OPTIMIZED GRID LINKED PV SYSTEM WITH ZETA CONVERTER FOR ENHANCED EFFICIENCY

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ABSTRACT

The need for efficient converters is essential for the incorporation of solar PV systems with grid infrastructure to control voltage and maximize energy transmission. Using a Zeta converter and the Incremental Conductance (INC) MPPT algorithm, this study explores a grid-linked photovoltaic scheme. The Zeta converter plays a crucial role in stabilizing DC link voltage despite fluctuating solar irradiance, considering a consistent output between 290V and 600V.Through dynamic tracking and maintenance of the PV array's MPP, the INC MPPT approach improves system efficiency. In addition to optimizing energy extraction, this integrated strategy guarantees steady power transmission to the grid, reducing fluctuations and enhancing overall performance. The proposed scheme demonstrates significant improvements in voltage regulation, energy efficiency, and reliability, making it a viable solution for modern renewable energy applications.However, designing an optimal control strategy for the zeta converter is essential to balance the efficiency, transient response and voltage stability. Its ability to regulate voltage effectively enhances the performance of photovoltaic systems, preventing fluctuations from affecting downstream components. Proposed Simulation outcomes provide the efficacy of the proposed system under dynamic operating conditions, highlighting its effective power transfer. This study provides a comprehensive framework for implementing Zeta converters in Grid-linked PV schemes, bridging the gap between renewable energy generation and grid stability.

Keywords: *Grid-Linked PV Scheme, Zeta Converter, DC Link Voltage, Voltage Regulation, Renewable Energy*

1 INTRODUCTION

Grid-linked PV systems need effective power conversion due to naturally occurring fluctuations in solar energy. An essential component that helps regulate and boost the PV arrays unpredictable output to satisfy grid or linked load needs is a DC-DC converter. Peak performance and energy efficiency are ensured by these converters, which enable PV power to be smoothly incorporated into the existing grid design while preserving a constant DC link voltage.

In [1], a high voltage gain PV scheme using a Zero voltage transition (ZVT) boost regulator. This design addresses the challenge of low output voltage from PV arrays by efficiently boosting it to an elevated bus voltage. A full-bridge inverter is part of the scheme to control the output current and stabilize the potential. Low THD and a quick dynamic response are guaranteed by the incorporation of compensating units. A 2-kW prototype is used to test the implementation of a reduced MPPT approach, which lowers system complexity and costs. [2] focuses on a robust Model predictive control (MPC) approach for a boost regulator in a Grid-linked PV scheme. The Continuous-Time Model predictive control (CTMPC) predicts system behavior using Taylor series expansion and addresses prediction inaccuracies due to parametric uncertainties and external disturbances by incorporating a disturbance observer. The composite controller enhances dynamic performance and achieves robust voltage regulation, validated through experimental results. In [3], a hybrid control approach for a boost regulator in a Grid-linked solar PV scheme was investigated. The hybrid controller integrates an MPPT controller using the INC and a FLC to maintain stable DC output[4]. By connecting outputs of multiple PV-tied boost regulator in sequence, the system achieves dual functionalities of MPPT and voltage regulation. Simulation outcomes show the schemes capability to provide DC link voltage and maximize power under varying input and load conditions. In [5], a Grid-linked Photovoltaic System using a chaotic PWM based DC-DC MPPT circuit was analyzed. The proposed system incorporates a seven-level multilevel inverter to enhance energy injection into the grid while reducing switching frequency and improving reliability. A dual regulator with an active snubber circuit is used to extract and boost PV energy efficiently. The method is validated through experimental comparison with a parallel boost converter, showcasing improved efficiency and reduced switching losses.[6] presents a multiphase interleaved boost converter integrated with a PV module using the PO MPPT procedure. The system simulation and design are conducted in MATLAB/Simulink, incorporating a closed-loop three-phase inverter. The PO procedure is chosen for its faster dynamic response and superior PV output voltage regulation compared to the INC method, highlighting its applicability in Grid-linked PV schemes.

In [7], a two-stage Grid-linked PV scheme featuring a Cuk converter and INC MPPT procedure were presented. The study compares this design with a Grid connected Photo-voltaic System (GCPVS) using a Boost regulator, emphasizing the advantages of reduced current ripples at the load side due to the capacitor-based energy transfer in the Cuk converter. The single-stage system is noted for higher efficiency by eliminating additional losses associated with two-stage configurations. [8] Presents a new dual-leg architecture single-stage buck-boost inverter invention. Without utilizing a DC link capacitor, this inverter improves voltage control and lowers leakage current by reducing the number of passive components and switching frequency components. Verified by simulations and real-world testing, the suggested system is appropriate for PV applications for power conversion. Because of its multi-stage operation, it delivers excellent efficiency. Its continuous input current also decreases electromagnetic interference.

In [9], an MPPT procedure-based boost regulator designed for constant power generation in Grid-linked PV schemes was presented. The PV array model utilizes algebraic loops for accurate iterative solutions, ensuring dynamic control. The MPPT controller employs a Generalized PO procedure to adjust the duty ratio to obtain power under changing inputs. A 100kW PV module linked to a 25kV grid is modeled in MATLAB and benchmarked against existing systems, demonstrating superior performance and efficiency. An enhanced INC method for MPPT in grid-tied scheme is the main emphasis of [10]. For smooth integration with DC/AC converters, the technique optimizes the PV scheme's design characteristics, such as the boost converter's duty cycle, inductor, and capacitor. The method increases the efficiency of electricity generation while lowering the number of switches. MATLAB was operated to study the scheme's design and performance, demonstrating precise tracing of the highest power and high panel efficacy under various circumstances.

In [11], the limitations of conventional PV schemes in islanded operation and proposes the Synchronous Power Controller as a solution was discussed. Without changing the control structure, the SPC allows PV schemes to function flawlessly in both grid-linked and island modes. The Synchronous Power Controller (SPC) based solution enables grid-feeding converters to support islanded grid operation by including energy storage. Results from experiments and simulations show how well the SPC works to preserve system stability while guaranteeing a continuous power supply during grid disruptions. In order to directly integrate multi-megawatt PV energy competencies into medium-voltage networks, [12] investigates the development of low potential converters. Transformers and line filters are necessary for conventional low-voltage systems, which raises their cost and complexity. These parts are removed by medium-voltage converters, allowing for economical and effective grid integration. The article highlights the relevance of medium-voltage converter circuit topologies and control strategies in achieving global renewable energy objectives by reviewing recent research, technological difficulties, and possible developments in these areas.[13] Examines the state and developments of grid-linked PV schemes worldwide, with an emphasis on inverter operation and design for increased efficiency. The study discusses single- and three-phase inverter topologies and associated control strategies while classifying PV systems and inverter combinations. Emphasis is placed on key execution parameters like regulated grid power injection, MPPT efficiency, and minimal THD. To achieve high-performance grid-tied PV systems, the research also outlines future trends and inverter selection criteria.

The Zeta converter has benefits including improved regulation in dynamic situations and the ability to buck-boost voltage. It guarantees accurate tracking of the PV modules MPP even in the presence of fluctuating temperature and irradiance when combined with an effective MPPT procedure, like INC. This combination opens the door for dependable and effective solar energy use by addressing major issues with PV schemes, such as power fluctuations and grid instability. The zeta converter improves the power conversion efficiency by regulating the DC voltage output more effectively compared to traditional converters like buck-boost or SEPIC.

2 SYSTEM DESCRIPTION

A grid-linked solar PV scheme that effectively supplies solar electricity to the grid at a steady voltage and frequency (400 V, 50 Hz) is showed in Fig.1 The system is made up of a photovoltaic array that uses sunlight to create DC power. Temperature and sun irradiation have an impact on the PV modules output voltage and current. To continue a steady DC-link potential a Zeta converter is used to improve the PV modules fluctuating voltage. This provides system stability and compatibility with downstream components.

Using the INC MPPT algorithm, energy extraction is maximized. By continually monitoring the PV parameters to trace the MPP, it dynamically modifies the duty ratio of the Zeta. A 3-phase inverter receives the regulated DC electricity and transforms it into grid-integrable AC power. To ensure grid compliance, a filter at the inverter output smoothes the waveform and eliminates harmonic distortions. The system ultimate output is high-quality AC power that is supplied into the three-phase grid, preserving power quality while promoting effective energy use. The significance of sophisticated MPPT control, voltage regulation, and harmonic filtering in guaranteeing dependable grid-linked PV power generation is demonstrated by this configuration.

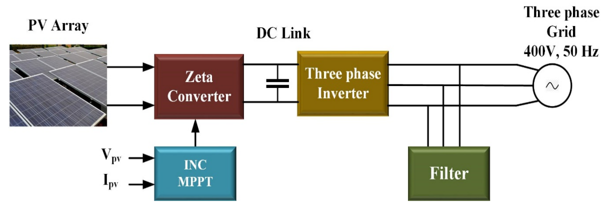

Figure 1. Representation of the Proposed scheme with Zeta Converter

2.1 PV Model

The behavior of a PV cell as a p-n junction diode and semiconductor principles form the basis of PV modeling. The basic equations that explain how PV cells work are as follows: A PV cell's output current is determined by

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

I_{ph} is the photo current, while I is the output current. The diode current is I_d. Leakage resistance causes I_{sh} to be shunt current. The current passing through the diode is expressed by the following equation(2)

$$I_d = I_s\left(\frac{qV_d}{e^{nkT}} - 1\right) \tag{2}$$

where V_d is the voltage of diode, n is the diode factor, k is the Boltzmann factor, and I_s is the reverse saturation current. T represents the absolute temperature, and the current produced is given in the equation (3)

$$I_{ph} = (I_{phref})\frac{G}{G_{ref}}\left(1 + \alpha(T - T_{ref})\right) \tag{3}$$

G stands for solar irradiance, G_{ref} for reference irradiance, α for temperature coefficient, Tref for reference temperature, and I_{phref} for photogenerated current under reference circumstances. All of the basic elements, including photogenerated current, diode current, and shunt current, are combined to create the overall equation controlling the I-V properties of a PV, In general, the equation is

$$I = I_{ph} - I_s\left(e^{\frac{q(V+IR_s)}{nkT}} - 1\right) - \frac{V+IR_s}{R_{sh}} \tag{4}$$

The PV equivalent circuit & characteristics id represented in the Fig.2 & 3 respectively.

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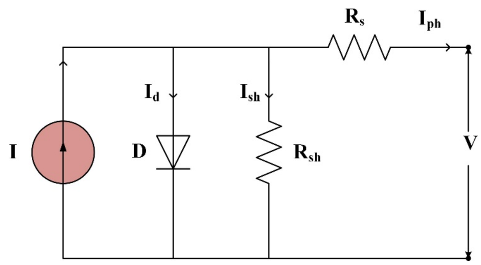

Figure 2 Equivalent Circuit of PV

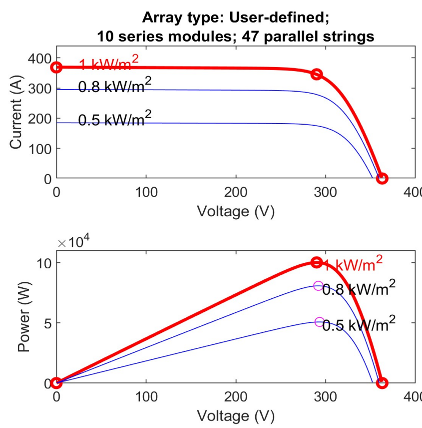

Figure 3 Characteristics of PV module

2.2 INC MPPT Control

The INC MPPT functions on the basis of the (dP/dV) with respect to voltage equals zero. The algorithm determines the direction of the working point adjustment by detecting the small variation in PV voltage (dV) and current (dI). The configuration is at the MPP when $dI/dV = -I/V$. The operating point is to the left side of the MPP, and the voltage must be raised if $dI/dV > -I/V$. In contrast, the working point is to the right of the MPP and the voltage must be lowered if $dI/dV < -I/V$.

Unlike the P&O approach, the INC algorithm precisely determines the MPP without bouncing around it, making it ideal for quickly changing environmental variables such fluctuating temperature or irradiance. The program guarantees optimal energy extraction from the PV array by continually monitoring the MPP. Its implementation is also very simple and effective, which makes it perfect for real-time applications. To keep the PV modules working point at the MPP, the procedure dynamically modifies the duty ratio of a converter.

3 ZETA CONVERTER

3.1 Working of Zeta Converter

The PV schemes and other applications with variable input voltages can benefit from the boost and buck voltage conversion capabilities of the Zeta converter. Through the regulation of a switch's duty cycle, the Zeta converter provides a controlled output voltage. Two inductors, a capacitor for energy transfer, and a diode for directed current flow are used in this architecture. In grid-linked PV schemes, its capacity to function with continuous input and output currents makes it perfect for reducing ripple and enhancing efficiency. The Zeta converter is used in PV applications to regulate the potential from the PV module to a level suitable for the DC connection, ensuring a constant voltage even in the face of fluctuating external conditions.

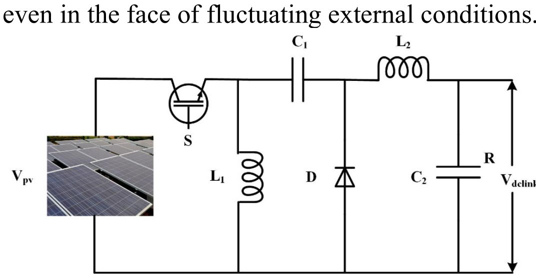

Figure 4 Circuit of Zeta Converter

There are mode of working for a Zeta converter, depending on the switch status. Energy is conserved by the input inductor L1, which is connected to the input voltage source Vpv in Mode 1 (Switch ON), as the current passing through it increases. The voltage at L1 is equal to the input voltage. Simultaneously, the output inductor L2 and the load both receive energy releases from the transfer capacitor C1. L2 ensures consistent output throughout this time by charging and supplying energy to the load.

When the switch is in Mode 2 (Switch OFF), the energy saved in L1 is moved to the transfer capacitor C1. While the output inductor L2 keeps providing energy to the load, the input inductor L1 releases its saved energy to charge C1. This guarantees that even when the switch is off, the load voltage will remain constant and steady. During this phase, the inductor and capacitor continue to maintain the load even while the current flowing through L2 declines. The Zeta converter can function well in both boost and buck configurations thanks to these two modes, which allow it to maintain a controlled output voltage despite input variations. The converter's voltage conversion ratio is provided by

$$V_{dclink} = V_{pv}\frac{D}{1-D} \tag{5}$$

The Duty cycle is given by

$$D = \frac{V_{dclink}}{V_{pv} + V_{dclink}} \tag{6}$$

The Inductance and Capacitance is evaluated by the following equation (7-10)

$$L_1 = \frac{V_{pv} D}{\Delta i_{L1} f_s} \tag{7}$$

$$L_2 = \frac{V_{pv} D}{\Delta i_{L2} f_s} \tag{8}$$

$$C_1 = \frac{i_o D}{\Delta V_c f_s} \tag{9}$$

$$C_2 = \frac{D\, V_{pv}}{8 \,.\, \Delta V_{C2}\, f^2 L_2} \tag{10}$$

Where V_{pv}= Input Voltage (From PV)
V_{dclink} = Output Voltage
D = Duty Cycle
L_1 & L_2 = Inductors
C_1 & C_2 = Capacitors
f_s = Switching Frequency
i_{L1}= Current through the inductor

3.2 PV with INC MPPT Control using Zeta Converter

Fig. 4 depicts a PV scheme with a Zeta converter fitted for efficient energy regulation and MPPT. The DC power from the PV array is sent to the Zeta converter. To keep a constant output voltage (Vdc link), the converter's input inductor (L1), output inductor (L2), diode (D), and transfer capacitor (C1) work together. Depending on input conditions, the Zeta converter ensures either voltage boosting or bucking while maintaining a steady DC link voltage.

To dynamically modify the converter's duty cycle and ensure the system operates at the MPP, the INC MPPT procedure keeps an eye on the PV parameters. Capacitor C2 stores the output voltage before sending it to the DC connection, ensuring power quality and stability. In grid-connected systems, this configuration is frequently utilized to effectively capture and control solar energy.

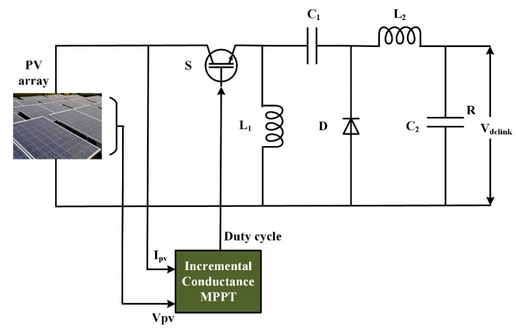

Fig.5 PV with INC MPPT Control

3.3 Grid Inverter Control

The control system shown in the Fig.6 represents a grid-linked inverter control structure that utilizes d-q axis control and feed-forward decoupling to ensure stable operation under varying grid conditions. The control is based on transforming the grid-side voltages and currents into a synchronous rotating reference frame, where control of active and reactive power becomes straightforward.

The Clarke Transformation converts the three-phase grid voltage Vabc into a two-axis stationary reference frame (Vαβ).The αβ to dq Park Transformation converts the stationary reference frame signals (Vαβ) into a (Vd,Vq) using the phase angle (ωt) provided by the Phase locked loop (PLL).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \cos(\omega t) & \sin(\omega t) \\ -\sin(\omega t) & \cos(\omega t) \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{12}$$

The PLL synchronizes the control system with the grid by determining the voltage angle (ωt) and frequency. This ensures the rotating reference frame aligns with the grid voltage vector. The Outer Loop controls the DC-link potential by comparing the reference voltage to the actual DC voltage and generating the reference Id current.

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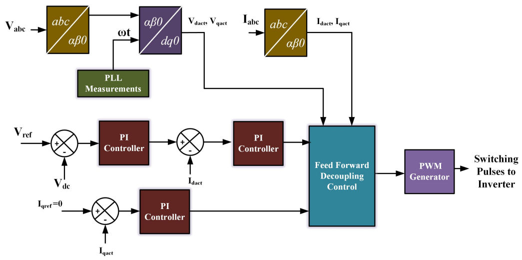

Figure 6 Inverter Control

The Inner Loop maintains current tracking by comparing the (Idref,Iqref) with the actual currents (Id,Iq). The Iq component is often set to zero to ensure no reactive power is injected into the grid. Feed-forward decoupling is essential for ensuring independent control of the d and q-axis currents in the presence of coupling terms caused by the synchronous frame. The dynamic equations for a grid-linked inverter in the d−q frame are

$$V_d = L\frac{dI_d}{dt} + RI_d - \omega L I_q + V_d^* \tag{13}$$

$$V_q = L\frac{dI_q}{dt} + RI_q - \omega L I_d + V_q^* \tag{14}$$

Feed-forward decoupling removes the coupling terms using the following equations

$$V_d^* = V_d + \omega L I_q \tag{15}$$

$$V_q^* = V_q - \omega L I_d \tag{16}$$

These equations ensure that Id controls the active power, and Iq independently controls the reactive power.

4 RESULTS & FINDINGS

The simulation of the grid linked zeta converter is presents in two scenarios with constant & varying irradiance condition. Here the PV panel power maximum power is 1.001 MW with an OC voltage of 36.3 V & SC current of 7.84 A. It consists of 47 series strings & 10 series modules per string.

Scenario-1 Operating at 1000 W/m2

In this scenario the PV irradiance in fixed as 1000 W/m2 , The PV parameters during this scenario is represented in the Fig.7, Here the maximum power obtained is 0.9951 MW. The grid parameters is specified in Fig.8.

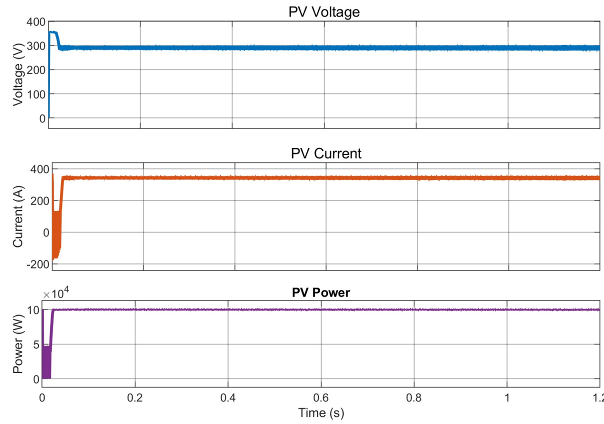

Figure 7 PV parameters during scenario-1

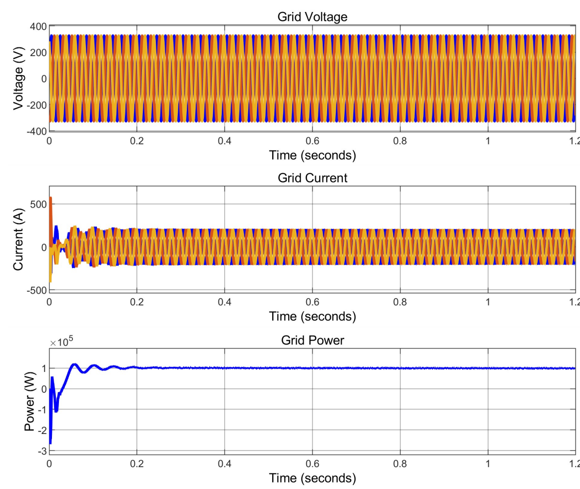

Figure 8 Grid parameters during scenario-1

It is inferred that the grid power is maintained constant, as the zeta converter regulates the constant output voltage across the DC link the grid power is maintained constant & the grid receives power from the PV effectively.

Scenario-2 Operating at Varying irradiance

In this scenario, the PV is operated at varying irradiance, The variation in irradiance is give as follows, From 0 to 0.5s it is 1000 W/m2 , 0.5 to 0.9s it is 800 W/m2 & 0.9 to 1.2s it is 500 W/m2, Here the irradiance is reduce gradually.

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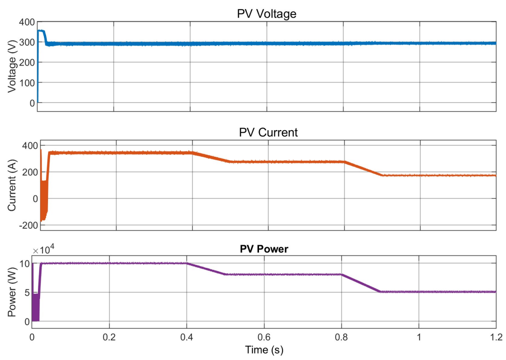

Figure 9 PV parameters during scenario-1

Table 1 Power & Efficiency during varying irradiance

Irr (W/m2)	Theoretical power (MW)	Power Obtained (MW)	Efficiency (%)
1000	1.001	0.9951	99.41
800	0.8074	0.8032	99.48
600	0.50754	0.5055	99.60

Table.1 presents the theoretical and obtained power values, as well as the efficiency of a photovoltaic system under varying levels of irradiance using INC MPPT. It shows how the system performs at different irradiance levels.

At an irradiance of 1000 W/m², the theoretical power generated by the system is 1.001 MW, and the obtained power is 0.9951 MW, resulting in an efficiency of 99.41%. As the input decreases to 800 W/m², the theoretical power drops to 0.8074 MW, and the obtained power is 0.8032 MW, with efficiency increasing slightly to 99.48%. When the irradiance further decreases to 600 W/m², the theoretical power becomes 0.50754 MW, and the obtained power is 0.5055 MW, with the efficiency improving to 99.60%.The data indicates that the system maintains high efficiency across all irradiance levels, demonstrating its ability to convert solar energy into electricity effectively even under reduced sunlight conditions.

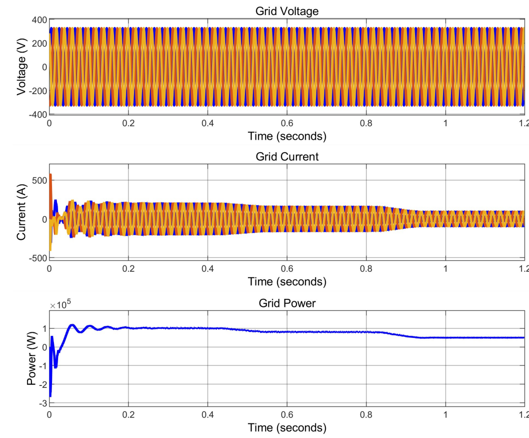

Figure 10 Grid parameters during scenario-2

The grid parameters for scenario-2 are shown in Fig. 10. In this case, the grid power will decrease as the irradiance changes, and the zeta converter will keep the DC link voltage constant at 600V regardless of the input power change. As a result, the zeta converter's use in grid-linked PV schemes ensures efficient operation regardless of input condition changes.

5 CONCLUSION

The addition of a Zeta converter into a grid-linked PV system has proven to be highly effective in ensuring consistent and efficient energy transfer under both steady and fluctuating irradiance conditions. Using the INC MPPT algorithm, the proposed scheme accurately tracks the MPP of the PV array, optimizing energy extraction. Simulation results validate the system's ability to maintain a stable DC link voltage of 600 V, regardless of solar irradiance variations.

Under constant irradiance of 1000 W/m² (Scenario 1), the system achieved a peak power output of 0.9951 MW, demonstrating its capability to deliver reliable energy to the grid. In Scenario 2, the system effectively adapted to varying irradiance (1000 W/m², 800 W/m², and 600 W/m²), maintaining an efficiency above 99% across all conditions. This adaptability ensures reliable performance even under dynamic environmental conditions. The Zeta converter plays a vital role in stabilizing the output voltage, and mitigating the effects of input fluctuations on grid performance. By ensuring efficient grid power management, the system facilitates seamless integration with grid infrastructure. The high efficiency and robust reliability observed in this study underscore the feasibility of deploying Zeta converters in modern renewable energy applications. These findings establish a strong foundation for advancing grid-linked PV systems, offering a scalable and sustainable solution for enhanced grid stability and renewable energy utilization. However, designing an optimal control strategy for the zeta converter is essential to balance the efficiency, transient response and voltage stability. Its ability to regulate voltage effectively enhances the performance of photovoltaic systems, preventing fluctuations from affecting downstream components.

REFERENCES

[1] Yang, B., Li, W., Zhao, Y., & He, X. (2009). Design and analysis of a grid-connected photovoltaic power system. *IEEE transactions on power electronics*, *25*(4), 992-1000.

[2] Errouissi, R., Al-Durra, A., & Muyeen, S. M. (2016). A robust continuous-time MPC of a DC–DC boost converter interfaced with a grid-connected photovoltaic system. *IEEE Journal of Photovoltaics*, *6*(6), 1619-1629.

[3] Haripriya, T., Parimi, A. M., & Rao, U. M. (2016, January). Performance evaluation of DC grid connected solar PV system for hybrid control of DC-DC boost converter. In *2016 10th International Conference on Intelligent Systems and Control (ISCO)* (pp. 1-6). IEEE.

[4] Srinivasa Rao Jalluri , Dr. J. Bhavani , Jupalli Pushpa Kumari , Dr. T. Nireekshana, Inverter Control using ANN in Grid linked PV, Wind & Battery system ,*Nanotechnology Perceptions (2024)*

[5] Bosco Raj, T. A., Ramesh, R., Maglin, J. R., Vaigundamoorthi, M., William Christopher, I., Gopinath, C., & Yaashuwanth, C. (2014). Grid connected solar PV system with SEPIC converter compared with parallel boost converter based MPPT. *International Journal of Photoenergy*, *2014*(1), 385720

[6] Sahu, P. K., Mohanty, A., Ganthia, B. P., & Panda, A. K. (2016, January). A multiphase interleaved boost converter for grid-connected PV system. In *2016 International Conference on Microelectronics, Computing and Communications (MicroCom)* (pp. 1-6). IEEE

[7] Syam, M. S., & Kailas, T. S. (2013, June). Grid connected PV system using Cuk converter. In *2013 Annual International Conference on Emerging Research Areas and 2013 International Conference on Microelectronics Communications and Renewable Energy* (pp. 1-6). IEEE.

[8] Suresh, K., & Parimalasundar, E. (2023). Newly designed single-stage dual leg DC-DC/AC buck-boost converter for grid connected solar system. *International Journal of Circuit Theory and Applications*, *51*(11), 5452-5469.

[9] Rao, C. V. R., Ganesh, M. S. R., Sekhar, K. C., Sudha, R. P., Dangeti, L. K., & Duvvuri, S. S. (2019, March). A generalized mppt controlled dc-dc boost converter for pv system connected to utility grid. In *2019 Innovations in Power and Advanced Computing Technologies (i-PACT)* (Vol. 1, pp. 1-5). IEEE

[10] Bakar Siddique, M. A., Asad, A., Asif, R. M., Rehman, A. U., Sadiq, M. T., & Ullah, I. (2023). Implementation of incremental conductance MPPT algorithm with integral regulator by using boost converter in grid-connected PV array. *IETE Journal of Research*, *69*(6), 3822-3835.

[11] Rodriguez, P., Citro, C., Candela, J. I., Rocabert, J., & Luna, A. (2018). Flexible grid connection and islanding of SPC-based PV power converters. *IEEE Transactions on Industry Applications*, *54*(3), 2690-2702

[12] Islam, M. R., Mahfuz-Ur-Rahman, A. M., Muttaqi, K. M., & Sutanto, D. (2018). State-of-the-art of the medium-voltage power converter technologies for grid integration of solar photovoltaic power plants. *IEEE Transactions on Energy Conversion*, *34*(1), 372-384

[13] Zeb, K., Uddin, W., Khan, M. A., Ali, Z., Ali, M. U., Christofides, N., & Kim, H. J. (2018). A comprehensive review on inverter topologies and control strategies for grid connected photovoltaic system. *Renewable and Sustainable Energy Reviews*, *94*, 1120-1141.