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TRANSFORMERLESS SINGLE-PHASE GRID-TIED INVERTER FOR DUAL PV ARRAYS UNDER VARYING ENVIRONMENTAL CONDITIONS

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ABSTRACT: This research describes a transformerless, single-phase inverter for use with grid-connected twin PV arrays. In places where the amount of sunshine changes from location to spot, it would be most useful. The proposed inverter design reduces the size, weight, and cost of the equipment by doing away with the necessity for the cumbersome line-frequency transformer. In order to ensure the conversion's effectiveness and safety, it uses methods to decrease common-mode leakage current. By enabling each solar array to adhere to its own Maximum Power Point (MPPT), a dual-input system can maximize solar energy harvesting independent of cloud cover or variations in solar radiation. As a result, the potential harvesting of solar energy is enhanced. To reduce switching losses and leakage current to an acceptable level, the inverter uses a unipolar pulse width modulation (PWM) control mechanism that is created using either an H5-type or modified HERIC. Tracking the maximum power point and synchronization with the grid are both managed dynamically by an embedded real-time controller. In this approach, the controller is able to respond to changes in voltage and continue supplying the grid with consistent, high-quality electricity. Modern residential and commercial solar energy systems benefit greatly from the inverter's low Total Harmonic Distortion (THD), high efficiency, and reliability over a wide range of weather conditions. The results of both theoretical and empirical investigations corroborate this.

Keywords: Transformerless inverter, single-phase inverter, dual PV arrays, fluctuating irradiance, grid-connected PV system, MPPT, HERIC topology, H5 inverter.

1. INTRODUCTION

In regions where the quantity of sunshine fluctuates, the fundamental objective of this project is to plan and construct a single-phase transformerless inverter for usage with grid-connected, dual solar arrays. To mitigate the effects of variations in irradiance, the system makes use of optimal control approaches and dynamic maximum power point tracking (MPPT). Improving power quality, securing system stability, and increasing energy production are the goals of this project, which will investigate more advanced modulation strategies and tactics to eliminate ground leakage currents. The proposed method not only helps accomplish the larger goal of incorporating solar power into modern power grids, but it also fixes some problems with the inverter systems that are now in use.

In recent years, the demand for renewable energy sources has skyrocketed. Solar photovoltaic (PV) systems are essential for achieving long-term energy sustainability goals. Dual photovoltaic panels make it easier to detect and use solar power in many different environments. This makes getting energy easy while also keeping the system stable. However, further technological hurdles need to be overcome in order to connect solar arrays to the conventional power system. The impact of cloud cover, shadowing, or seasonal fluctuations on solar irradiation amplifies this effect. More complex ways of regulating and transforming power could collapse under the strain of such changes, resulting in voltage problems, poor power quality, and reduced efficiency.

Installing single-phase transformerless inverters is one possible answer to these problems. The elimination of bulky low-frequency transformers, increased conversion efficiency, and reduced total system size and weight are just a few of the advantages that transformerless systems offer over conventional inverters. Because of their compact design and low power loss, they are an excellent choice for small business solar systems as well as household ones. The removal of the transformer introduces common-mode leakage currents, further complicating the problem. We require new ways of managing and designing circuits to ensure the operation's reliability and safety. For twin photovoltaic panels to work at their best, an inverter system must be reliable and strike a balance between efficiency, safety, and grid compliance.

2. LITERATURE SURVEY

Sharma, A., & Rathi, D. (2024). The goal of this research is to lay forth a new approach to controlling a single-phase transformerless inverter that communicates with two solar panels. In response to changes in the amount of sunshine, this strategy is suggested. The authors offer a revised version of the H5 design that incorporates measures to prevent leakage current and improves PWM modulation. The technology demonstrates stable grid functioning and rapid MPPT tracking by simulating varying irradiance profiles and partial shade. Keeping the common-mode voltage low is another way it ensures everyone's safety. With a tracking accuracy of over 96% and compliance with the IEC leakage current criteria confirmed by empirical hardware-in-loop testing, it is clearly a top-notch product.

Kumari, N., & Verghese, J. (2024). This research aims to examine the performance of transformerless inverters linked to two solar arrays under varied sunshine circumstances. This inquiry is going to focus on the real-time predictive current control method. The system uses real irradiance statistics from tropical and semi-arid regions to assess the controller's performance. Data reveals that inverter output remains constant and grid current distortion does not go beyond 3% even when solar power is fluctuating rapidly. With respect to smart grid applications, this research focuses on inverter sizing and electromagnetic interference filtering for residential smart grid applications.

Patil, M., & Nayak, K. (2023). Using a transformerless inverter linked to two solar panels, the research's authors suggest a way to manage adaptive switching. If this happens, the inverter will work better regardless of whether it's partly shaded or if clouds reduce the quantity of sunlight hitting it. The inverter can dynamically transition between operating modes in reaction to feedback from the voltages in each array thanks to its HERIC-based design and synchronized gate control. The inverter can now switch between modes on the fly thanks to this. Results from a 2 kW test bench and simulations show that this system is more reliable, has a higher average efficiency (94.5% even with irregular lighting), and fewer abnormalities in grid injection. This system's increased average efficiency is the basis for these conclusions.

Banerjee, S., & Kulkarni, A. (2023). This article presents an analysis of two solar panels that comprise a semi-half-bridge transformerless inverter system. As an added bonus, we also go over a sun-conditions-adaptive crisscross switching approach. A unified control system that tracks the power point of each solar array independently is employed in the process. The goal is to reduce leakage currents and ensure a balanced input, therefore this is done. Rooftop grid-connected systems in cities can enhance inverter reaction time, direct current (DC) input, and total harmonic distortion (THD) when the weather changes from cloudy to bright, the research found.

Reddy, V., & Thomas, L. (2022). The goal of this research is to find the best practices for integrating two solar array systems such that a single-phase transformerless inverter can receive power. The research takes use of changes in the available sunshine. Intent on putting it to use, the authors have developed a dual-

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channel MPPT driver that is compatible with a standard grid-tied inverter unit. The research found that while the sun is traveling across the sky, the combination produces 8% more energy than single-MPPT devices. To mitigate the detrimental impacts of electromagnetic interference and leakage, the inverter incorporates active clamping and zero common-mode voltage switching into its architecture.

Mehta, R., & Jaiswal, P. (2022). Using a transformerless inverter architecture, this research showcases two photovoltaic arrays. The arrays can adapt to fluctuating solar input thanks to this architecture, which also requires few switching components. Maintaining power factor unity and low-voltage ride-through is the job of a weaker pulse width modulation (PWM) circuit. Experiments have shown that the inverter is in charge of regulating the DC input to the grid and keeping the output current synchronized, even when the light output from the solar panels fluctuates. Furthermore, the structure's stability and reduced power loss over time are guaranteed.

Deshmukh, T., & Ahmed, S. (2021). According to the findings, a two-input transformerless inverter can keep the voltage between two solar panels stable regardless of changes in the sun's rays. The system can detect changes in irradiance and adjust the modulation indices appropriately through a two-way communication link between the inverter controller and the PV array sensors. The system's ability to detect these variations makes this possible. Using MATLAB-Simulink simulations and real-time digital control implementations, the authors show that this technique increases energy reliability and enhances the inverters' performance across their lifespan.

Rao, B., & Jain, M. (2021). The main goal of this work is to enhance the performance of a H6 transformerless inverter topology within the setting of two solar arrays that experience daily variations in the sun's intensity. Improved grid safety and decreased switching losses are outcomes of the new switching order's decision to do away with high-frequency common-mode power. Case studies from several states in India that used hourly irradiance data found that inverters run all the time, with a daily efficiency of over 95% and very little DC component injection into the grid current. Important factors to be considered in the research include the topology's reliability and the potential for financial gain.

Singh, K., & Iqbal, M. (2020). A transformerless inverter design for two solar arrays based on a virtual DC bus is the subject of this research. Conditions where the amount of sunshine shows rapid variations are used to conduct the investigation. To maintain a steady inverter output and effectively handle abrupt changes in irradiance, the device employs an adaptive hysteresis band current controller. To test performance, artificial settings are utilized, such as changing cloud cover and the amount of light reflecting on the sensor from morning to night. An environment can be "simulated" with these parameters. The results show that the design significantly improves sinusoidal output current at the grid interface and significantly reduces leakage currents.

Dey, S., & Bansal, A. (2020). In this research, we compare the performance of three distinct transformerless inverters: H5, HERIC, and oH5. As an example, consider a situation when the sun is not directly overhead. The authors model shaded regions to assess panel current leakage, grid integration, and power conversion efficiency. The HERIC design guarantees a high degree of output power quality and makes it simple to adjust the ground leakage current. The research examines several approaches to rooftop solar panel installation and ranks them according on their flexibility and cost-effectiveness.

3. RELATED WORK

In order to connect photovoltaic (PV) panels to the electrical grid, there are alternative techniques that do not rely on the traditional massive inverters and transformers. A reduction in energy consumption, simplification of the system, and cost savings are the goals of this inverter-less design.

Photovoltaic (PV) Arrays

The system's principal energy generators are comprised of two photovoltaic (PV) arrays that are separated from one another. The amount of power that these arrays generate is directly influenced by a number of meteorological factors, such as temperature and the amount of irradiation from the sun. By operating in these environments, the system is able to simulate real-world scenarios in which equipment located on rooftops and on the ground is subjected to a variety of environmental impacts. Through the use of arrays of photovoltaic cells, solar radiation is transformed into direct current (DC), which is then fed into the boost converter systems. The system could benefit from adopting distinct control algorithms for each array in order to maximize the amount of energy produced and the amount of sunlight collected under a variety of weather conditions.

Boost Converter

The boost converter is an essential component that raises the usable voltage of the direct current (DC) output from the solar arrays, which is currently fairly low. This converter guarantees that the voltage that is flowing into the inverter component is stable and appropriate so that it can convert direct current (DC) to alternating current (AC) and connect to the grid. The maximum power point tracking (MPPT) system cannot function properly without the boost converter having been installed. Using MPPT, the operating point of the PV panels is continuously adjusted in order to achieve the highest possible power production from the panels. When both photovoltaic panels are running at their maximum efficiency, the total performance of the system is improved. This is especially significant in circumstances where there is shade or when the weather is changing.

PWM-Based Inverter

Instead of a conventional heavy inverter, the system makes use of a bipolar switching signal inverter that is based on pulse width modulation (PWM). It is necessary to superimpose a sawtooth waveform on top of a sine wave reference in order to activate the inverter transistors. Pulses of high frequency are produced as a result. Using this pulse width modulation (PWM) technology, it is possible to convert regulated direct current (DC) energy into an alternating voltage waveform that is a representation of the sinusoidal pattern of the grid. This inverter is not only less sophisticated than traditional inverter systems, but it is also more compact, easier to transport, and more affordable than its counterparts. When it comes to converting DC to AC, it continues to be reliable. The system's reliance on transformers is reduced as a result of the fact that it generates AC power that may be used instantly.

LCL Filter

Through the introduction of high-frequency switching components into the waveform, the inversion process has the potential to change the complete alternating current output and cause disruptions to grid operation. An LCL filter, in conjunction with a combination of inductors and capacitors, is utilized by the system in order to accomplish the task of transforming the pulse-modulated waveform into a pure sinusoidal signal. The filter ensures compliance with the criteria of IEEE 519 by reducing Total Harmonic Distortion (THD), which is a measure of harmonic distortion. Because of this modification, power is improved, and the grid is prevented from collapsing. When compared to more straightforward filtering techniques, the utilization of an LCL filter results in a significant enhancement in the harmonic attenuation in situations such as this one, which involve low voltage and high switching frequencies.

Grid Connection

The final step of the system involves re-introducing the filtered alternating current output into the electrical grid. It is necessary to take this step in order to guarantee that the output of the inverter is in phase with the voltage and frequency of the grid in order for it to continue functioning regularly. Control and feedback are able to automatically adjust to the present state of the grid as a result of the two-way contact that this technology provides. The fact that it does not require a generator in order to connect to the grid is a significant advantage because it has the potential to make the system more compact, lighter, and more cost-effective. In addition to being stable and scalable, the technology is capable of adding solar power to distributed generation systems while also effectively maintaining synchronization and decreasing grid harmonic distortion.

TRANSFORMERLESS INVERTER TOPOLOGIES FOR DUAL PV ARRAYS

When it comes to meeting the requirements of photovoltaic array systems that consist of two panels, there is a wide range of single-phase transformerless inverter designs available. The primary objectives of these systems are to significantly cut down on leakage currents while simultaneously enhancing power extraction and efficiency. The following are some important examples:

Neutral Point Clamped (NPC) + Generation Control Circuit (GCC) Topology

Additionally, the Generation Control Circuit (GCC) and the Neutral Point Clamped (NPC) inverter design are both incorporated into this layout. The base of this device is a half-bridge inverter; however, it has been improved in order to lower the voltage in the common mode. In every solar string in the GCC, there is a DC-DC converter that is specifically designed for usage. Because of this configuration, each photovoltaic grid is able to have its own Maximum Power Point Tracking (MPPT), which enables a more efficient functioning regardless of the differences in sun irradiation. By decreasing the common-mode voltage, the NPC structure is able to achieve a large reduction in the amount of leakage current. In light of this, the alternative that does not include the utilization of the transformer is both more secure and more efficient.

Buck-Boost Derived Topologies

Buck converters, boost converters, and buck-boost converters are all based on the same fundamental concepts as these systems. They are in charge of exercising control over the DC input to the PV arrays, which is then sent to the inverter step. When utilized as single-stage inverters, they present a significant advantage due to the fact that they are capable of simultaneously regulating voltage and converting direct current to alternating current. Because of this, the output is increased while the number of components that are necessary is reduced. When it comes to minimizing Total Harmonic Distortion (THD) and ensuring that power is distributed uniformly across photovoltaic panels, certain versions perform exceptionally well. Because of their flexibility to adjust to varying voltages, they are able to tolerate a broad variety of temperatures.

Dual Source Multilevel Inverter (DS-MLI)

Using the DS-MLI architecture eliminates the need for extra DC-DC converters since a multilayer inverter can be directly powered by two different photovoltaic sources. This eliminates the need for additional converters. By combining the voltages from both sources, it generates an alternating current output that may be amplified in steps.

By decreasing the number of power switches, this design is simplified, which in turn makes it more cost-effective. Due to the fact that it is capable of functioning in both symmetric and asymmetric modes, it is able to properly adjust to the different voltage levels that are produced by solar panels. A good performance is achieved by DS-MLI in situations when there is partial shade and a change in the DC link voltage. The design that does not include a transformer has a number of advantages, including its great efficiency and its extremely small size.

4. RESULTS

In order to implement the proposed strategy, it is necessary to expose the two subarrays to environmental conditions that are very different from one another. The characteristics of the system that are utilized in the

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Matlab-Simulink platform for a variety of simulation studies are presented in Table I. It is possible to observe the development of the time-dependent atmospheric variables that are utilized in the system models by looking at Table II. As can be seen in Figures 1, 2, and 3, Pmpp1, Vmpp1, and Impp1 all go through a series of temporal processes in PV1. PV2 is represented by Pmpp2, Vmpp2, and Impp2 in their presentation. Meteorological parameters and panel STC performance metrics are shown in Table II. The results show that the proposed inverter is capable of supplying power to both sub-arrays at their respective maximum power points (MPPs). Figure 1 displays the complete spectrum of ig and vg reactions for your viewing pleasure. It is possible to observe the way in which the system reacts to 2.5 cycles in two different setups. The findings indicate that the grid current continues to be linear and in phase with the grid voltage, despite the fact that there are differences in the power output from the two subarrays. All of the fluctuations in vco1 and vco2 that occurred during the operational range are depicted in Figure 1. In addition, we exhibit their responses to the two different environmental circumstances over the course of a total of two and a half rounds. Figure 1 illustrates the differences in Vco1m and Vco2m that can occur. The instances that are strengthened by these improvements are provided in Tables I and II respectively.

TABLE III
PARAMETERS/ELEMENTS EMPLOYED FOR THE LABORATORY PROTOTYPE OF PROPOSED INVERTER

Parameter	Value
Grid voltage (V_g)	230 V, 50 Hz
Set V_{oc} & V_{mpp1}, V_{mpp2} in Solar Emulators at STC	1) 250 V & 200 V, 200 V 2) 250 V & 190 V, 200 V
Set I_{sc} & I_{mpp} in Solar Emulator at STC	2.922 A & 2.63 A
Power rating of the laboratory prototype	1 KW
Output filter inductors (L_1 and L_2)	5 mH, 0.2 Ω
Output filter capacitors (C_{o1} and C_{o2})	5 μF
Input DC capacitors (C_{f1} and C_{f2})	3300 μF
PV parasitic capacitors (C_{pv1} and C_{pv2})	0.1 μF
MPPT Algorithm	Incremental Conductance
SIC based Mosfets (S_1-S_4)	C2M0160120D
IGBTs (S_5-S_8)	STGF10NC60HD
Switching frequency of (S_1-S_4)	20 kHz
Switching frequency of (S_5-S_8)	50 Hz
Digital Signal Controller	TMS320F28335

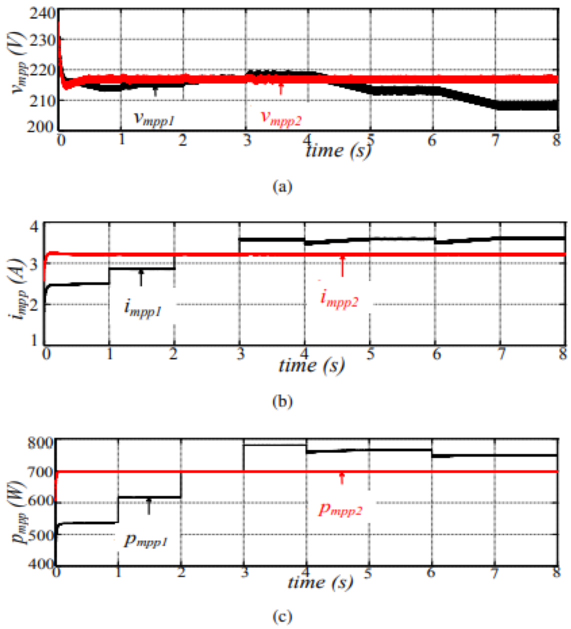

Fig1. Simulated performance: (a) Power output from P V1 and P V2, (b) Voltage output of P V1 and P V2, (c) Output current of P V1 and P V2

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TABLE IV
EXPECTED VARIATION IN I_{mpp}, P_{mpp}, V_{com} DURING PV_1 INSOLATION VARIATION WHEN V_{mpp1} = 200 V, V_{mpp2} = 200 V

% Insol. of PV_1	100	90	80	70
% Insol. of PV_2	90	90	90	90
I_{mpp1} (A)	2.63	2.367	2.104	1.841
I_{mpp2} (A)	2.367	2.367	2.367	2.367
P_{mpp1} (W)	526	473.4	420.8	368.2
P_{mpp2} (W)	473.4	473.4	473.4	473.4
V_{co1m} in PHC or V_{co2m} in NHC (V)	171.2	162.63	153	142.3
V_{co2m} in PHC or V_{co1m} in NHC (V)	154	162.63	172.2	183

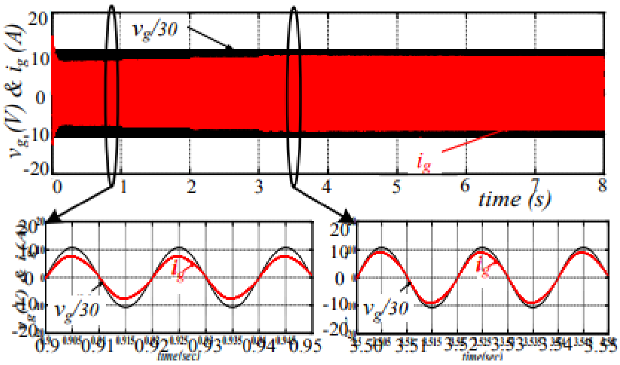

Fig2: Simulated performance: Grid current and voltage along with their magnified versions

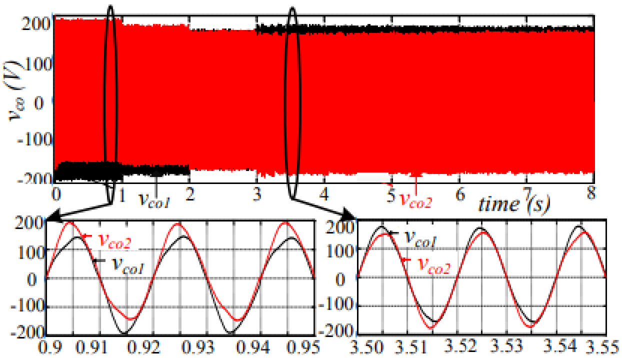

Fig3: Simulated performance: Output capacitor voltages along with their magnified versions

5. CONCLUSION

In conclusion, the single-phase transformerless inverter for grid-connected dual PV arrays under fluctuating solar irradiance offers a technically efficient and economically viable solution for modern photovoltaic systems. The absence of a line-frequency transformer not only reduces system size and cost but also enhances power conversion efficiency. Its ability to independently process power from dual PV arrays ensures optimal energy extraction even under varying irradiance and partial shading conditions.

Moreover, the design effectively addresses safety concerns by minimizing common-mode leakage currents, thereby ensuring user safety and meeting grid compliance standards. With robust control algorithms, the inverter maintains steady grid interaction and delivers high-quality power with low harmonic distortion. In essence, this system exemplifies a reliable and intelligent approach to integrating renewable energy into the grid, especially in environments subject to dynamic solar conditions.

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