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Research IJPECC

Emerging Solutions for Enhancing Grid Connectivity in PV Inverter Designs

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Abstract

The photovoltaic (PV) cell is one kind of renewable energy source that harnesses sunlight to create electrical current without the need for any kind of mechanical or thermal coupling. PV cells are typically joined to form PV modules, which have 72 PV cells total. Depending on temperature and sun irradiation, PV modules can generate a DC voltage between 23 and 45 volts and a maximum output of 160 watts. With a few notable exceptions, the electrical infrastructure worldwide operates on AC voltage, with the distribution grid having a voltage of 120 or 230 volts. As a result, PV modules cannot be connected to the grid directly; instead, an inverter is required. The inverter's two primary responsibilities are to maximize energy harvesting, load the PV module optimally, and introduce a sinusoidal current into the grid. As a result, studies have been conducted on inverter technologies, which are employed to connect a single photovoltaic module to the grid. The development of the inverter prioritizes mass production, high dependability and low cost.

Keywords: PV cell, inverter, DC-DC/AC converter, renewable energy, grid-connectivity

INTRODUCTION

The concepts of DC-AC inverters for PV applications involve converting the direct current (DC) produced by PV modules exposed to sunlight into alternating current (AC). This topic focuses on inverters designed to connect a single PV module as the power source to a low-voltage AC public utility network as the load.. PV technology operates whenever sunlight is present, with increased electricity generation occurring under more intense light and when sunlight strikes the PV modules perpendicularly. Sunlight consists of photons, which are bundles of radiant energy [1–4]. Conversion of sunlight to electricity is shown in Figure 1.

Size and Shape of PV Cell

PV cells come in many sizes and forms. The most prevalent shapes are squares, rectangles and circles. The material a PV cell is built of determines upon its size, shape and the quantity of PV cells needed for a single PV module. Size and shape of a PV cell is shown in Figure 2.

Photovoltaic Arrays are Made up of Individual Cell

These photovoltaic cells are configured in series and/or parallel circuits to increase voltage, current and overall power output. Each module comprises of PV cells enclosed between a transparent front sheet, usually glass, and a protective back sheet made of tough plastic or glass, shielding them from damage and weather. An aluminum frame can be added around the PV module for easy mounting

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onto support structures. Photovoltaic arrays, as shown in Figure 3., consist of one or more PV modules assembled as a pre-wired unit ready for field installation. A PV array constitutes the complete power-generating system, consisting of any number of modules and panels [5].

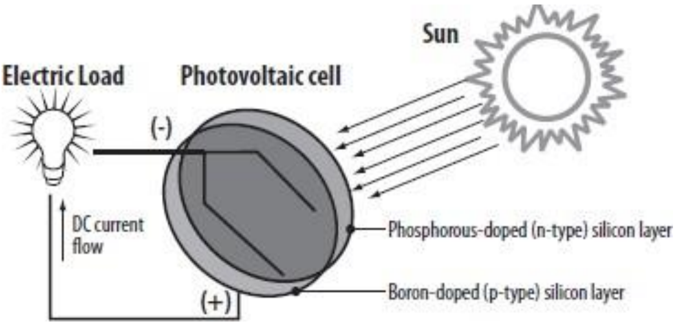

Figure 1. Conversion of sunlight to electricity.

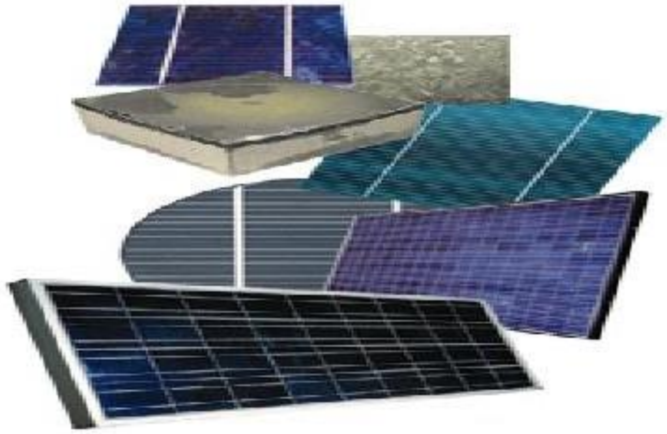

Figure 2. Size and shape of PV cell.

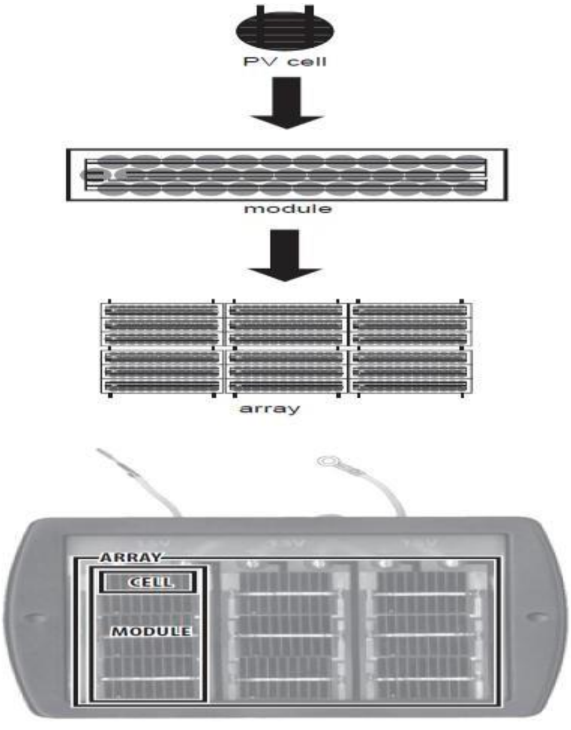

Figure 3. Photovoltaic arrays are made up of individual cell.

Grid-connected PV System

What does the grid represent? It is the system of cables that carries electricity from the power plants to residences, educational institutions and other locations. This network of power lines is connected to a system that is grid-connected. An inverter, also known as a power conditioning unit (PCU), is the main element of a system that is connected to the grid. The PV system's DC power is converted by the inverter into AC power that complies with the utility grid's specifications for voltage and power quality. This implies that no battery or other storage is required because it can feed the electricity it generates into the electrical grid and pull it down as needed [6–8]. Grid-connected PV system in tree form is shown in Figure 4.

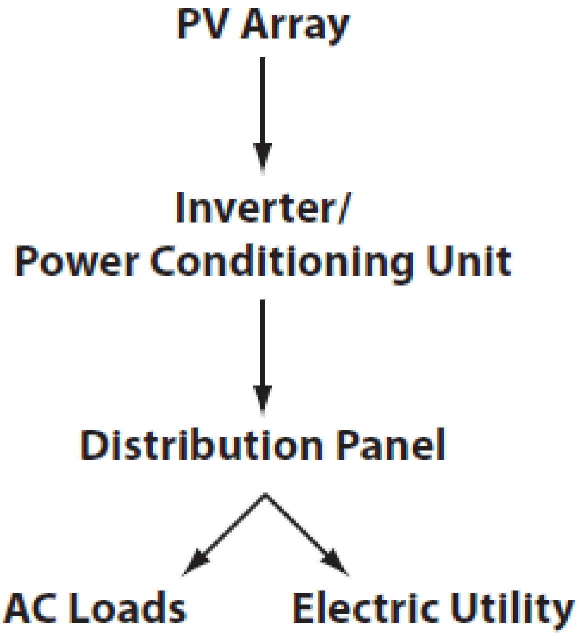

Figure 4. Grid-connected PV system.

WORKING OF PV CELL

Photovoltaic Cell

PV arrays are constructed from solar cells. These consist of silicon and other semiconductor-related materials. A tiny semiconductor wafer is given specific treatment to create a positive and negative electric field on opposite sides. Its construction might be square or circular. It is composed of different semiconductor materials. Nonetheless, the primary application for both polycrystalline and monocrystalline silicon is in the business sector. Basic PV cell structure is shown in Figure 5.

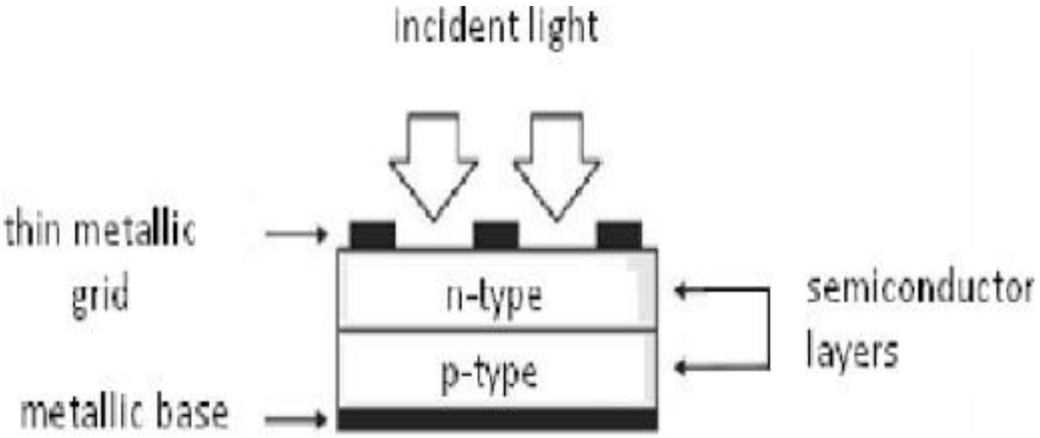

Figure 5. Basic PV cell structure.

The photoelectric effect is the fundamental idea behind how photovoltaic cells operate. The phenomenon known as the photoelectric effect is the ejection of an electron from the conduction band caused by the matter's absorption of sunlight at a specific wavelength. DC-equivalent circuit is shown in Figure 6.

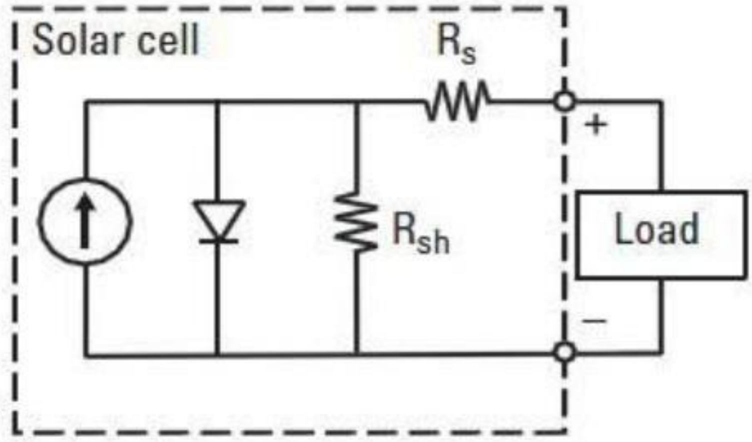

Figure 6. DC-equivalent circuit.

$$V_V = (A*K *T_C/e)\ln \left[\left(I_{ph} + I_0 - I_C/I_0\right) - R_S *I_C\right] \tag{1}$$

The symbols used are:
V_C=cell output voltage
T_C=reference cell operating temperature
R_S=series resistance of cell
I_{ph}=photo current, the function of irradiation level and junction temperature
I_o=reverse saturation current of the diode
I_C=cell output current

K=Boltzmann constant (1.38*10-23 j/k) e = electron charge (1.602*10-19 C) Enclosure thus making a photovoltaic module or solar panel. Modules are then strung together into a photovoltaic array.

The electrons in the valence band go to the conduction band if the absorbed energy exceeds the semiconductor's band gap energy. In the semiconductor's lit area, this results in the creation of two electron-holes . The conduction band that was formed is now free to move. The action of the electric field within the PV cell forces these free electrons to travel in a specific direction. By connecting the top and bottom metal plates of the PV cell, current—which is made up of these moving electrons—can be taken out and used externally. The necessary power is produced by the current and voltage that are produced by the electric fields, that are already there [7]. Typical I-V characteristics and P-V characteristics of solar panel is shown in Figures 7 and 8 respectively.

Basically, the PV cell output voltage is the result of photocurrent, that is mostly controlled by load current based on the amount of solar radiation present during operation.

After that, the laminate is assembled into a waterproof and protective shell to form a solar panel or PV module. After that, the modules are connected to form a solar array.

A PV array's modules are connected in series to get the required voltage, and then each string is connected in parallel to increase the system's current output.

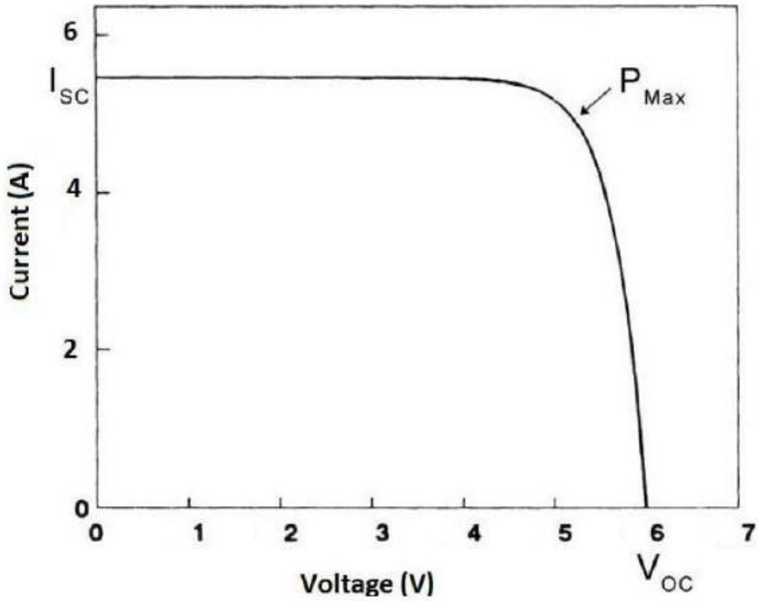

Figure 7. Typical I-V characteristics of solar panel.

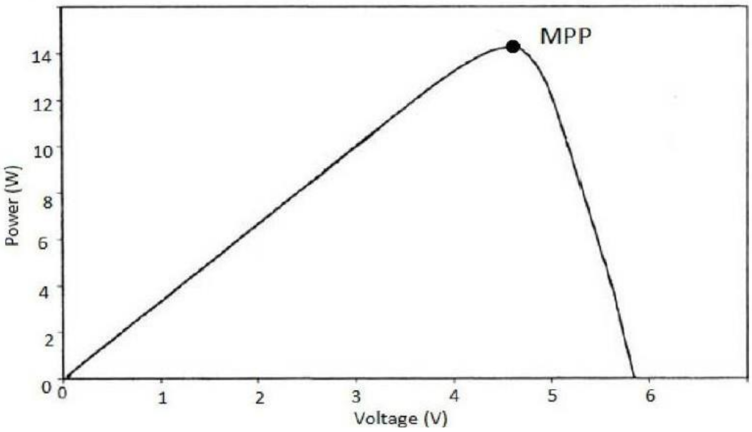

Figure 8. Typical P-V characteristics of a solar panel.

The variable DC output of a PV solar panel is converted by a solar or PV inverter into a utility frequency AC, that can then be used by an off-grid electrical network or supplied into a commercial electrical grid. The usage of standard commercial appliances is permitted by the PV system. For usage with photovoltaic arrays, solar inverters offer specific features including maximum power point tracking and anti-islanding prevention.

Grid-connected PV generation System

The PV array, the inverter device (which has the capability of recording maximum power) and the control system make up the primary components of a grid-connected PV generation system [9, 10]. Grid-connected PV generation system structure is shown in Figure 9.

AIMS OF PV PAPER

Objectives

This paper's primary goal is to create an inverter for use with AC modules. The goal is to create innovative and affordable ways to feed electrical power produced by PV modules into the grid. The project's output must be an inverter that can run on a single 120–160 W into the PV module. The inverter ought to be designed with mass production, excellent dependability and low cost in mind.

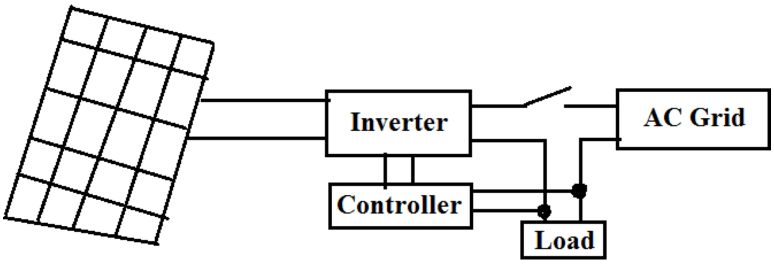

Figure 9. Grid connected PV generation system Structure.

Outline of the Paper

A description of the photovoltaic device's working principles follows. The PV cell and module's electrical and thermal models follow from this. Lastly, the behavior of the PV module and cell at various operating points is investigated.

There are also some safety and compliance-related standards mentioned. The overview of PV inverter topology provides an overview of various topologies and system layouts seen in the single- and dual-stage DC-AC inverter families. For every topology, they provide an estimate of the costs and power losses. The final topology is chosen based on the estimations.

The power-electronic circuit design is showcased. This covers the DC-AC inverter as well as the DC-DC converter. There is documentation about the controller design used in the PV inverter. The PV inverter has been examined and validated.

This also covers the work's innovations and recommendations for more work.

METHODOLOGY

A review is conducted on several photovoltaic technologies, such as thin-film and monocrystalline silicon modules. It was also discussed how the photons inside the PV module are converted to electrons. In the end, a model of the PV module was created, accounting for both the current produced by the incoming sunlight and the intrinsic P-N junction.

Some components of the PV module, such as the capacitances and resistances, are also briefly explained. Using the model, the impact of voltage/current ripple and partial shadow at the PV module terminals on power degradation was examined on the basis of the PV module analysis, the current and anticipated future grid interface standards and the requirements for the inverter design. The primary details are: The voltage range for PV modules is 23 V to 50 V. The maximum PV power is 160 W. Utility companies guarantee the grid voltage's RMS value within the range of 197 V to 253 V; and for 50% generation (80 W), the power factor must be greater than 0.95. There are two alternative system designs: one where the inverter and PV module are mounted on the roof as a single unit, or where the inverter is located inside the house. The chosen inverter was created with the criteria in mind, prioritizing affordability and effectiveness. While the size of the DC-link inductor was optimized with regard to cost, the transformer used in the DC-DC converter was selected based on a trade-off between power losses and cost. The DC-DC converter is controlled by a specialized current mode controller (integrated circuit, or IC), with the current obtained from the PV module serving as the reference. In this manner, the PV module's operating point can be adjusted.

A comparison of several MPPT algorithms revealed that the conventional methods had several issues while attempting to determine the maximum power point (MPP). A brand-new MPPT method has been put forth and examined using real PV modules as well as a PV emulator.

For the inverter, a single-phase PLL is also intended. When the real frequency differs from the nominal frequency, there are two ways to reduce the ripple into the PI controller that is included. These are the alternative implementations of the trigonometric functions that were mentioned. There are four distinct methods for calculating the grid voltage value, that have been assessed, and the RMS methodology has been: • Inductor, diode, power analyzer, oscilloscope, SMPS, chosen as the most precise answer.

The controller is built on a traditional PI controller, using the peak current reference as the PI controller's output. SMPS, oscilloscope, diode, inductor and power analyzer.

The grid-connected reduced order LR-filter's stability is assessed in relation to parameter changes. In order to achieve a minimum phase system, the appropriate size of the damping resistor included in the LCL filter is established, and the stability is also assessed for the full-order model of the LCL filter. After a brief discussion of three potential voltage feed-forward systems, a 20 ms delayed signal was applied in the control. In order to lower the harmonic currents, a brief discussion on blanking time effect compensation was also included. In order to prevent MOSFET shoot-through, the blanking time should be kept to a minimum without the need for adjustment. The interfaces between the PV module and the inverter as well as those between the grid and the inverter are measured as part of the evaluation. A measuring circuit and protection circuit are used. Block diagram of inverter PV system is shown in Figure 10.

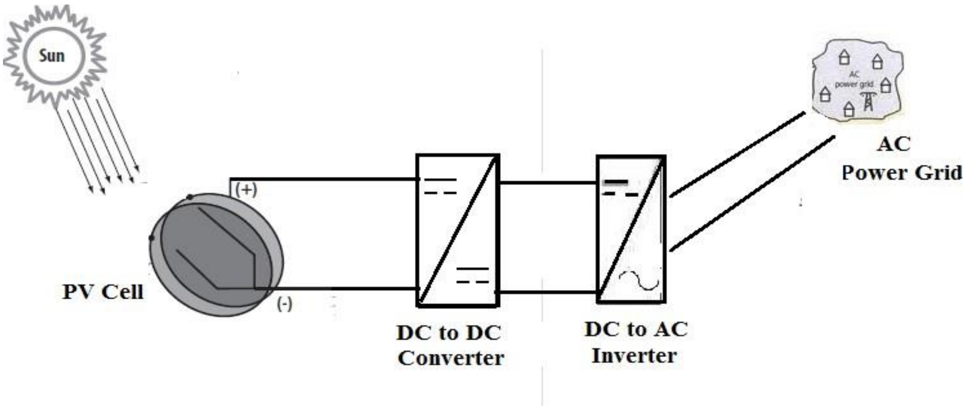

Figure 10. Block diagram of inverter PV system.

COMPONENTS

- *Controllers:* Control of PV current and control of grid current.
- *MPPT:* Optimizing of the captured energy from the PV module.
- *Filter:* L filter, LC filter and LCL filter are used.
- *Capacitor:* Electrolytic capacitors are used.
- *IC:* IC issued to control the DC-DC converters.
- *PLL (Phase Locked Loop):* To synchronize the inverter with the grid.
- *MOSFET:* For PWM.

EXPECTED OUTCOME OF RESEARCH WORK

Developing an inverter for the AC module—that consists of a single PV module plus a DC-AC inverter connected to the grid—has been the primary goal of the research described in this paper. Finding an affordable solution with high dependability—that is, a long lifespan—and great efficiency has been the main goal. This was achieved by conducting a theoretical analysis of the ratings, cost and efficiency of numerous inverter topologies. Based on this analysis, a topology was chosen for additional design. Theoretical analysis, bolstered by numerical simulations and observations on the realized prototype, also informed the design of the chosen topology. The following is a summary of the research's primary conclusions:

A theory explaining how low-frequency ripple in the PV module's voltage and current causes a decrease in available power is given. Based on the stated PV module lifetime, the inverter's desired lifetime is equal to 25 years.

The calculated monthly maximum solar irradiance and the daily maximum temperature recorded over a ten-year period form the basis of the conclusion.

- Both inverters have low efficiency due to huge internal currents, but they both provide adequate power decoupling with small capacitors—the fly-back inverter even with film capacitors.
- A technique for comparing various inverter topologies analytically is suggested, with an emphasis on component stress and ratings, cost and efficiency.
- A brand-new MPP tracker (MPPT) method is developed that tracks the MPP during sudden changes in the weather and partial shadowing of the PV module, hence solving certain issues with the existing approaches. By first sweeping (scanning) the PV module's voltage-current characteristic, the algorithm finds the global MPP. The MPP coordinates are noted, and until the voltage across the PV module deviates farther from the recorded MPP voltage, the recorded MPP current serves as a new benchmark for the subsequent regular operating period (non-scanning time).
- Lastly, the completed prototype is examined in comparison to the requirements.
- The grid voltage monitoring has the ability to identify is a landing procedure, but the coefficient of loss comparison of voltage is not within the specified range-source DC.
- Since frequency monitoring is not included in the prototype, it has not been tested.

CONCLUSIONS

Sunlight is converted into electrical DC power by the PV module, an all-electric device. Since the early 1970s, PV modules have been connected to the A utility grid via solid-state power electronic inverters. The current-source DC-DC converter, and converter that the inverter has, are used in this study. Other issues might arise, but the current-source converter also resolves the issues with the rectifier's diode requirements.

It would be interesting to look into more repeated control for canceling harmonic currents and various grid current controllers, such as the resonant controller. Investigating the impact of blanking time compensation can improve grid performance by lowering harmonics, among other things. There are two main duties to be completed: (1) injecting a sinusoidal current into the grid; and (2) testing the inverter's immunity to abnormalities and optimizing the PV modules' operating point to extract the most energy possible.

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In particular, research should be done on the effects of various waveform generators, for the current reference, and various current control schemes. In both cases—when the grid voltage is harmonically mixed and when it is pure sinusoidal. Analyze the AC module concept using the SWOT (Strengths, Weaknesses, Opportunities and Threats) method to determine if it is superior to other ideas like the string and multi-string concepts. Distinct , has been identified as the top contender by means of a thorough examination and, at last, the next step for product development. An efficient, dependable and cost-effective prototype of the inverter has been constructed and tested.

Future Work

There are plenty of intriguing facts and issues that need further research in the future. Some of the most common ones are as follows:

- PV module diagnosis and series resistance measurement in the modules and connections can alert the operator to check the systems for faulty connectors and advise them to eliminate the partial shadow's cause (e.g., a local impurity of the modules).
- To improve efficiency and reduce the need for the rectifier's diodes, an active clamp circuit should be incorporated into the DC-DC converter. Cost-loss analysis of the DC voltage source should be done.
- To achieve the intended lifetime of 25 years, a more thorough examination of the inverter's lifespan based on hourly temperature change and the applied power semiconductors is likely required. Only the daily maximum temperature inside the applied electrolytic capacitor is taken into consideration by the analysis used in this paper.
- To determine if burst-mode operation leads to increased efficiency or decreased grid performance, a thorough analysis and testing of the optimized prototypes are necessary. Although burst-mode is thought to boost efficiency, if a lot of PV electricity is deployed, flicker may also occur on the grid. Optimize the inverter with respect to the protection and measurement circuits, the microcontroller and the switch mode power supply.

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