovoltaic cells generate power as a result of this imbalance.[4]

The solar system's current is then either immediately put to use or stored in a battery after being gathered on cables. It's a myth that solar cells can't function in cloudy weather. On overcast days, however, their power output will be lower than on bright ones.

1.2 Importance and Applications of PV Energy Systems

Photovoltaic (PV) energy systems are making a huge impact in the world of renewable energy. By converting sunlight directly into electricity, these systems offer a “sustainable and eco-friendly alternative to conventional energy sources”. The world has been powered by burning fossil fuels since decades and this has a very bad environmental effect. PV systems provide a promising solution to help reduce our carbon footprint.

One of the biggest advantages of PV systems is their ability to generate clean energy from a virtually limitless resource—sunlight. Unlike traditional power plants that rely on coal, oil, or gas, PV systems do not produce harmful emissions or pollutants. This makes them a key player in efforts to combat global warming and improve air quality [6] .

PV systems are also incredibly versatile. They can be used in a variety of settings, from small residential rooftops to large-scale solar farms. For homeowners, installing PV panels can reduce electricity bills and provide a degree of energy independence. On a larger scale, solar farms can supply power to thousands of homes, contributing significantly to the energy grid.

1.3 DC-Link Inverters in PV Systems

As most home and grid applications need alternating current (AC), DC-link inverters are an essential component of photovoltaic (PV) systems for transforming the DC power produced by solar panels into AC. When we know what they do and why they're important, we can see

how they affect the dependability and efficiency of solar power systems.[3]

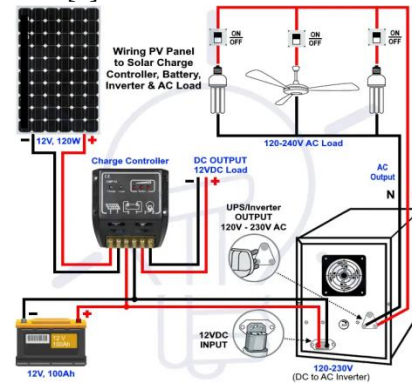


Fig. No.1 DC-Link Inverters in PV Systems

The implementation of this technology involves integrating the multi-level inverter with other system components, such as MPPT (Maximum Power Point Tracking) controllers and voltage regulators. These components work together to ensure that the PV system operates at its highest efficiency, delivering optimal power output and maintaining stable voltage levels.

1.4 Voltage Regulation

Voltage regulation is vital in a PV system to ensure that the inverter operates efficiently and the power output remains stable. “Solar panels generate direct current (DC) power, which needs to be converted into alternating current (AC)” for use in most electrical systems. However, the voltage from the solar panels can fluctuate due to changes in sunlight intensity, temperature, and load conditions.

To address these fluctuations, a voltage regulator is employed. Specifically, the “Perturb and Observe (P&O) based Voltage Regulator (POVR)” is a popular choice. The POVR adjusts the operating point of the PV system to maintain a stable DC voltage while maximizing power extraction. By continuously monitoring and adjusting the voltage, the POVR ensures that the inverter can deliver consistent performance, even when environmental conditions change. This regulation is crucial for maintaining high efficiency and preventing potential damage to the system components [6-8].

2. Literature Reviews

(Khasim et al., 2021) [5] A new asymmetrical 21-level multilevel inverter architecture for photovoltaic (PV) applications is introduced by the authors in their paper.

The 21-level output voltage may be achieved utilising asymmetric DC sources and the suggested architecture, which does not include an H-bridge. All three metrics—device size, cost, and impact—are ameliorated by this. The PV standalone system relies on the solar panels producing a steady DC voltage magnitude. To do this, it employs the “maximum power point tracking (MPPT) of efficiency, cost-effectiveness, device count, and overall design. The total harmonic distortion (THD) is shown to be less than 5% in both the modelling and experimental findings, which is in accordance with IEEE standards. While simulations are conducted in MATLAB/Simulink, a hardware prototype is tested and validated experimentally in the lab under dynamic load fluctuations.

(Manoharan et al., 2017) [6] The article proposes a novel design for an economical power conditioning system (PCS) that makes use of a “photovoltaic (PV) single-sourced asymmetric cascaded H-bridge multilevel inverter (MLI)”. Even though the voltage levels are the same in both types of topologies, the asymmetric MLI architecture uses fewer components. Modulation index threshold associated with inverter output level decrease is larger than symmetrical MLI, however. Because of this issue, the modulation index limitation is greater than the symmetrical MLI's. As a result, the PCS requires an additional voltage pre-regulator when operating bias varies widely.

(Malathi, 2022) [7] Demand for energy from the power grid has skyrocketed over the last decade, thanks to an increase in both the number of consumers and the prevalence of high-power enterprises. This is why there has been a dramatic rise in global emissions due to the generation of conventional energy. Consequently, the incorporation of renewable energy sources into the power system has increased significantly. Photovoltaic systems have surpassed all others in popularity and potential, leading to an increase in installed PV capacity throughout the world to fulfil electricity demands. Power electronics are crucial to photovoltaic production, and the need for efficient power electronic converters is on the rise.

(Sangari et al., 2015) [8] Using a grid-connected photovoltaic system, the article describes an H-Bridge Multi Level Inverter. A grid-connected photovoltaic (PV) inverter primarily aims to feed the electricity generated by solar panels back into the grid. The H Bridge inverter is a high-power, high-efficiency device. By analysing total harmonic distortion and switching losses at various switching frequencies, this research studies the performance of solar plants and suggests a topology for H Bridge Multi Level Inverters that may account for voltage profile changes among the panels throughout the day. Results from both simulations and experiments confirm

the suggested multi-level inverter's working principle and performance.

(Sivamani et al., 2024) [9] For low to medium power applications, the idea of a cascaded multilevel inverter with an isolated DC supply provides effective options for producing high-quality output voltage. Using little DC sources or batteries, it takes the output voltage from three stages and forms it into a sinusoidal shape in a number of steps. Significant benefits, such as reduced voltage stress, bearing noise, and total harmonic distortion (THD), have been observed.

(Prasad & Dhanamjayulu, 2023) [10] Advancements in renewable energy sources (RES), grids, and electric vehicles (EVs) have spurred advancements in MLI topologies in recent scenarios. When it comes to meeting complex needs, the new topologies are head and shoulders above the competition. Thus, for current uses, these new topologies are best. This study provides a comprehensive overview of current MLI topologies, controllers, and PWM approaches, taking into account both physical and performance-related factors. In order to help readers choose the best MLI topology and PWM method for PV systems,

(Neelima & Dinesh, 2024) [11] There has been growing interest in the environmental and economic benefits of integrating renewable energy sources, such as solar photovoltaic (PV) systems, into the power grid. However, these technologies also introduce power quality challenges, including reactive power control issues, voltage fluctuations, and harmonics. To address these challenges, the study proposes a fuzzy logic-based control mechanism. This approach uses the power generated by solar panels to operate a multilevel inverter, enhancing the power quality of grid-connected devices. The integration of solar PV systems into the grid can cause problems like voltage swings, harmonics, and reactive power imbalances. To mitigate these issues, the study introduces a fuzzy logic control mechanism that powers a multilevel inverter with solar PV.

3. Methodology

This section describes the study's methodology, which included developing, simulating, and analysing a photovoltaic (PV) system that included a “boost DC-DC converter and a multi-level DC-link (MLDCL) inverter”. The methodology encompasses the accurate modeling of the PV module using a single diode model, the design of the boost converters for voltage regulation, and the configuration of a “31-level asymmetrical switch-diode MLDCL inverter”. Additionally, the chapter discusses the

implementation of a Capacitor Compensator (CC) circuit to address issues related to inductive loads. Each section of this chapter provides a comprehensive explanation of the components, their functions, and their interactions within the system, ensuring a thorough understanding of the research approach and its technical intricacies. “PV Module and Boost DC-DC Converter”

In this study, we utilize a single diode model for the PV module, which is meticulously modeled to account for both “shunt resistance (R_P) and series resistance (R_S)”. This model is essential for accurately simulating the behaviour of the “PV module under various conditions”, ensuring the reliability and efficiency of the overall system.

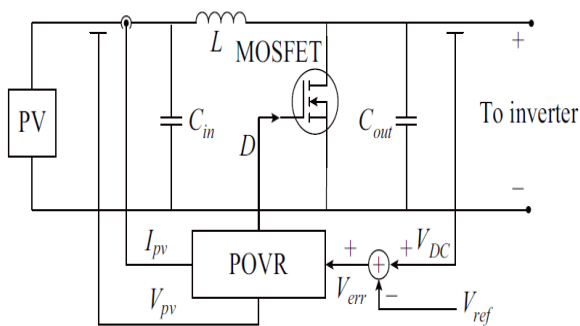


Fig. No. 2 Boost converter with PV source and proposed POVR

4. Boost Converters for Voltage Regulation

To enhance and regulate the PV voltages before they are fed into the multi-level DC-link (MLDCL) inverter, boost converters are employed. These converters play a critical role in maintaining the desired voltage levels and ensuring the system's stability and efficiency. The boost converters are designed to increase the output voltage from the PV modules to the required level for the inverter operation.

4.1 Feedback Mechanism in Boost Converters

The figure illustrates the configuration of a boost converter along with its feedback mechanism used at each PV stage. The feedback mechanism is crucial for regulating the output voltage and ensuring that it matches the desired reference voltage. Key components in the diagram include: **C_{in} and C_{out}** : These terms respectively denoted the “input and the output capacitors”. The input capacitor (C_{in}) is essential for ensuring a continuous and stable output from the PV panel. It helps to smooth out any fluctuations in the input voltage, thereby providing a steady input to the “boost converter”. The “output capacitor (C_{out})” is

responsible for maintaining the stability of the “output voltage”.

I_{pv} and V_{pv} : The PV module’s current and voltage are represented by these respectively. Monitoring these parameters is essential for the effective operation of the boost converter and for ensuring that the maximum power is extracted from the PV module.

V_{err} : This is the voltage error, and it is defined as the difference among the “actual output voltage (V_{DC}) of the boost DC-DC converter and the reference DC voltage (V_{ref})”. The voltage error is used in the feedback loop to adjust the operation of the boost converter and maintain the desired output voltage.

V_{DC} and V_{ref} : V_{DC} denotes the “actual output voltage of the boost DC-DC converter”, whereas V_{ref} is the “reference DC voltage”. The reference voltage is the desired voltage level that the boost converter aims to achieve. The feedback mechanism continuously compares the actual output voltage with the reference voltage and adjusts the converter's operation accordingly.

Different MPPT techniques There are different techniques used to track the maximum power point. Few of the most popular techniques are: 1) Perturb and observe (hill climbing method) 2) Incremental Conductance method

4.2 Perturb and Observe Method

Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn’t stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

4.3 Incremental Conductance Method:

The incremental conductance algorithm uses two voltage and current sensors to sense the output voltage and current of the PV array. In the incremental conductance method, the array terminal voltage is always adjusted according to the MPP voltage which is based on the incremental and instantaneous conductance of the PV module. Figure 3 shows that the slope of the P-V array power curve is zero

at the MPP, increasing on the left of the MPP and decreasing on the right-hand side of

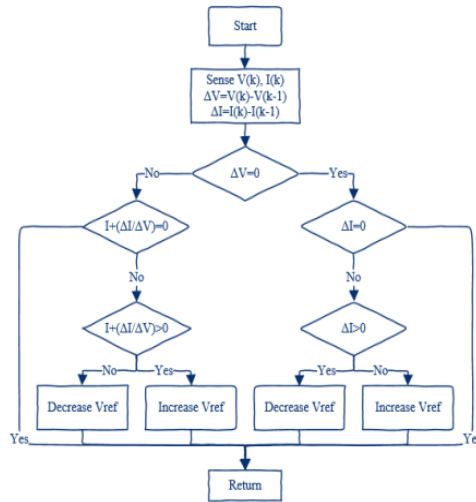


Fig. No.3 The MPP. Flow chart for incremental conductance algorithm.

4. Conclusion

The successful implementation of the 15-level multi-level inverter topology is done using Simulink blocks from the library browser. We suggest a power over voltage regulator (POVR) for standalone systems that can keep the voltage at the DC-DC boost converters' outputs at the correct level and yet provide maximum power under full load, regardless of the ambient circumstances.. The regulating approach may re-track the required DC-link voltage with low reaction time even when irradiance, reference value, and load vary rapidly. To further reduce voltage spikes caused by inductive loads, a CC circuit is also suggested.

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