



Grid-Connected PV System with Interleaved Boost Converter to Maximize the Efficiency of Solar Energy

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ABSTRACT: In order to optimize solar energy efficiency, this study describes a grid-connected photovoltaic (PV) system that has been coupled with an interleaved boost converter. Optimizing solar power plants' performance has grown crucial as the demand for renewable energy rises. The voltage from the PV array is increased to the necessary grid voltage using an interleaved boost converter, which is renowned for its capacity to lower ripple and improve efficiency. In order to ensure that the PV system always runs at its peak power production, this system uses Maximum Power Point Tracking (MPPT) methods to dynamically adapt to changing solar irradiation and temperature conditions. Current ripple is decreased by interleaving the converter phases' switching, which lowers electromagnetic interference (EMI) and increases dependability. According to simulation and experimental data, the suggested system guarantees stable operation with fewer components, lowers losses, and greatly increases energy conversion efficiency. The system's capacity to adjust to changing environmental circumstances is further improved by the integration of an advanced MPPT algorithm with the interleaved boost converter. This work presents a viable way to improve grid-connected PV systems' energy efficiency, which will help make solar power generation more economical and sustainable. The proposed strategy is validated through simulation using MATLAB 2021a /Simulink software.

Keywords: photovoltaic system, maximum power point tracking, boost converter

1. Introduction

Every day, more and more electricity is consumed. The traditional energy sources, on the other hand, are running out quickly. These include coal and mineral oil, which is used to make gasoline, diesel, etc. In order to meet growing power requirements, alternative ways of generating energy must be discovered. The increasing energy requirements will be met by the widespread use of renewable energy, such as solar power systems. Continuing advances in solar technologies such as solar power generation systems (PVs) and solar thermal energy have made solar energy more accessible, efficient and

economically profitable. PV systems that use semiconductor materials to convert solar directly to electricity dramatically improve efficiency and cost reduction, allowing for extensive introductions to live, commercial and industrial applications.

Solar energy plays a key role in the global shift towards decarbonization and in reducing dependence on traditional fossil fuels. This is recognized as a key component of the renewable energy portfolio and complements other sources such as wind, hydropower and geothermal

energy. Furthermore, solar energy is particularly suitable for dispersed energy generation. This makes it an attractive option for network independent and remote areas where access to traditional power infrastructure is present or does not exist. The three topologies of the PV system off grid, the on-grid and Hybrid Solar Energy Systems, are further divided into groups. How to save energy is included in the solar energy system outside the grid. Since no battery is required, you can also supply a backup stream to the load without sunlight. On the other hand, solar energy systems on the network do not require batteries to generate daytime electricity, making them cheaper, bulkier and less dangerous.

Continuing research and technological innovation have significantly improved the efficiency of solar energy systems. Modern solar panels (PVs) can now convert a higher percentage of solar radiation into usable electrical energy. Innovations in materials such as perovskite solar cells, thin layer technology, and bifacial solar panels have surpassed the limits of solar energy production. At the same time, advances in power electronics (e.g., inverters, MPPT algorithms) have led to improved energy conversion efficiency, grid synchronization, and overall system performance. Solar energy storage technologies, including batteries and heat storage systems, are also advancing, allowing better integration of solar energy into networks through the handling of the intermittent nature of solar production. These innovations allow you to store excess energy generated during the day and use it when the sun is not shining, increasing the reliability and consistency of solar energy.

In the system of solar energy, grid connection refers to the connection of a solar photovoltaic system along with the utility grid, allowing the generated solar power to be delivered directly to the electrical network. This connection enables the use of solar energy in conjunction with the traditional power grid, providing a more adaptable, dependable, and sustainable supply of

energy. Grid-connected solar systems are one of the most common and efficient way to use the solar power. They offer several advantages including the ability to compensate for power, deliver energy which are clean, and improve grid stability.

The design and control of a neutral inverter with three phases of the structure of an integrated solar power system consists of a PV array, DC/DC converter, three-level NPC inverter, LC filter, and grid [1]. The 3-level NPC inverter is developed excluding a galvanic isolation transformer and its current controller is advanced to minimize leakage currents although common-mode voltage loops in the PV systems. A prototype of 13kW NPC inverter with an LC filter was manufactured and evaluated, resulting in a low total harmonic distortion of less than 3% total harmonic distortion and its efficiency is 97.5% at the peak load.

The maximum power point tracker (MPPT) method for solar panels (PVs) using initial characteristic impedance (ICI) of performance circuits is presented. The proposed MPPT algorithm uses only a single voltage sensor [2]. Although the input impedance is theoretically dependent on the load resistance, the use of the proposed algorithm has been shown to receive the maximum available PV performance without prior knowledge of the load resistance value. This technology is primarily a basic DC-DC converter and can be applied to any DC-DC power converter circuit to basic DC-DC converters than Buck, Buck, Buck-Boost, Cuk, SEPIC, Zeta. A ZETA performance converter circuit was selected to verify the proposed method.

The three-stage NPC PWM inverter is a type of multi-stage inverter that provides higher quality output waveforms than traditional two-level inverters [12]. This is a type of electronic current converter used in renewable energy such as wind turbines and PV systems. Converts a direct current power supply to an alternating current source. It can also deal with high performance

levels, providing better efficiency compared to other topologies.

An innovative technique to improve maximum power point tracking (MPPT) in solar PV systems which gets affected by partial shading, a typical problem in it is the reduction of efficiency [13]. POA improvements include the integration of sophisticated adaptation mechanisms that allow for a more accurate response to fluctuating radiation intensity typical of partially shaded environments. The results show a significant improvement in efficiency. This will ensure that the improved POA maintains a sophisticated energy record even under suboptimal sunlight conditions. Furthermore, the robustness of the improved algorithm rapidly changes to the radiation intensity, which is characteristic of partially shaded solar PV systems. Our results highlight the potential of POAs expanded as a robust and adaptive solution to optimize solar energy collection and provide significant advantages for solar systems in areas susceptible to tints. This work not only contributes to the field of optimizing renewable energy, but also provides valuable knowledge in the development of more resistant and more efficient solar energy systems.

2. Proposed Methodolgy

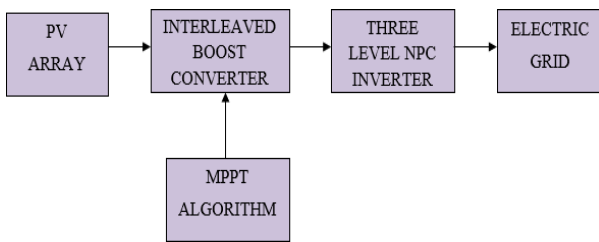


Figure 1: Block diagram of proposed work

Figure 1 shows the proposed diagram of a grid-connected solar power system with interleaved boost converters. This design allows the system to extract the maximum solar energy which is available and convert it into stable, high-quality alternating current outputs, delivering it to the network with minimal losses and high efficiency. Combining the benefits of MPPT, interleaved DC boost converter and advanced inverter technology, this system promises higher

efficiency, reduced losses and improved overall performance compared to traditional systems. This makes it an ideal option for future solar power generation facilities aimed at producing renewable energy on a large scale.

2.1 A PV Array Module

A solar array is an important component in any of the solar energy system. It is used for capturing sunlight and converting it into electrical energy. These cells are typically made up of semiconductor materials like silicon and which also have the ability to produce electrical power when it is exposed to sunlight through the photovoltaic effect.

The equivalent circuit of a photovoltaic (PV) array are usually shown as a combination of different elements that model the electrical properties of the solar cells. The typical model is the single-diode model, in which a PV cell is represented as a diode in parallel with a current source.

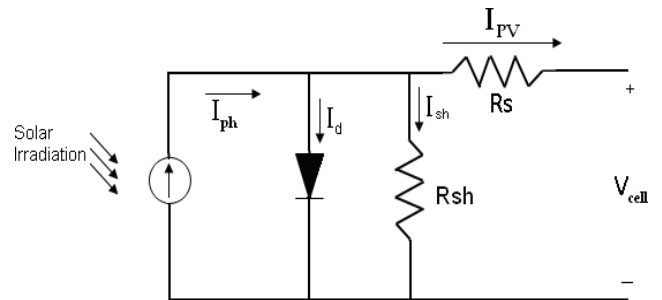


Figure 2: Equivalent of PV module

The Shockley equation is used to govern the current flowing through the diode:

$$I = I_L - I_S \quad (1)$$

$$V + IR_S$$

$$I_D = I_0 [\exp (nVT) - 1] \quad (2)$$

Where

$$V_o = V + IR_S \quad (3)$$

V_o = voltage appearing across diode.

V = load voltage I_L = Photo generated current

R_S = Internal (series) resistance of the system.

R_{sh} = shunt resistance

I_o = reverse saturation current of the diode.

T = Temperature in kelvin

K = Boltzmann constant

Table 1: Electrical characteristics of PV module

Parameter	Value
Rated power	130 watts
Voltage at maximum power (V_{mp})	17.33 V
Current at maximum power (I_{mp})	7.1 A
Open circuit voltage (V_{oc})	25V
Short circuit current (I_{scr})	8.5 A
Total number of cells in series	36
Total number of cells in parallel	2

2.2 Proposed P&O Algorithm

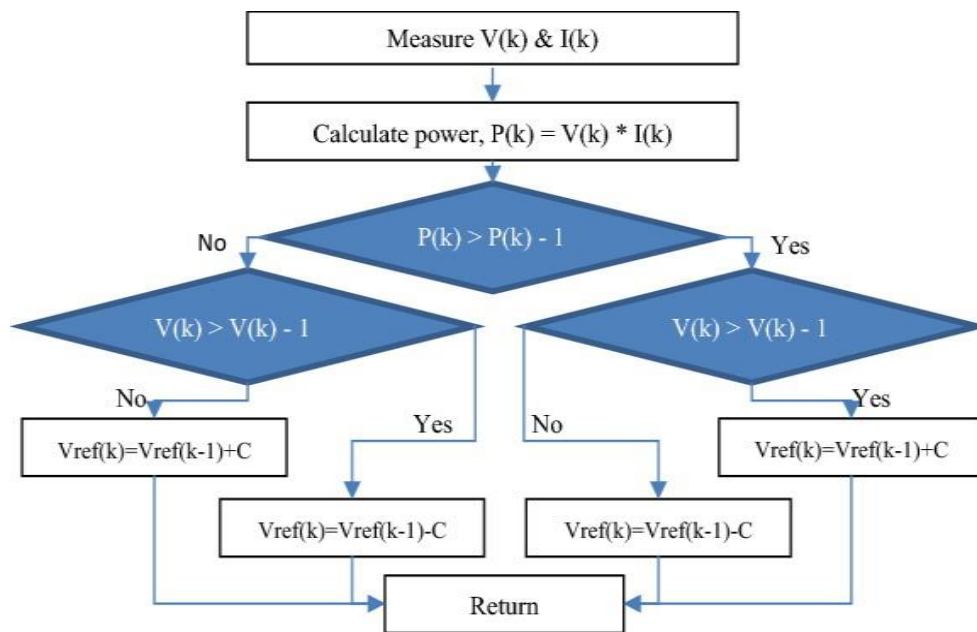


Figure 3: Flowchart of perturb & observe algorithm

2.3 Interleaved Boost Converter

An Interleaved Boost Converter is a type of DC-DC converter used to increase low input voltages to higher output voltages. This improves the performance of standard boost converters, tightening several phases in parallel and switching cycles. This reduces ripple current and increases efficiency.

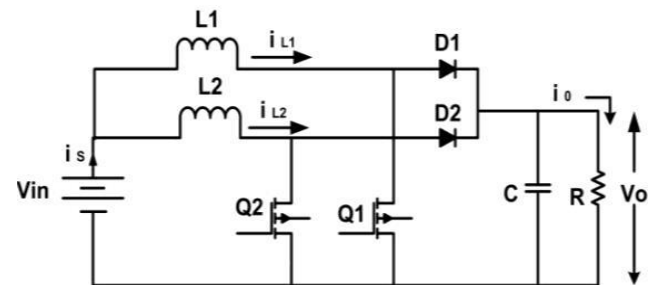


Figure 4: Interleaved boost converter

The inductance of inductors $L1$ and $L2$ are having the same value which is equivalent to L for simple calculations. Duty cycle of $S1$ was denoted by $D1$ and duty cycle of $S2$ denoted as $D2$. In both the switches the values of duty cycle were equivalent to D . The converters' operating

mode can be explained as:

Mode 1: T1 ON

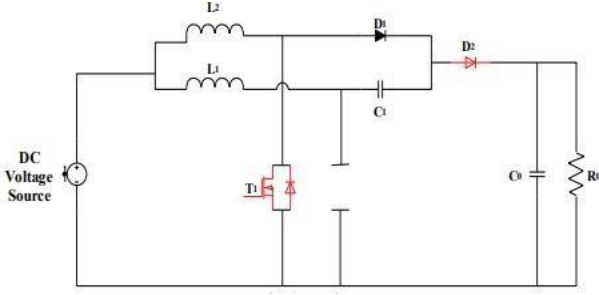


Figure 5: Mode 1

For inductor L1

$$V_{in} = L1 \, dI1 / dt \quad (4)$$

For inductor L2

$$V_{in} - V_o = L2 \, dI2 / dt \quad (5)$$

Assume $\Delta I = I2 - I1$

$$V_{in} = L1 (\Delta I / t1) \quad (6)$$

$$t1 = L1 (\Delta I / V_{in}) \quad (7)$$

Mode 2: During T1 off & T2 ON

For inductor L1

$$V_{in} - V_o = -L1 \, dI / dt \quad (8)$$

$$t2 = \Delta I L1 / (V_o - V_{in}) \quad (9)$$

Substitute $t1 = DT_s$ and $t2 = (1-D) T_s$

$$\Delta I = (V_o - V_{in}) * t2 / L \quad (10)$$

$$= V_{in} * DT_s / L = (V_o - V_{in}) / L (1 - D) T_s \quad (11)$$

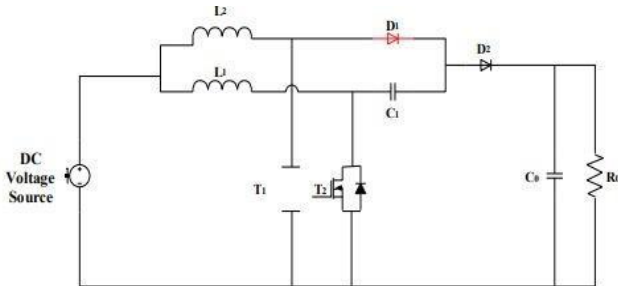


Figure 6: Mode 2

Total time period

$$T = t1 + t2 = \Delta I / V_{in} + \Delta I / (V_o - V_{in}) \quad (12)$$

$$T = \Delta I / V_o \quad (13)$$

Peak to peak ripple current

$$T = 1 / f \quad (14)$$

$$\Delta I = V(V_o - V_{in}) / f L v_o \quad (15)$$

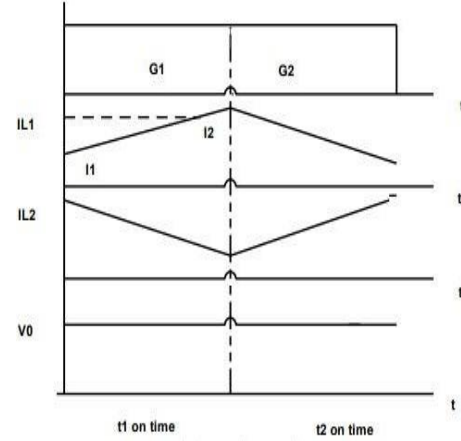


Figure 7: Operating waveform

For output capacitor

$$\Delta V_c = V_c - V_c(t - 0) = 1/C \int I_c dt \quad (16)$$

$$\Delta V_c = I t1 / C \quad (17)$$

Substitute

$$t1 = (V_o - V_{in}) / (V_o * f) \quad (18)$$

$$\Delta V_c = I_{ok} / f c \quad (19)$$

2.4 Three Level NPC Inverter

A Three-Level Neutral Point Clamped (NPC) Inverter are a kind of multi-stage inverter used to convert DC power into alternating power. This is called a "three-layer" inverter, and is because it creates three different levels of output voltages: positive, zero and negative voltage levels. NPC inverters are often used in high performance applications such as motor drives, renewable energy systems, their efficiency, harmonious distortion reduction, and improved quality of voltage wave shapes.

A 3-level NPC inverter is a kind of multilevel inverter that offers a several advantages over conventional two-level inverters:

- **Reduced total harmonic distortion (THD):** The three-level inverter is less harmonious at the output voltage, leading to cleaner and more efficient alternating power with improved quality. This is extremely important for network connections where performance quality is closely regulated.
- **Lower switching losses:** A three-level

inverter reduces voltage step size compared to a two-level inverter. This means that switching is less frequent and switching losses are reduced. This makes it more efficient, especially when performance levels are high.

- **Improved thermal performance:** When switching losses are reduced, the three- stage NPC inverter will have less heat, increasing overall system efficiency and reliability.
- **Higher voltage capability:** By generating several voltage levels, the three-level inverter can handle higher voltages without straining the components.

The three-stage neutral point (NPC) inverter is a powerful solution for highly effective applications with high efficiency requiring smooth, high-quality alternating current outputs.

3. Result and Discussion

3.1 Simulation output

Figure 7 shows the output power of the solar panel in the context of a grid-connected solar power system with interleaved boost converters using the MPPT algorithm and a three-stage NPC inverter. This depends on the variety of factors that including the solar exposure, MPPT algorithms.

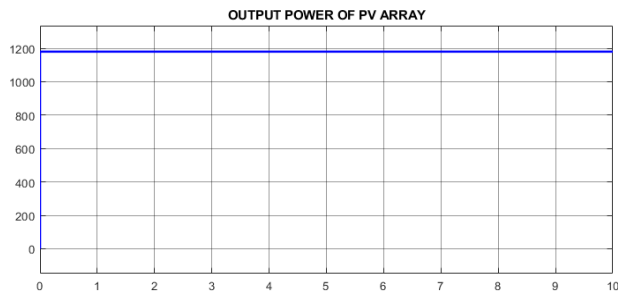


Figure 8: Output power of PV array

Figure 8 shows the output voltage of interleaved boost converter. The output voltage of the interleaved boost converter depends on the input voltage from the solar panel and work cycle D. This is set by the MPPT algorithm to ensure maximum performance.

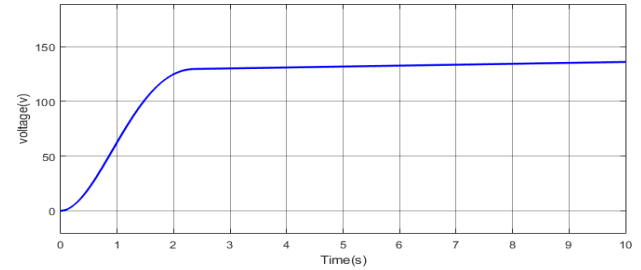


Figure 9: Output voltage of interleaved boost converter

Figure 9 shows output current measurements for three levels of neutral inverter. The output current of a three-stage NPC inverter in a grid-connected PV system with interleaved boost converters using MPPT is primarily performance dependent. This is generated by the PV system, the voltage chasting function of the boost converter, and the modulation technology used in reverse. By calculating the DC performance provided by the PV system, the efficiency of the boost converter and inverter, and the required AC voltage, you can estimate the alternating currents delivered to the network or load.

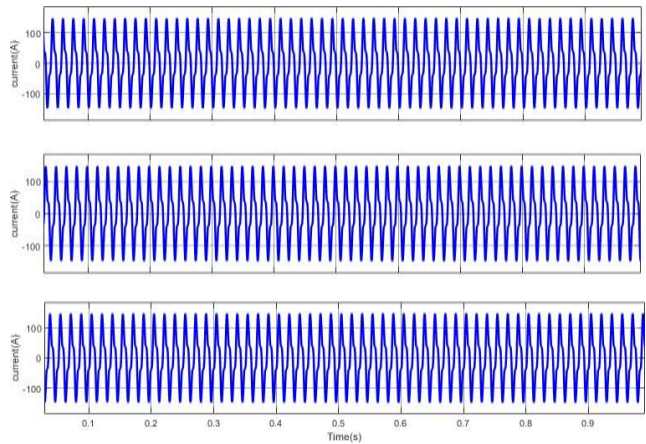


Figure 10: Output current of three level NPC inverter

Figure 10 shows the output voltages of the three NPC inverters from the NPC. The output current of the three-stage NPC inverter depends primarily on the performance generated. By calculating the DC performance provided by the PV system, the efficiency of the boost converter and inverter, and the required AC voltage, you can estimate the alternating currents delivered to the network or load.

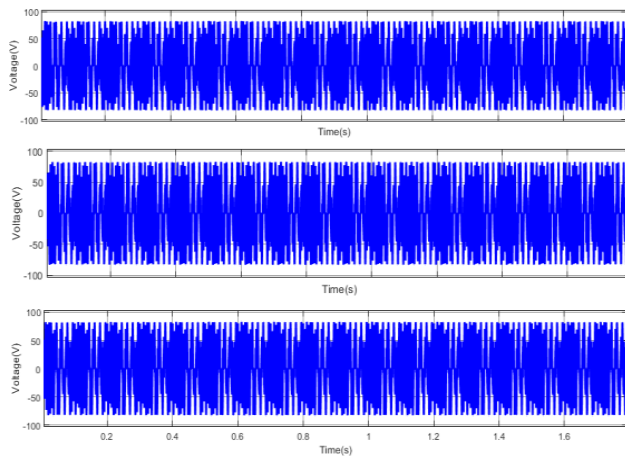


Figure 11: Output voltage of three level NPC inverter

Figure 11 shows the output voltage of a three-phase change supply. The output voltage from the three- phase exchange inverter of a grid-connected PV system depends on the DC input voltage and is carefully set to accommodate the network. The inverter ensures that the alternating current outputs are synchronized with the network in terms of voltage size and frequency, allowing efficient power injection into the grid.

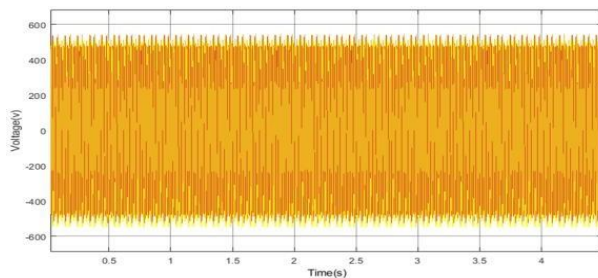


Figure 12: Output voltage of three phase ac supply

Figure 12 shows the output current for the three phases of varying power supply. The inverter that converts DC current from the PV panel to AC is responsible for determining the current delivered to the grid. The output current of a three-phase change supply depends on the PV system, the main voltage, and the power source generated by the system's performance factor.

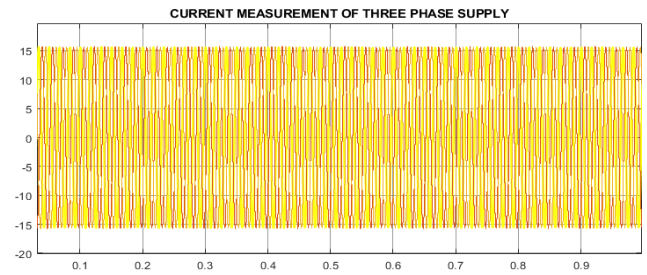


Figure 13: Output current of three phase ac supply

4. Conclusion

In conclusion, a grid-connected PV System with a Three-Level NPC Inverter and an Interleaved Boost Converter is a dependable and extremely effective way to convert solar energy and integrate it into the electrical grid. By dispersing load stress over several stages, increasing efficiency, and lowering current ripple, the interleaved boost converter improves performance. Consequently, the lifespan of the system is increased and component wear is decreased.

High-quality AC output with lower Total Harmonic Distortion (THD) is possible with a three-level NPC inverter, which eliminates the need for intricate filtering and guarantees more seamless grid connection. Both domestic and large-scale solar energy applications can benefit from the combined interleaving and multilayer inversion technique, which improves system efficiency, power quality, and grid compatibility. This system architecture is essential to increasing the use of solar energy and fostering a more sustainable and effective energy grid since it maximizes energy conversion, lowers losses, and enhances power quality.

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