# Grid-connected double-stage PV system with space vector PWM inverter and MPPT

**Ankathi Manjula, A. Ramesh Babu**
Department of Electrical and Electronics Engineering, Sathyabama Institute of Science and Technology, Chennai, India

**Article Info**

***Article history:***

Received Oct 12, 2023
Revised Jun 28, 2024
Accepted Jul 19, 2024

***Keywords:***

Grid
IGBT inverter
MPPT
PV cell
SVPWM technique

**ABSTRACT**

Because of the increasing demand for non-conventional energy sources, photovoltaic system integration into the electrical grid is becoming more crucial. It is advised to employ a double-stage grid-connected PV system. This can be employed with the main parts boost converter, which helps to boost the DC output from the PV channels. And next one is the space vector pulse width modulation (SVPWM) inverter which can provide better harmonic performance and higher efficiency compared to traditional PWM methods. The SVPWM technique is employed to modulate the inverter output, generating a sinusoidal AC waveform that matches the grid frequency and voltage. By adjusting the pulse width to achieve effective and trustworthy grid integration. To maximize power extraction takes place by using maximum power point tracking (MPPT). The SVPWM inverter is crucial in converting DC power to AC power and enabling grid connection. Utilizing SVPWM allows exact control of voltage magnitude, frequency, and phase angle to provide high-quality sinusoidal AC output voltage. The power quality of the electricity pumped into the grid is improved by this precise management, which also ensures adherence to grid standards and reduces harmonic interference.



***Corresponding Author:***

Ankathi Manjula
Department of Electrical and Electronics Engineering, Sathyabama Institute of Science and Technology
Chennai, Tamil Nadu, India
Email: manju.ankathi708@gmail.com

## 1. INTRODUCTION

As the world seeks to transition towards cleaner and more sustainable energy sources, photovoltaic solar systems have emerged as a prominent solution for electricity generation [1]-[2]. Grid-connected photovoltaic systems efficiently utilize solar energy by integrating it into the existing electrical grid infrastructure. T using a boost converter in a double-stage grid-connected photovoltaic system innovatively enhances the system's grid compatibility and performance [3]. This introduction provides an overview of this advanced solar energy solution [4]. A double-stage grid-connected PV system with a space vector pulse width modulation (SVPWM) inverter is a sophisticated solar energy setup that maximizes energy extraction from PV arrays and ensures efficient integration with the electrical grid [5]-[6]. It offers numerous advantages in terms of energy efficiency, grid support, and environmental sustainability, making it a valuable solution for renewable energy generation and grid stability [7]-[8]. A DC-DC converter is frequently employed in a double-stage system to maximize energy extraction from the PV array [2]-[5]. This converter efficiently adjusts voltage and current levels to meet the requirements of subsequent stages. It may incorporate features such as maximum power point tracking (MPPT) to optimize the PV array's power output [9]. The SVPWM inverter is a vital component in the system, converting the direct current output from the PV array into alternating current that is compatible with grid connection [10]. SVPWM is a sophisticated control technique used in inverters to generate high-quality sinusoidal AC waveforms with minimal harmonic distortion and high efficiency [11]. It assures grid compatibility and maximizes the use of DC power that is already available [12]-[13]. The grid-connected, double-stage PV system uses a controller to ensure efficient operation. The MPPT, voltage regulation, and grid synchronization algorithms of this controller are standard. Advanced control algorithms are often employed to effectively manage the power flow between the PV array and the grid [14]-[15].

## 2. GRID-CONNECTED DOUBLE-STAGE PV SYSTEM

Figure 1 shows the block diagram of the proposed paper. The PV panels capture sunlight and generate DC electricity, representing the initial energy harvesting stage [16]. A boost converter is used to optimize power extraction from the PV array. It increases the DC voltage to a level that maximizes power output [17]-[18]. Despite changing environmental factors, the system will always function effectively at or close to the PV array's maximum power point (MPPT). The MPPT system continuously monitors the PV array's voltage and current to determine the optimal operating point for maximum power production [19]. It adjusts the boost converter's operation to maintain the PV array at this maximum power point [20]-[21]. The DC electricity produced by the PV array is converted into alternating current, which is acceptable for grid connection, using a sophisticated grid-tied inverter [22]. The grid-tied inverter ensures that the AC output closely matches the grid's voltage, frequency, and phase, enabling seamless grid connection without disruptions [23]. The double-stage photovoltaic (PV) system, which is connected to the electrical grid, is linked via a point of common coupling. [24], [25]. This is the point where the AC output from the inverter is synchronized with the grid's parameters and injected into the grid with the help of a control scheme.

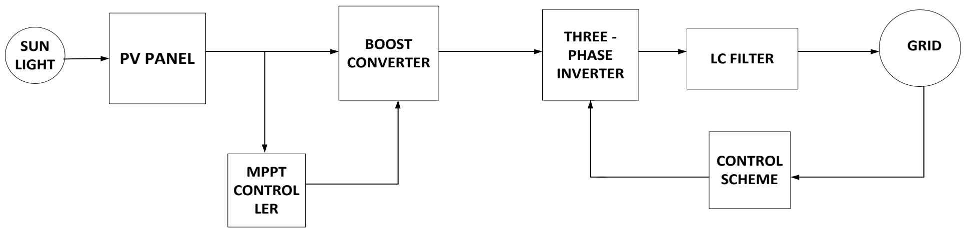


Figure 1. Double-stage photovoltaic system block diagram

### 2.1. PV cell

A photovoltaic (PV) cell utilizes the photovoltaic effect to directly convert sunlight into electricity by dislodging electrons from atoms in semiconductor materials through the interaction with photons from sunlight. PV cells are typically made from semiconductor materials, such as silicon. The PV cells are composed of a P-type layer, which is made of boron-doped silicon, and an N-type layer, which is made of phosphorous-doped silicon. These layers are positioned on top of a boron-doped silicon layer. When sunlight interacts with the PV cell, it generates an electric voltage and current by inducing the movement of electrons from the P-type layer to the N-type layer. Additionally, PV cells have two electrical contacts, with one located on the front and the other on the back. These contacts allow for the collection of the generated electrical energy. On their own, PV cells produce a limited amount of electrical power, typically in the range of 0.5 V to 0.6 V as direct current when not connected to a load. A solar module, also referred to as a PV module or solar panel module, consists of a series of interconnected PV cells enclosed within a protective material such as tempered glass and encapsulant. Its primary purpose is to increase power output compared to individual PV cells. Modules come in various sizes, with standard sizes such as 60-cell or 72-cell modules being common. Larger modules contain more PV cells, resulting in higher power output. They are configured to produce specific voltage and current outputs, usually in the range of 12 to 48 volts.

### 2.2. P&O algorithm of MPPT

The algorithm referred to as the "P and O" algorithm, or the "perturb and observe" algorithm, is widely employed in maximum power point tracking (MPPT) for photovoltaic systems. MPPT is an essential technique utilized in solar power systems to optimize the power generated by solar panels by consistently monitoring the point at which the panels function at their highest power output. In the P&O algorithm Initially, the algorithm operates the PV system at a certain operating point. It slightly perturbs this operating point by a small increment. The power has increased or decreased. If the power has increased, it continues perturbing in the same direction. If the power has reduced, the perturbation direction is reversed, leading to a continuous repetition of steps where the operating point is adjusted in each iteration until the algorithm reaches convergence at the maximum power point.

### 2.3. Boost converter

A boost converter, also referred to as a step-up converter, is a DC-DC converter that elevates the voltage level of a DC input voltage to a higher DC output voltage. The mathematical equations for a boost converter can be obtained from its operational principles and circuit elements. Presented below are the essential formulas and equations for a boost converter. The duty cycle represents the percentage of time during which the transistor switch is in the on state, typically regulated by a pulse width modulation (PWM) signal.

The duty cycle is given by: D = Ton / T, where Ton is the on-time of the switch and T is the switching period. The voltage gain of a boost converter is the ratio of the output voltage to the input voltage.

Voltage gain: Vo/Vin = 1 / (1 - D)

The input current can be calculated using the output current and duty cycle.

Input current: Iin = Io / D
Output power: Pout = Vo * Io

### 2.4. Three-phase inverter

Figure 2 represents the structure of a three-phase bridge inverter. It typically takes a DC voltage input, often sourced from solar panels or other sources. The inverter is composed of six semiconductor switching elements, commonly insulated gate bipolar transistors (IGBTs), set up in a bridge configuration. These devices are divided into upper and lower arms, with each arm containing three switches corresponding to the three phases of the AC output. The primary function of the bridge inverter is to generate a three-phase AC voltage from the DC input. This is achieved through space vector pulse width modulation.

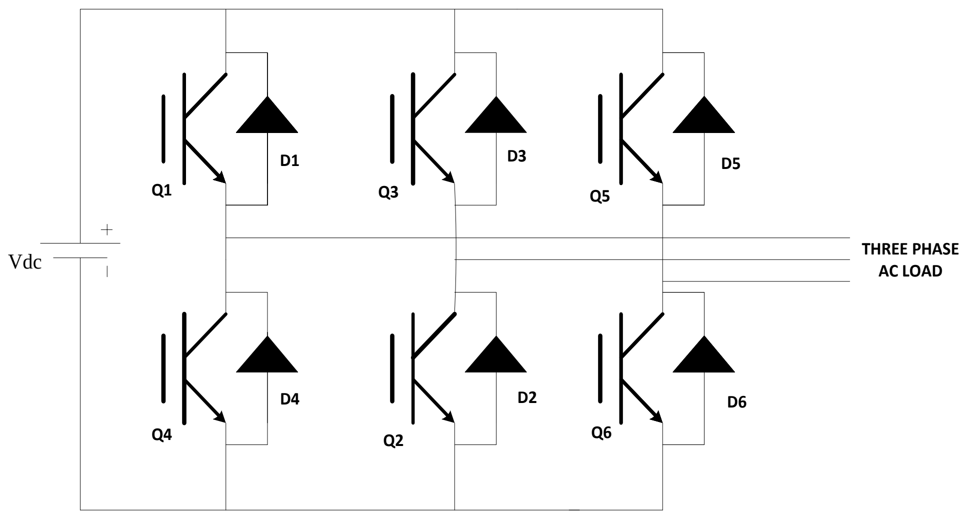


Figure 2. Three-phase full bridge inverter

### 2.5. Space vector pulse width modulation

Space vector pulse width modulation (SVPWM) is a powerful technique for controlling inverters, especially in applications where precision, reduced harmonics, and grid synchronization are essential. It optimizes the switching patterns of the inverter's power devices to generate high-quality AC waveforms, ensuring a reliable and efficient operation, particularly in grid-connected systems. The desired output voltage magnitude ($V_{ref}$) and phase angle ($\theta_{ref}$) for each phase of the inverter. These values are often obtained from a control algorithm or user input. To simplify control calculations, the desired three-phase voltages ($V_{ref}$) are converted into a two-dimensional reference frame called the α-β reference frame. This conversion is done using the inverse Clarke transformation. The α-β reference frame represents the desired voltages in a coordinate system that simplifies the control process.

$$V_{ref} = 2/3\,[V_a(t) + \alpha\, V_b(t) + \alpha 2 V_c(t)] \quad (1)$$

Where $\alpha = e^{j2\pi/3}$ and $\alpha 2 = e^{j4\pi/3}$.

$$V_a = V_m \sin wt$$
$$V_b = V_m \sin (wt_{-120°})$$
$$V_c = V_m \sin (wt_{-240°}) \quad (2)$$

$$V_{ref} = \sqrt{V_d^2 + V_q^2} \quad (3)$$

Figure 3 represents the $V_{ref}$ for the D and Q axes.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{pmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{pmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (4)$$

The relationship between the line-to-line voltage vector [$V_{ab}$, $V_{bc}$, $V_{ca}$] and the switching variable vector [a, b, c] can be expressed as follows:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{pmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 1 & 0 \end{pmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

the phase voltage vector [$V_a$ $V_b$ $V_c$] and the switching variable vector [a, b, c] are related by (5).

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = V_{dc}/3 \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (5)$$

In a complex plane, two orthogonal systems ($V_d$, $V_q$) form the basis for defining a vector. The reference voltage, $V_{ref}$, can be expressed as the sum of $V_d$ and $jV_q$. To represent the eight switching states of the inverter output in binary code, three bits ($2^3$=8) are required. These states are denoted as S1(0,0,1), S2(0,1,1), S3(0,1,0), S4(1,1,0), S5(1,0,0), S6(1,0,1), and S7(1,1,1). Figure 4 shows the 7 switching states.

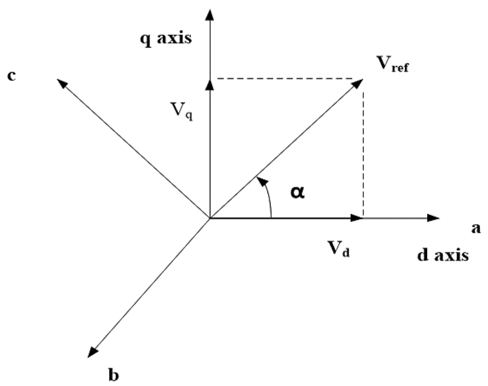


Figure 3. Representation of $V_{ref}$

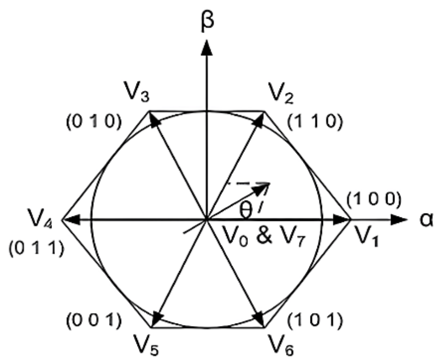


Figure 4. Space vector pulse width modulation representation

## 2.6. LC filters

It is a key technique in modern motor drives and power electronics systems LC filters, which consist of inductors (L) and capacitors (C), are commonly used in grid-connected photovoltaic (PV) systems for several important purposes. LC filters are essential components that greatly enhance the efficiency, power integrity, and dependability of these systems. A key application of LC filters is their ability to minimize or eradicate harmonic distortion in the output current or voltage of grid-connected inverters. LC filters can do harmonic mitigation, reducing total harmonic distortion (THD) to make the grid voltage cleaner and more sinusoidal.

### 2.7. Grid requirements to interconnect with PV system

Grid-connected PV systems need to meet strict requirements regarding voltage, frequency, phase alignment, and power quality to ensure reliable and efficient integration with the grid, and also PV systems must minimize harmonic distortion to maintain power quality. Harmonics can lead to overheating and damage to electrical equipment. Inverters are designed to filter out harmonics and ensure that the output waveform is as close to a pure sine wave as possible. The integration of PV systems never introduces flicker or voltage transients. The advanced control technique SVPWM, and the ability to manage reactive power play a crucial role in achieving these objectives while contributing to grid stability and reliability.

## 3. DESCRIPTION OF THE CIRCUIT

Figure 5 shows the grid-connected double-stage PV system with space vector PWM inverter. This solar power system optimizes the efficiency and integration of photovoltaic (PV) arrays with the electrical grid. The PV array consists of individual solar panels that harness sunlight to produce DC electricity. To ensure optimal performance, a DC-DC converter or maximum power point tracking controller is employed to monitor and maximize the power output of the PV array by tracking the maximum power point (MPP) where the panels operate most effectively. This stage ensures voltage compatibility and maximizes power output, adapting to changing environmental conditions. The DC power is efficiently optimized and then routed into an inverter connected to the grid. The primary function of the inverter is to change the DC electricity produced by the PV array into alternating current, which is the type of electricity often utilized in households and the electrical grid. The inverter synchronizes the AC output with the grid's voltage and frequency, ensuring that the power generated matches the grid's requirements. It continuously monitors grid conditions and efficiently manages power flow, feeding excess electricity back into the grid when available and needed or drawing power from the grid when necessary to meet load demands.

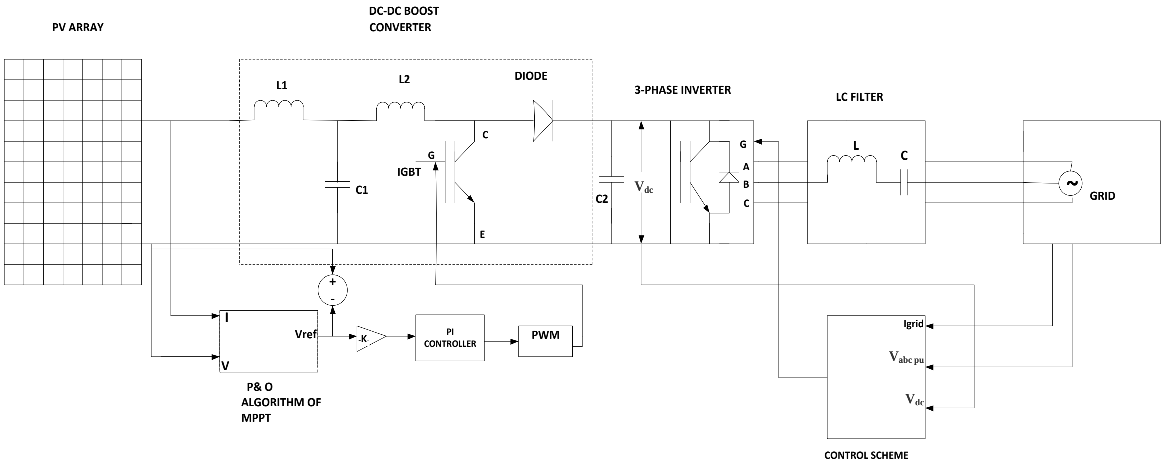


Figure 5. Double-stage grid-connected PV system

### 3.1. Control scheme

Figures 6 and 7 show the control scheme for the interconnection of the grid with the PV system without any mismatching conditions. The control scheme consists of an ABC frame, DQ frame, SVPWM, PLL, and PI controllers. The first step involves obtaining reference signals, which typically represent the desired output voltage magnitude and frequency, synchronized with the grid or another source. If the reference signals are given in a stationary reference, an inverse Park transformation is performed to convert them into a rotating reference frame, often the DQ frame. This simplifies the control algorithm representation in the DQ frame. In the DQ frame, reference signals are represented as a rotating phasor, making it easier to control the inverter. SVPWM divides the space between the minimum and maximum voltage vectors into sectors and calculates the space vector representing the desired output voltage. The control scheme identifies the industry in which the space vector falls, determining the combination of switching states required for the inverter.

Based on the identified sector and desired output voltage amplitude, the control scheme calculates the duty cycles necessary for the upper and lower transistors in each phase leg of the inverter. SVPWM generates

PWM signals for each phase leg. It uses a triangular carrier waveform and compares it to the reference signals to produce PWM pulses controlling the inverter's transistor switching. The generated PWM signals control the switching of the inverter's power devices ensuring the output voltage closely follows the desired reference signal. Feedback from sensors measuring actual output voltage and current is often incorporated for closed-loop connections.

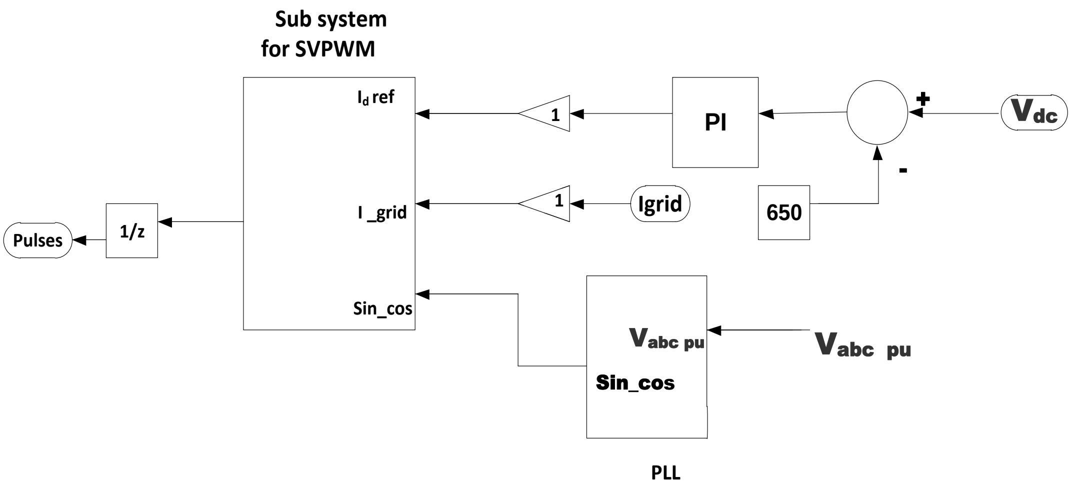


Figure 6. Control scheme

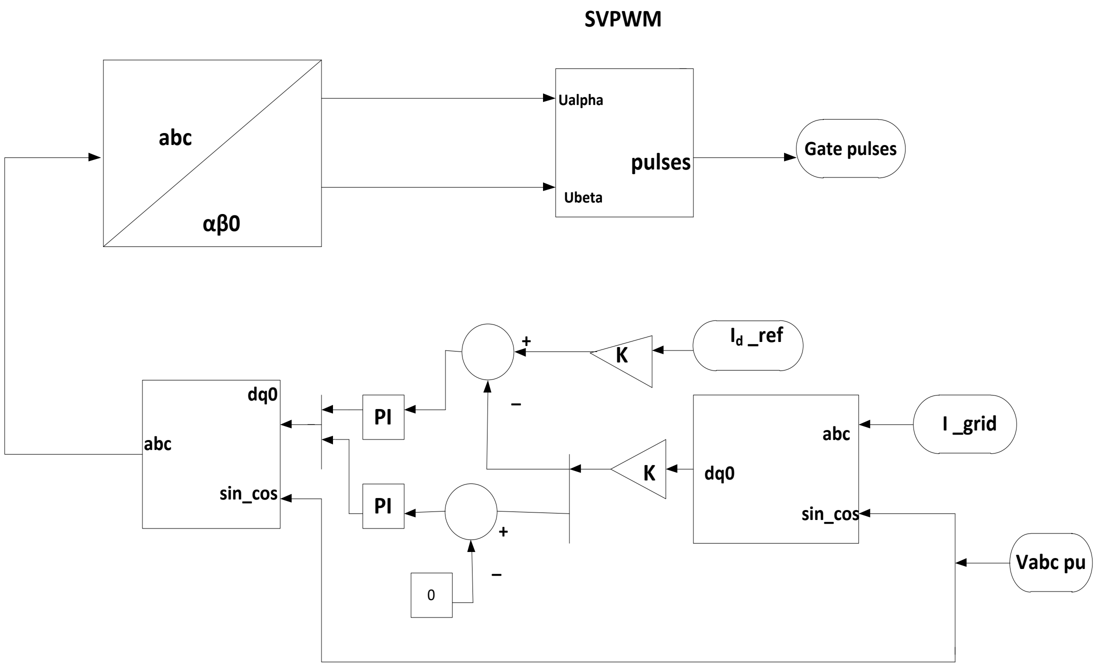


Figure 7. Space vector pulse width modulation

## 4. SIMULATION RESULTS

Figure 8 represents the PV panel output, and this voltage is in DC form. After 0.5 seconds that DC voltage gets stable, and we can get more DC electrical output by increasing the connection of PV panels. Figure 9 represents the three-phase output voltage of the inverter, this voltage has less harmonics, and this inverter’s voltage perfectly matches with grid voltage.

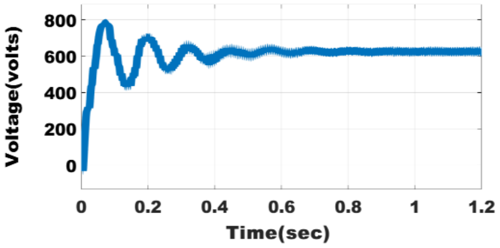


Figure 8. Photovoltaic panel's DC output voltage

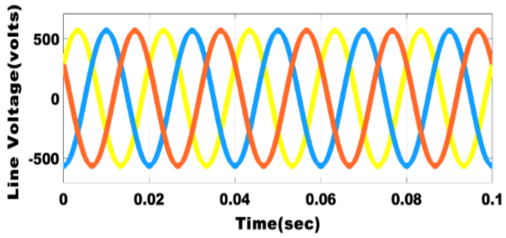


Figure 9. The inverter's three-phase output voltage

Figure 10 represents the fast Fourier transform analysis of the three-phase output voltage of the inverter. It can show the level of harmonics, and these harmonics are very low, THD is 0.06%. Figure 11 represents the three-phase output current of the inverter, this current fluctuates at starting after 0.5 seconds, and it can get stable. And that final current is perfectly matched with the grid current. Figure 12 represents the fast Fourier transform (FFT) analysis result of the three-phase output current of the inverter, this shows the harmonics level of current, and that harmonics are very low with THD 1.69%. According to the results no mismatching conditions between the PV system and grid.

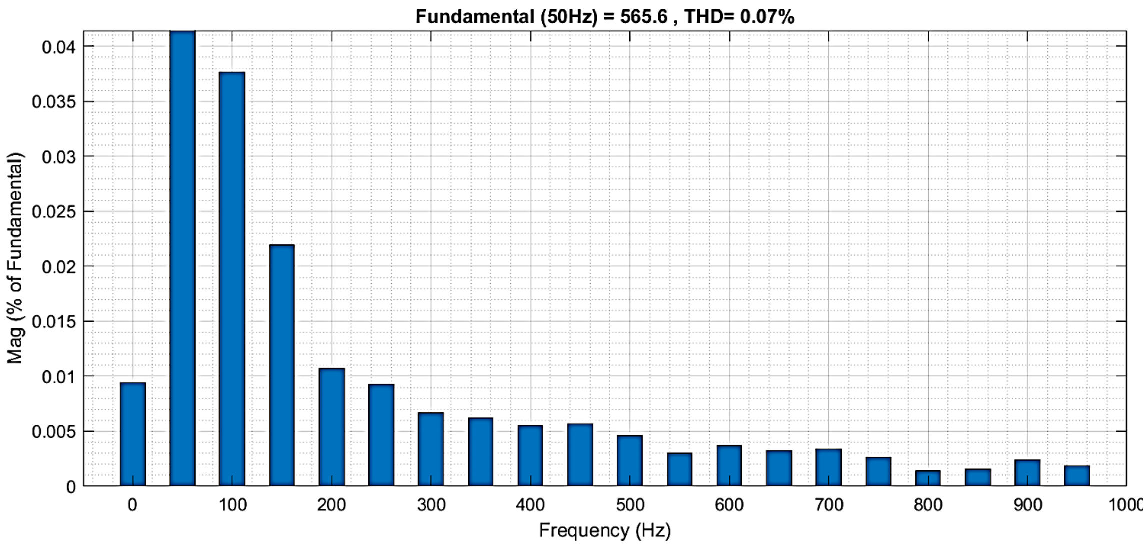


Figure 10. FFT analysis result of the three-phase output voltage of the inverter

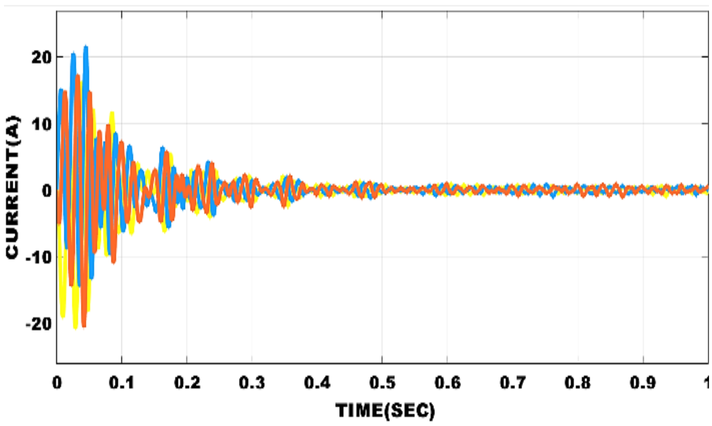


Figure 11. The current output of the inverter is in three phases

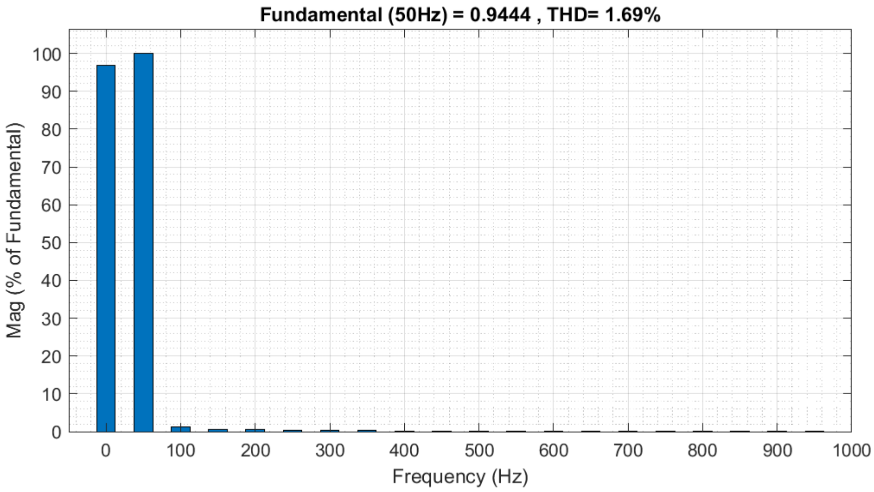


Figure 12. FFT analysis result of the three-phase output current of the inverter

## 5. CONCLUSION

In conclusion, this paper highlights the importance of aligning the PV system with the grid. The combination of SVPWM and MPPT in this double-stage grid-connected PV system presents a reliable and eco-friendly solution for maximizing solar energy usage. It maximizes energy production, ensures grid compatibility, and promotes a greener and more reliable energy future. Its potential for further advancements and contributions to a cleaner energy landscape makes it a promising technology for the future.

## REFERENCES

[1] N. Hamrouni, M. Jraidi, and A. Chérif, "New control strategy for 2-stage grid-connected photovoltaic power system," *Renewable Energy*, vol. 33, no. 10, pp. 2212–2221, 2008, doi: 10.1016/j.renene.2007.12.021.

[2] A. Ramesh Babu, T. A. Raghavendiran, V. Sivachidambaranathan, and J. B. P. Glady, "Novel cascaded H-bridge sub-multilevel inverter with reduced switches towards low total harmonic distortion for photovoltaic application," *International Journal of Ambient Energy*, vol. 39, no. 2, pp. 117–121, 2018, doi: 10.1080/01430750.2016.1269683.

[3] A. Manjula, P. Shivani, M. Nithin, V. Rajendhar, R. P. Kumar, and V. Kumar, "Enhancing Solar Energy Grid Integration with SVPWM Controlled Three-Leg Inverter," in *International Conference on Sustainable Communication Networks and Application, ICSCNA 2023 - Proceedings*, 2023, pp. 783–787, doi: 10.1109/ICSCNA58489.2023.10370679.

[4] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "A technique for improving P&O MPPT performances of double-stage grid-connected photovoltaic systems," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 11, pp. 4473–4482, 2009, doi: 10.1109/TIE.2009.2029589.

[5] L. Huang, D. Qiu, F. Xie, Y. Chen, and B. Zhang, "Modeling and stability analysis of a single-phase two-stage grid-connected photovoltaic system," *Energies*, vol. 10, no. 12, 2017, doi: 10.3390/en10122176.

[6] A. Rameshbabu, G. T. Sundarrajan, and J. B. Paul Glady, "Asymmetrical Cascaded H-Bridge 31 Level Inverter with Low THD for PV Application," in *2021 International Conference on Innovative Computing, Intelligent Communication and Smart Electrical Systems (ICSES)*, 2021, doi: 10.1109/ICSES52305.2021.9633836.

[7] H. Zhang, H. Zhou, J. Ren, W. Liu, S. Ruan, and Y. Gao, "Three-phase grid-connected photovoltaic system with SVPWM current controller," in *2009 IEEE 6th International Power Electronics and Motion Control Conference, IPEMC '09*, 2009, pp. 2161–2164, doi: 10.1109/IPEMC.2009.5157759.

[8] V. Sureshkumar and S. Arun, "Three-phase current source inverter using space vector PWM for grid-connected applications," *The International Journal Of Engineering And Science (IJES)*, vol. 3, no. 2, pp. 35–38, 2014.

[9] M. S. Mollik, S. M. S. H. Rafin, A. Al Mamun, A. M. M. Irfeey, A. S. Soliman, and O. A. Mohammed, "Improved Performance of a Two-Stage Converter Topology Using Incremental Conductance-Based MPPT Design for Grid-Tied PV Systems," in *Conference Proceedings - IEEE SOUTHEASTCON*, 2023, pp. 490–497, doi: 10.1109/SoutheastCon51012.2023.10115210.

[10] H. Xu, X. Wang, L. Huang, J. Qian, and J. Lou, "Research on Two-Stage Three-Phase Photovoltaic Grid-Connected System with MPPT," in *2019 4th International Conference on Power and Renewable Energy, ICPRE 2019*, 2019, pp. 57–60, doi: 10.1109/ICPRE48497.2019.9034825.

[11] K. Chenchireddy, M. G. Basha, S. Dongari, P. Kumar, G. Karthik, and G. Maruthi, "Grid-Connected 3L-NPC Inverter with PI Controller Based on Space Vector Modulation," in *2023 9th International Conference on Advanced Computing and Communication Systems, ICACCS 2023*, 2023, pp. 94–98, doi: 10.1109/ICACCS57279.2023.10113092.

[12] S. Sreenu, J. Upendar, and B. Sirisha, "Analysis of switched impedance source/quasi-impedance source DC-DC converters for photovoltaic system," *International Journal of Applied Power Engineering*, vol. 11, no. 1, pp. 14–24, 2022, doi: 10.11591/ijape.v11.i1.pp14-24.

[13] K. Chenchireddy and V. Jegathesan, "Multi-Carrier PWM Techniques Applied to Cascaded H-Bridge Inverter," in *Proceedings of the International Conference on Electronics and Renewable Systems, ICEARS 2022*, 2022, pp. 244–249, doi: 10.1109/ICEARS53579.2022.9752442.

[14] X. Han, X. Ai, and Y. Sun, "Research on large-scale dispatchable grid-connected PV systems," *Journal of Modern Power Systems and Clean Energy*, vol. 2, no. 1, pp. 69–76, Mar. 2014, doi: 10.1007/s40565-014-0043-5.

[15] A. Gopinath and M. R. Baiju, "Space Vector PWM for Multilevel Inverters - A Fractal Approach," in *2007 7th International Conference on Power Electronics and Drive Systems*, Nov. 2007, pp. 842–849, doi: 10.1109/PEDS.2007.4487802.

[16] J. Upendar, S. R. Kumar, S. Sreenu, and B. Sirisha, "Implementation and study of fuzzy based KY boost converter for electric vehicle charging," *International Journal of Applied Power Engineering*, vol. 11, no. 1, pp. 98–108, 2022, doi: 10.11591/ijape.v11.i1.pp98-108.

[17] F. Slama, H. Radjeai, S. Mouassa, and A. Chouder, "New algorithm for energy dispatch scheduling of grid-connected solar photovoltaic system with battery storage system," *Electrical Engineering and Electromechanics*, no. 1, pp. 27–34, 2021, doi: 10.20998/2074-272X.2021.1.05.

[18] A. Manjula, K. Chenchireddy, G. S. Shetty, G. Chethala, C. P. Kumar, and T. S. Shekar, "Enhancing Grid Connectivity with a Double-Stage PV System," in *International Conference on Self Sustainable Artificial Intelligence Systems, ICSSAS 2023 - Proceedings*, 2023, pp. 1644–1648, doi: 10.1109/ICSSAS57918.2023.10331806.

[19] Y. Guo, G. Wang, D. Zeng, H. Li, and H. Chao, "A Thyristor Full-Bridge-Based DC Circuit Breaker," *IEEE Transactions on Power Electronics*, vol. 35, no. 1, pp. 1111–1123, Jan. 2020, doi: 10.1109/TPEL.2019.2915808.

[20] Y. Chen, J. Liu, J. Zhou, and J. Li, "Research on the control strategy of PV grid-connected inverter upon grid fault," in *2013 International Conference on Electrical Machines and Systems, ICEMS 2013*, 2013, pp. 2163–2167, doi: 10.1109/ICEMS.2013.6713201.

[21] B. P. Singh, S. K. Goyal, and S. A. Siddiqui, "Grid Connected-Photovoltaic System (GC-PVS): Issues and Challenges," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 594, no. 1, doi: 10.1088/1757-899X/594/1/012032.

[22] F. Zheng, M. Ding, and J. Zhang, "Modelling and simulation of grid-connected PV system in DIgSILENT/PowerFactory," *IET Conference Publications*, 2013, pp. 1–6, doi: 10.1049/cp.2013.1867.

[23] N. Kishore, K. Shukla, and N. Gupta, "A Novel Three-Phase Multilevel Inverter Cascaded by Three-Phase Two-Level Inverter and Two Single-Phase Boosted H-Bridge Inverters," in *Proceedings of the 11th International Conference on Innovative Smart Grid Technologies - Asia, ISGT-Asia 2022*, 2022, pp. 330–334, doi: 10.1109/ISGTAsia54193.2022.10003609.

[24] Z. Yuan and J. Cheng, "Research on space vector PWM inverter based on artificial neural network," in *Proceedings - 6th International Symposium on Computational Intelligence and Design, ISCID 2013*, 2013, vol. 2, pp. 80–83, doi: 10.1109/ISCID.2013.134.

[25] V. K. Vinayak and N. Lal Shah, "Review on Standalone and Grid Connected Photovoltaic System with Benefits," *Research Journal of Engineering Technology and Medical Sciences*, vol. 05, no. 01, pp. 2582–6212, 2022, [Online]. Available: www.rjetm.in/.


## BIOGRAPHIES OF AUTHORS

**Ankathi Manjula** received the B.Tech. and M.Tech. from JNTUH, Hyderabad, India in 2012 and 2014 respectively, and is pursuing a Ph.D. in Sathyabama Institute of Science and Technology, Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai 600119, Tamil Nadu, India. She is working presently as an assistant professor at Teegala Krishna Reddy Engineering College, Hyderabad, India. She has presented and published technical papers in various national and international journals and conferences. His areas of interest include power electronics, power quality, and multilevel inverters. She can be contacted at email: manju.ankathi708@gmail.com.

**Dr. A. Ramesh Babu** received a B.Tech. from Manonmaniam Sundaranar University, Tamil Nadu, India in 2001. M.Tech. and Ph.D. from Sathyabama Institute of Science and Technology, Tamil Nadu, India in 2008 and 2018 respectively. Currently working as associate professor in the Electrical and Electronics Engineering Department of Sathyabama Institute of Science and Technology, Chennai 600119, Tamil Nadu, India. He has presented and published technical papers in various national and international journals and conferences. He can be contacted at email: rameshbabu.eee@sathyabama.ac.in.