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EFFICIENT BI-DIRECTIONAL DC/DC CONVERTER WITH MAXIMUM POWER POINT TRACKING IN PV APPLICATIONS

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ABSTRACT: This research introduces a non-isolated, efficient bi-directional DC/DC converter (NIMBC) that is optimized for a photovoltaic (PV) power system. It will enhance the efficiency of battery charging and discharging. In order to mitigate switching losses, suppress overvoltage, and optimize energy efficiency, the system implements state-of-the-art circuit technologies, including an RCD snubber circuit and a soft-switching (SS) circuit with zero-current switching (ZCS). A combination of the RCD snubber's capacity to maintain stable performance during turn-off phases and the SS circuit's capacity to reduce heat generation and energy dissipation during switch operation results in improved reliability. The converter also integrates a sophisticated Maximum Power Point Tracking (MPPT) technology that surpasses conventional methods such as Incremental Conductance (IC) and Radial Basis Function Network (RBFN) by effectively adapting to fluctuating solar conditions. This innovative method results in optimal energy extraction, reduced Total Harmonic Distortion (THD), and guaranteed exceptional power quality. The system has been validated through PSIM and MATLAB/Simulink simulations to address critical PV concerns, optimize energy flow, and reduce power losses, making it a dependable and efficient solution for the constantly evolving renewable energy industry.

Keywords: MPPT, Non-Isolated DC-DC, Snubber Circuit, PV, Renewable Energy, Street Light

1. INTRODUCTION

Regardless of the continuing discussion about the best grid-tied inverters for technological advancement, power electronics will significantly influence the future of the energy sector. With the decline in power device losses, it is now possible to improve efficiency by reducing inductance in the power loop. The LLCL-filter is a cutting-edge power filter developed for grid-connected voltage source inverters (VSIs), which is one example of a technological advancement in this field. Its main benefit is a decrease in total inductance, in contrast to the ubiquitous LCL-filter, which is still considered standard because of how easy it is to implement[6]. A major step forward in inverter technology, the LLCL-filter reduces inductance without sacrificing efficiency.

A wide range of power sources and configurations are often investigated in grid-tied single-phase inverters. One of these unique designs that showcases cutting-edge operational principles is the "buck in buck, boost in boost" topology. Using a half-bridge inverter, the efficacy of this topology is shown at different stages of operation. The "boost" state behavior of this inverter is investigated using a small-signal modeling approach. To maintain consistency and control performance, an indirect current control mechanism is used [8].

These developments highlight how important it is to use current filtering methods and inverter designs to make grid-tied systems more efficient and dependable. The adoption of more efficient energy systems is made possible by these advancements, which speed up the process of adapting to the ever-changing energy landscape by solving problems like inductance reduction and performance optimization [2],[3],[4].

PHOTOVOLTAIC CELL PANEL

The solar Remote Area lantern's main part is the solar panel. The process begins with the absorption of solar radiation and ends with the generation of electricity. The gadget runs on this energy, which also serves to charge the battery. Most importantly, the light relies on monocrystalline silicon solar cells that work by harnessing the photovoltaic effect. This process uses radiant heat and sunshine to create electron-hole pairs, which interact with the P-N junction and help produce electricity. Polycrystalline silicon produces a photoelectric conversion efficiency of 11-13%, with a range of 13-15%; in comparison, monocrystalline silicon yields a far higher efficiency. Furthermore, the most cutting-edge innovation in solar technology, thin-film photovoltaic cells, have increased the possibilities for environmentally friendly uses and energy conversion [2], [3].

PHOTOVOLTAIC CONTROLLER

An effective and trustworthy small-scale photovoltaic solution is the solar remote region illumination system. The use of low-power components ensures simplicity, affordability, and ease of maintenance. These components include a controller circuit that lowers power loss to less than 1% of the working current and an operational amplifier that works as a voltage comparator. The use of LED indicators helps keep batteries from being overcharged or overdischarged, which improves their operation. To further control the energy flow to the load and battery, as well as to maintain the DC bus voltage and buffer any extra energy from the solar panel, the control system uses super capacitors. This novel layout takes into account important factors, making it an environmentally friendly and workable answer to the problem of meeting the energy demands of outlying areas [7], [8].

BATTERY SUPPORTED MPPT BATTERIES

Nighttime utilization of stored energy is the primary function of batteries in off-grid photovoltaic (PV) systems. Nevertheless, the voltage of a dead battery frequently differs from the PV panel's maximum power point voltage at dawn. Because it starts charging at a lower voltage and makes sure the battery gets the best energy transfer possible, Maximum Power Point Tracking (MPPT) is really useful in this situation [4]. When PV output surpasses local demand and the battery is fully charged, MPPT shifts the operating point of the panel to match consumption, preventing energy loss [5]. However, this causes a different problem for grid-tied systems. In other cases, like spacecraft systems, the panel can keep running at full speed and still provide cooling benefits by diverting the sun's excess energy to a resistive load. One simple and effective way to manage energy is using grid-connected photovoltaic systems, which typically send the power produced by solar modules straight to the power grid[6].

2. RELATED WORKS

Modern life would not be possible without electric electricity, which is necessary for running machines and meeting energy demands. One of the best ways to combat climate change and satisfy the growing energy needs of different countries is to use renewable energy sources. Among the many renewable energy sources available to humans, solar power stands out due to its abundance. At this time, solar power is crucial for meeting the energy needs of many different areas. One common technique that turns sunlight into electricity is photovoltaic cells, or PVCs. It is common practice to arrange these cells in series and parallel to create a photovoltaic (PV) system, which can produce the required voltage and power levels [2], [3].

Because PVCs do not behave linearly, a maximum power point tracker (MPPT) is necessary for efficient energy harvesting. A very effective kind of maximum power point tracking (MPPT) circuit is the boost converter. However, an efficient MPPT algorithm is required to attain optimum power generation under conditions of variable irradiance [4], [5].

Z. Wang et al: The difficulties of choosing characteristic parameters, the viability of estimating, and the real-world uses of battery state-of-health (SOH) estimation are all covered in this research. An innovative ICA-based method for estimating battery SOH is suggested in the research, with an emphasis on optimising the IC curve model's parameters to provide more realistic and accurate predictions. Health factors (HFs) are identified by extracting peak values and positions from the IC curve, which is derived and refined using the wavelet filtering approach [1].

Y. Li et al: This article presents a functional ocean wave energy harvester (OWEH) that makes use of a swing-body mechanism. The transmission gearing turns the system's rotor, which is powered by an electromagnetic power module (EPM) and a swing body that senses the movement of ultra-low-frequency waves. By utilizing electromagnetic and dynamic models, the OWEH's energy generation may be optimized. Furthermore, external loads can be automatically charged and discharged from lithium batteries through the power management circuit [3].

Y. Shang et al: The present switched-capacitor (SC) equalizers' sluggish operation, low reliability, and enormous size are the main points of this research. To find a happy medium between size, efficiency, and cost, an improved mesh-structured SC equalizer (MSSCE) is suggested. When applied to a succession of battery cells, the MSSCE finds the shortest balancing paths, which improves equalization speed and efficiency [7].

Q. Wang et al: This research presents a technique for evaluating electric vehicle (EV) performance data to determine cell inconsistency in series-connected battery systems. Utilizing substantial EV operation data, a number of primary consistency indicators (CIs) are created. These include the charging voltage curve, internal resistance, and open-circuit voltage (OCV). An adaptive forgetting factor recursive least-squares technique is used to moderate fluctuations in model parameter identification, and the Thevenin equivalent circuit model is applied to demonstrate battery dynamics [4], [5].

M. Landi et al: This research presents two quick ways to check the health of lithium-ion batteries, which are used in vehicle-to-grid (V2G) systems. The second approach makes use of neural networks, whereas the first one makes use of fuzzy logic. Both methods require the initial characterization of batteries from the same family for successful operation. As shown by experimental data, the suggested solutions are efficient in managing V2G fleets and yield accurate results with low processing demands [6].

3. EXISTING SYSTEM

- The world's fossil fuel supply is rapidly decreasing, and pollution is getting worse. This has led to a dramatic increase in worries about these issues in recent years.
- The conventional energy needs of the transportation industry could be met by switching from raw fossil fuels to electricity if battery charging becomes more commonplace.
- To tackle the low points in the load profile, a decentralized system for charging batteries was put in place, which takes use of the flexibility of battery charging loads.
- Hierarchical coordinated control is a suggested way for managing plug-in electric vehicle (PEV) charging in multifamily homes.
- A front-end boost DC-DC converter and a back-end inverter make up the two-stage PV generating system in the original design.
- The second setup makes use of a conventional, single-stage full-bridge inverter to provide the required DC voltage through the series connection of many strings of PV panels.

4. PROPOSED SYSTEM

More complicated control systems, lower overall efficiency, and more expenses are the results of the component interactions in a two-stage power inverter.

Any application that calls for energy storage must have a way to let electricity flow in both directions through a port that links the storage units. Differentiating between sources and loads is superfluous as all ports are typically handled as bidirectional. As a result, rather than multi-input or multi-output, the converter that is being addressed in this article is called a multiport converter. The article supports the idea that storage units and freight can likewise be seen as sources in this context.

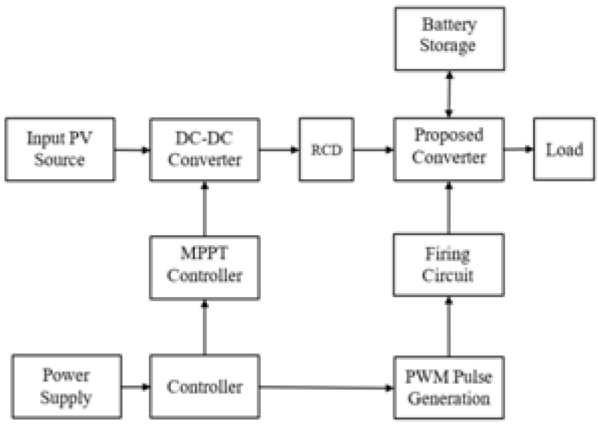
- By pooling resources like power conversion devices, the multiport design has many advantages over traditional systems. Overall, the system becomes more efficient with this method since fewer parts and conversion stages are needed.
- Solar panels with a low direct output voltage are linked in series to produce the required DC bus voltage.
- Nevertheless, the DC bus voltage could be significantly affected by the shadowing or failure of a single multi-string PV panel.
- Using a transformer-free integrated step-up inverter is one way to fix this problem.

- An integrated step-up inverter improves performance and reliability of a grid-connected, non-isolated power production system, which is introduced in this endeavor.
- With the suggested inverter, a photovoltaic system or battery can be powered even when the input voltage is inadequate.
- Isolation and adaptability for input voltages above and below the battery voltage are features of the suggested IMBC.
- The RCD circuit prevents overvoltage even when switches are not in use or are in the middle of a transition.
- Minimizing energy consumption and losses while attaining high efficiency.

PROPOSED BLOCK DIAGRAM

Proposed Technique

One optimization method used in renewable energy systems to make photovoltaic (PV) systems work better is Maximum Power Point Tracking (MPPT), which is based on algorithms. Its style is derived from nature.



PV module

The figures. showcase the features of the PV module. The I-V and P-V characteristic curves make 2 and 3 obvious. You can see how the PV module works by playing about with the temperature and irradiance settings. Figures 2 and 3 show that as the irradiance level grew, the PV module's MPPT increased as well. In a PV module, the maximum power point tracking (MPPT) characteristic drops with rising temperature. In a similar spirit, the MPPT grows as irradiance does. With this PV array, 100 kW of solar irradiation at 1000 W/m2 is possible. Fifty strings of 2.5 series-connected modules linked in parallel make up the user-defined array of the 100 kW PV system (50 * 2.5 * 800.2 W = 100 kW).

Boost Converter

Using a boost converter to raise the PV's output voltage from 100 V to 120 V, the MPPT-based algorithm treats the MOSFET as an electrical switch and then adjusts the duty cycle to generate this output.

MPPT for Solar PV System

As shown in the diagram that is attached, the simulation model of the solar PV system is created using MATLAB/Simulink. Equipped with a Soltech ISTH-215-P solar panel, the model primarily consists of the switching block and the NIMBC_MPPT subsystem.

The PV array voltage and the NIMBC output voltage, V_1, are compared by a comparator in the NIMBC_MPPT subsystem. The reference input of the comparator is the voltage that the PV array produces. A proportional-integral-derivative (PID) controller, which calculates the duty cycle signal from the voltage differential between the PV voltage and the output voltage, uses this voltage differential to generate the signal.

A gate signal is generated by the pulse width modulation (PWM) generator, which controls the MOSFET, after receiving this duty cycle signal. In order to control the boost converter's functioning and optimize the power collected from the PV array, the system adjusts the PWM duty cycle based on the comparator's determination of the voltage difference.

5. SIMULATION DESIGN AND RESULTS

Ensure that the simulation time is in sync with the sequential transmission of 100 PV array input data points, the suggested solar energy harvesting model is run for one second. Instead of using a continuous simulation method, the NIMBC inquiry makes use of a discrete one. The amount of the training dataset and the training technique determine how accurate the NIMBC forecasts are. When the dataset is big enough, the NIMBC achieves minimum prediction errors.

A lookup table supplies the solar panel with its input data, which includes the temperature of the array and the amount of sunlight reaching the panel. To keep everything running smoothly and on schedule, we use a clock to sync this data with the simulation.

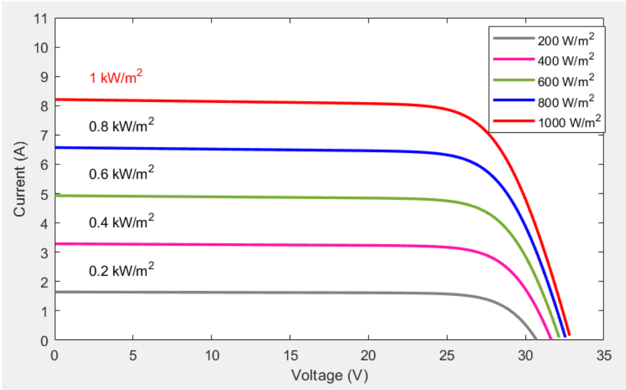


Fig1: Characteristics of PV Panel

By simulating a PV array in MATLAB/SIMULINK, we can show how different input conditions affect the optimal power point. Twenty all-back-contact solar cells form one continuous strand in the model 100 kW photovoltaic array. For different cell temperatures at G = 1000 W/m 2 and different degrees of solar irradiation at Tc = 25 ◦C, the figure shows the current-voltage and power-voltage relationships, respectively.

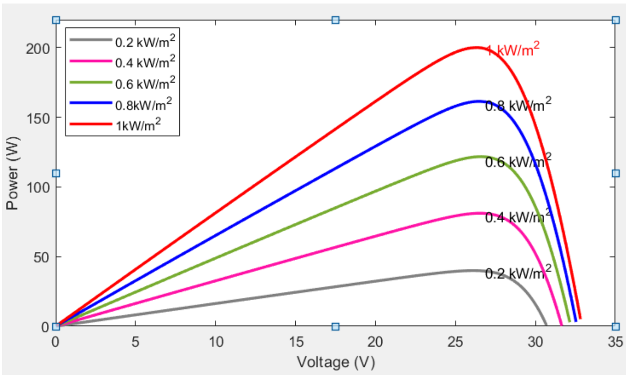


Fig2: Characteristics of PV Panel

According to these results, variations in the external environment cause the maximum power point of a solar system to be constantly changing. Accordingly, MPPT systems are required to consistently gather all of the electricity from PV panels or arrays.

sun radiation, array temperature, demand power, and power output are all factors that constitute the relationship. Variations in PV array temperature and solar irradiation have a direct impact on the discharge power and generated power, according to the NIMBC MPPT topology. Throughout the course of the simulation, we track variables such as temperature, irradiance, power generation, and load power. At 15 degrees Celsius, the array was subjected to the lowest possible sun irradiation of 200 W/m², and the lowest possible power production was 100 W. Even so, when the array temperature is 35°C and the peak solar irradiation is

1000 W/m2, the MPPT performance requirements are satisfied, and the maximum power production is 400 W.

When designing the MPPT technology for NIMBC, a number of factors are taken into account, including temperature, solar irradiation, and the maximum voltage generated by the PV array. A exact reading of the sun's irradiance and temperature is fed into the PV array by the solar data subsystem. Using this data, we can find the solar panel's maximum voltage, current, and power output under different weather scenarios.

Input data from the solar panel's voltage is analyzed by a neural network. The input and output information used by the MPPT system design is based on the solar panel's nominal voltage, rated current, and temperature coefficients. This strategy ensures that MPPT performance is accurate and flexible across different environmental circumstances.

SIMULATION MODEL

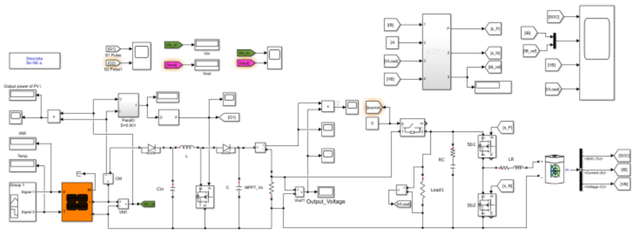


Fig 3: Proposed Simulation

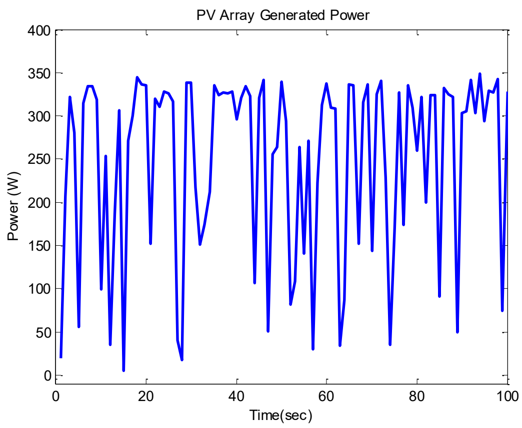


Fig 4: Power versus time generated from the PV array

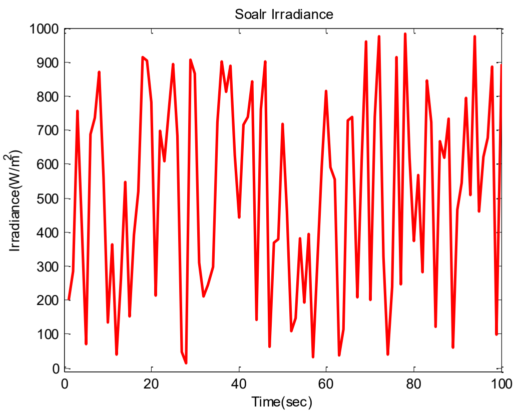


Fig 5: Irradiance versus time of the solar panel

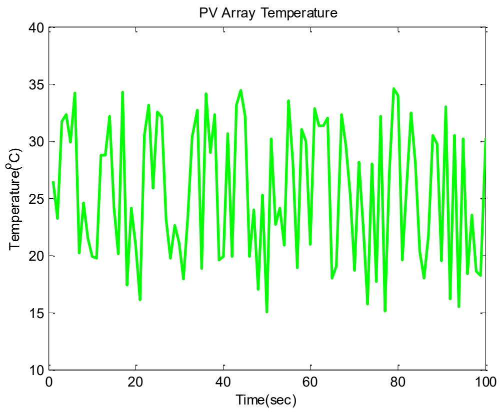


Fig 6: Temperature vs. time of the solar panel.

6. SIMULATION RESULTS

In the presence of changeable external conditions, the simulation results show that the variable step incremental conductance (INC) technique for MPPT based on NIMBC significantly increases the DC output power. This method also speeds up the stabilization process of the system, making it more responsive to changes in solar radiation and temperature. The approach improves efficiency and maximizes power extraction by modifying the step size dynamically. For this reason, the INC technique based on NIMBC is a workable strategy for increasing the efficiency of PV systems in different kinds of environments.

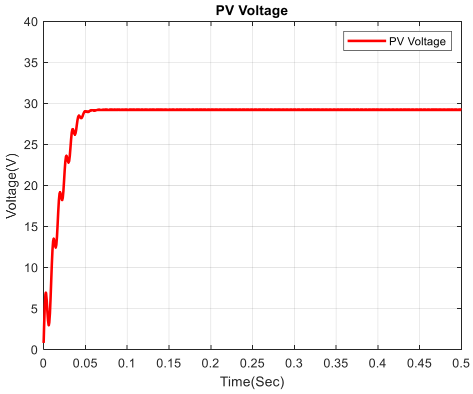


Fig7:Output PV Panel Voltage

BATTERY CHARGING MODE OUTPUT

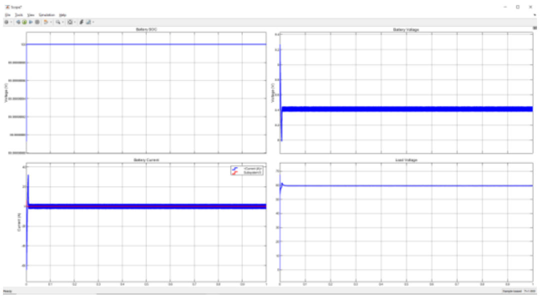


Fig8: Charging mode output

MPPT OUTPUT VOLTAGE DURING CHARGING

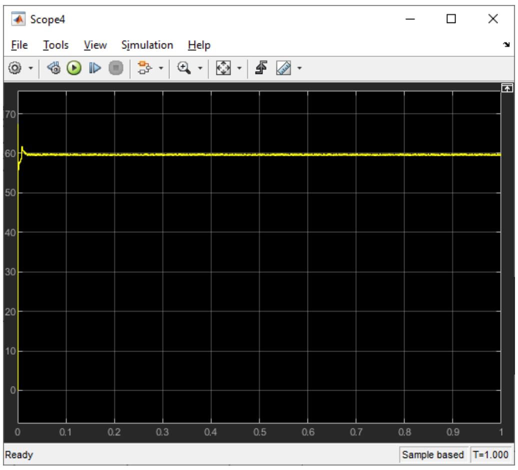


Fig9: Charging Output

BATTERY DISCHARGING MODE OUTPUT

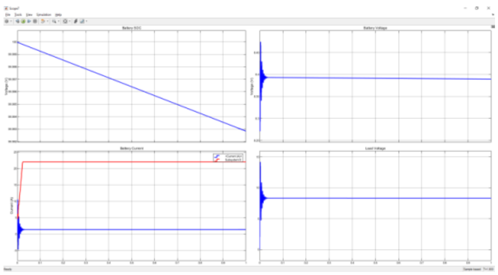


Fig10: Discharging Mode output

MPPT OUTPUT VOLTAGE DURING DISCHARGING

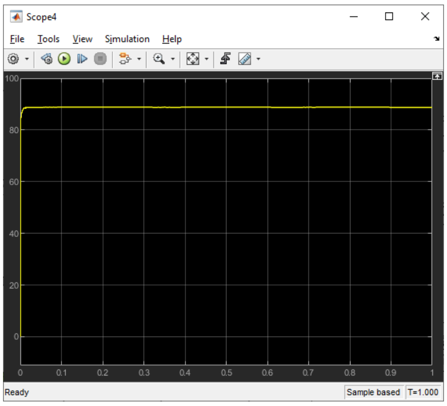


Fig.11: Discharging Output

ADVANTAGES

- Low cost
- Reduced bus voltage
- Reduced component counts
- High efficiency
- Voltage gain is increased

APPLICATION

Applications include:

- Multi-output power supplies
- Interleaved power supplies
- Single-stage power-factor correctors
- Boost integrated power supplies
- LED drivers

These applications benefit from improved efficiency and optimized power management, suitable for diverse energy conversion and lighting needs.

7. CONCLUSION

Featuring an integrated RC snubber circuit, this research presents a novel NIMBC prototype. The fast off-voltage rise and poor conversion efficiency due by leakage inductance are two problems that this prototype aims to fix for traditional converters. Integrating IMBC and SS cell technologies, the prototype achieves Zero-Current Switching (ZCS) and Zero-Voltage Switching (ZVS) during the primary (Q1) and auxiliary (Q2) switch transitions. In addition to improving overall efficiency, this also drastically cuts down on electromagnetic interference (EMI) and switching losses. Using fixed-frequency PWM technology instead of traditional hard-switching approaches, the converter maximizes performance while reducing current stress. Integration of PWM with ZCS improves operational efficiency and system reliability. The simulation results are supported by experimental data from a 150 W prototype, which shows that converters based on NIMBC have the ability to solve power electronics problems with electromagnetic interference, efficiency, and reliability. These results show that you performed really well.

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