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BUCK–BOOST-BASED GRID-CONNECTED PV INVERTER FOR MAXIMUM POWER EXTRACTION FROM DUAL PV ARRAYS UNDER MISMATCHED ENVIRONMENTAL CONDITIONS

Dr. P. SRAVAN KUMAR, *Associate Professor & HOD, Dept of EEE,*
SREE CHAITANYA INSTITUE OF TECHNOLOGICAL SCIENCES, KARIMNAGAR

ABSTRACT: This paper recommends a photovoltaic (PV) inverter that is connected to a single-phase grid without a transformer. The inverter optimizes the power output of two serial subarrays in either buck or boost mode. This is accurate despite the fact that each subarray has its own environment. The construction of a subarray with the fewest serially connected solar photovoltaic modules is facilitated by an inverter that can operate in either buck or boost mode, depending on the application. As a result, the power output of each subarray increases in response to varying environmental conditions. In order to safeguard the common mode voltage from high-frequency components, the design necessitates the inverter management technique and architecture. This is required by the design. This is implemented to maintain the amplitude of the leakage current in the PV array within a predetermined range. The range can exhibit a high level of operational effectiveness. The feasibility of the project is ascertained through a comprehensive investigation of the system, the development of a mathematical model, and the implementation of rigorous computer simulations. In order to validate the concept, additional investigation is required in addition to the 1.5-kW laboratory prototype.

Keywords*—Buck and Boost based photovoltaic (PV) inverter, grid connection, maximum power point (MPP), mismatched environmental condition, series connected module, single phase, transformer less.*

1. INTRODUCTION

Photovoltaic (PV) energy is a clean, renewable, environmentally sustainable source of energy. The depletion of fossil fuels, the increasing global power demand, and the escalating apprehension regarding greenhouse gas emissions have expedited the adoption of grid-connected photovoltaic (PV) systems. Grid-connected transformerless (GCT) photovoltaic (PV) inverters are widely utilized in various PV system layouts. This is due to their efficiency, cost-effectiveness, compactness, and enhanced power density. The removal of the transformer enhances conversion efficiency, decreases system weight, and minimizes power losses. Transformer-less solar systems require a high DC-link voltage to effectively inject power into the utility grid. To provide the requisite voltage, many photovoltaic modules are interconnected in parallel.

Mismatched environmental conditions (MEC) significantly impede the effectiveness of solar systems. The performance of photovoltaic modules in actual installations differs from laboratory circumstances due to factors such as partial shading, cloud movement, dust

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accumulation, avian excrement, manufacturing discrepancies, module degradation, temperature variations, and panel orientation. Under these atypical operating conditions, the power output of the PV array is diminished due to the modules generating non-uniform current and voltage. The least efficient module dictates the performance of the entire series-connected string, constraining the string current irrespective of temperature or shading variations in an individual module. This thus diminishes the efficiency and energy yield of the photovoltaic (PV) system, thereby inhibiting its effective utilization of solar energy.

Mismatches also result in the emergence of multiple local maximum power points (LMPPs) on the power-voltage (P-V) characteristics of the solar array. This renders the MPPT systems ineffectual. Traditional MPPT methodologies, like Perturb and Observe (P&O) and Incremental Conductance (INC), may sometimes converge at local maxima rather than the Global Maximum Power Point (GMPP). This leads to significant solar energy wastage. This issue is resolved by presenting many advanced MPPT algorithms. Examples include Ppaper Swarm Optimization (PSO), Genetic Algorithms (GA), Artificial Neural Networks (ANN), Fuzzy Logic Controllers (FLC), and hybrid optimization techniques. These techniques improve tracking precision in conditions of partial shadowing; but, they cannot mitigate the power losses resulting from the electrical mismatch among the photovoltaic modules.

Numerous hardware-based solutions have been explored to mitigate mismatch losses. Photovoltaic modules or strings are frequently coupled with DC-DC converters or power electronic equalizers. These converters enable each module to function autonomously at its Maximum Power Point (MPP), hence enhancing energy harvesting substantially. To enhance energy harvesting in sub-optimal conditions, module-integrated converters, differential power processing converters, and maximum power point tracking designs have been utilized. However, they require advanced control algorithms, sensors, switching devices, and electrical power components. The augmentation of component quantity elevates installation expenses, enhances circuit complexity, diminishes system reliability, and induces power losses during converter operation.

To mitigate these limitations, researchers have suggested photovoltaic system configurations that partition the PV array into subarrays. Each subarray is individually adjusted to attain the ideal operating point. This configuration yields reduced mismatch losses and requires fewer power electronic converters in comparison to module-level power optimization methods. Minimized converters reduce implementation costs, streamline system design, and enhance reliability. Nonetheless, elevated voltage loads on switches, heightened control complexity, and diminished efficacy under swiftly fluctuating environmental conditions persist in many subarray-based methodologies.

The recent introduction of buck-boost technology in grid-connected solar inverters has demonstrated potential for enhancing power extraction under mismatched conditions. The solar array has two or more subarrays, each independently regulated and linked to distinct buck-boost converters. The

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converters regulate the voltages of the subarrays to maintain them at or near their optimal power levels. The converter functions in buck or boost mode, modulating the output voltage based on the solar panel's irradiance. This variable voltage regulation allows the inverter to maximize energy extraction from the solar arrays under varying irradiance and temperature conditions while maintaining a constant DC-link voltage.

The utilization of a combination of buck and boost stages offers several technical advantages. A reduced quantity of PV modules should be linked in series to achieve the inverter input voltage. Due to the converter's capability to adjust input voltage levels. This enhances the design flexibility of the system, rendering it suitable for rooftop installation in confined spaces. The buck-boost configuration decreases the voltage stress on the semiconductor switches by approximately 50% relative to conventional inverter configurations. Low voltage stress enables high frequency switching devices that minimize switching losses and allow for the utilization of smaller passive components (e.g., capacitors and inductors). This enables the inverter to be compact, lightweight, and energy-efficient, while yet ensuring superior dynamic performance.

Utilizing appropriate filters in high-frequency operations enhances power density and diminishes electromagnetic interference. The efficacy of buck-boost converters has improved by the utilization of wide-bandgap semiconductor devices, including SiC and GaN transistors. These advancements enhance thermal efficiency, diminish conduction losses, and elevate switching rates. Contemporary buck-boost solar inverters can attain conversion efficiencies of 97-99%, making them appropriate for grid-connected photovoltaic applications throughout residential, commercial, and industrial sectors.

The proposed buck-boost architecture outperforms transformer-less topologies for photovoltaic inverters under mismatch situations. Smaller passive components enhance global maximum power extraction, minimize mismatch losses, and decrease the number of solar modules in series, hence reducing voltage stress on the power switches. The control system and hardware are streamlined, enhancing reliability and reducing installation and maintenance costs. The independent management of several photovoltaic subarrays facilitates efficient functioning, even when different sections of the array encounter disparate levels of solar irradiation or temperature.

Consequently, the buck-boost grid-connected solar inverter serves as an effective and economical alternative for enhancing energy extraction from photovoltaic arrays under adverse environmental conditions. The proposed design features fewer components, enhanced conversion efficiency, effective maximum power point tracking, and adaptive voltage regulation, thereby augmenting the efficiency of current solar power generation systems. This project represents a promising initiative in smart grid and renewable energy, as it enhances efficiency and ensures a reliable power supply. In these applications, the significance of solar energy and system reliability is paramount.

2. PROPOSED INVERTER

An inverting stage is incorporated after

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the phase of the dc-to-dc converter in this investigation to construct the dual-buck and boost-based inverter (DBBI). PV1 and PV2 are solar photovoltaic array subarrays that contain two dc-dc converter segments, conv1 and conv2, respectively. CONV1 and CONV2 are the two components of the dc-to-dc converter stage. Parts of the CONV1 section include:

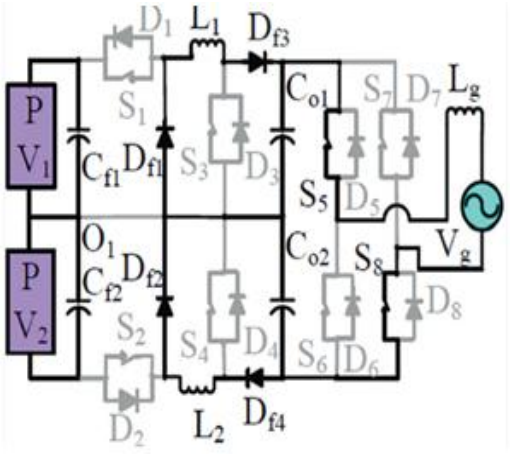


Fig.1. Dual buck and boost basedInverter.

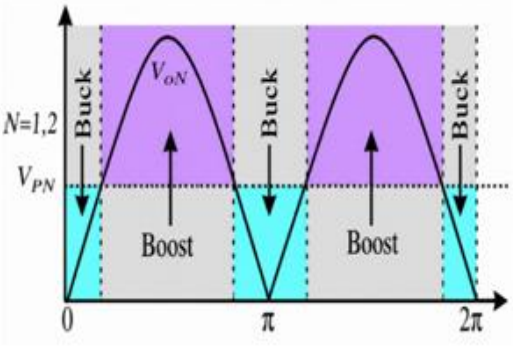


Fig 2. Buck stage and boost stage of the proposed inverter.

The components that make up a circuit include self-commutating filters, inductors, capacitors, L1, Cf 1, and Co1. Free-wheeling diodes Df 1 and Df 3 are the components that make up the circuit overall. Their antiparallel body diodes, D1 and D3, as well as the self-commutating switches S1 and S3 are responsible for this. Switches S1 and D3 are also capable of self-commutation, which is an additional feature. Among the components that make up the CONV2 sector of the schematic diagram are filter inductors, capacitors L2, Cf 2, and Co2, as well as antiparallel body diodes D2 and D4, freewheeling diodes Df 2 and Df 4, and self-commutated switches S2 and S4. On display in Figure 1 are the self-commutated switches (S5, S6, S7, and S8) as well as the body diodes (D5, S6, S7, and S8) that are a part of the inverting stage. Antiparallel body diodes include the free-wheeling diodes D2 and D4 as well as the self-commuting switches S2 and S4. A representation of the inversion stage can be found in Figure 1.

This component, which is sometimes referred to as a "filter inductor" in the industry, is responsible for connecting the grid and the inverter stages. Within this picture, the parasitic capacitance that exists between the solar photovoltaic array and the ground potential is represented by capacitor pairs. Enjoy looking at Figure 2 in your leisure time. This mode is enabled in a manner that is analogous to buck mode when Vpv1 is equal to or lower than Vco1. When the value of Vpv2 is equal to or lower than the value of Vco2, the buck mode occurs. When the value of Vpv2 is equal to or lower than the value of Vco2, the buck mode can commence.

When PV1 and PV2 are utilized, the voltages that are produced by the MPP are Vpv1 and Vpv2. The voltages that are produced by CONV1 and CONV2 are referred to as vco1 and vco2, respectively, and they are what differentiate MPP voltages from other voltage signals. It is dependent on MPP that these voltages are present. It is the sinusoidal alteration of the duty ratios of S1 and S2 in buck mode operation that is responsible for the generation of the sinusoidal grid current. S3 and S4 remained unchanged throughout

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this process. When Vpv1 is higher than Vco1, CONV1 begins to increase. A boost is seen by CONV2 whenever Vpv2 is equal to or greater than Vco2.

The duty ratios of boost mode transitions are increased and then sinusoidally adjusted in order to maintain sinusoidal IG. This makes it possible to maintain sinusoidal IG. It is imperative that both S1 and S2 be operational at all times in order to generate sinusoidal irradiation while the mode is in operation. In order to guarantee that the power factor is kept at unity, it is necessary to synchronize the grid voltage vg with the sinusoidal switching pulses that are produced by the CONV1 and CONV2 switches.

In order to function properly, it is necessary to engage switches S5 and S8 during the positive half-cycle (PHC) and deactivate them during the negative half-cycle (NHC). In order to ensure that a negative half-cycle (NHC) is performed correctly, switches S6 and S7 need to be lighted, while switches S5 and S8 need to be left in their disengaged positions. Figure 3 depicts the proposed inverter, which can be seen operating in all modes, including standby mode.

3. RESULTS

The inverter's efficacy is illustrated through the examination of a two-subarray solar array. Each subarray is composed of four "CS6P-165PE" Canadian solar polycrystalline modules that are connected in series [25, 26]. Table I displays the MPP parameters for each subarray under STC. These situations are elaborated upon below. Simulation and testing were simplified by parameters and elements.

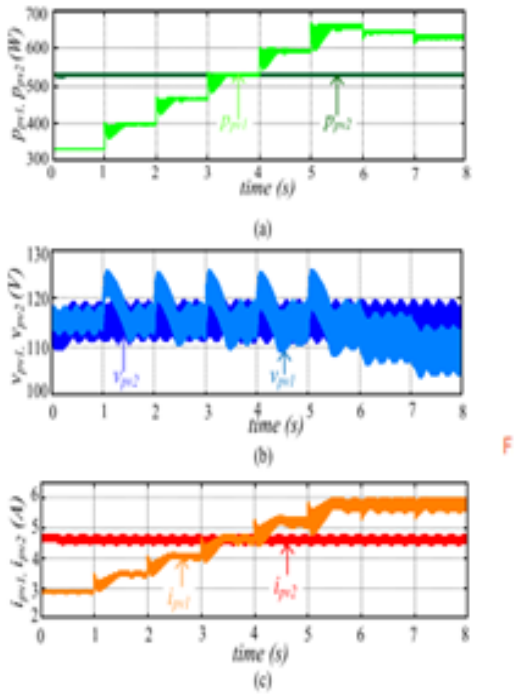


Fig Simulated waveform. Variation in(a)ppv1 and ppv2 , (b) vpv1 and vpv2 , and(c)ipv1 and ipv2 during entire range of operation.

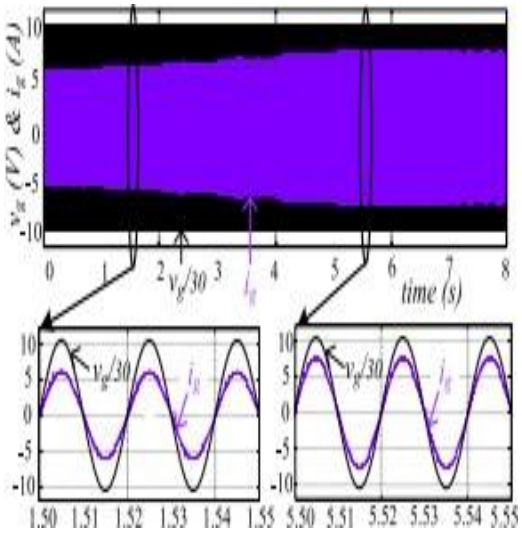


Fig. Simulated waveform.vg and ig and their magnified views.

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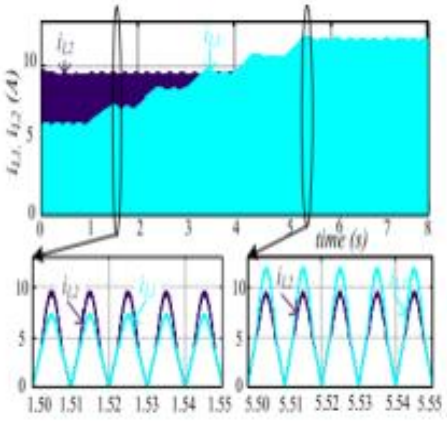


Fig Simulated waveform.iL1 and iL2and their magnified views.

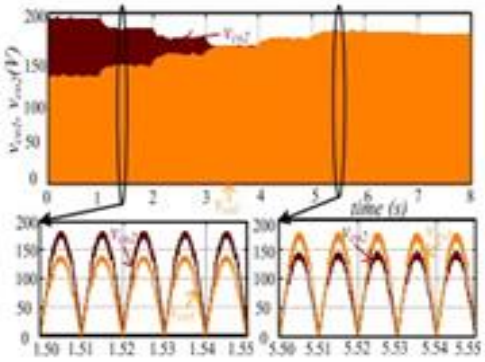


Fig Simulated waveform.vco1 and vco2 and their magnified view

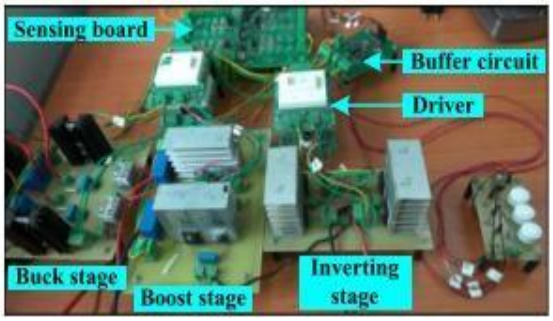


Fig Experimental prototype of the proposed inverter.

The following scenarios are considered: (a) PV1 insolation is 60% and PV2 is 80%; (b) PV1 is 100% and PV2 is 80%; (c) PV1 and PV2 are larger; and (d) PV1 is 40% and PV2 is 80%.

4. CONCLUSION

This paper suggests the development of a single-phase GCT buck and boost photovoltaic (PV) inverter. The inverter enables the operation of two subarrays at their maximum power points. This inverter was intriguing for a variety of reasons, such as: A successful approach to reducing the impact of MECs on PV arrays has been demonstrated in the past. Third, operational efficiency (euro = 97.02%) was achieved, and second, a significant amount of money was saved. It was advantageous to execute component translators independently. 4) In order to maintain the MPP capabilities of component converters, a straightforward MPPT method was devised. Additionally, the leakage current of the PV array was below the requirement of VDE 0126-11-1. In addition to conducting a mathematical analysis of the converter, a small signal model was developed. The criteria and methods employed to determine the values of system output filter components are the focus of this investigation. System operation was guaranteed by comprehensive modeling studies. The success of the strategy was determined through the extensive testing of a 1.5 kW inverter prototype that was specifically designed for this purpose in the real world. The strategy had the potential to be successful.

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