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Grid-Connected Photovoltaic Power System Using Boost-Half-Bridge Converter

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Abstract: *This paper focuses on the power electronics used in the renewable energy systems especially in the photovoltaic applications. In recent years, interest in natural energy has grown in response to increased concern for the environment. Due to the limitations in the energy available from conventional sources, worldwide attention is being focused on renewable sources of energy. Especially, the energy obtained from solar arrays, becomes more and more important. In grid connected applications, a modular micro-inverter integrated with each photovoltaic (PV) panel can reduce the overall system cost and increase the system reliability and MPPT efficiency. In order to make the PV generation system more flexible and expandable, the backstage power circuit is composed of a high step-up converter and a pulse width-modulation (PWM) inverter. The traditional voltage-fed-full-bridge DC-DC converter suffers high cost, low transformer efficiency and discontinuous input current problems. A current-fed-half-bridge converter topology is utilized herewith continuous input current current, low cost and high efficiency features. A 210 W single-phase PV microinverter system with galvanic isolation is presented. By integrating microinverter to each PV panel, localized MPPT of each individual PV panel can be achieved, thus loading to fast tracking speed and higher system efficiency.*
Keywords *- PV array, boost-half-bridge, grid-connected photovoltaic (PV) system, maximum power point tracking, repetitive current control.*

I. INTRODUCTION

As a solution for the depletion of conventional fossil fuel energy sources and serious environmental problems, focus on the photovoltaic (PV) system has been increasing around the world. Grid connected solar energy technology is the fastest growing technology in the world today [1]-[3]. Grid connected converters are required to transfer green energy from solar system into the main grid. The first grid-connected inverters were based on Silicon Controlled Rectifiers (SCR) technology which was also limited in control and came with a high harmonic content which requires the use of bulky filters [3]. With the introduction of MOSFET for high power applications, the control of the grid connected inverters became more advanced.

In single phase grid connected photovoltaic power systems, the concept of microinverter has become a future trend for its removal of energy yield mismatches among PV modules, possibility of individual PV-module-oriented optimal design, independent maximum power point tracking, and "plug and play" concept [4]-[5]. The low voltage solar output can be connected to the grid by using a converter with high step up ratio. Hence, a boost-half-bridge DC-DC converter cascaded by an inverter is the most popular topology, in which a HF transformer is often implemented within the DC-DC conversion stage. By replacing the secondary half-bridge with a diode voltage doubler, a new boost-half-bridge converter can be derived for unidirectional power conversions [5]-[7]. The promising features such as low cost, high reliability and high efficiency, circuit simplicity can be obtained by use of the converter with minimal semiconductor devices. The repetitive current control technique is an effective solution for the elimination of periodic harmonic errors and has been previously investigated and validated in the un-interruptible power system, active power filters, boost-based PFC circuits, and grid-connected inverters/PWM rectifiers. In this paper, a plug-in repetitive current controller which is composed of a proportional part and an RC part is proposed to enhance the harmonic rejection capability [8].
The synchronized sinusoidal current can be injected to the grid by using a full bridge PWM inverter with an output LCL filter. Sinusoidal current with a unity power factor is supplied to the grid through a third-order LCL filter. In general, its performance is evaluated by the output current total harmonic distortions (THDs), power factor, and dynamic response [9]-[10]. The maximum Power Point (MPP) is the point in which maximum power is delivered from the solar cell to the PV system. MPPT is performed by the boost-half-bridge converter by using numerous MPPT techniques such as perturb and observe method, incremental conductance method, ripples correlation method, etc. In this proposed system, an optimal P&O method has been developed to limit the negative effect of the converter dynamic responses on the MPPT efficiency. A closed-loop control technique has been proposed to minimize the PV voltage oscillation [11]-[12].

The galvanic isolation is introduced on the DC side in the form of a high frequency DC-DC transformer. The pulse width modulation control is applied to both the dc–dc converter and the inverter. A constant voltage dc link decouples the power flow in the two stages such that the dc input is not affected by the double-line-frequency power ripple appearing at the ac side. The fast dynamic response is achieved during the transients of load. In order to reach an optimal efficiency of the boost-half-bridge converter, ZVS techniques can be considered for practical implementation [13]-[14]. The MPPT function block in a PV converter system increases the efficiency.

II. BOOST-HALF-BRIDGE PV MICROINVERTER

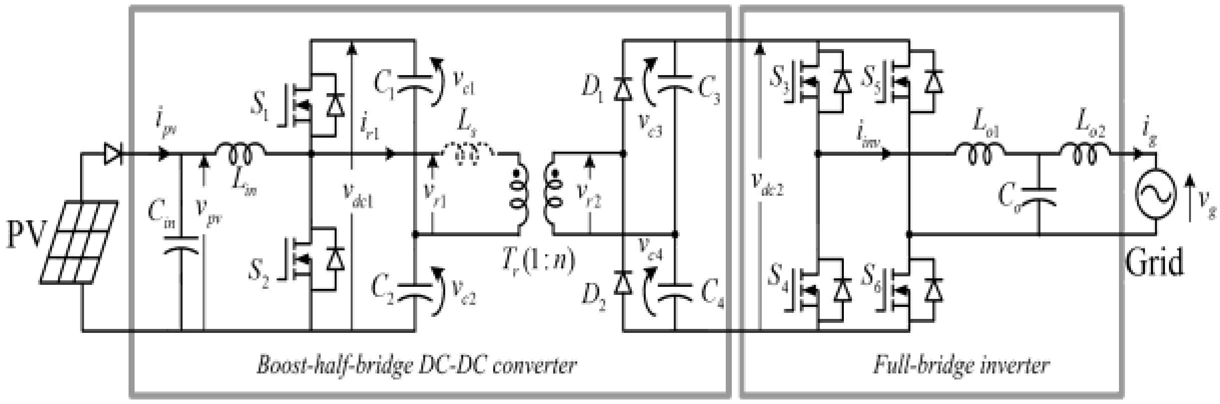

Figure 1. The boost-half-bridge PV microinverter topology

The topology of the boost-half-bridge micro inverter for grid connected PV systems is depicted in Fig 1. The proposed circuit is composed of two decoupled power processing stages. The conventional boost converter is modified by splitting the output dc capacitor into two separate ones. C_{in} and L_{in} denote the input capacitor and boost inductor, respectively. The center taps of the two MOSFETs (S_1 and S_2) and the two output capacitors (C_1 and C2) are connected to the primary terminals of the transformer T_r, just similar to a half bridge. The transformer leakage inductance is reflected to the primary is represented by L_s and the transformer turns ratio is 1: n. A voltage doubler composed of two diodes (D_1 and D_2) and two capacitors (C_3 and C_4) is incorporated to rectify the transformer secondary voltage to the inverter dc link. A full-bridge inverter composed of four MOSFETs (S_3–S_6) using synchronized PWM control serves as the dc–ac conversion stage. Sinusoidal current with a unity power factor is supplied to the grid through a third-order LCL filter (L_{01}, L_{02}, and C_0).

The duty cycle of S_1 is denoted by d_1. The switching period of the boost-half-bridge converter is T_{sw1}. The PV current and voltage are represented by i_{PV} and v_{PV}, respectively. The voltages across C_1, C_2, C_3, and C_4 are denoted by v_{c1}, v_{c2}, v_{c3}, and v_{c4}, respectively. The transformer primary voltage, secondary voltage, and primary current are denoted as v_{r1}, v_{r2}, and i_{r1} respectively. The low-voltage side (LVS) dc-link voltage is v_{dc1} and the high- voltage side (HVS) dc-link voltage is v_{dc2}.

The switching period of the full bridge inverter is Tsw2. The grid voltage is v_g. The boost-half-bridge converter is controlled by S_1 and S_2 with complementary duty cycles. Neglect all the switching dead bands for simplification. When S_1 is ON and S_2 is OFF, v_{r1} equals to v_{c1}. When S_1 is OFF and S_2 is ON, v_{r1} equals to $-v_{c2}$. At steady state, the transformer volt-second is always automatically balanced. In other words, the primary volt-second A_1 (positive section) and A_2 (negative section) are equal, so are the secondary volt-sec A_3 (positive section) and A_4 (negative section). Normally, D_1 and D_2 are ON and OFF in a similar manner as S_1 and S_2, but with phase delay t_{pd} due to the transformer leakage inductance. Ideally, the transformer current waveform is determined by the relationships of $v_{c1} - -v_{c4}$, the leakage inductance L_s, the phase delay t_{pd}, and S_1's turn-on time $d_1T_{sw1.}$

The ZVS techniques can be considered for obtaining optimal efficiency of the boost-half-bridge converter. It is worth noting that engineering tradeoffs must be made between the reduced switching losses and increased conduction losses when soft switching is adopted. When viewing from the full-bridge inverter, the boost-half- bridge converter just operates identically as a conventional boost converter, but with the extra features of the galvanic isolation as well as the high step-up ratio. The simple circuit topology with minimal use of semiconductor devices exhibits a low total cost and good reliability. In order to achieve fast dynamic responses of the grid current as well as the dc-link voltage, a current reference feed forward is added in correspondence to the input PV power.

Typically, the MPPT function block in a PV converter/inverter system periodically modifies the tracking reference of the PV voltage, or the PV current, or the modulation index, or the converter duty cycles. If the converter dynamics are disregarded in the MPPT control, undesirable transient responses such as LC oscillation, inrush current and magnetic saturation may takes place. MPPT is performed by the boost-half-bridge DC–DC converter. An optimal P&O method has been developed to limit the negative effect of the converter dynamic responses on the MPPT efficiency. The closed-loop control technique has been proposed to minimize the PV voltage oscillation. However, the converter dynamic behavior associated with the MPPT operations can also influence the converter efficiency and functioning of the system. A customized MPPT producing ramp-changed PV voltage is then developed.

III. DESCRIPTION OF SYSTEM CONTROL

The boost half bridge PV micro inverter system is controlled by a digital approach. The PV voltage and current are both sensed for calculation of the instantaneous PV power, the PV power variation, and the PV voltage variation. The MPPT function block generates a reference for the inner loop of the PV voltage regulation, which is performed by the dc–dc converter. At the inverter side, the grid voltage vg is sensed to extract the instantaneous sinusoidal angle θg, which is commonly known as the phase lock loop. The inverter output current is pre-filtered by a first-order low-pass filter on the sensing circuitry to eliminate the HF noises. MPPT technique is used to extract maximum power in order to increase the efficiency of the system. The filter output is then fed back to the plug-in repetitive controller for the inner loop regulation. Either v_{dc1} or v_{dc2} can be sensed for the dc-link voltage regulation as the outer loop. In practice, the LVS dc-link voltage v_{dc1} is regulated for cost effectiveness. In order to achieve fast dynamic responses of the grid current as well as the dc-link voltage, a current reference feed forward is added in correspondence to the input PV power. The closed-loop control technique has been proposed to minimize the PV voltage oscillation.

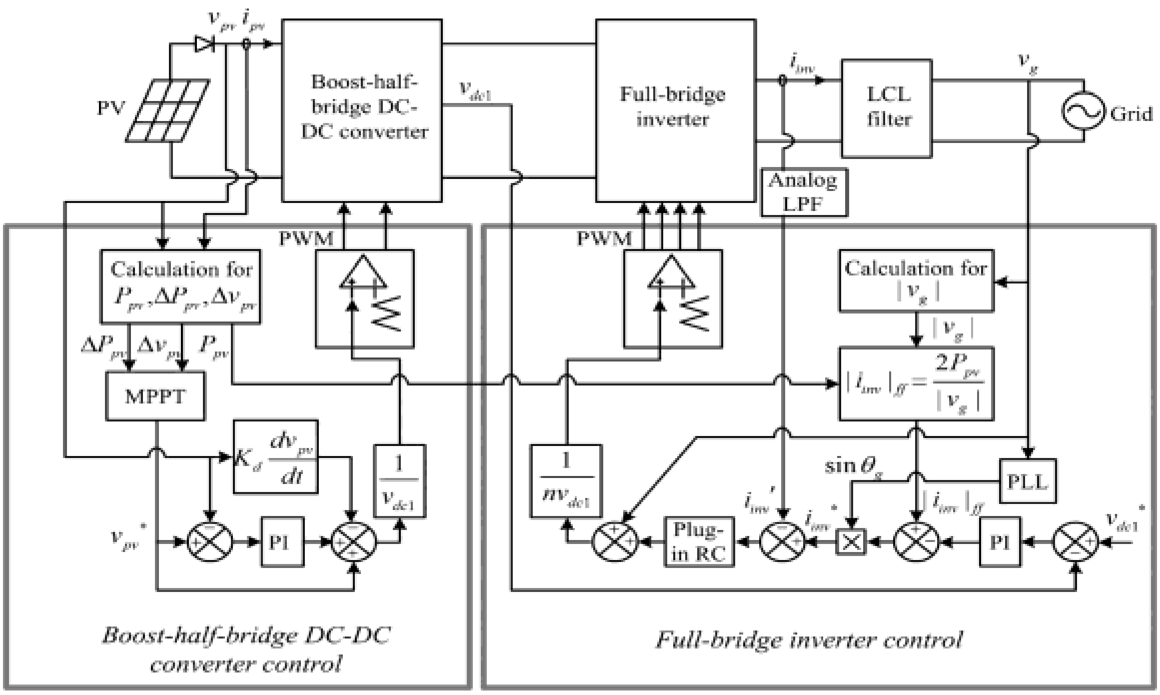

Figure 2. Architecture of the proposed PV microinverter system control

IV. Plug-In Repetitive Current Controller

Using an LCL filter in a grid-connected inverter system has been recognized as an attractive solution to reduce current harmonics around the switching frequency, improve the system dynamic response, and reduce the total size and cost. Typically, an undamped LCL filter exhibits a sharp LC resonance peak, which indicates a potential stability issue for the current regulator design. Hence, either passive damping or active damping techniques can be adopted to attenuate the resonance peak below 0 dB. The current sensor is placed at the inverter side instead of the grid side.

V. Boost-Half-Bridge Converter Control

The PV voltage is regulated instantaneously to the command generated by the MPPT function block. High bandwidth proportional-integral control is adopted to track the voltage reference and to minimize double-line-frequency disturbance from LVS dc link. The capacitor voltage differential feedback is introduced for active damping of the input LC resonance. Typically, the MPPT function block in a PV converter/inverter system periodically modifies the tracking reference of the PV voltage, or the PV current. In most cases, these periodic perturbations yield step change dynamic responses in power converters. The v_{C1}–v_{C4} is changing dynamically in accordance with d_1. As a result, at any time, the charge and discharge rate of C_1-C_4 must be limited such that the transformer flux is not saturated. For the sake of control simplicity and low cost, developing a customized MPPT method by carefully taking care of the boost-half-bridge converter dynamics.

VI. Modeling Of Proposed System Using Matlab/Simulink

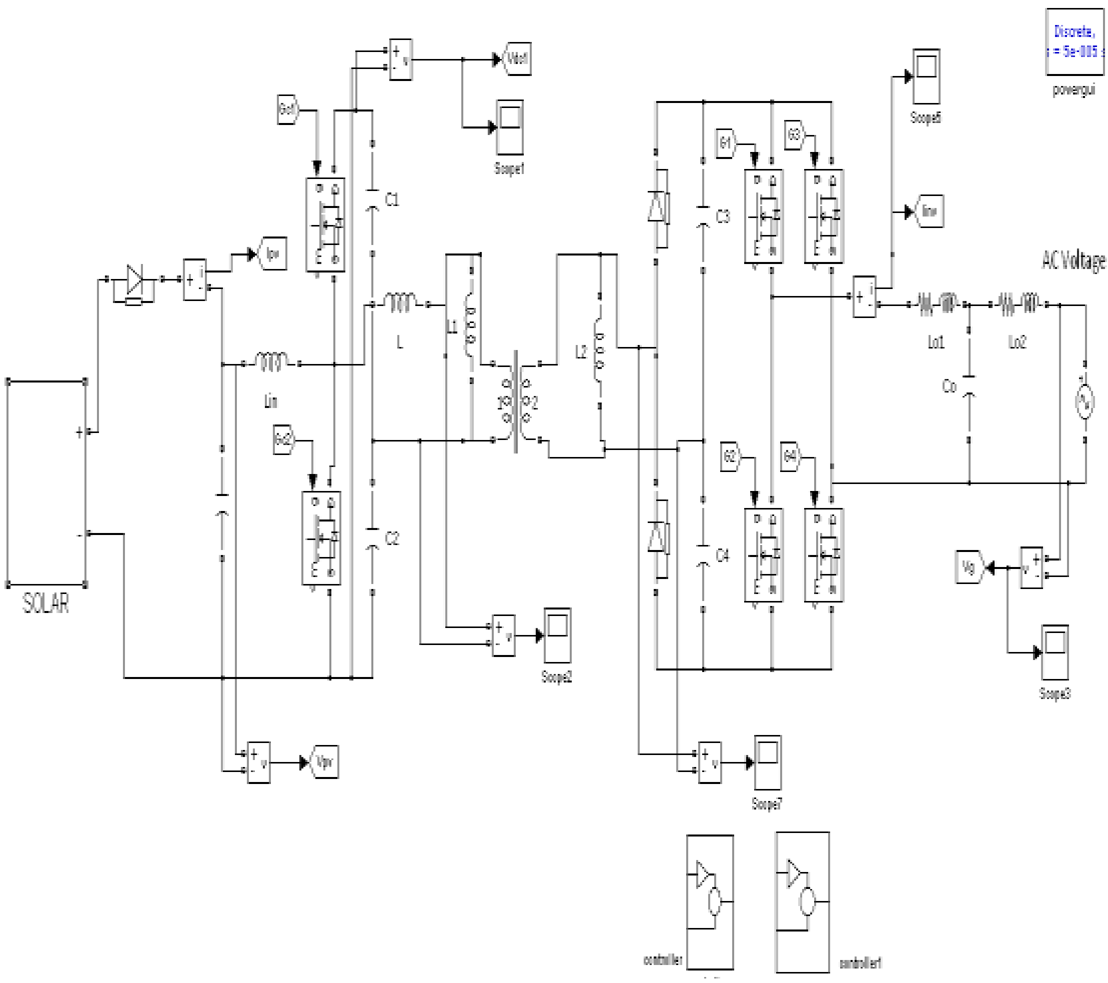

Figure 3. Simulation model of the proposed system

VII. Variable Step Size Mppt Algorithm

For simplicity, it is assumed that the PV module is working under the standard irradiance (1000W/m) and the room temperature (25° C). It is worth mentioning that some MPPT techniques calculate the step size online relying on the instantaneous values of ΔP_{PV} and Δv_{PV} in order to make the MPPT more adaptive. However, the sensed ΔP_{PV} and Δv_{PV} are vulnerable to noises, particularly, when they are small. Therefore, an alternative method is adopted for robustness. Two points S_{PV1} and S_{PV2} on the dP_{PV}/dv_{PV} curve are selected to divide the PV operating points into three different zones. In zone 0, PV output power is close to the MPP, where a fine tracking step size is used to approach the exact MPP. In zones 1 and 2, a larger tracking step size is applied to boost up the tracking speed. The adopted MPPT algorithm is shown in Figure. The tracking step sizes in zones 0, 1, and 2 are represented by Δv_{ref0}, Δv_{ref1}, and Δv_{ref2} respectively. For the sake of control simplicity and low cost, developing a customized MPPT method by carefully taking care of the boost-half-bridge converter dynamics.

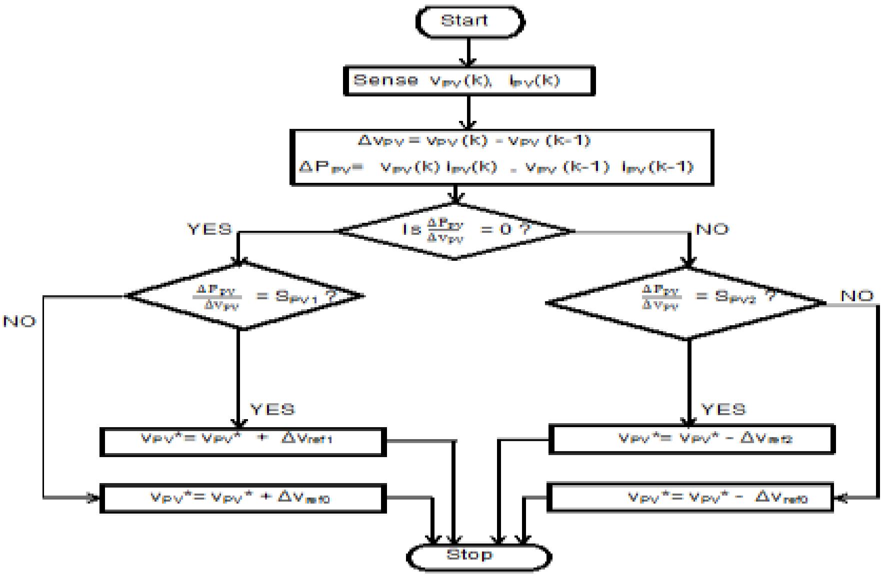

Figure 4. Flow chart of the variable step-size MPPT

VII. Simulation Results

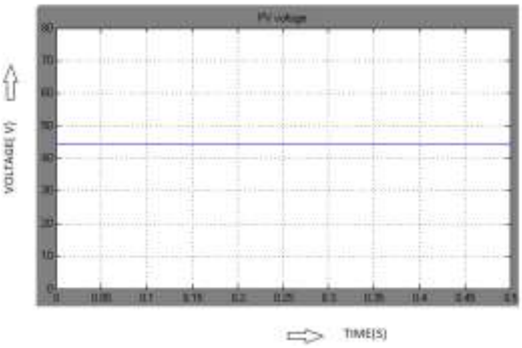

Figure 5. Input PV voltage

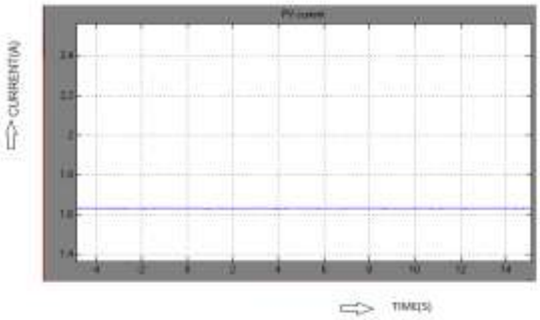

Figure 6. Input PV current

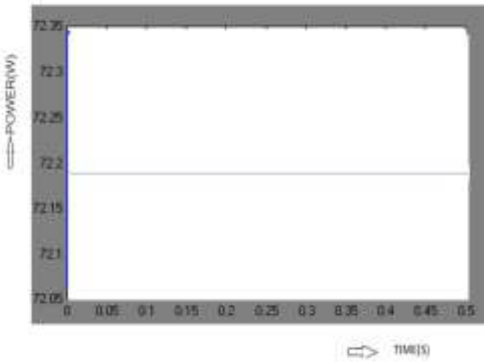

Figure 7. Input PV power

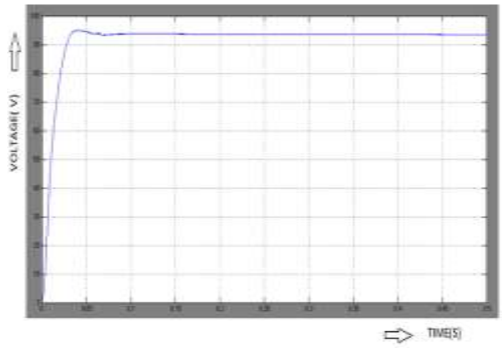

Figure 8. PV output using MPPT

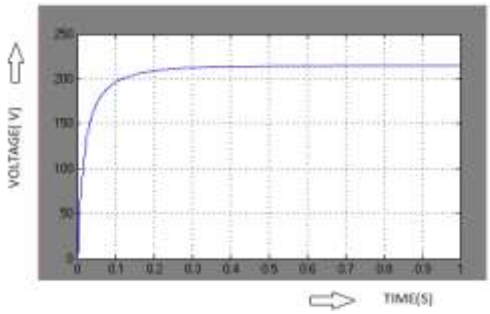

Figure 9. Boost converter output voltage

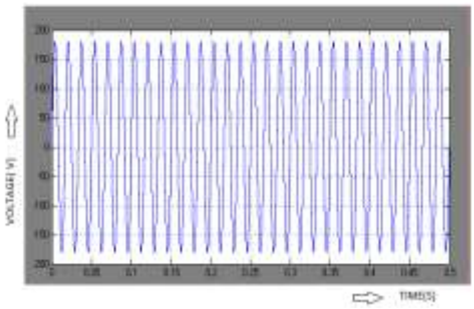

Figure 10. Output AC voltage

VIII. Conclusion

A boost-half-bridge micro inverter for grid-connected PV systems has been presented. The minimal use of semiconductor devices, circuit simplicity, and easy control, the boost-half-bridge PV micro inverter possesses features of low cost and high reliability. The boost- half-bridge dc–dc converter has a high efficiency (97.0%–98.2%) over a wide operation range. And also the current injected to the grid is regulated precisely and stiffly. Under both heavy load and light load conditions, high power factor (>0.99) and low THD (0.9%–2.87%) are obtained. The ramp-changed reference generated by the customized MPPT method for the PV voltage regulation guarantees a correct and reliable operation of the PV micro inverter system. Fast MPP tracking speed and a high MPPT efficiency (>98.7) is achieved by the variable step-size technique provides a correct and reliable operation of the PV micro inverter system.

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