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TRANSFORMER-LESS INVERTER DESIGN FOR PHOTOVOLTAIC SYSTEMS: THE H5 TOPOLOGY APPROACH

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ABSTRACT: There are two main ways to generate energy: conventional and unconventional. Nuclear power, coal, and natural gas are some of the most used conventional energy sources today, even though they have devastating effects on the environment. It is critical to generate part of the needed electricity from sustainable resources like wind and solar. A decrease in emissions of greenhouse gases, an increase in demand for renewable energy, and the need to provide power to underserved areas are the primary motivators for this initiative. Using an H5 converter architecture can improve solar energy efficiency in single-phase AC applications. The suggested design makes it easier to control the DC voltage output by incorporating solar panels and batteries into DC-DC boost converters with two inputs. Because it drastically cuts down on leakage current, the H5 design is perfect for AC applications that use single-phase transformerless inverters and have power demands that fluctuate. Through the use of MATLAB process modeling, we can evaluate the practicability of the suggested approach. In order to test and validate the converter's outputs and functionality, a prototype is now in development. We will run the simulation using a different program, maybe MATLAB.

Keywords: H5 Transformerless Inverter, Photovoltaic System, Efficiency, Grid Integration and Power Conversion.

1. INTRODUCTION

The constant availability of photovoltaic (PV) electricity has led some to regard it as a promising and alluring renewable energy source. Over 45 percent of the world's energy will likely come from photovoltaic (PV) arrays in the future, according to experts. Both standalone and connected to utility networks, the arrays have the potential to generate power. Photovoltaic (PV) panels have been more and more integrated into power grids in the past several years. A DC-to-AC inverter followed by a line transformer is the most common method used. However, traditional line transformers have a lot of negative aspects, such as being heavy and bulky, not very efficient, and expensive to run. The issue of leakage current has prompted a plethora of proposed solutions.

The use of transformerless inverters is an interesting and possibly useful technique to investigate, particularly in freewheeling modes. The photovoltaic (PV) array and the inverter and the grid make up the alternating current (AC) component, and these devices help to separate the two. In order to maximize the utilization factor, it is essential to optimize the power output of the photovoltaic (PV) array for systems that do not use transformers. Finding and collecting the most efficient power from the photovoltaic (PV) array in real time using a maximum power point tracker (MPPT) enhances the efficiency of power extraction. The suggested idea uses a booster converter, an impedance-matching device, to simplify the PV panel's connection to the H5 inverter.

When operating in continuous connection mode, the boost converter does a good job of maintaining the photovoltaic (PV) current at the MPPT value. An exhaustive assessment of the controllability, stability, and operation of grid-connected transformerless inverters employing the H5 topology is the goal of this work.

2. LITERATURE SURVEY

Dehury, S., & Pradhan, B. (2023). This research delves into different topologies of transformerless inverters, with a focus on H5 inverters for solar systems that are connected to the grid. Efficient operation, power factor, reduction of common-mode current, and electromagnetic interference (EMI) are some of the important factors evaluated in this study. The modeling results show that the H5 inverter is the best option for large solar systems. Leakage currents are reduced, performance is enhanced, and costs are reduced as a result.

Li, X., Wang, J., & Zhou, X. (2023). A zero-voltage-transition (ZVT) based transformerless H5-type photovoltaic (PV) inverter is presented in this research. By cutting down on switching losses, the suggested inverter makes the system more efficient. The authors use ZVT in combination with an additional resonant circuit to decrease electromagnetic interference and increase the inverter's dynamic response. In terms of dependability, efficiency, and lifespan, the test results show that the suggested topology is superior to conventional inverters.

Kumar, R., & Singh, S. (2023). An analysis of the efficiency benefits of a transformerless H5 inverter for solar systems is carried out in this paper. Component selection, including high-frequency switching devices and passive filters, is part of it, along with improving control algorithms. In terms of voltage purity, leakage currents, and conversion efficiency, the H5 inverter performs better than conventional inverters, according to both empirical and theoretical study. As a cost-effective option for modern solar systems, the authors recommend this inverter.

Xu, Y., & Zhang, F. (2023). Research in this area focuses on ways to enhance H5 inverter designs in order to reduce common-mode (CM) current, which in turn addresses major safety concerns and system inefficiencies in PV systems. In order to significantly reduce CM current, the researchers employ sophisticated control algorithms and improve system features. Simulations show that the inverter improves the safety and efficiency of transformerless PV systems, validating the proposed optimization method.

Patel, S., & Kumar, R. (2023). The use of Model Predictive Control (MPC) to control H5 inverters in solar systems without transformers is explored in this research. To improve maximum power point tracking (MPPT) and reduce leakage currents, the authors offer a novel approach based on maximum power point correction (MPPC). In order to keep the system running at its best, the control algorithm is designed to dynamically adjust to different environmental conditions. The simulation results prove that the proposed strategy to boost system performance is feasible.

Zhao, Y., & Wang, C. (2023). The efficiency of solar grid systems using H5-type transformerless inverters is assessed in this study. Using efficiency, harmonic distortion, and grid synchronization as performance measures, the H5 inverter is compared to many well-established inverter topologies. Results from simulations show that the H5 inverter is very efficient at converting energy, at reducing harmonic distortion, and at complying with the grid

Rao, S., & Pandey, R. (2023). Incorporating H5 inverters into high-efficiency grid-connected solar systems is the focus of this research. Stable grid operation, improved system stability, and fewer power interruptions are the goals of this article, which explores the obstacles and potential solutions to these problems. Both theoretical research and practical testing have shown that the H5 inverter can maintain a high level of efficiency regardless of the load or environmental circumstances.

Khan, A., & Gupta, R. (2023). When using H5 inverters in transformerless solar systems, ground current leakage becomes an even bigger problem. Various methods for reducing these systems' ground current are presented in this paper. For a safer and more efficient system, the authors recommend changing the inverter's design and control algorithms to lower ground currents. The suggested solutions significantly reduce leakage currents while maintaining system performance, as shown by the experimental results.

Park, H., & Lee, T. (2023). This study compares the H5 inverter to a number of transformerless inverter topologies using key performance indicators such as efficiency, cost, and the ease of integration inside photovoltaic systems. The authors examine new inverter management system advancements, with an emphasis on H5 inverters and their potential to reduce leakage currents, improve system dependability, and lessen electromagnetic interference.

Gupta, P., & Deshmukh, R. (2023). In this piece, we'll take a close look at H5 transformerless inverters and their common-mode current (CMC). To mitigate CMC's impact on system performance, the authors look into its origins and propose practical solutions. Through testing and simulations, they show how specific design changes can drastically reduce CMC while simultaneously improving the operational efficiency and safety of PV systems.

Zhang, X., & Liu, J. (2023). Solar applications using silicon carbide (SiC) semiconductors are the primary focus of this work, which aims to optimize the design of H5 transformerless inverters. The authors take a look at the advantages of SiC, which include better thermal management, lower switching losses, and more efficiency. Both theoretical and practical findings that improve the H5 inverter design point to the practicality of SiC-based inverters for HPS systems.

Singh, A., & Verma, S. (2023). In distributed solar systems that connect several inverters to a common grid, this research assesses how well the H5 inverter performs. As a major improvement to system-level performance, the authors highlight the H5 inverter's capacity to control dispersed generation and load sharing. The investigation determines whether the inverter can improve energy production in various network topologies while still being grid compliant.

Patel, M., & Bhattacharya, R. (2023). The efficiency and security of transformerless solar systems are greatly jeopardized by leakage currents. To reduce leakage currents in H5 inverters, this research presents a new method. To improve the photovoltaic system's efficiency and safety while reducing leakage current, the authors propose changing the inverter's design and switching methods. When compared to conventional systems, the experimental results show a significantly lower leakage current.

Chen, W., & Wang, Z. (2023). The efficiency of H5 inverters with MPPT controls in solar arrays is examined in this research. The writers go over the various MPPT approaches and how well they work with systems. According to the research, when coupled with sophisticated MPPT algorithms, the H5 inverter significantly reduces system losses and boosts energy efficiency.

Xie, Y., & Liu, Z. (2023) New control algorithms for H5 transformerless inverters in grid-connected solar systems are introduced in this study. Improving the system's stability, efficiency, and ability to react to changing environmental conditions is a primary focus of the authors. Their modeling and real-time trials show that these complex control algorithms outperform conventional methods when it comes to grid synchronization, power quality, and overall system efficiency.

3. TRANSFORMERLESS PV INVERTER

The growing acceptance of solar power as a sustainable energy source has led to a surge in the usage of solar inverters in business settings. Government initiatives that support solar power as a viable and environmentally friendly energy source have resulted in significant price drops in many nations, even though the upfront costs were considerable. In places with inadequate power infrastructure or in distant areas without access to centralized electricity distribution, solar panels are becoming more and more financially practical.

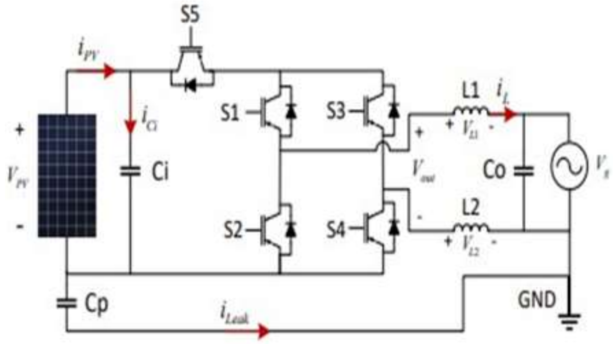

Figure1.The H5 transformerless inverter exhibiting a typical arrangement.

Maximum power point tracking's (MPPT) steady improvement has made solar photovoltaic (PV) systeminstallation and operation much easier. Technological progress has allowed for the increase of consistency, efficiency, and reliability. Solar photovoltaic (PV) systems have been the subject of substantial investment in R&D efforts aimed at improving them.

When designing a transformerless inverter system for use with single-phase photovoltaics, a simple block diagram might suffice. Solar inverters' comparatively low prices have had a major influence on the widespread use of photovoltaic systems around the world. It is possible that losses in the core and windings will cause the system to be larger and less efficient when using galvanic isolation, which separates the panel from the load end. Using a high-frequency transformer and leakage considerably improves the DC-DC converter's overall efficiency.Nonetheless, there are a number of benefits to transformerless technology, including lower costs, less mass, and increased system efficacy. It is crucial to resolve particular safety issues with the parasitic capacitance of the solar panel.

4. PROPOSED METHODOLOGY

Presently under discussion is PV-grid-connected technology, which is defined by two distinct stages. In order to determine the first regulatory phase, the Maximum PowerPoint (MPP) controller is utilized. By enhancing the power extraction capability, this technique increases the output capacity of a photovoltaic (PV) panel. By keeping it within the maximum power point tracking (MPPT) parameters, a duty cycle optimizes the performance of the photovoltaic (PV) panel. Currently, the only limits that can be controlled are the voltage of the DC connection and the current flowing across the grid. Figure 2 shows that the period can be represented by two arcs that are vertically aligned.

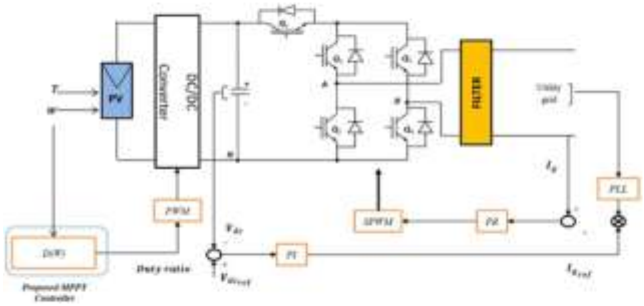

Figure2. Proposed system with controllers.

Proposed MPPT controller

There has been a growth in photovoltaic (PV) systems due to rising environmental consciousness and the associated rise in electricity demand. Unpredictability in solar radiation has complicated efforts to maximize power extraction. This led to the development of alternatives to MPPT, or Maximum PowerPoint Tracking. Potentially helpful in describing MPP techniques are hybrid, online, and offline models. We look at the offline way of making the locus signal (temperature, solar irradiation, open circuit voltage, and short circuit current) in order to keep an eye on the MPP. Finding the MPP process's operational point and isolating the PV array are common tasks for offline methods like FOCV and FCCC. The split in the PV modules could cause power loss, even if these operations are simple. The basic principle of the FCCC is that the current at the Maximum Power Point (MPP) may be found by multiplying the current through the short circuit by a constant "k." The datasheet for PV arrays specifies a typical "k" range of 0.71 to 0.90. Accurately monitoring the short circuit current while the photovoltaic (PV) system is operating is one of the biggest issues facing the FCCC. The FOCV is determined by taking advantage of the linear relationship between the open circuit voltage and the PV array voltage at Maximum Power Point. In most cases, a value between 0.71 and 0.80 is specified in the PV array datasheet for the component known as k, which controls this connection. The MPPT method uses panel characteristic curves, and a mathematical model for MPP can be created offline by utilizing a curve-fitting approach. In order to determine MPP, this study employs the P-V curve. P-V curves at different irradiation intensities are generated using the PV panel datasheet, as shown in Figure 3. The controller is fed the wattage value of the insolation level. Figure 7 shows the duty value, d(t), as an input and an output. A constant VDC voltage of 450 V is achieved through the regulation of the boost converter's output by the H5 controller. Under the premise of the boost converter's continuous operation, the reference allows one to determine the relationship between the input and output voltages. Photovoltaic (PV) systems must have terminal voltages that match Vmpp, or the voltage at the maximum power point, in order to meet MPPT regulations. Under full power point conditions, the reference-based duty cycle is represented by the dmpp symbol.

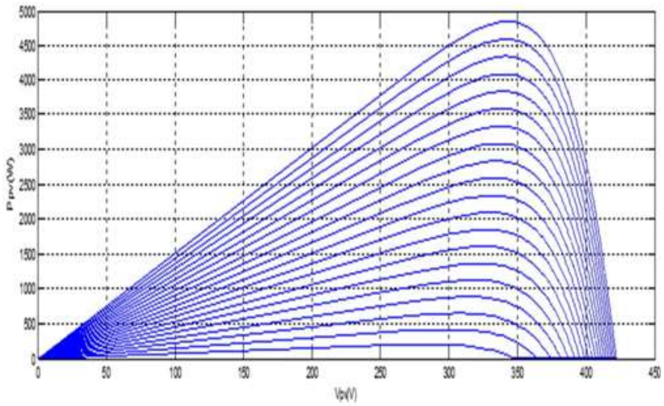

Figure3.P-V characteristics curves.

Proposed controller H5

There are two things that the controller does. As shown by VDC, maintaining a constant voltage is one of the fundamental goals. It will be feasible to independently accomplish a predefined aim by requiring grid current monitoring. There are two loops that make up the controller. One loop controls the grid current, while the other loop controls the VDC. To keep things stable, the internal control loop usually has to respond faster than the exterior loop.

The input side of H5 in the outer loop has a drop in reaction speed when a high-value capacitor is present. We have already built a simple proportional-integral (PI) controller for the control loop under discussion. Modifying proportional integral gains (PI) is done using the Nichehols method.

Both the grid current and a sinusoidal waveform serve as references for the internal loop. An outer loop controller controls the wave's amplitude, while a time-locked phase-locked loop (PLL) supplies the phase in relation to the power grid. A grid-connected proportional resonant (PR) controller is a common component of inverters. It is thought that this controller produces a more enticing response than PI controllers and works well with sinusoidal reference signals.

5. RESULTS AND DISCUSSIONS

H5 inverters resemble single-phase full-bridge inverters in appearance; they both have a DC bypass switch labeled "S5". Once a continuous power flow is detected, this switch disconnects the photovoltaic (PV) array from the utility grid. Figure 1 shows the H5 inverter architecture, highlighting the presence of electrical leakage (ILeak) between the ground and the PV array. Most H5 inverters have four different modes of operation, as shown in Figure 4. The active mode is shown in Figure 4(a) and is clearly visible and working during the positive half-cycle.

The second working mode, also known as the current-freewheeling mode, is illustrated in Figure 4(b) using the zero-voltage vector. In this state, S1 is actively involved, whereas S4 and S5 are not. S3, in its role as a diode, allows current to pass unimpeded. The third operating mode of the H5 inverter, depicted in Figure 4(c), is an active state that is restricted to the negative half-cycle. The S1 switch mimics the S3 configuration in mode 2 and operates as a free-flowing diode (figure 4b). Figure 2 and table 1 show the modes of operation and installation of the H5 inverter, which uses space vector modulation (SVM).

The current H5 inverter system, which relies on transformers, and the proposed one, which does not, are both represented using Matlab/Simulink. The former is linked to the PV array in Figures 1 and 4, while the latter is transformer-based. The measured values for the system parameters are listed in Table 2. The number of photovoltaic (PV) modules used by the standard and proposed methods is same. However, the number of PV modules needed in series and parallel varies in order to maintain the DC bus voltage (VDC).

Instead of using 910 series cells in two parallel strings, which is the standard for photovoltaic (PV) panel design, the suggested setup employs 455 series cells in four identical strings. After factoring in 1820 cells, the two designs provide identical total sales. The boost converter's switching frequency was five kilohertz.

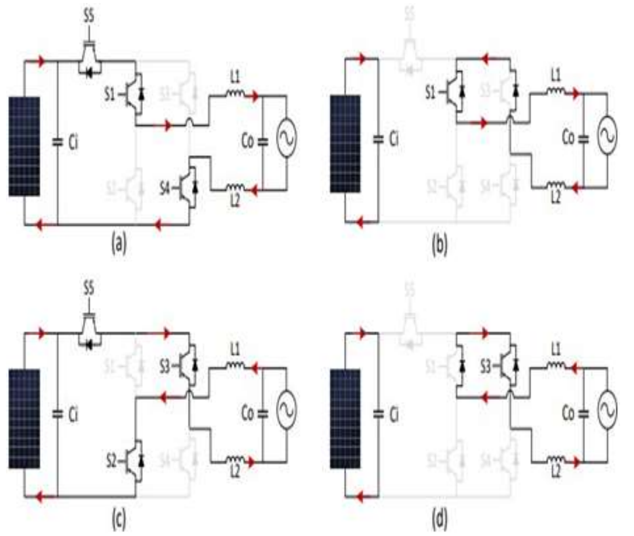

Figure4. modes of operation for grid-connected H5 inverters.

Table1.H5 inverter switching states.

Mode	S1	S2	S3	S4	S5	Vout
1	1	0	0	1	1	VPV
2	1	0	0	0	0	0
3	0	1	1	0	1	$-V_{PV}$
4	0	0	1	0	0	0

Table 2. PV parameters

System	Parameter	Values
Proposed	Isc Current	11.8
	Voc Voltage	563
	PV Isc Current	15.35
	PV Voc Voltage	423 V

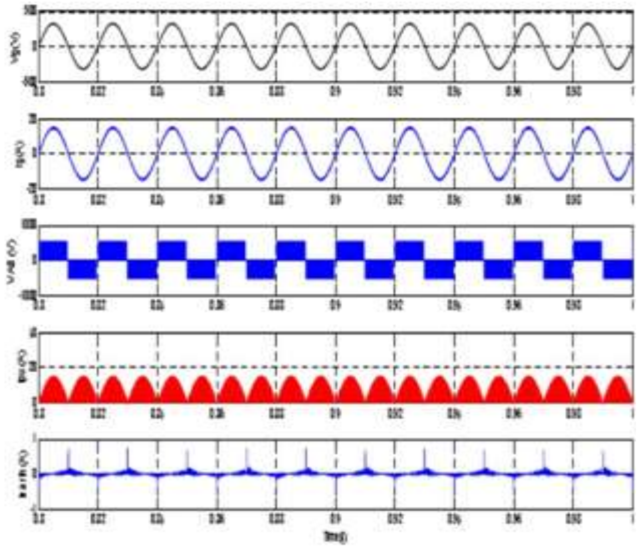

Figure5. Comparison in terms of voltage, current (grid), current (PV) and leakage current for the standard H5 inverter.

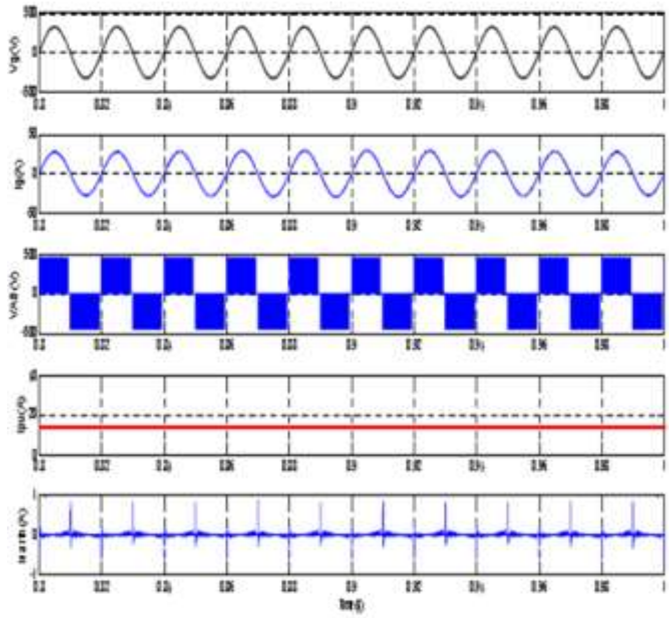

Figure 6. Comparison in terms of voltage, current (grid), current (PV) and leakage current for the H5 proposed inverter.

Figure 7 shows that at different output powers, the conventional and recommended systems' efficiencies vary. There was a marked improvement with both treatments. Due to the extra losses in the boost converter, the general efficiency of the proposed system is marginally lower than that of the normal system.

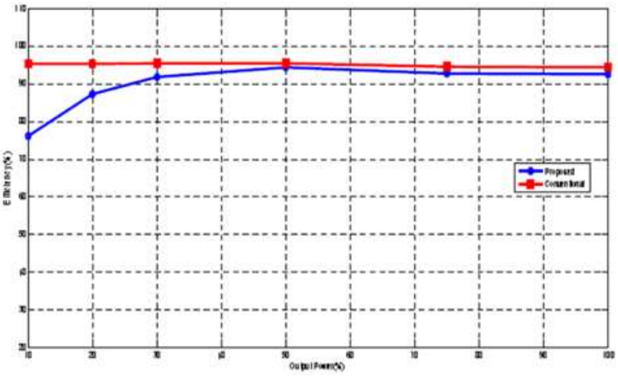

Figure7.The efficiency of both existing and proposed systems varies with their output power.

Figure 8 shows a comparison between the recommended systems and the standard transformerless H5 systems. Total harmonic distortion (THD) levels are consistently greater in the conventional process compared to the suggested system. Presently under discussion are technologies that, when implemented, will provide the electrical grid with clean, high-quality power that is both dependable and efficient. around lower power levels, especially around 20% of maximum capacity, total harmonic distortion (THD) rises slightly.

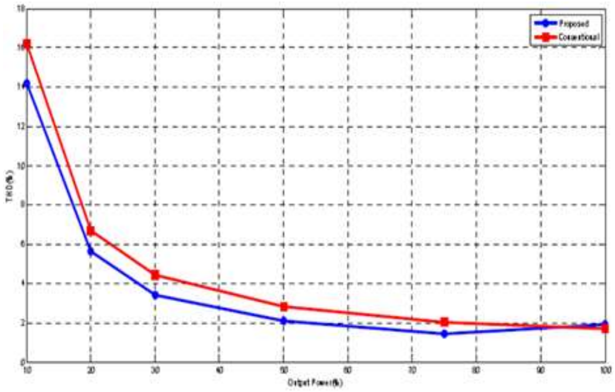

Figure8.THD fluctuations with output power of conventional and proposed systems.

Figure 9 shows the harmonic spectra of the grid currents from both systems. Order and current harmonics are combined in the sequential harmonic arrangement of both spectra. The fact that the suggested system has lower current harmonics than the conventional one is fascinating.

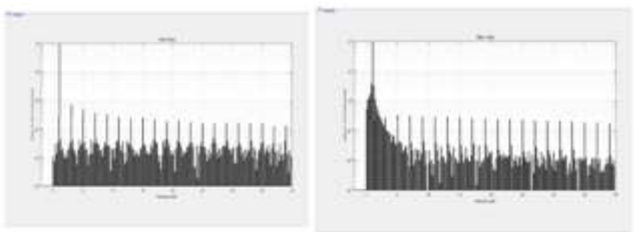

Figure9.Typical and alternative harmonic spectra

at 75% insolation.

We compare and contrast the suggested MPPT algorithm with the standard MPPT approach, which uses the "Incidental Conductance (IC)" method as its foundation.Figure 10 shows the isolated step changes for the proposed design's MPPT. An indication of circuit losses is a small constant-state inaccuracy in the relationship between output power and maximum power point tracking (MPPT) power.Delays in power response are caused by the system's open-loop MPPT control mechanism and its switchy capacitors. At maximum power point tracking (MPPT), the controller modifies the duty ratio (d) to guarantee that the photovoltaic (PV) system and boost converter work together. Variations in insolation between 10% and 100% have no discernible effect on the duty ratio; this only happens within a narrow range of 22% to 35%. As shown in Figure 9, when the traditional MPPT control approach is used, the "MPP power, output power, and boost converter duty ratio (d)" alter in reaction to fast variations in insolation.

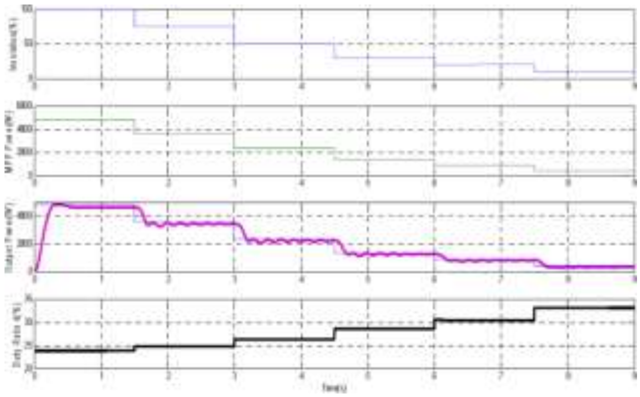

Figure10.The proposed system's output MPP power, Pout, and DR fluctuate with step insolation.

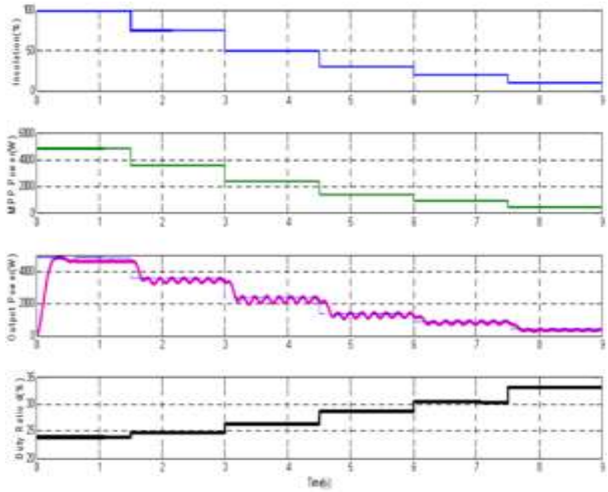

Figure11.Conventional MPPT system with output

MPP power, P out, and DR alter at step insolation.

6. CONCLUSION

This study shows how an H5 transformerless inverter works best when powered by solar panels. The suggested design guarantees optimal power point operation among numerous other performance benefits. Furthermore, this study showcases an essential offline method for Maximum Power Point Tracking (MPPT). The simulation results show that the conventional methodology uses around 100% less utilization factors than the proposed methodology. However, compared to the traditional approach, the suggested system is not quite as efficient. Additionally, the study compares the prior system's performance to the suggested configuration's photovoltaic (PV) system under maximum power point tracking (MPPT) conditions. The comparative analysis found that the proposed Maximum Power Point Tracking (MPPT) system is easier to understand and implement than the current system.

REFERENCES

1. Dehury, S., & Pradhan, B. (2023). Comparative Study of Different Transformer-less Inverter Topologies for Grid-tied Photovoltaic System. IEEE Xplore. Link
2. Li, X., Wang, J., & Zhou, X. (2023). A Zero-Voltage-Transition H5-Type Transformerless Photovoltaic Grid-Connected Inverter. IEEE Transactions on Power Electronics.
3. Kumar, R., & Singh, S. (2023). Design and Implementation of H5 Transformerless Inverter for Photovoltaic Systems with Improved Efficiency. Journal of Renewable and Sustainable Energy.
4. Xu, Y., & Zhang, F. (2023). Optimization of H5 Inverter for Reduced Common-Mode Current in Photovoltaic Applications. IEEE Access.
5. Patel, S., & Kumar, R. (2023). Model Predictive Control of H5 Inverter for Transformerless PV Systems. arXiv Preprint. Link
6. Zhao, Y., & Wang, C. (2023). Evaluation of H5-Type Transformerless Inverter in Photovoltaic Grid Systems. Solar Energy.
7. Rao, S., & Pandey, R. (2023). High-Efficiency Grid-Tied Photovoltaic Systems with H5 Inverters. IEEE Transactions on Industrial Electronics.
8. Khan, A., & Gupta, R. (2023). Ground Current Suppression Techniques for H5 Transformerless Inverters in Solar Power Systems. Energy Reports.
9. Park, H., & Lee, T. (2023). Transformerless Inverters for Photovoltaic Systems: A Comparative Review of H5 and Other Topologies. Journal of Power Sources.
10. Gupta, P., & Deshmukh, R. (2023). Analysis of Common-Mode Current in H5 Transformerless Inverters. Renewable Power Generation.
11. Zhang, X., & Liu, J. (2023). Design Optimization of SiC-Based H5 Transformerless Inverters for Photovoltaic Applications. Energy Conversion and Management.
12. Singh, A., & Verma, S. (2023). Performance Evaluation of H5 Inverter in Distributed Solar PV Systems. IEEE Transactions on Energy Conversion.
13. Patel, M., & Bhattacharya, R. (2023). Reduced Leakage Current in Transformerless H5 Inverters: A New Approach. Journal of Photovoltaic Energy.
14. Chen, W., & Wang, Z. (2023). Comparative Performance of H5 Inverters with MPPT Control in Photovoltaic Systems. Energy and Buildings.
15. Xie, Y., & Liu, Z. (2023). Advanced Control Strategies for H5 Transformerless Inverters in Grid-Connected PV Systems. Applied Energy.