Faculty of Engineering

DEVELOPMENT OF SINGLE-PHASE TRANSFORMERLESS DC-AC INVERTER FOR PHOTOVOLTAIC SYSTEM

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DEVELOPMENT OF SINGLE-PHASE TRANSFORMERLESS DC-AC INVERTER FOR PHOTOVOLTAIC SYSTEM

DUSTINE IBAU EMANG

A dissertation submitted in partial fulfilment
of the requirement for the degree of

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At the completion of my Final Year Project, I am filled with a sense of accomplishment and gratitude.

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ABSTRACT

The aim of this project is to develop a single-phase transformerless DC-AC inverter system, with a focus on reducing switching losses and mitigating the effects of leakage currents. The implementation of buck-boost transformerless inverter is used to decrease switching losses and the leakage current. The expected impact of this research is significant as it has the potential to improve the efficiency and reliability of single-phase transformerless inverter systems. The use of transformerless inverters can significantly reduce the size and cost of inverter systems, making them more accessible and attractive for a wider range of applications. Additionally, the proposed techniques for reducing switching losses and leakage currents can further improve the efficiency and performance of these systems, making them more competitive in the market. Overall, this research aims to contribute to the development of more effective and sustainable energy solutions that can benefit society by reducing the reliance on fossil fuels and mitigating the impact of climate change. The results of this project have the potential to be applied in a variety of settings, including residential, commercial, and industrial inverter systems, making it a valuable contribution to the field of renewable energy.

ABSTRAK

Matlamat projek ini adalah untuk membangunkan sistem penyongsang DC-AC tanpa pengubah fasa tunggal, dengan tumpuan untuk mengurangkan kehilangan pensuisan dan mengurangkan kesan arus bocor. Pelaksanaan penyongsang tanpa pengubah buck-boost digunakan untuk mengurangkan kehilangan pensuisan dan arus bocor. Impak yang dijangkakan daripada penyelidikan ini adalah penting kerana ia berpotensi untuk meningkatkan kecekapan dan kebolehpercayaan sistem penyongsang tanpa pengubah fasa tunggal. Penggunaan penyongsang tanpa transformer boleh mengurangkan saiz dan kos sistem penyongsang dengan ketara, menjadikannya lebih mudah diakses dan menarik untuk pelbagai aplikasi yang lebih luas. Selain itu, teknik yang dicadangkan untuk mengurangkan kehilangan pensuisan dan arus bocor boleh meningkatkan lagi kecekapan dan prestasi sistem ini, menjadikannya lebih berdaya saing dalam pasaran. Secara keseluruhannya, penyelidikan ini bertujuan menyumbang kepada pembangunan penyelesaian tenaga yang lebih berkesan dan mampan yang boleh memberi manfaat kepada masyarakat dengan mengurangkan pergantungan kepada bahan api fosil dan mengurangkan kesan perubahan iklim. Hasil projek ini berpotensi untuk digunakan dalam pelbagai tetapan, termasuk sistem penyongsang kediaman, komersil dan perindustrian, menjadikannya sumbangan berharga kepada bidang tenaga boleh diperbaharui.

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LIST OF ABBREVIATIONS

DC-AC	Direct Current Alternating Current
PV	Photovoltaic
GaN	Gallium Nitride
PWM	Pulse Width Modulation
SPWM	Single Pulse Width Modulation
CM	Common Mode
BBTI	Buck-Boost Transformerless Inverter
LVRT	Low-voltage ride-through
FB-DCB	Full Bridge Inverter with DC Bypass
ML-NPC	Neutral point clamp converter
SiC	Silicon Carbide
MPPT	Maximum Power Point Tracker
CMV	Common Mode Voltage

CHAPTER 1

INTRODUCTION

1.1 Background

In the last century, the development of DC-AC inverter systems has transformed the electricity business. DC-AC inverters, commonly known as grid connected inverters, are pieces of equipment that are utilized to turn direct current (DC) energy into AC, or alternating current. These inverters are essential components of several green energy infrastructures as well as grid-tied applications that permit the transmission of electricity from the grid to a user's house or company. In renewable power, motor driving, and emergency backup applications, the DC-AC inverters are the principal power electronic conversion equipment [1]. As the need for renewable energy sources has grown, so too has the necessity for efficient and dependable DC-AC inverters. It is crucial for all industrial applications, including as electric cars and renewable energy systems [2]. Furthermore, photovoltaic (PV) is well-known and gaining popularity because to its reasonable cost and simple operation, particularly in transformer-less inverter-based grid-connected distribution generating systems [3]. There is a significant amount of research being conducted in the subject of renewable energy now. The photovoltaic system is a formidable competitor in the market. As a consequence, tremendous progress is being made in the field of electronics in order to maximize energy harvesting from renewable sources. The inverter stage has a key role in determining the efficiency, longevity, and size of the whole system. Therefore, it is not unexpected that varied inverter topologies have emerged to solve the various system-related difficulties.

Figure 1.1: Example of Transformerless Inverter

The advent of transformer-less inverter systems has been one of the most significant developments in the development of DC-AC inverter systems throughout the years. The development of efficient and dependable DC-AC inverter systems has been a major focus of study over the past several decades. The development of transformer-less DC-AC inverters has garnered a great deal of attention due to its potential to reduce size, cost, and complexity while enhancing performance [3]. This project will provide an overview of the evolution of DC-AC inverter systems, with a special emphasis on the development of single-phase transformer-less DC-AC inverter systems and associated issues, such as leakage current and switching losses. The event of a leaking of current between the actual earth of the parasitic capacitances and of the sun powered module terminals is one of the significant disadvantages of transformer-less systems. The current leaking is subject to the parasitic capacitances and well known mode voltage of the panel [4]. Plus, in power electronics, switching losses often account for a substantial portion of overall system losses [5]. In order to create an AC waveform, these early inverters were based on the commutation principle, in which current is exchanged between two or more circuits. In the early 20th century, the commutating inverter was the most popular form of inverter, but it was quickly supplanted by the far more efficient transistorized inverter.

This was a significant advancement in the development of DC-AC inverters since it increased their efficiency and reduced their cost.

Transformer-less DC-AC inverter systems represent significant progress in the field of inverter technology. Transformer-less DC-AC inverters are based on the voltage multiplication concept, where the DC input is converted to AC by switching the voltage across a set of transistor switches instead of a transformer [5]. The compact size and light weight of transformer-less single-phase DC-AC inverters is one of their primary advantages [6]. Since they do not require a hefty transformer, they may be constructed to occupy significantly less space than systems that utilize transformers. This makes them appropriate for applications with limited area, such as electric cars and residential structures. Moreover, transformer-less single-phase DC-AC inverters are more efficient than their transformer-based equivalents. They are able to convert more of the DC input power into AC output power since they do not require a transformer. This results in enhanced efficiency, which may be particularly useful in situations where energy efficiency is a big priority, such as solar energy conversion, where energy efficiency is a major concern. Transformer-less inverters can be built to achieve output outputs of 10kW or more [6]. Transformer-less inverters are now the most prevalent type of inverter and are utilized in a variety of applications, including solar energy systems, electric car chargers, and UPS systems [6]. Despite all of the advantages of transformer-less inverters, one of the most serious difficulties they face is leakage current. When a stray capacitance exists, it can create a path for small leakage currents to flow from the PV arrays to the ground. These leakage currents are commonly referred to as ground leakage currents. The magnitude of these currents is typically small, but it can vary depending on several factors such as the capacitance value, PV array voltage, environmental conditions, and system design [6]. When leakage current flows through the insulation, it creates a path for power to be dissipated as heat. This power loss is undesirable because it reduces the overall efficiency of the inverter. The power that should ideally be transferred from the primary winding to the secondary winding is partly lost as heat in the insulation [7]. Additionally, transformer-less inverters are susceptible to switching losses, which occur as the inverter transitions between states. Hence, in order to produce a high-quality design for such inverters, device switching losses must be meticulously modelled due to their trend toward higher switching frequencies and leakage current must be reduced in the system.

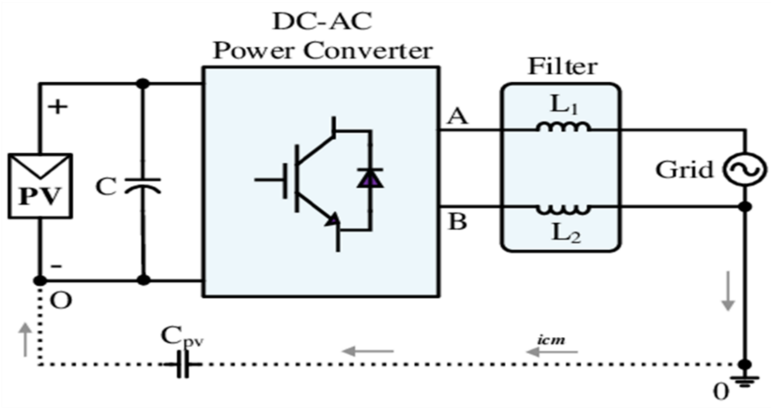

Figure 1.2: An L-filter design of a transformerless inverter

1.2 Problem Statement

Developing inverter that does not have transformer for single-phase system for photovoltaic (PV) systems has become an increasingly important research focus due to the increasing demand for distributed power generation. Transformerless PV inverters offer a number of advantages over traditional transformer-based inverters, such as cheaper, more reliable, reduced size and lighter mass, higher power density, and faster dynamic response [8]. However, there are challenges associated with the design of a transformerless inverter, such as high switching losses, and large leakage currents.

The main challenge is the high switching losses that are associated with the device, which can lead to excessive power losses and reduce its efficiency. The switching losses occur both during the switch on and switch off procedures of the transistor [9]. Furthermore, a large leakage current in the inverter can lead to additional power losses and reduce its overall efficiency. Switching losses refer to the energy dissipated or lost during the switching transitions in electronic devices such as inverters. In the context of single-phase transformerless DC-AC inverters used in photovoltaic (PV) systems, switching losses are a specific type of energy loss that occurs during the conversion of DC power from the PV panels to AC power that can be used by electrical loads or fed into the grid. Switching losses are the energy losses that occur during the switching of power electronic devices, such as the semiconductor switches within the power electronics inverters that are used in PV systems. These losses are typically a fraction of the whole energy generated by the photovoltaic system, but they add up over time and can lead to a decrease in system efficiency and a reduction in the overall energy production of the system [6].

The main types of losses associated with switching are conduction losses, which are caused by the current that flows through the switch during the switching process, and switching losses, which are caused by the switching of the power switches. Switching losses occur when the power switch is turned on and off, resulting in a voltage and current spike, as well as a decrease in the efficiency of the power electronic inverter. The higher the switching frequency, the higher the switching losses, as the power electronic inverter must switch more often to maintain the desired output voltage and current. As the switching frequency increases, the amount of switching losses also increases, resulting in a decrease in the efficiency of the power electronic inverter and a reduction in the energy production of the PV system [6].

Single-phase transformerless inverters typically operate at high switching frequencies, meaning that the power switches (such as IGBTs or MOSFETs) switch on and off more frequently compared to inverters with transformers. This high switching frequency is necessary to achieve the desired AC output waveform. However, the increased switching frequency also poses challenges. The frequent switching places greater stress on the power switches and other components of the inverter. Over time, this can lead to higher rates of component failure. Failures can occur due to numerous factors, including excessive heat generated during switching, increased voltage and current stresses, and the accumulation of stress cycles on the components. When failures occur in the inverter, the efficiency of the power electronic conversion process is compromised. Failed components may cause disruptions or abnormalities in the power flow, resulting in decreased efficiency and energy production of the PV system. In some cases, a failure in one part of the inverter can lead to a complete shutdown of the system, resulting in no power production until the issue is resolved [6].

Leakage currents in can reduce performance and lifespan. Understanding leakage currents is essential for system efficiency and reliability. Leakage currents cause PV power losses. Leakage currents indicate inefficiency in the inverter, which converts solar panel-generated DC into AC for electrical systems. These currents bypass the intended circuitry and waste electricity. The inverter's efficiency declines, reducing the PV system's usable power. Leakage currents increase power losses. System temperature rises. Resistive losses occur when current travels through unexpected routes. These heat losses raise temperature. System components can suffer from higher temperatures [7].

Solar panels function worse at higher temperatures. Temperature decreases solar cell efficiency, reducing power output. Cell performance decreases due to semiconductor material properties. Leakage currents' high heat can also destroy materials and components, shortening the system's lifespan. Leakage currents can shorten the lifespan of electrical components like inverters. Inefficient inverters raise temperature and thermal stress, which accelerates component ageing and deterioration [6]. This may increase component failure and system reliability over time. By using a transformer in the inverter, the input and output sides are physically separated by the transformer's insulation. This separation acts as a barrier, preventing most of the leakage current from passing through. It ensures that the current flows in the desired path, from the input to the output, without significant losses or unintended current paths. Hence, the absence of transformer can increase the chance of leakage current flowing through the inverter. Current leakage might result in wasteful and intermittent tripping. In severe circumstances, it might induce an increase in voltage on accessible conductive elements. In addition, the leakage current causes system safety difficulties, power losses, harmonic distortion in grid current, and electromagnetic interference problems [10]. In conclusion, leakage currents can be a major issue in single-phase transformerless DC-AC inverters for photovoltaic systems. The presence of these currents can lead to an increase in power losses and harmonic distortion in the system.

1.3 Objectives

The primary purpose of this study is to build a trustworthy single-phase transformerless DC-AC inverter system in order to manage the typical challenges associated with it. It is planned to make use of the system in order to achieve the goals listed below.:

1. To develop a single-phase transformerless DC-AC inverter system
2. To design a single-phase transformerless DC-AC inverter system with reduced switching losses
3. To mitigate leakage currents in single-phase transformerless DC-AC inverter system

1.4 Project Scope

This project will involve the developing a single-phase transformerless DC-AC inverter system. The inverter design will optimize switching losses while mitigating the effect of leakage currents. The project will include the development and testing of a prototype inverter, and the evaluation of the performance of the inverter. The project deliverables will include a working prototype and a report detailing the performance of the inverter.

1.5 Research Questions

What are the best methods for developing an efficient transformerless DC-AC inverter for photovoltaic system will be the research topic for the study on this report. The goal of this inquiry is to determine the ideal methods for reducing the switching losses and reduce the leakage current in the system. Through this study, the I will be able to pinpoint the crucial elements that ensure the effective development of transformerless DC-AC inverter for PV system that has low switching losses and reduced leakage currents. Therefore, the research questions are the following:

1. How to develop a single-phase transformerless DC-AC inverter system
2. How to reduce switching losses in the transformerless DC-AC inverter system?
3. How to decrease the leakage currents in the transformerless DC-AC inverter system

1.6 Hypothesis

By using a certain design strategy, it is possible to create a topology system with reduced leakage current and low switching losses. This is something that may be accomplished.

Chapter 2

LITERATURE REVIEW

2.1 Overview

The studies of literature in this section focuses on the design of a single-phase DC-AC inverter system without a transformer for solar installations. The review focuses on the optimization of switching losses, the reduction of leakage currents, the design and development of a prototype inverter, and the assessment of the inverter's performance. Several satisfactory results from the analysis of the literature indicate that a transformerless DC-AC inverter system may be created and improved to maximise switching losses and limit the influence of leakage currents. In addition, the literature evaluation has revealed a number of topics that deserve more study. Overall, the literature study shows that the construction of a DC-AC inverter system for solar systems without a transformer is possible. However, further study is required to enhance the inverter's performance and assure its safe operation in grid-connected systems. This research project aims to solve these difficulties via the design, testing, and performance assessment of an inverter prototype. The findings of this study will shed light on the design and optimization of transformerless DC-AC inverters for solar systems and influence future studies in this field.

2.2 Related Studies

Recent research on transformer-less single-phase DC-AC inverter systems has focused on reducing switching losses and minimising the impact of large circulating currents in an effort to reduce energy consumption. Others have focused their efforts on the creation of control methods to restrict the amount of leakage current. Because of this research, the performance of single-phase transformerless inverters has been improved, therefore setting the framework for the creation of an inverter that is highly efficient, dependable, and cost-effective.

2.2.1 Studies About Switching Losses

Switching losses are extremely important to consider when designing photovoltaic (PV) inverters because of the potential impact they have on the inverter's efficiency as well as its overall performance. In recent years, there has been a growing interest in the development of transformerless photovoltaic (PV) inverters because of the several benefits that they bring in comparison to conventional transformer-based inverters, such as lower size, weight, and cost. Nevertheless, transformerless inverters have more switching losses than conventional inverters because of the increased switching frequency and higher voltage stress placed on the switches.

The research paper that Bhagyashree Karur and Sanjeevkumar R.A. authored was made available in September of the year 2020. The majority of the research focuses on finding solutions to issues brought on by switching losses and improving the functionality of grid-connected photovoltaic (PV) inverters [11]. In order to get rid of leakage current in the common mode (CM) and cut down on switching losses, the authors propose a contemporary design for a transformerless multilevel inverter. The vast majority of conventional photovoltaic (PV) inverters that connect to the grid make use of isolation transformers, which results in increased losses and decreased efficiency. Inverters that do not utilise a transformer are gaining popularity as a solution to these issues. However, these inverters do not have isolation, which results in CM leakage current. This current causes the panels to be damaged, brings down the power quality, creates electromagnetic interference, and raises concerns about safety. (k-1) levels make up the proposed architecture for the inverter, where k is the total number of switches in the system. The authors investigate a variety of ways of operation in order to achieve steady functioning despite variations in the voltage supplied by the PV. They verify the functionality of three-, five-, and seven-level inverters by running simulations with the use of tools provided by MATLAB and Simulink.

As part of the modelling work, the performance of the maximum power point tracking (MPPT) algorithm is evaluated, and a comparison of the total harmonic distortion (THD) at various voltage levels is carried out. In order to follow the maximum power point of the PV system, the recommended inverter architecture employs the