ISSN (Online): 2583-7052

International Journal of Advanced Trends in Engineering and Management (IJATEM)
Vol. 03 (08), August 2024, pp. 01-14

Article Title: Crow Search Optimized Pi Control Approach for Photovoltaic Connected Grid System

Crow Search Optimized Pi Control Approach for Photovoltaic Connected Grid System

E. Immanuvelbright

Assistant Professor, Department of Electrical and Electronics Engineering, Erode Sengunthar Engineering College, Perundurai, Erode, 638057, India. immanuvelbright@gmail.com

ABSTRACT

This paper presents an advanced Photovoltaic (PV) grid connected system utilizing a Superlift Luo Converter (SLC) to enhance energy conversion efficiency and system performance. The proposed system integrates a Crow Search Algorithm (CSA) optimized Proportional Integral (PI) controller to regulate the output of SLC. The SLC is employed to boost the voltage from the PV panels, enhancing energy extraction. The VSI, controlled by the optimized PI controller, ensures stable and efficient power transfer to the grid. An LC filter is incorporated to mitigate harmonics and ensure compliance with grid standards. The use of CSA for PI controller optimization improves dynamic response and system robustness. This results accomplished using MATLAB demonstrate that the proposed system achieves high efficiency, improved stability, and superior grid compliance compared to conventional approaches. The comparative analysis presented in this work demonstrates that the proposed approach significantly outperforms traditional methods, achieving an impressive efficiency of 95.2%. This highlights the effectiveness of the new system in optimizing performance, making it a valuable alternative to established techniques. This approach highlights the effectiveness of combining advanced converter topologies and optimization techniques to enhance PV grid-connected systems.

Keywords: Photovoltaic (PV) System, Super Lift Luo Converter, Optimized PI Controller, Single-Phase VSI (Voltage Source Inverter), Grid Integration

1 Introduction

As the demand for Renewable Energy Sources (RESs) increases, PV systems are becoming crucial in reducing dependence on fossil fuels [1]. However, integrating PV systems into the electrical grid presents challenges such as efficient power conversion and maintaining grid stability and power quality. Solar irradiation (G) and cell temperature (Tc) change throughout the day, affecting PV array power [2] [3]. Advancements in power electronics now enable photovoltaic (PV) systems to connect to either the grid (AC) or dedicated loads (DC). In DC systems, DC/DC boost converters are used to increase the DC voltage from the source to a higher level by varying the duty cycles of the circuit's switches [4].

In a PV connected grid system, various converters manage power flow and grid integration. The boost converter is essential for increasing DC voltage but faces efficiency losses, complex control, output ripple, and component stress [5]. The buck-boost converter allows bidirectional voltage adjustment with flexibility and a compact design but struggles with lower efficiency,

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higher ripple, and complex control [6]. The Cuk converter offers both step-up and step-down capabilities with high efficiency and stable output but has challenges with control complexity, component stress, and size [7]. The SEPIC converter handles voltage adjustments while maintaining polarity and delivering high efficiency but can be complex to control, stress components, and be bulky [8]. The Luo converter is effective for bidirectional voltage conversion with high efficiency but faces issues such as complex control, increased component stress, and a larger size [9]. To overcome all this converter, Single Leg Converter is employed in this work is simple and cost-effective but has limitations in voltage range, efficiency at extremes, output ripple, and component stress, making it less versatile compared to SEPIC, Luo, or Cuk converters [10].

To regulate the Super Lift Luo Converter operation, various controllers are available, including the Particle Swarm Optimization (PSO) [21] algorithm, which optimizes key parameters in PV connected grid systems through collective intelligence. While PSO enhances performance and sustainability, it become trapped in local optima. The Whale Optimization Algorithm (WOA) [22], inspired by humpback whales' hunting techniques, is effective in exploring large solution spaces but also suffers from premature convergence. Similarly, the Gray Wolf Optimization (GWO) [23] algorithm mimics the social hierarchy of gray wolves, providing strong convergence and versatility, though it may struggle with parameter sensitivity. The Firefly Optimization Algorithm (FOA) [24], which simulates fireflies flashing behavior, effectively explores the solution space but can face challenges in complex landscapes due to its sensitivity to parameters [11]. In contrast, the Crow Search Optimized PI Controller overcomes the limitations of all these controllers by offering enhanced adaptability and robustness, with a superior ability to balance exploration and exploitation, ultimately providing better performance in the Super Lift Luo Converter [25].

The demand for sustainable energy has boosted the use of photovoltaic (PV) systems in grid-connected applications, reducing carbon footprints. This system features the Super Lift Luo Converter for enhanced efficiency, Pulse Width Modulation (PWM) for precise control, and a Grow Search Optimized Proportional-Integral (PI) controller for stability. A one-phase Voltage Source Inverter (VSI) converts DC to grid-compatible AC, while an LC filter reduces harmonics and improves power quality. This integrated approach enhances solar energy efficiency and addresses grid integration challenges, supporting a sustainable energy future.

2 Related Works

Fazel Mohammadi *et al* (2023) [16] have proposed a PV connected grid system using Super Lift Luo Converter, an advanced DC-DC converter designed to enhance energy conversion efficiency and flexibility, particularly for high voltage gain applications. However, its complex design, which incorporates additional inductors and capacitors, complicates implementation and troubleshooting compared to simpler converters.

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Udoka C. Nwaneto *et al* (2023) [17] have implemented a PV connected power grid using the Dynamic Phasor (DP) method. This approach enables analytical calculations of maximum power point (MPP) voltage and current, with accuracy verified against a detailed switching model. However, its effectiveness decreases in highly nonlinear systems conditions, resulting in less reliable outcomes.

Bo Zhang *et al* (2021) [18] have developed a PV connected grid system using Linear Active Disturbance Rejection Control (LADRC) technology**.** This system integrates filter functions effectively to reduce noise pollution in voltage measurements. However, this integration adds complexity to the system, making it more challenging to implement and maintain compared to simpler control strategies.

Fubao Wu *et al* (2021) [19] have presented a PV connected grid system using Static Synchronous Generator (SSG). This study analyzes the impact of capacitor energy storage on system inertia and evaluates control parameters such as droop coefficient and DC voltage outer loop coefficients. However, tuning these controls is complex due to the interactions between the droop and proportional/integral coefficients, making optimal performance challenging.

Mahmoud F. Elmorshedy *et al* (2022) [20] have proposed a PV connected grid system using DC coupled hybrid microgrid. This system integrates solar PV and wind power generation using coordinated Model Predictive Control (MPC) techniques to optimize power generation. However, its complexity and costs, along with the need for specialized training, may deter organizations from investing in it and limit its usability.

3 Proposed System Description

Photovoltaic (PV) connected grid system that incorporates a solar PV array and a super lift Luo converter as shown in Fig 1. The converter efficiently boosts the voltage from the PV array, maximizing power output and enhancing energy conversion. To further improve system performance, a crow search optimized controller is employed, dynamically adjusting the converter parameters for optimal energy management. Additionally, a proportional-integral (PI) controller is integrated to enhance the stability and responsiveness of the system, ensuring accurate regulation of the output.

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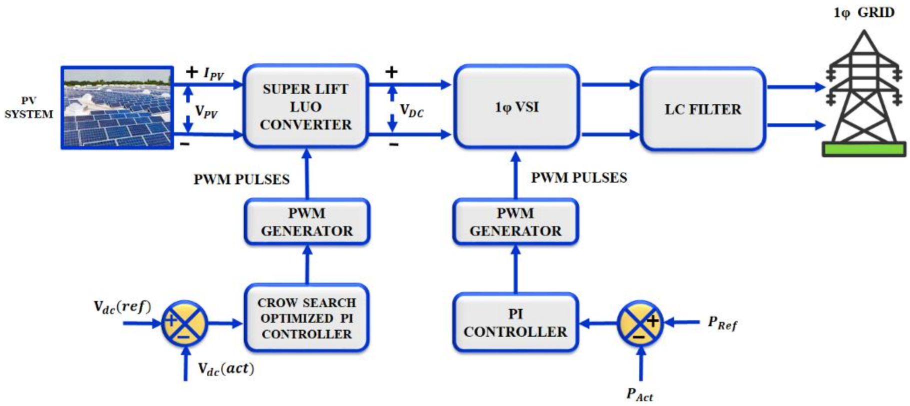

Figure 1: *Performance enhancement of PV connected grid system using optimized PI controller.*

A single-phase voltage source inverter (VSI) converts the boosted DC output into AC, ensuring compatibility with the grid. To minimize harmonics and improve output quality, an LC filter is included before the grid connection. This comprehensive control strategy facilitates seamless integration into the grid, providing a reliable and efficient renewable energy supply. The system enhances the performance of the PV setup while ensuring effective energy management and compliance with grid standards.

4 Proposed System Modelling

4.1 Photovoltaic (PV) Array

In PV system modeling, a PV array converts sunlight into electrical energy by connecting multiple solar panels in series and parallel to achieve the desired voltage and current output. Made up of silicon solar cells assembled into modules, the array's performance is represented by its current voltage (I-V) curve, Fig 2 shows PV cell circuit, voltage change under varying conditions. The photovoltaic (PV) array is modelled using the single-diode model, which defines its current-voltage characteristics. The output current I_{pv} is given by,

$$I_{pv} = I_{ph} - I_0(e^{\frac{qV_{pv}}{KT}} - 1) \tag{1}$$

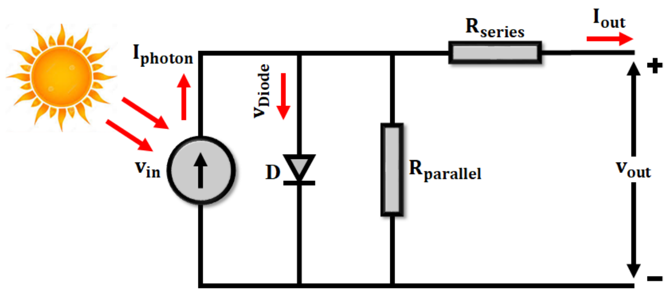

Figure 2: *PV cell circuit.*

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Here, I_{ph} is the photo generated current, I_0 is the reverse saturation current, q is the charge of an electron, k is Boltzmann's constant, T is the temperature in kelvin, and V_{pv} is the output voltage. This model effectively captures the relationship between current and voltage under varying conditions, facilitating the analysis of the PV system performance.

4.2 Super Lift Luo Converter

The Super-Lift Luo Converter is pivotal in a PV connected grid system, adjusting DC voltage levels with high efficiency and significant voltage gain. It operates by utilizing switching equations to manage the duty cycle of its switches and the dynamics of its inductor and capacitor. The converter's performance is evaluated based on its voltage conversion ratio and efficiency, ensuring effective power adjustment and management as shown in Fig 3.

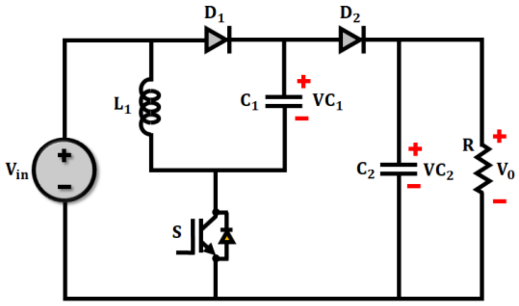

Figure 3: *Super Lift Luo Converter.*

4.2.1 Basic operation of super lift Luo converter

Mode 1

During switch on period DT the voltage V_{c1} across C_1 increase toV_{in}, while the current i_{L1} through inductor L_1 also increases rapidly due toV_{in}. At this point, diode D_2 becomes blocked. So i_{D2} = 0 and I_0=$\frac{V_0}{R}$. So that during model 1 will be (inductorL_1, is charged, capacitor C_1 is charged toV_{in}, capacitor C_2 is supplied the load, D_1 is ON and D_2 is OFF) [13].

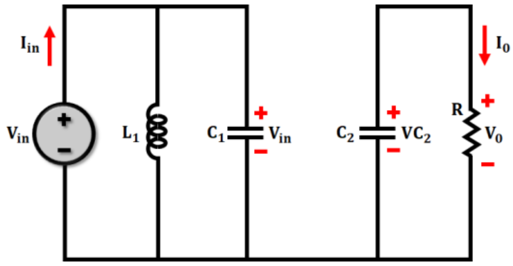

Figure 4: *Equivalent circuit of mode 1.*

The circuit equation of model derived as follows:

$$V_{L1} = V_0 \tag{2}$$

$$L_1 \frac{\Delta 1_{L1(closed)}}{DT} = V_0 \tag{3}$$

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$$\Delta i_{1,1(closed)} = \frac{V_0 DT}{L_1} = \frac{V_{in} DT}{L_1} \quad (4)$$

Mode 2

While switch off period$(1-D)T$, when switch S is opened, the inductor current i_{L1} flows through L_1, C_1 .At this time, diode D_1 is OFF and while D_1 is ON).

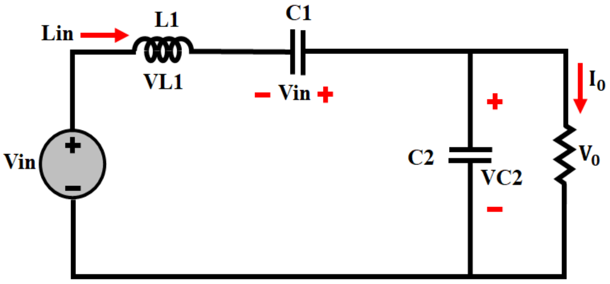

Figure 5: *Equivalent circuit of mode 2.*

During mode 2, the inductor current i_{L1} increase with voltage of $(V_0 - 2V_{in})$, In mode 1, the i_{L1} increase withV_{in}. This section includes current waveforms and the derivatives of the circuit equations.

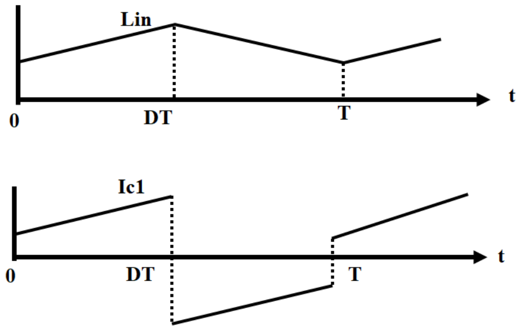

Figure 6: *Waveforms of currents.*

Then,

$$V_0 = V_{in} - V_{L1} + V_{in} \quad (5)$$

$$-V_{L1} = V_0 - 2V_{in} \quad (6)$$

$$-L_1 \frac{\Delta i_{L1(opened)}}{(1-D)T} = V_0 - 2V_{in} \quad (7)$$

$$\Delta i_{L1(opened)} = \frac{(V_0 - 2V_{in})(1-D)T}{L_1} \quad (8)$$

At steady state operation

$$\Delta i_{L1(closed)} + \Delta i_{L1(opened)} = 0 \quad (9)$$

$$\frac{V_{in}DT}{L_1} - \frac{(V_0 - 2V_{in})(1-D)T}{L_1} = 0 \quad (10)$$

$$\frac{V_{in}DT}{L_1} = \frac{(V_0 - 2V_{in})(1-D)T}{L_1} \quad (11)$$

$$\frac{V_{in}D}{(1-D)} = V_0 - 2V_{in} \quad (12)$$

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$$V_0 = \frac{2-D}{1-D} V_{in} \tag{13}$$

According to equation (12), the voltage transfer gain is:

$$G = \frac{V_0}{V_{in}} = \frac{2-D}{1-D} \tag{14}$$

4.3 Crow search optimized PI controller

Crows are incredibly intelligent beings recognized for their problem solving abilities. They monitor other birds trying to get food. Inspired by this behavior, Askarzadeh introduced a ground breaking method known as the Crow Search Algorithm (CSA), this approach treats search agents as crows in flock. Each crow remembers its food hiding spots and steal others, while moving randomly with certain probability.

The position of a crow is defined by

$$X_i^a = [X_i^a(1), X_i^a(2), \ldots, X_i^a(d)]^T \tag{15}$$

Where: a represents the crow's number, i denotes the iteration, and d refers to the search directions. In each iteration, two paths will be established for crow z to follow crow y.

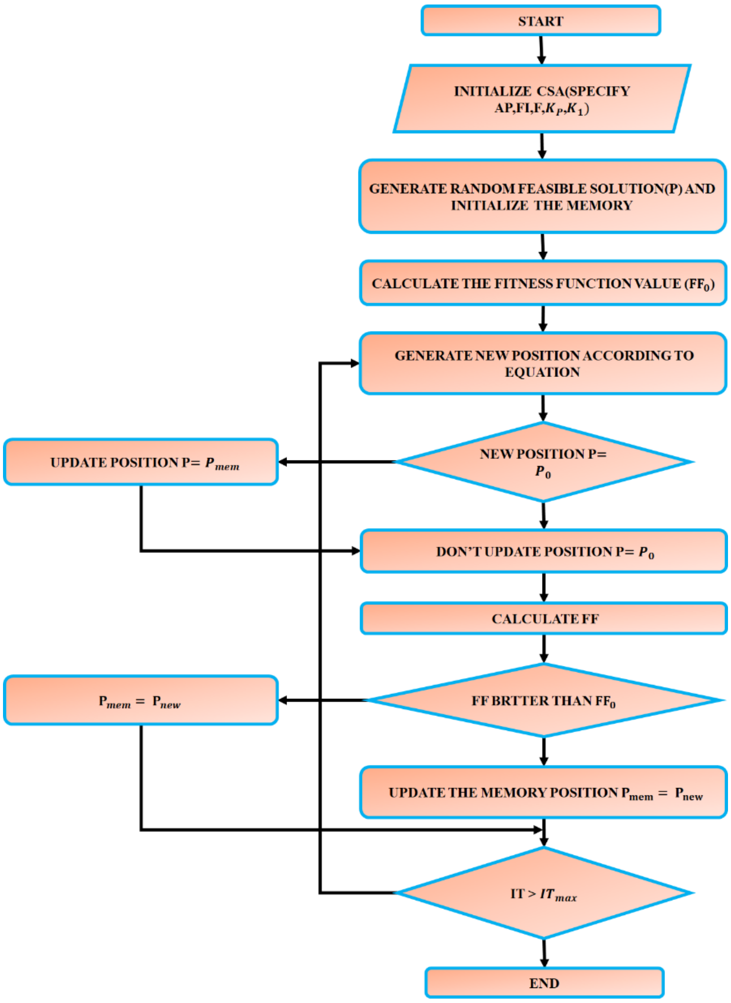

Figure 7: *CS optimized PI controller.*

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(a) Path 1: Crow a ignores crow b position and instead moves toward its best food source.

$$X_{i+1}^{a} = X_i^a + r^a\, f_i^a (m_i^b - X_i^a) \qquad r_b > A_i^a \tag{16}$$

Where: r^a is the random number, f_i^a represents flight length, and f defines the optimal points. A_i^a Indicates the crow's perceptual probability, and m_i^b is the food location of individual b.

(b) Path 2: Noticing crow z approach, crow y fly to a random spot.

$$X_{i+1}^{a} = random \tag{17}$$

After calculating position of all crows in i-th iteration, food source matrix m is updated.

$$X_{i+1}^{a} = random \tag{18}$$

The fitness of the crows is recorded and updated in each iteration. Fig 6 shows the CSA flow chart.

5 Results and Discussion

The proposed system utilizes a Crow Search Optimized PI Controller in conjunction with a Super Lift Luo Converter. This converter effectively boosts voltage and generates smooth waveforms, enhancing the overall performance of the photovoltaic system. The Voltage Source Inverter (VSI) converts the DC output to grid compatible AC with low Total Harmonic Distortion (THD), as demonstrated through MATLAB simulation. This configuration enables efficient power conversion and ensures high power quality, making it a reliable solution for grid connected PV applications. Additionally, integration of the Crow Search Algorithm for optimizing the PI controller parameters contributes to improved system stability and responsiveness. The success of this system creates opportunities for future research, especially in the investigation of adaptive control strategies, scalability for larger installations, and the integration of energy storage solutions to enhance reliability and performance in changing environments.

Specification Table

Parameter	Description
Solar PV System	
Open circuit voltage	37.25V
Short circuit voltage	8.95A
Series connected solar PV cell	3
Parallel connected solar PV cell	15.35
Maximum voltage	29.95V
Maximum Current	8.35A
Super Lift Luo	
L	1mH
C_1	4.7μF
C_2	2200 μF
Switching frequency	10KHz

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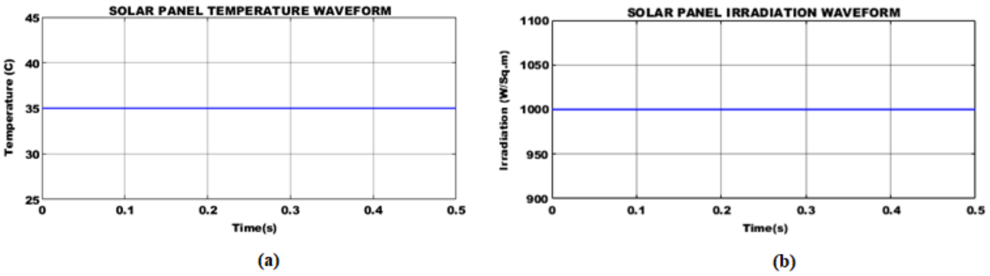

Figure 7: *System waveform: (a) temperature and (b) irradiation.*

Fig 7 illustrate waveforms of fluctuations in solar irradiation and temperature. Fig 7(a), the temperature rises from 25 °C to 35 °C in 0.25 seconds and Fig 7(b) depicts irradiation increasing from 800 W/m² to 1000 W/m² in 0.26 seconds. This rapid fluctuation are consistent.

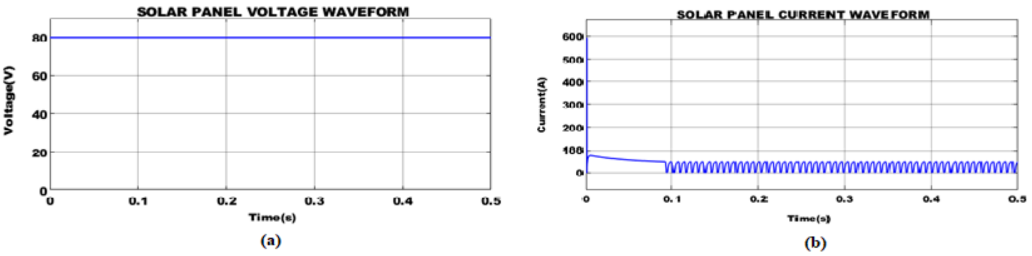

Figure 8: *PV panel waveform: (a) voltage and (b) current.*

The output current and voltage of the PV panel vary with changes in temperature and solar irradiation, as shown in Fig. 8. The voltage increases from 65 V to 80 V with rising irradiation, while the current sharply rises from 145 A to 900 A.

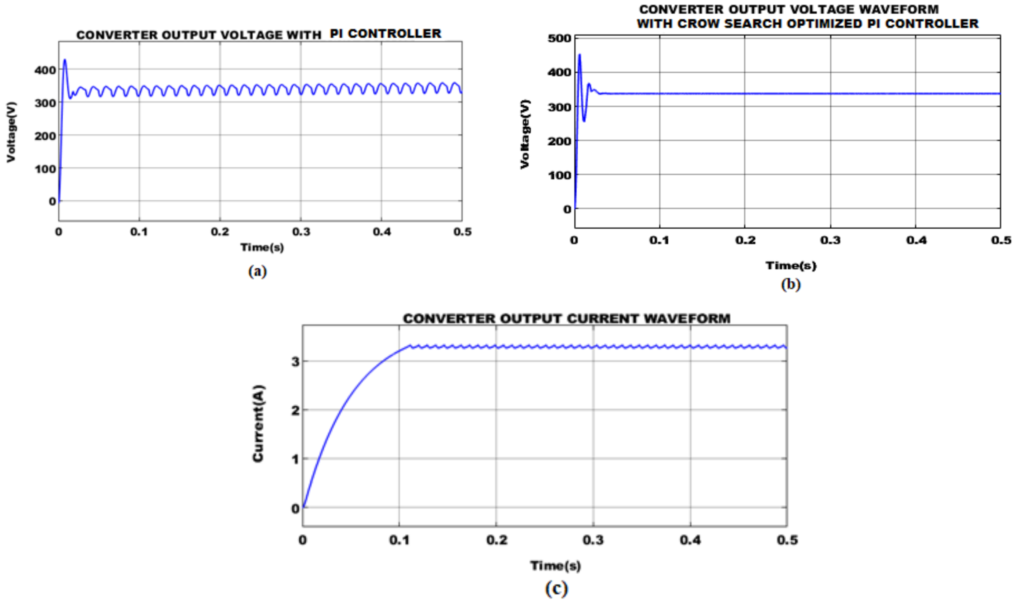

Figure 9: *Output converter waveform.*

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Figure 9 shows that the standard PI controller reaches 600 V in 0.4 seconds, whereas the Crow Search optimized PI controller achieves the same voltage in just 0.1 seconds, with a constant current of 3.5 A.

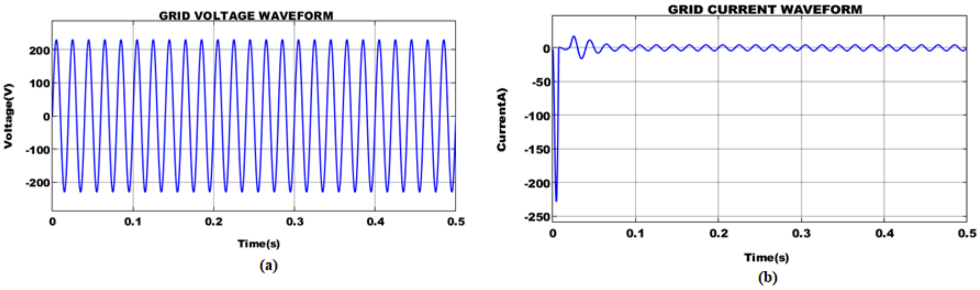

Figure 10: *Output waveform for grid: (a) voltage and (b) current.*

Fig 10 shows the output waveform of the grid system. Fig 10(a) illustrate the grid voltage output waveform is a constant 230V. Fig 10(b) shows the current waveform, with a negligible value of 8A.

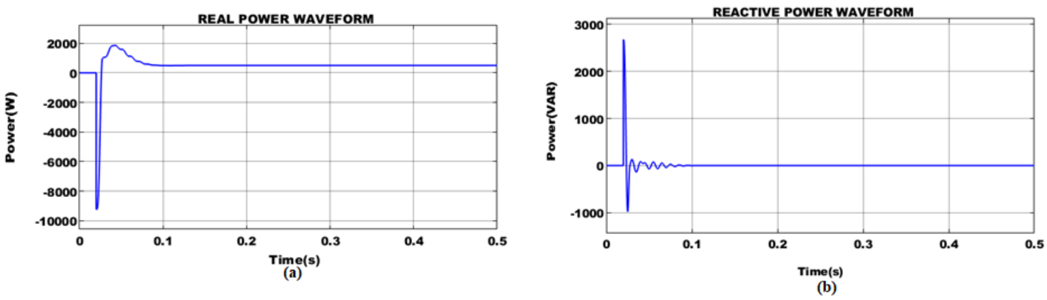

Figure 11: *Output grid waveform: (a) Real and (b) Reactive.*

Figure 11(a) depicts the real power waveform stabilizing after its peak. Figure 10(b) illustrates the reactive power waveform, which remains constant after a certain point.

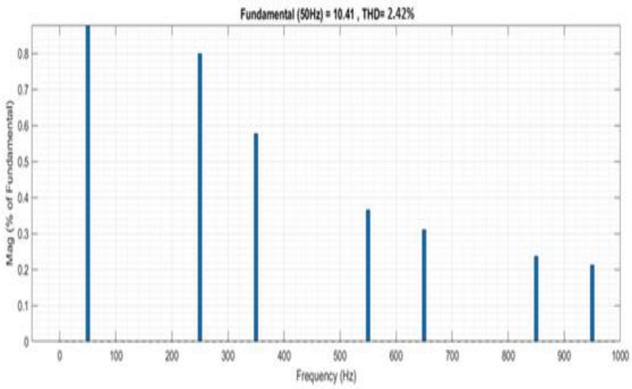

Figure 12: *THD Waveform.*

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Fig 12 shows the THD waveform, using the Crow Search Optimized PI Controller with the Super Lift Luo Converter reduces the Total Harmonic Distortion (THD) to 2.42%. This enhancement improves power quality and reduces strain on the electrical infrastructure, demonstrating the advantages of advanced control strategies in photovoltaic systems.

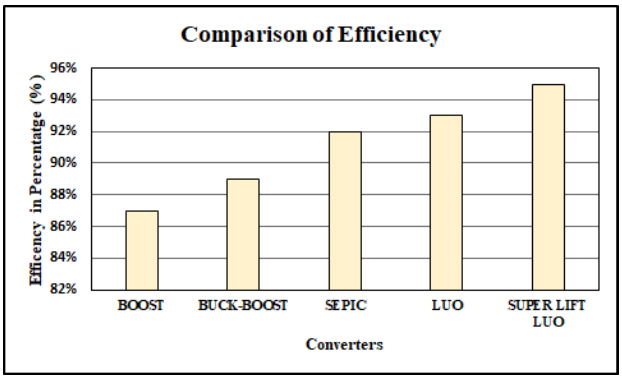

Figure 13: *Comparison of efficiency.*

Fig 13 denotes the efficiency of the proposed converter with existing topologies, including Boost, Buck-Boost, SEPIC, Luo, and Super Lift Luo. The Super Lift Luo integrated Luo converter achieves an efficiency of 95.2%, surpassing the other four, its combined features enhance voltage regulation with reducing fluctuations.

Table 2: *Settling Time Comparison.*

Controllers	Settling Time
PI	-
GA-PI	3.95s
PSO-PI	2.60s
CSO-PI	0.1s

Table 2 reveals that the proposed system exhibits lower settling time for the CSA than all other controllers, including GA and PSO.

6 Conclusion

The integrated modeling of the photovoltaic system, along with its components, effectively enhances energy efficiency and reliability in grid-connected applications. By utilizing advanced control strategies and optimized converters, the system achieves improved voltage regulation and reduced power losses. The seamless interplay between the PV arrays, super-lift Luo converter, optimized PI controllers, one-phase VSI, and LC filter ensures that the generated solar energy is efficiently converted and fed into the grid. This approach not only supports the transition to renewable energy sources but also contributes to the overall stability and resilience of the energy supply. From the comparative analysis in this work demonstrates that the proposed approach achieves better performance, with an efficiency of 95.2%, compared to traditional methods.

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