

MATLAB Simulation of Partial Power Converter with Dual-Mode Inverter for Solar Conversion

Koushik Middhe^{1,*}, Chandrakala Rathlavath¹, Lavanya Attepu¹, V. Dhanunjaya²

Abstract

The growing insertion of solar photovoltaic (PV) systems in the modern power systems requires high-efficiency, compact and reliable power conversion solutions. The traditional PV conversion system generally uses full-power processed DC-DC converters followed by inverters, which increases conduction and switching power losses, especially at higher power ratings. To overcome these challenges, this paper proposes a partial power processed resonant converter with a dual-mode transformer-less inverter for efficient solar PV power conversion. In the proposed system, only a portion of the total solar PV power is processed through the DC-DC converter stage, and the rest of the power is directly fed to the DC link, thus resulting in a substantial reduction in overall power losses. A series resonant DC-DC converter is used to realize soft-switching, which reduces switching stresses and improves system efficiency. The dual-mode transformer-less inverter validates flexible system operation for different PV and loading conditions while ensuring high power quality. The proposed system is modeled and simulated using MATLAB/Simulink and its performance analyzed for various operating conditions. A comprehensive comparison analysis with a conventional full-power processed solar PV conversion system is conducted in terms of system efficiency, power processing ratio, switching power losses, and total harmonic distortion (THD). Simulation results confirm that the proposed system ensures higher conversion efficiency and lower power losses while ensuring compliant power quality, thus making it a prospective solution for high-efficiency solar PV systems.

Keywords: Boost-type partial power converter, dual-mode inverter, MPPT, DC link, Series resonant converter, soft-switching, ZVS/ZCS

INTRODUCTION

The increasing trend towards the use of clean and sustainable energy sources has contributed significantly to the increased adoption of solar photovoltaic (PV) systems in the past few years. Solar PV systems are widely used because of their abundance, eco-friendliness, and suitability for decentralized energy generation. Nevertheless, the electrical current generated by solar PV systems varies naturally, as it is largely dependent on solar irradiance and temperature [1].

*Author for Correspondence

Koushik Middhe
E-mail: 23215a0203@bvr.it.ac.in

¹Student, Department of Electrical and Electronics Engineering, BV Raju Institute of Technology (JNTUH), Narsapur, Medak, Telangana, India

²Assistant Professor, Department of Electrical and Electronics Engineering, BV Raju Institute of Technology (JNTUH), Narsapur, Medak, Telangana, India

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Conventional solar PV systems commonly use full-power processing topologies, in which the entire generated power is processed by DC-DC converters and DC-AC inverters. Although this topology is simpler to control and guarantees power conditioning, it has several limitations. The processing of the entire generated power using multiple conversion stages results in increased switching and conduction losses, increased thermal stress on the semiconductor devices, and decreased overall system efficiency. As the power generated increases, these losses become more severe, requiring increased heatsinks and decreasing system reliability with time [2].

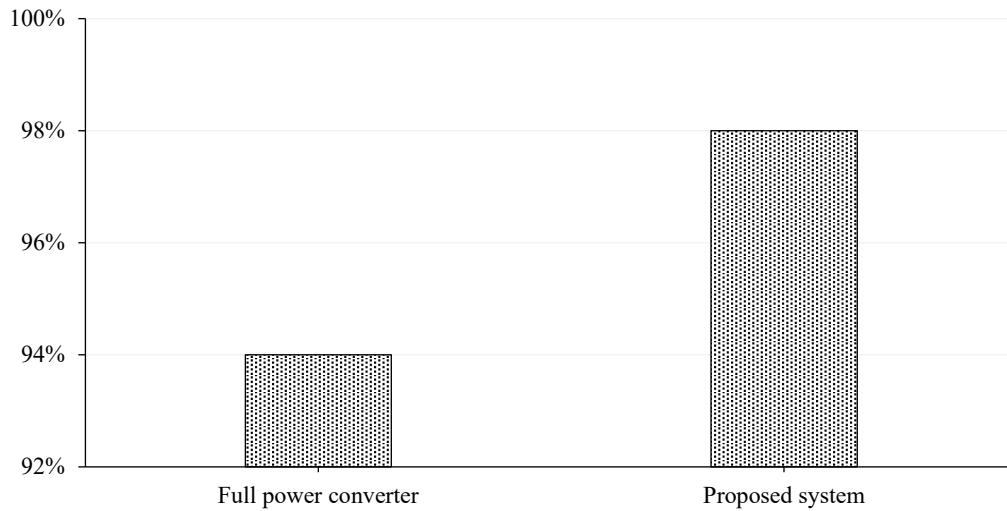


Figure 1. Efficiency comparison graph.

To overcome these problems, partial power processing (PPP) has been proposed as a promising alternative to traditional full-power conversion. In PPP-based systems, only a portion of the overall PV power is processed by the power converter, and the remainder is delivered directly through a bypass path. This method significantly reduces the amount of processed power handled by the active switching components, resulting in lower power losses, improved efficiency, and reduced thermal stress [3].

Resonant power converters have recently received considerable attention owing to their capability to support soft-switching operations. By achieving zero-voltage switching (ZVS) and zero-current switching (ZCS), resonant converters significantly reduce switching power losses and electromagnetic interference, allowing for high-frequency switching and miniaturized system design [4]. Among the different types of resonant converters, series resonant converters are more appropriate for PV systems that require high efficiency and small size from Figure 1.

BOOST-TYPE PARTIAL POWER CONVERTER

In conventional PV systems using full-power DC-DC converters, the entire PV power is processed through the switching components before being supplied to the load or grid, leading to increased losses. To overcome these difficulties, a Partial Power Processed (PPP) boost converter, as shown in Figure 2, is proposed, in which only a fraction of the overall PV power, specifically the differential voltage component, is processed through the boost converter, whereas the remaining overall PV power is supplied to the DC link.

In the proposed system, a PV array is connected to a DC-link voltage that is slightly higher than the operating voltage of the PV array. A boost converter is used to process only the difference between the PV array voltage and DC-link voltage. This greatly reduces the amount of power processed through the switching components of the boost converter compared with conventional systems. The key advantages of this technology are reduced switching losses, increased efficiency, smaller thermal requirements, and higher power density [5–7].

Modes of Operation

Switch ON State

When the IGBT is switched ON, the diode becomes reverse-biased, and the inductor stores energy from the PV source. During this time, the DC link capacitor supported the load. The inductor current increases linearly owing to the applied voltage from the PV source.

- Inductor voltage:
- Inductor current slope:

$$V_L = V_{PV}$$

$$di_L / dt = V_{PV} / L$$

- For the given system

$$V_{PV} = 450 \text{ V}, L = 2 \text{ mH}$$

For a switching frequency $f_s = 10 \text{ kHz}$ and duty cycle D , the ripple current is

$$\Delta I_L = (V_{PV} \times D) / (L \times f_s)$$

$$\text{With } D = 0.357: \Delta I_L = (450 \times 0.357) / (0.002 \times 10000) = 8 \text{ A}$$

Switch OFF State

When the IGBT is switched off, the diode becomes forward-biased, and the energy stored in the inductor is transferred to the DC-link capacitor, causing the output voltage to be higher than the PV voltage.

Inductor voltage:

$$V_L = V_{PV} - V_{DC}$$

Under steady-state CCM operation, volt-second balance gives:

$$V_{DC} = V_{PV} / (1 - D)$$

$$D = 1 - (V_{PV} / V_{DC})$$

$$\text{For } V_{PV} = 450 \text{ V}, V_{DC} = 700 \text{ V}: D = 1 - (450 / 700) = 0.357$$

The output DC-link current is determined from power balance:

$$I_{DC} = P_{PV} / V_{DC}$$

$$P_{PV} = V_{PV} \times I_{PV} = 450 \times 65 = 29.25 \text{ kW}$$

$$I_{DC} = 29250 / 700 = 41.8 \text{ A}$$

Thus, the converter steps up the voltage from 450 to 700 V while reducing the current from 65 to approximately 42 A.

Partial Power Calculation

The differential voltage handled by the converter is:

$$\Delta V = V_{DC} - V_{PV} = 700 - 450 = 250 \text{ V}$$

The fraction of power processed is:

$$P_{PPP} / P_{PV} = \Delta V / V_{DC} = 250 / 700 = 0.357$$

So the processed power is:

$$P_{PPP} = 0.357 \times 29.25 = 10.4 \text{ kW}$$

Therefore, the Total PV power was 29.25 kW, power processed by the boost stage was 10.4 kW, and directly transferred power was 18.85 kW. Approximately 64.3% of the total power bypasses the active switching.

Selection of Components

The boost inductor is selected such that the converter operates in continuous conduction mode (CCM) while maintaining an acceptable current ripple. The inductor value is calculated as:

$$L = (V_{PV} \times D) / (\Delta I_L \times f_s)$$

$$L = (450 \times 0.357) / (8 \times 10000) = 2 \text{ mH}$$

The DC-link capacitor ensures voltage stability and minimizes the ripple. The DC-link current from power balance is $I_{DC} = 29250 / 700 = 41.8 \text{ A}$. Considering the small voltage ripple, a capacitor value of $C = 5000 \mu\text{F}$ was selected. The boost converter uses an IGBT as the main switch and a fast-recovery diode for energy transfer during the off state. Tables 1 and 2 show the converter and its design specifications.

Table 1. Specifications.

Parameter	Specifications
Rated power (per module)	218.87 W
Rated voltage at MPP	29.3 V
Rated current at MPP	7.47 A
Open circuit voltage	36.6 V
Short circuit current	7.97 A
No of panels	117(13s × 9p)
Operating temperature	25°C
Irradiance	1000 W/m ²

Table 2. Converter and design specifications.

Parameter	Specifications
Input voltage	450 V
Output voltage	700 V
Input current	66 A
Input power	29.7 kW
Power processed	10.6 kW
Switching frequency	10 kHz
Duty cycle	0.357
Boost inductor	2 mH
DC link capacitor	5000 μF

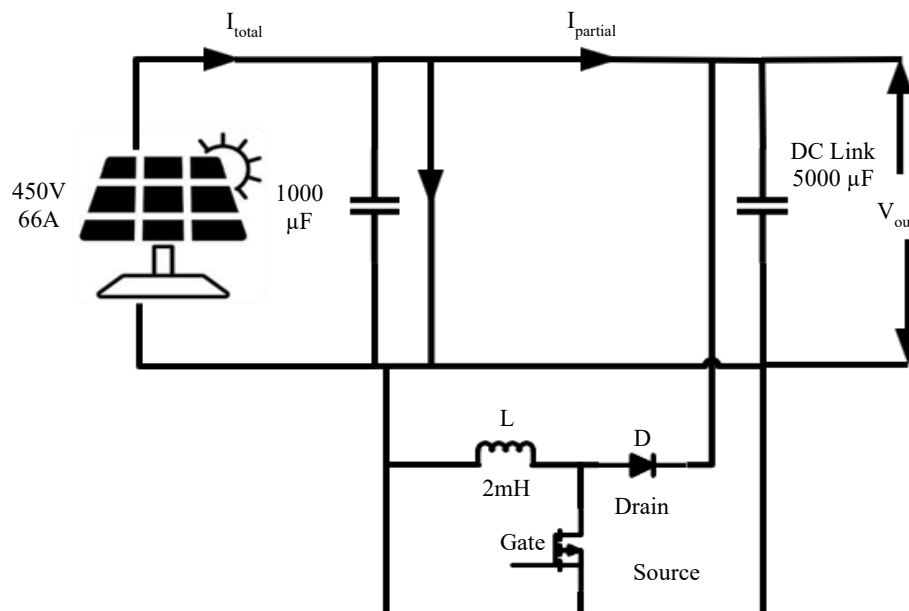


Figure 2. Boost-type partial power processed (PPP) converter circuit diagram.

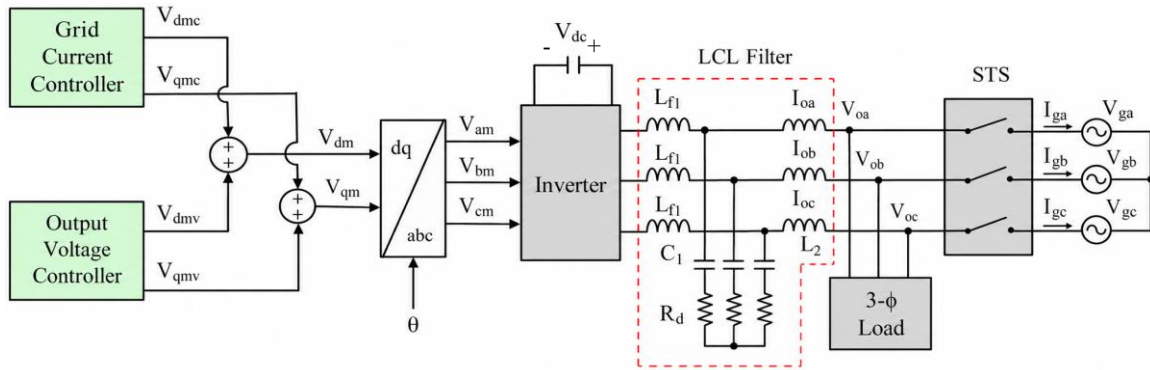


Figure 3. Dual mode inverter.

DUAL MODE INVERTER

The proposed system, as shown in Figure 3, employs a three-phase dual-mode voltage source inverter (VSI) to interface the regulated DC power obtained from the series resonant converter (SRC) with either the utility grid or a standalone load. The SRC provides a stable DC-link voltage of approximately 700 V, which acts as the input to the inverter. The inverter converts this DC voltage into three-phase AC power through pulse-width modulation (PWM) switching of six semiconductor switches. The inverter operates in two modes: grid-connected and standalone load modes, which are selected using manual three-phase breakers.

The three-phase breakers are connected between the inverter output filter inductors and grid/load terminals. When the grid breaker is closed, the inverter operates in a grid-connected mode and injects power into the grid. When the grid breaker is opened, the load breaker is closed, allowing the inverter to support a standalone load. This operation is performed smoothly while maintaining system stability [8].

Grid-Connected Mode Operation

For grid-connected mode operation, the inverter is synchronized to the grid voltage using a phase-locked loop (PLL) circuit. The PLL extracts the grid phase angle θ to perform a Park transformation of the three-phase grid voltages and inverter output currents into a synchronously rotating reference frame:

$$\begin{aligned} [v_d] &= 2 [\cos\theta \cos(\theta-2\pi/3) \cos(\theta+2\pi/3)] [v_a] \\ [v_q] &= -[-\sin\theta -\sin(\theta-2\pi/3) -\sin(\theta+2\pi/3)] [v_b] \end{aligned}$$

The instantaneous active and reactive power injected into the grid are expressed as:

$$\begin{aligned} P &= (3/2)(v_d \cdot i_d + v_q \cdot i_q) \\ Q &= (3/2)(v_q \cdot i_d - v_d \cdot i_q) \end{aligned}$$

For unity power factor operation, the reactive current reference is set to zero:

$$i_{q_ref} = 0$$

Thus, the active power delivered to the grid becomes:

$$P = (3/2) \times v_d \times i_d$$

The DC link voltage is regulated by comparing the measured DC voltage V_{dc} with the reference value $V_{dc_ref} = 700$ V. The resulting error is processed through a PI controller that generates the reference current i_{d_ref} . The inverter output voltages generated by PWM switching are

$$\begin{aligned} v_a &= m \times (V_{dc}/2) \times \sin(\omega t) \\ v_b &= m \times (V_{dc}/2) \times \sin(\omega t - 120^\circ) \end{aligned}$$

$$v_c = m \times (V_{dc}/2) \times \sin(\omega t + 120^\circ)$$

Standalone Load Mode Operation

When the grid breaker is opened and the load breaker is closed, the inverter operates in a standalone mode, behaving as a voltage-controlled AC source that supplies power directly to the local load. The inverter generates three sinusoidal reference signals internally:

$$v_a = V_m \times \sin(\omega t)$$

$$v_b = V_m \times \sin(\omega t - 120^\circ)$$

$$v_c = V_m \times \sin(\omega t + 120^\circ)$$

These reference signals were compared with a high-frequency triangular carrier waveform to produce PWM switching signals for the inverter switches. The output filter inductors smooth the switching waveforms and generate sinusoidal output currents. The power delivered to the standalone load is

$$P_{load} = \sqrt{3} \times V_{LL} \times I_L \times \cos \phi$$

COMPUTATIONAL STUDIES

To validate the effectiveness of the proposed partial power-processed resonant converter integrated with a dual-mode inverter, detailed computational studies were conducted using MATLAB/Simulink. The complete system, consisting of a PV array, PPP boost converter, series resonant converter (SRC), and three-phase dual-mode inverter, was modeled using Simscape Electrical blocks.

The PV array delivered nearly 450 V and 65 A, equaling a rated power of nearly 29 kW under standard conditions. The delivered power is processed through the PPP boost converter, where only the differential power is handled by the switching stage, and the remaining power is transferred directly to the DC link.

The SRC further regulates the DC-link voltage to approximately 700 V, thereby ensuring stable inverter operation. The inverter is controlled using a synchronous reference frame (dq-axis) control strategy to regulate the active and reactive power flow in both the grid-connected and standalone modes [9, 10].

The computational studies focused on evaluating the system performance in terms of partial power processing capability, loss reduction, efficiency improvement, and harmonic performance (Table 3).

Table 3. Comparison table.

Sl. No	Parameters	Conventional converter	Proposed system	Improvements
1	Power Processed by Converter	100% of total power	30–40% of total power	Reduced converter stress
2	Converter Losses	High	Low	Improved efficiency
3	Efficiency	92–94%	95–98%	+3–5% increase
4	Switching Losses	High (Hard switching)	Very Low (ZVS/ZCS in SRC)	Significant reduction
5	Thermal Stress	High	Low	Increased lifespan
6	DC-Link Voltage Stability	Moderate ripple	Very low Ripple (690–700 V)	Improved stability
7	Transient Response	Slower	Faster (≈ 0.2 s settling)	Better dynamic response
8	Harmonic Distortion	Higher	Lower	Improved power quality
9	Real Power Injection	Less accurate	Close to theoretical (25–30 kW)	Improved tracking
10	Reactive Power	Non-zero (lagging/leading)	≈ 0 kvar	Unity power factor
11	Converter Rating	Full rated	Reduced rating	Cost reduction

SIMULATION RESULTS

The combined simulation results demonstrate the overall performance of the proposed partial power-processed (PPP) solar PV system.

From the PV characteristics shown in Figure 4–7, we can observe that the PV voltage stabilizes at approximately 450 V and the current settles at approximately 65 A after a small transient period, resulting in a steady output power of approximately 29 kW, which confirms proper MPPT operation.

The partial power processed by the boost converter, as shown in Figure 8, is approximately 9.5–10.4 kW, which proves that only approximately 35% of the total power is handled by the converter, while the remaining power is directly transferred to the DC link, reducing the switching losses and converter stress.

The DC link voltage, as shown in Figure 9, initially shows a small overshoot during startup but quickly settles between 690 and 700 V within 0.2 s, indicating good voltage regulation and fast dynamic response.

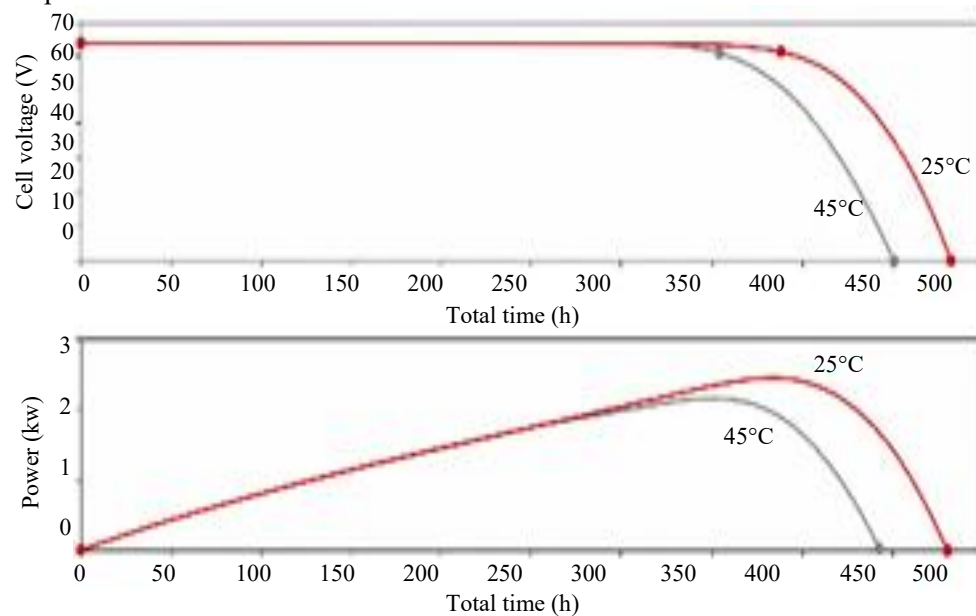


Figure 4. I-V and P-V characteristics.

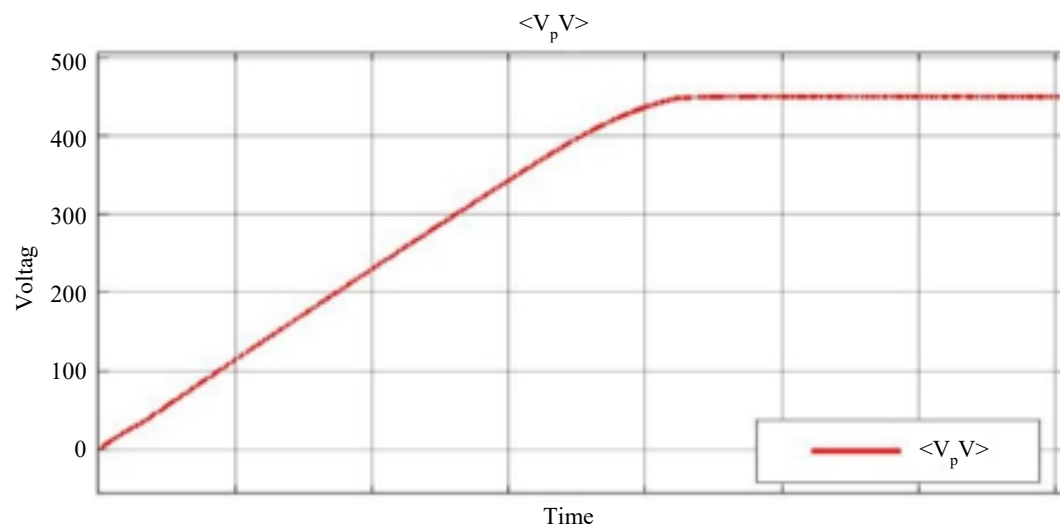


Figure 5. PV voltage waveform.

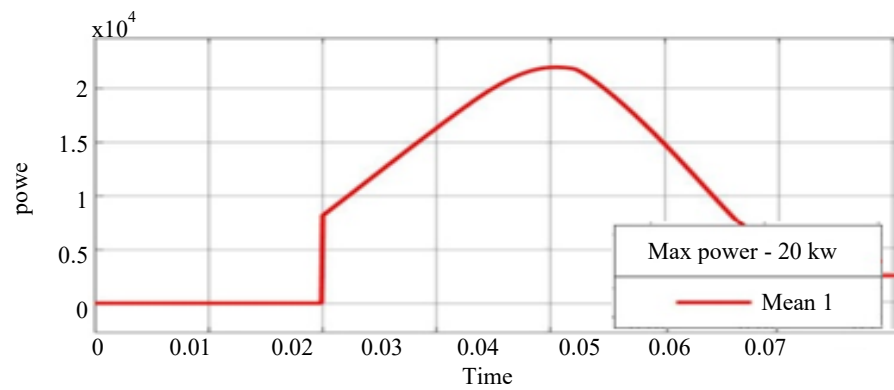


Figure 6. PV power waveform.

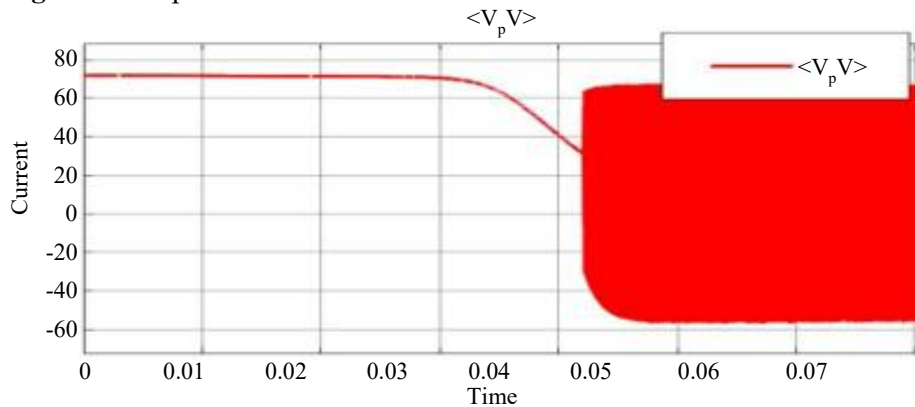


Figure 7. PV current waveform.

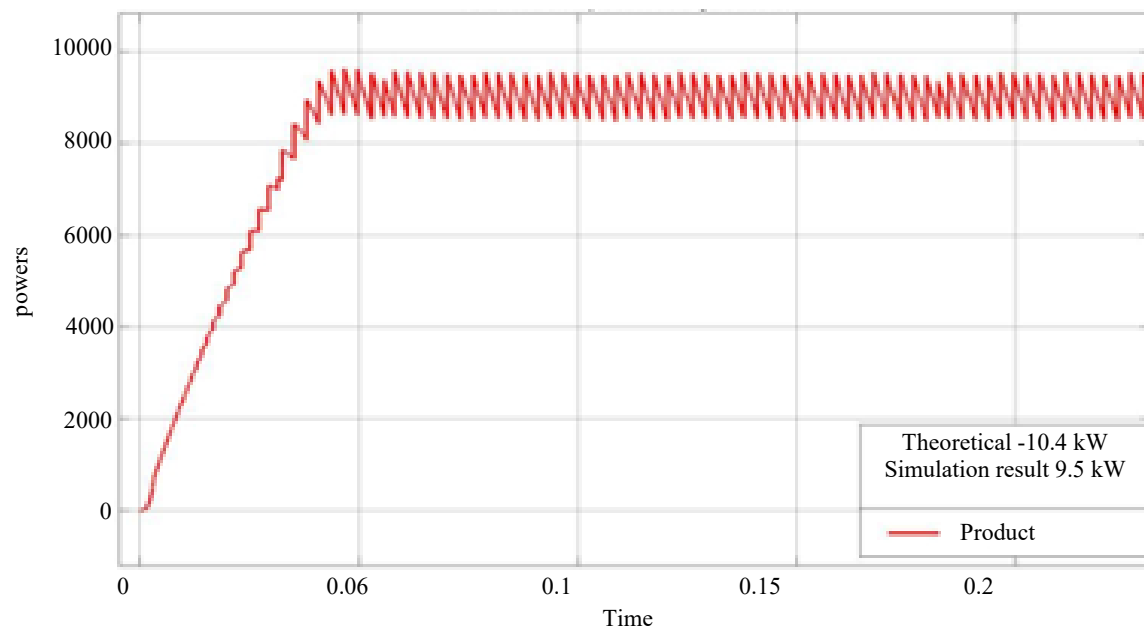


Figure 8. PPP by converter waveform.

The inverter real power output, as shown in Figure 10, gradually increased after synchronization and stabilized at approximately 25–30 kW, which is close to the theoretical value, confirming efficient power delivery.

Simultaneously, the reactive power, as shown in Figure 11, settles near zero after transient oscillations, proving that the inverter operates at a unity power factor with proper dq-axis control.

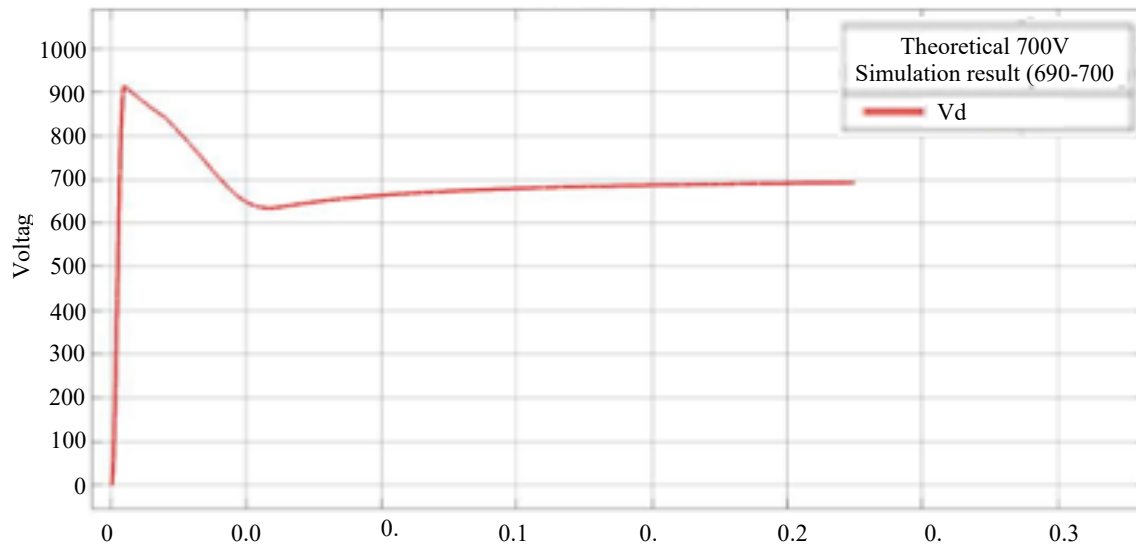


Figure 9. Dc link voltage waveform.

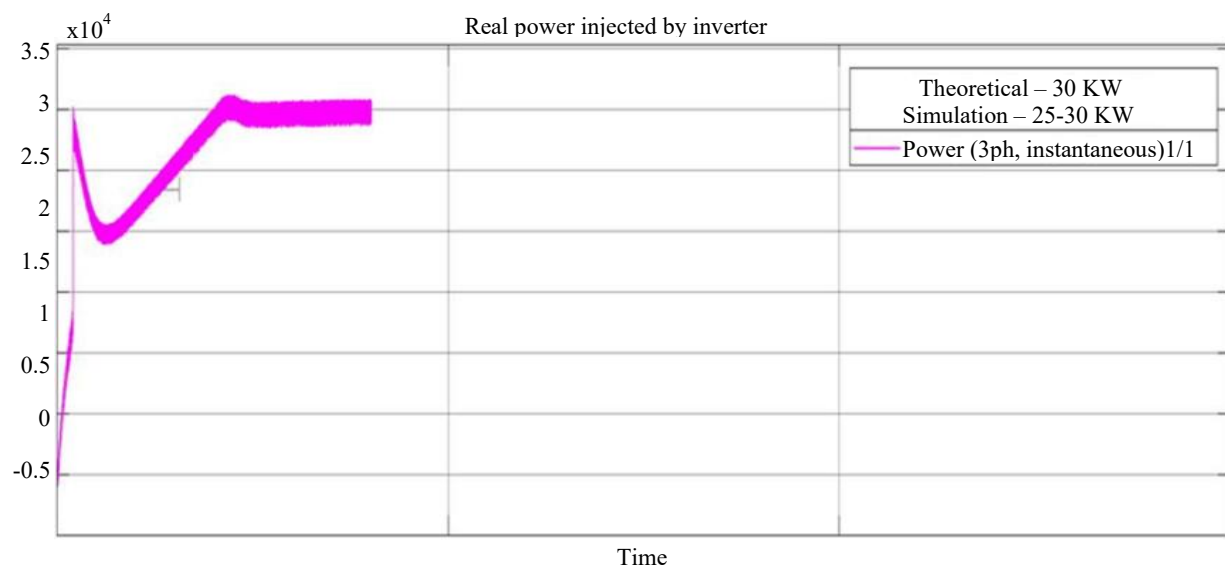


Figure 10. Inverter real power output waveform.

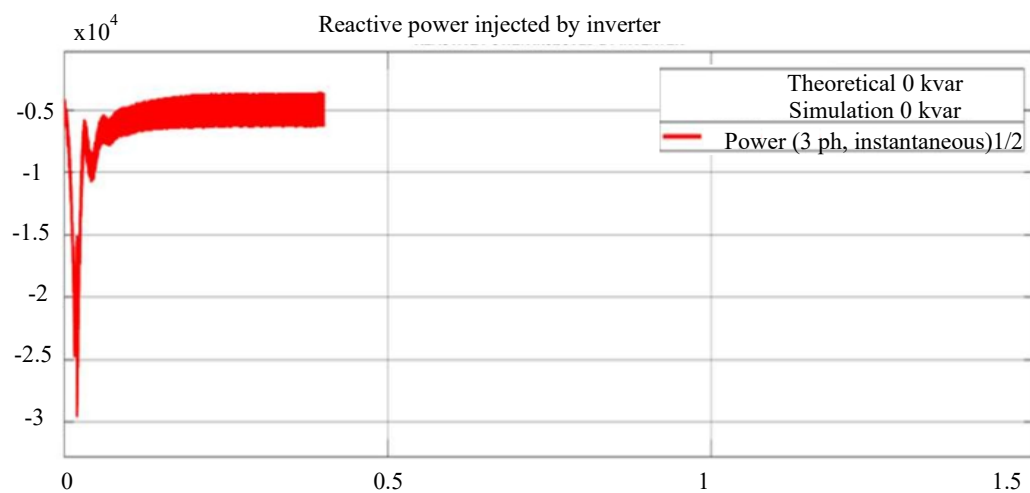


Figure 11. Inverter reactive power output waveform.

Overall, the simulation results confirm improved efficiency, reduced converter losses, stable DC link voltage, fast transient response, and good power quality compared with the conventional full-power converter system.

CONCLUSION

In this study, a photovoltaic power conversion system based on Partial Power Processing (PPP) and integrated with a Series Resonant Converter (SRC) and dual-mode inverter is proposed for efficient energy transfer during grid-connected and standalone modes of operation.

The proposed system processes only a portion of the total power generated, resulting in reduced losses and thermal stress on the power electronic devices. The Series Resonant Converter (SRC) offers a soft-switching capability (ZVS/ZCS), which results in reduced losses and electromagnetic interference, thus enhancing the system efficiency. The SRC also provides voltage regulation, thereby enhancing the overall system performance.

The simulation results validate the effectiveness of the proposed system. The partial power processed was significantly less than the total power generated, validating the key advantage of PPP operation.

The DC link voltage is regulated to approximately the reference value of 700 V with a negligible ripple. The dual-mode inverter guarantees reliable operation in both the grid-connected and stand-alone modes, providing a stable real power injection of approximately 25–30 kW, which is close to the theoretical value. Furthermore, the system maintains near-zero reactive power, ensuring a unity power factor. The controllers exhibited a fast transient response with settling times within 0.2 s.

Overall, the proposed system, which combines the PPP architecture, SRC-based soft-switching converter, and dual-mode inverter control, demonstrates superior performance in terms of efficiency, converter stress, and power quality, making it a promising tool for advanced photovoltaic energy systems.

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