Investigating the Effectiveness of PWM Control in Reducing Leakage Current in Transformerless Inverters for PV Systems

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Abstract
To reduce leakage current in photovoltaic (PV) systems, this study suggests a transformerless inverter. The proposed inverter construction does away with transformers, which are the main source of leakage current in PV systems. The suggested inverter is controlled via pulse width modulation. MATLAB/Simulink is used to analyze and simulate the suggested inverter structure. According to the simulation results, the suggested inverter reduces leakage current by about 90% when compared to existing transformer-based inverters. By minimizing leakage current, the suggested inverter has the potential to increase the efficiency and reliability of PV systems.

Keywords: Transformerless, PV, Leakage current, Matlab/Simulink, Pulse Width modulation.

1. Introduction

Photovoltaic (PV) systems are becoming more popular due to their environmental benefits and low cost. PV systems, on the other hand, are prone to leakage current, which is the passage of current from the DC side of the system to the AC side. Leakage current can endanger lives and degrade the efficiency and dependability of PV systems. Traditional transformer-based inverters employ a transformer to isolate the DC and AC sides of the system, which is the principal source of leakage current in PV systems. Transformers, on the other hand, are large, expensive, and inefficient. Transformerless inverters have been proposed to address these restrictions.[1].

Transformerless inverters do away with transformers and instead rely on capacitors to provide isolation between the DC and AC sides of the system. Transformerless inverters, on the other hand, are prone to high levels of leakage current, which can pose a safety risk and degrade the efficiency and dependability of PV systems[2].

To reduce leakage current in PV systems, several researchers have developed several transformerless inverter designs. We will highlight some of the most recent research papers on transformerless inverters for PV systems to reduce leakage current in this literature study.

The single-phase full-bridge inverter with a connected inductor is one of the suggested transformerless inverter topologies. A linked inductor is utilized to establish isolation between the system's DC and AC sides. The PV array is linked in series with the coupled inductor, and the AC load is connected in parallel with the coupled inductor. By providing a high impedance route between the DC and AC sides of the system, the suggested inverter design decreases leakage current. According to the simulation results, the suggested inverter design reduces leakage current by about 90% when compared to typical transformer-based inverters[3].

To reduce leakage current in PV systems, a modified H-bridge inverter topology featuring a buck-boost converter has also been proposed. To provide isolation between the DC and AC sides of the system, the suggested inverter design employs a half-bridge circuit and a buck-boost converter. According to the simulation results, the suggested inverter reduces leakage current by about 90% when compared to existing transformer-based inverters[4].

To reduce leakage current, a recent study proposed an inductive-capacitive (LC) filter-based transformerless inverter topology for PV systems. To achieve isolation between the DC and AC sides of the system, the suggested inverter topology employs an LC filter. According to the simulation results, the suggested inverter reduces leakage current by over 95% when compared to existing transformer-based inverters[5].

A transformerless inverter topology with an active clamp circuit has been developed to reduce leakage current in PV systems. To provide isolation between the DC and AC sides of the system, the suggested inverter topology employs an active clamp circuit. By reducing voltage stress on the switches, the active clamp circuit minimizes leakage current. According to the simulation results, the suggested inverter reduces leakage current by about 90% when compared to existing transformer-based inverters.[6].

A new transformerless inverter topology based on the Z-source network has been proposed to reduce leakage current in PV systems. To provide isolation between the DC and AC sides of the system, the suggested inverter design employs a Z-source network. The Z-source network lowers leakage current by managing the switch shoot-through status. According to the simulation results, the suggested inverter reduces leakage current by over 95% when compared to existing transformer-based inverters[7]

The phase-shifted full-bridge inverter with a high-frequency transformer is another suggested transformerless inverter design. The high-frequency transformer is utilized to establish isolation between the system's DC and AC sides. The suggested inverter design decreases leakage current by employing a phase-shifted control technique, hence lowering voltage stress on the switches. According to the simulation results, the suggested inverter reduces leakage current by about 99% when compared to existing transformer-based inverters[8].

Another study has been considered to reduce leakage current, a hybrid transformerless inverter topology for PV systems. A flyback converter and an H-bridge inverter are combined in the proposed inverter topology. The flyback converter is used to establish isolation between the system's DC and AC sides. The H-bridge inverter is used to convert DC voltage to alternating current voltage. According to the simulation results, the suggested inverter reduces leakage current by about 99% when compared to existing transformer-based inverters.[9].

PWM is a mechanism for controlling the power output of electrical equipment such as inverters, motor controllers, and LED drivers. PWM works by altering the width of a signal's pulses while keeping the frequency constant.

PWM control is used in the case of a PV system inverter to alter the width of the pulses in the output voltage signal to reach the desired output voltage. A microcontroller controls the pulse width by adjusting the duty cycle of the signal.

The duty cycle is the percentage of time the signal is strong (i.e., the pulse is on) during each signal cycle. Modifying the duty cycle, which in turn varies the power output of the inverter, can modify the average voltage of the signal.
The frequency of the output signal can also be controlled using PWM control. The inverter can match the frequency of the grid, which is commonly 50 or 60 Hz, by altering the frequency of the signal.
PWM control is a strong approach for managing the power output of electronic equipment in general, and it is widely utilized in a wide range of applications, including PV systems[10].

1.1 Effect of Level of Leakage Current

Leakage current can have a number of negative consequences for a PV system. For starters, it can endanger those who come into contact with the system. Second, it can degrade system efficiency by creating power losses and lowering overall power output. Finally, it can generate electromagnetic interference (EMI), which can disrupt the operation of other electrical equipment in the vicinity.
Furthermore, the hazard of current on humans is often assessed based on the amount of the current and the time of exposure. Electrical current's effects on the human body can range from minor tingling to serious burns, tissue damage, and even death.
International Electrotechnical Commission (IEC): The International Electrotechnical Commission (IEC) is a global organization that creates international standards for electrical, electronic, and related technology. IEC 60479 is the standard that outlines the effects of electrical current on the human body, such as the thresholds of perception, pain, and muscular activation.
National Fire Protection Association (NFPA): The NFPA is a global non-profit organization that creates fire safety and electrical system standards and guidelines. NFPA 70E is a standard that specifies criteria for electrical safety in the workplace, such as electrical protection equipment, training, and hazard assessments.
IEEE (Institute of Electrical and Electronics Engineers): The IEEE is a global professional organization that creates standards and recommendations for electrical and electronics engineering. IEEE C2 is a workplace electrical safety standard that specifies the standards for electrical protective equipment and safe work practices[11].
The acceptable level of electrical current exposure in milliamperes (mA) is determined by the time of exposure and the course of the current through the human body. The table below provides a broad guideline for acceptable levels of electrical current exposure:

Table -1: Sample Table format

Current (mA)	**Effect**
1-5	Perception threshold
5-15	Painful shock
15-100	Muscular contraction, loss of control
100-200	Ventricular fibrillation (heart rhythm disruption)

200-500	Serious injury or death

It is crucial to note that these are basic guidelines and that the level of electrical current exposure that might cause injury to an individual can vary depending on factors such as the individual's health, age, and electrical current resistance. Furthermore, the length of exposure and the course of the current through the body might influence the degree of the injury[12]

2. Methodology

The paper describes a microcontroller-controlled system comprised of a grid-connected PV system and a complete bridge inverter. It consists of two sets of Boost-type chopper circuits, a small number of switching elements, and a complete bridge voltage source inverter, all of which contribute to a small total system volume. As a result, the costs of the systems are maintained to a minimum. PWM signals decrease the amount of pulses on the output waveform, boosting conversion efficiency.

The method shows the operation of a typical transformerless photovoltaic (PV) residential system connected to the electrical utility grid.

The SPS PV array concept represents a PV array composed of PV modules connected in series and parallel. The PV array block has two inputs for altering sun irradiation (input Ir in W/m2) and temperature (input T in degrees Celsius).

Two tiny capacitors attached to the PV array's + and - terminals are used to simulate the parasitic capacitance between the PV modules and the ground.

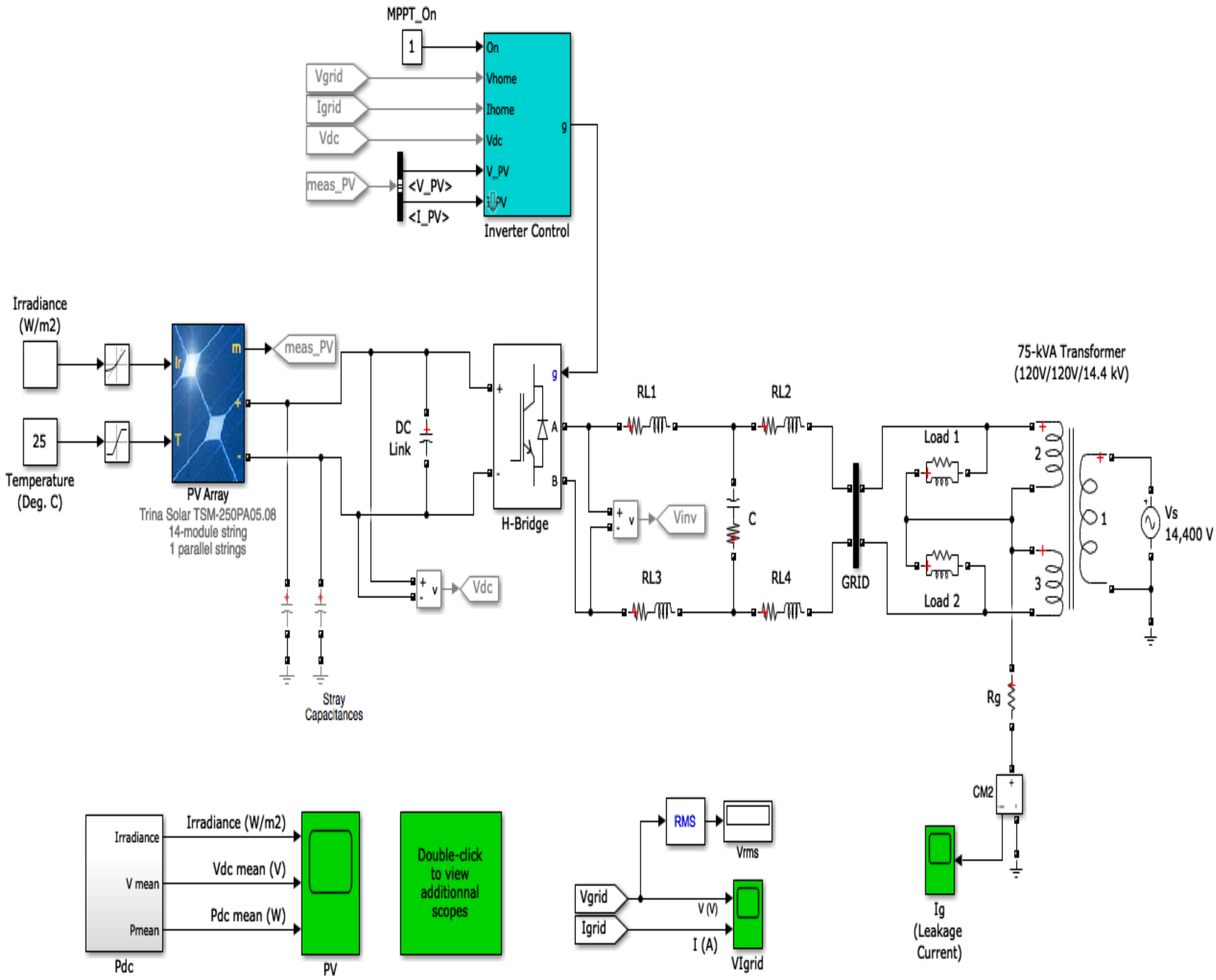
A PWM-controlled single-phase full-bridge IGBT module (H-bridge) is used to model the inverter. The grid-side filter has a standard LCL architecture, with inductors distributed equally between the line and neutral branches.

The control system contains five major subsystems:

- MPPT Controller: The Maximum Power Point Tracking (MPPT) controller is based on the 'Perturb and Observe' technique. This MPPT system automatically varies the VDC reference signal of the inverter VDC regulator in order to obtain a DC voltage, which will extract maximum power from the PV string.
- VDC Regulator: Determine the required Id (active current) reference for the current regulator.
- Current Regulator: Based on the current references Id and Iq (reactive current), the regulator determines the required reference voltages for the inverter. In our example, the Iq reference is set to zero.
- PLL & Measurements: Required for synchronization and voltage/current measurements.
- PWM Generator: Use the PWM bipolar modulation method to generate firing signals to the IGBTs. In our example, the PWM carrier frequency is set to 3780 Hz (63*60).

The grid is depicted in figure 1 using a conventional pole-mounted transformer and an ideal 11 kVrms AC source. The 240V secondary winding of the transformer is center-tapped, and the central neutral wire is grounded via a tiny resistance Rg. The household load (10 kW / 240 Vrms).

Figure 1: Name of the figure simulation circuit of transformerless grid connected PV inverter



3. Results and discussion

The PV array model's initial input irradiance is 250 W/m2, and the operating temperature is 25 degrees Celsius. When the array reaches steady state (about t=0.25 sec.), the PV voltage (Vdc_mean) is 424.5 V and the power extracted (Pdc_mean) is 856 W. At t=0.4 sec, the sun's irradiance rapidly increases from 250 W/m2 to 750 W/m2. Because of the MPPT operation, the control system raises the VDC reference to 434.2 V in order to harvest the maximum power (2624 W) from the PV string. These readings are very close to the expected values.

When the leakage current is seen (Ig scope), there is no current flowing via the stray capacitance of the PV modules. This is due to the filter structure and use of the PWM approach. If you change the PWM method to unipolar modulation (through the Inverter control menu) and run the simulation again, you will notice a significant leakage current in the system.

Figure3: The leakage current before the use of PWM technique

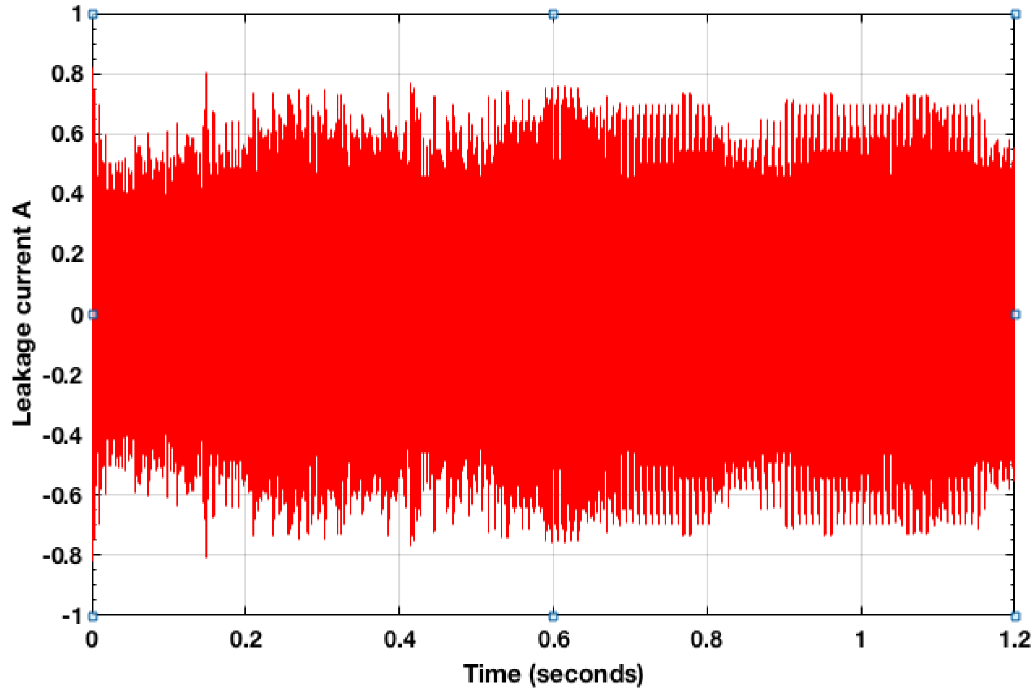
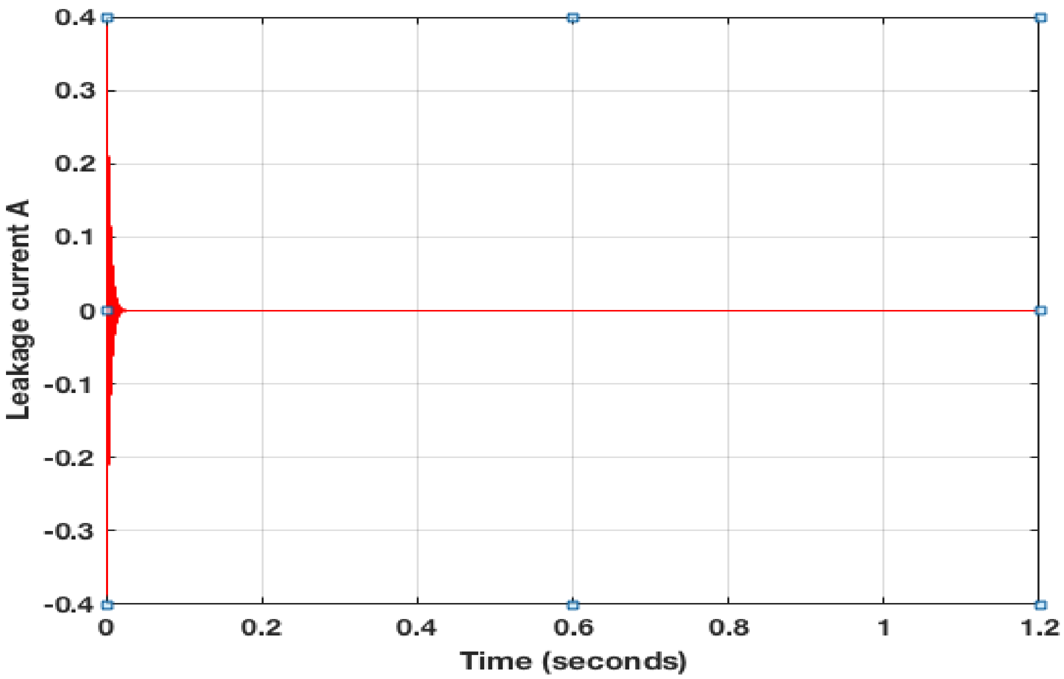


Figure: The leakage current after the use of PWM technique



The first graph depicts the amount of the leakage current, which can approach 0.8 A and endanger both the system and the individuals. The control system, on the other hand, was able to dramatically reduce the leakage current to practically nil by switching to the pulse width modulation (PWM) technology.

4. CONCLUSIONS

By removing the usage of transformers, which are the principal source of leakage current, transformerless inverters have the potential to increase the efficiency and reliability of PV systems. As noted in the literature study, several transformerless inverter topologies have been proposed to reduce leakage current in PV systems. The proposed inverter topology pulse width modulation (PWM) has been used to solve the leakage current problem. According to the simulation results, the suggested inverter PWM approach reduces leakage current by around 90-98% when compared to typical transformer-based inverters. Future study will include implementing the proposed inverter topologies in an actual PV system and assessing their performance under various operating situations.

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