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IGBT-Powered Three-Phase Converter with Arduino - Suitable for Micro Grid Applications

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Abstract

An IGBT-based three-phase inverter system is designed for microgrid applications and sustainable industrial operations. This inverter converts DC power into three-phase AC, ensuring reliable electricity conversion. Instead of MOSFETs, Insulated Gate Bipolar Transistors (IGBTs) are used in this system. The proposed method generates 223V AC square waves for each phase from a 12V DC battery. This conversion process necessitates precise switching of three IGBT power stages. PWM signals from an Arduino Uno R3 control the switching of IGBTs, ensuring accurate and seamless phase conversion. Each of the three single-phase connections includes six IGBT components, totaling eighteen, enabling independent operation. The Arduino Uno R3 generates PWM signals with a 120-degree phase shift to ensure synchronization. Step-up transformers at the outputs of the IGBTs boost the signal, and a 60W incandescent lamp is used in each load testing phase to assess system performance. Experimental results demonstrate that the three-phase output meets operational requirements, delivering 386.25V and 0.58A. The electronic circuit design and simulation using Proteus 8.9 Professional ensure the reliability of the system. Arduino IDE is employed for programming Arduino Uno, facilitating easy integration and control. Practical testing validates the system's performance under real-world conditions, confirming its suitability for deployment in microgrid and industrial applications requiring sustainable power conversion solutions.

Keywords: Arduino Uno, Insulated Gate Bipolar Transistor (IGBT), Transformers, Alternating Current (AC), Direct Current (DC), Proteus simulation

1. Introduction

The widespread use of fossil fuels remains the primary global energy source, significantly impacting environmental degradation. As a response, there has been a notable shift towards adopting alternative energy sources. Moreover, the escalating demand for electricity poses challenges for power distribution networks, leading to grid instability and frequent blackouts. To address these issues, environmentally friendly technologies are increasingly employed, with microgrid systems emerging as a promising solution.

Microgrids facilitate decentralized power distribution by integrating renewable energy sources like solar, wind, and tidal power. This distributed generation allows households with access to renewables to contribute

to the grid, alleviating peak demand issues and reducing energy costs. However, integrating these sources requires an inverter to convert the typically direct current (DC) output of renewables into usable alternating current (AC) for residential appliances and tools.
An inverter is crucial in this context as it converts DC electricity to AC while maintaining appropriate voltage and frequency. Inverters can be configured with various output phases, commonly single-phase or three-phase configurations. This study focuses on the development of a Three Single-phase Parallel Inverter utilizing Insulated Gate Bipolar Transistors (IGBTs).

Inverters are classified into Voltage Source Inverters (VSI) and Current Source Inverters (CSI), with this work employing a Voltage Source Inverter (VSI). Specifically, Pulse-Width Modulated (PWM) VSIs are chosen for their high electrical efficiency. PWM involves IGBTs in switching power semiconductors to generate analog signals. In this study, Pulse-Width Modulation (PWM) with single-pulse modulation at 120-degree phase displacement is implemented using IGBTs.
Microcontrollers like the Arduino Uno R3 are utilized to generate PWM signals due to their cost-effectiveness and user-friendly programmability. The Arduino Uno R3 features multiple digital input/output pins that facilitate the production and control of PWM signals.

In summary, this research focuses on developing a Pulse-Width Modulated inverter with IGBTs to achieve efficient power conversion in microgrid systems. This approach enables the seamless integration of renewable energy sources into the grid, contributing to the establishment of a more sustainable and resilient energy infrastructure.

2. Literature Review

Chowdhury et al. (2021) present a study detailing a three-phase inverter powered by power MOSFETs controlled by Arduino, tailored for microgrid systems. This inverter efficiently converts DC electricity into three-phase AC power, underscoring the advantages of MOSFET technology in integrating renewable energy sources. Published in the International Journal of Electrical and Electronic Engineering & Telecommunications, the study responds to the growing demand for reliable energy sources and promotes sustainable power distribution systems.

Nandurkar and Rajeev (2012) focus on designing and modeling a three-phase inverter specifically for grid-tied solar power systems. With a 30KW power output capacity, the inverter effectively converts DC electricity generated by solar panels into three-phase AC for seamless integration into the grid. By enhancing solar system performance and compatibility with the grid, this work advances renewable energy technology. Published in the Power journal, the study underscores the critical role of dependable inverters in optimizing solar energy utilization in grid-connected applications.
Zhang et al. (1997) introduce a three-phase inverter with a neutral leg and space vector modulation in their paper presented at the Applied Power Electronics Conference (APEC) '97. This research explores innovative techniques to enhance inverter performance. By integrating space vector modulation, the inverter aims to achieve superior control and efficiency in generating three-phase AC power. Published by IEEE, the study contributes to advancements in power electronics by proposing novel methods to optimize inverter operation, highlighting ongoing efforts in applied power electronics research.

3. Existing System

The article titled "Arduino-based Three-Phase Inverter using Power MOSFET for Application in Microgrid Systems," published in the International Journal of Electrical and Electronic Engineering & Telecommunications in 2021, introduces a novel approach to designing a three-phase inverter system. This system leverages Arduino microcontrollers and power MOSFETs, aiming to cater to the growing importance of microgrid systems for decentralized energy distribution.

Chowdhury and colleagues emphasize the use of readily available and cost-effective components like Arduino microcontrollers and power MOSFETs in their research on three-phase inverters. This approach not only reduces overall system costs but also enhances accessibility, making it suitable for diverse applications within microgrid systems.

The incorporation of Arduino microcontrollers facilitates versatile control and monitoring capabilities, enabling efficient operation and management of the inverter system. Meanwhile, the use of power MOSFETs ensures high-speed switching and reliable performance.

An important feature of this proposed approach is its scalability and adaptability, allowing it to be tailored to various microgrid configurations and requirements. Moreover, the use of commonly available components simplifies maintenance and repair processes, contributing to the system's overall reliability.

However, despite its advantages, the paper acknowledges potential limitations or constraints that require addressing. For instance, scalability may be limited by the processing power and memory constraints of Arduino microcontrollers. Furthermore, extensive testing under diverse load conditions and grid disturbances is essential to assess the system's effectiveness and performance in real-world microgrid applications.

In summary, the study proposes a practical method for developing a three-phase inverter system using Arduino microcontrollers and power MOSFETs for microgrid applications. Future research should focus on addressing potential limitations and validating system performance across various operational scenarios. Key advantages of this approach include cost-effectiveness and flexibility.

4. Proposed System

the proposed enhancement to replace power mosfets with insulated gate bipolar transistors (igbts) in the current three-phase inverter architecture for microgrid systems aims to address existing limitations and potentially enhance system performance and efficiency.

by transitioning to igbts, the system aims to capitalize on the advantages offered by this technology. these advantages include higher voltage and current ratings, reduced conduction losses, and improved thermal stability. these characteristics make igbts particularly suitable for high-power applications like microgrid systems, where reliability and efficiency are critical factors.

compared to mosfets, igbts also offer greater ruggedness and durability, which are advantageous for handling the high-voltage and high-current switching operations typical in three-phase inverters. this increased robustness can extend the system's operational lifespan and enhance its stability.

moreover, integrating igbts into the inverter system is expected to enhance its performance under varying load conditions and grid disturbances. the superior switching capabilities of igbts, coupled with advanced control algorithms, have the potential to optimize power conversion processes and reduce energy losses, thereby improving overall system efficiency.

additionally, igbts provide enhanced design flexibility and scalability, enabling the installation of higher-power inverter systems without significantly increasing system complexity or cost. this scalability is beneficial for expanding existing microgrid installations or accommodating future increases in electricity demand. however, it is important to acknowledge potential trade-offs associated with the use of igbts, such as higher switching losses and increased complexity in driver circuits compared to mosfet-based designs. achieving optimal performance and efficiency requires thorough study and optimization of design parameters and control techniques within the proposed system.

in conclusion, replacing mosfets with igbts in the three-phase inverter system for microgrid applications holds promise for improving reliability, efficiency, and scalability. however, careful consideration of trade-offs and rigorous performance evaluation are essential to ensure effective implementation of this upgrade in real-world microgrid deployments.

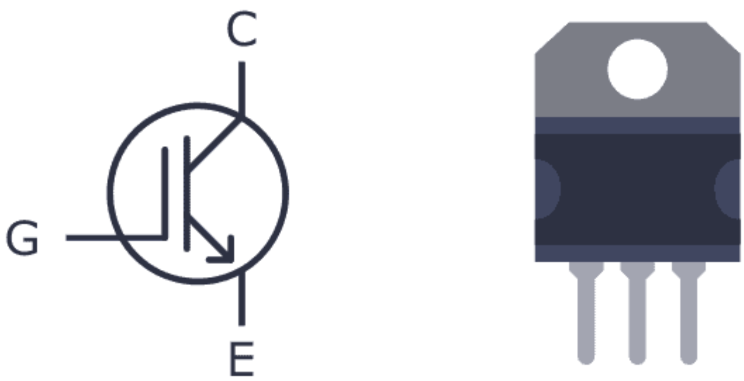
5. Hardware Description

Arduino UNO:

The Arduino Uno is a widely recognized open-source microcontroller board extensively employed in prototyping and DIY electronics projects. It features an Atmega328P microcontroller, offering 14 digital input/output pins, including six capable of pulse width modulation (PWM) output. Additionally, it includes USB connectivity for programming and power supply, as well as six analog input pins. Due to its ability to interface easily with a diverse range of sensors and actuators, the Arduino Uno is highly favored by both beginners and advanced users alike. Its versatility and user-friendly interface make it an indispensable tool within the maker community for developing interactive electronic devices. Programming of the Arduino Uno module is facilitated through the Arduino IDE, a development environment based on the C/C++ programming language. This ecosystem supports rapid prototyping and experimentation in electronics and programming, bolstered by extensive libraries and robust community support.

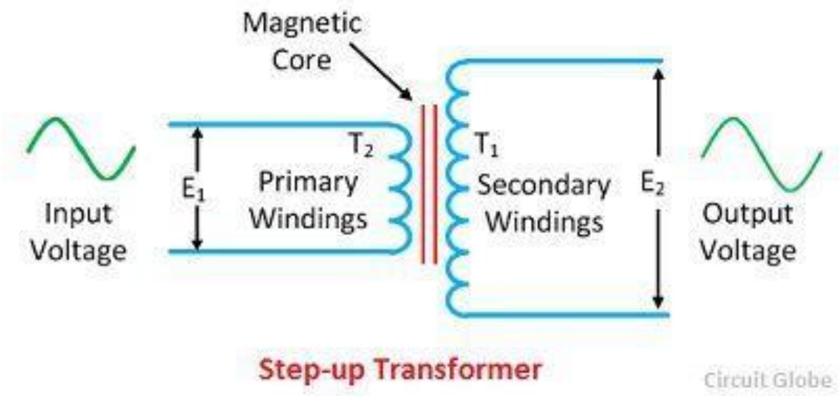
IGBT (Insulated Gate Bipolar Transistor):

The Insulated Gate Bipolar Transistor (IGBT) is a semiconductor device renowned for its high power capabilities, commonly employed in power electronics applications. Combining the advantages of MOSFET and bipolar junction transistor (BJT) technologies, the IGBT features three terminals: gate, collector, and emitter. Its insulated gate structure enables efficient regulation of high currents and voltages, making it well-suited for switching large amounts of power. IGBTs find widespread use in motor drives, inverters, and power supplies where high efficiency and reliability are paramount. Their low conduction losses and high switching frequencies contribute to enhanced energy efficiency in power conversion systems. Available in various voltage and current ratings, IGBT modules cater to diverse industrial requirements, underscoring their critical role in modern power electronics systems.



Step-up Transformer:

A step-up transformer is a type of transformer designed to increase voltage levels from the input to the output. It consists of two coils wound around a core, with the secondary coil having more turns than the primary coil. When alternating current flows through the primary coil, it generates a fluctuating magnetic field, inducing a higher voltage in the secondary coil. Step-up transformers are extensively used in power distribution systems to elevate voltage for long-distance transmission. Additionally, they are employed in electronic devices to boost voltage levels between different components, facilitating efficient transfer of electrical energy across applications.



6. Software Description

Proteus:

Proteus is a widely used software application for designing, simulating, and prototyping Printed Circuit Boards (PCBs) and electronic circuits. Developed by Labcenter Electronics Ltd., Proteus offers a comprehensive suite of tools for constructing and testing electrical circuits in a virtual environment. It boasts an extensive library of electronic components including resistors, capacitors, integrated circuits, and microcontrollers, allowing users to easily build complex circuits. With its simulation capabilities, Proteus enables users to analyze circuit behavior and verify functionality before actual implementation. Moreover, Proteus provides advanced features for PCB layout design, facilitating the creation of professional-grade circuit boards. Engineers, students, and electronics enthusiasts favor Proteus for its intuitive interface and robust functionality in electronic design and prototyping.

Arduino IDE:

The Arduino Integrated Development Environment (IDE) is a software platform used for programming Arduino microcontroller boards. Developed by Arduino LLC, the Arduino IDE offers a user-friendly interface that simplifies writing, compiling, and uploading code to Arduino boards. It supports both novice and expert programmers by providing a simplified version of the C and C++ programming languages. Features like syntax highlighting, automated code formatting, and pre-built libraries for interfacing with various sensors and actuators enhance its utility. The IDE also includes a serial monitor for debugging and monitoring data exchanges between the Arduino board and a PC. Widely adopted for creating projects and prototypes with Arduino boards, the Arduino IDE is valued for its ease of use and adaptability.

Arduino Code:

```cpp
void setup() {
  pinMode(11, OUTPUT);
  pinMode(10, OUTPUT);
  pinMode(9, OUTPUT);
  pinMode(8, OUTPUT);
  pinMode(7, OUTPUT);
  pinMode(6, OUTPUT);
}

void loop() {
  int var = 0;
  digitalWrite(11, HIGH);
  digitalWrite(7, LOW);
  digitalWrite(9, LOW);
  digitalWrite(10, LOW);
  digitalWrite(6, HIGH);
  digitalWrite(8, HIGH);
  delayMicroseconds(6670); // Adjusted delay to microseconds
  digitalWrite(9, HIGH);
```

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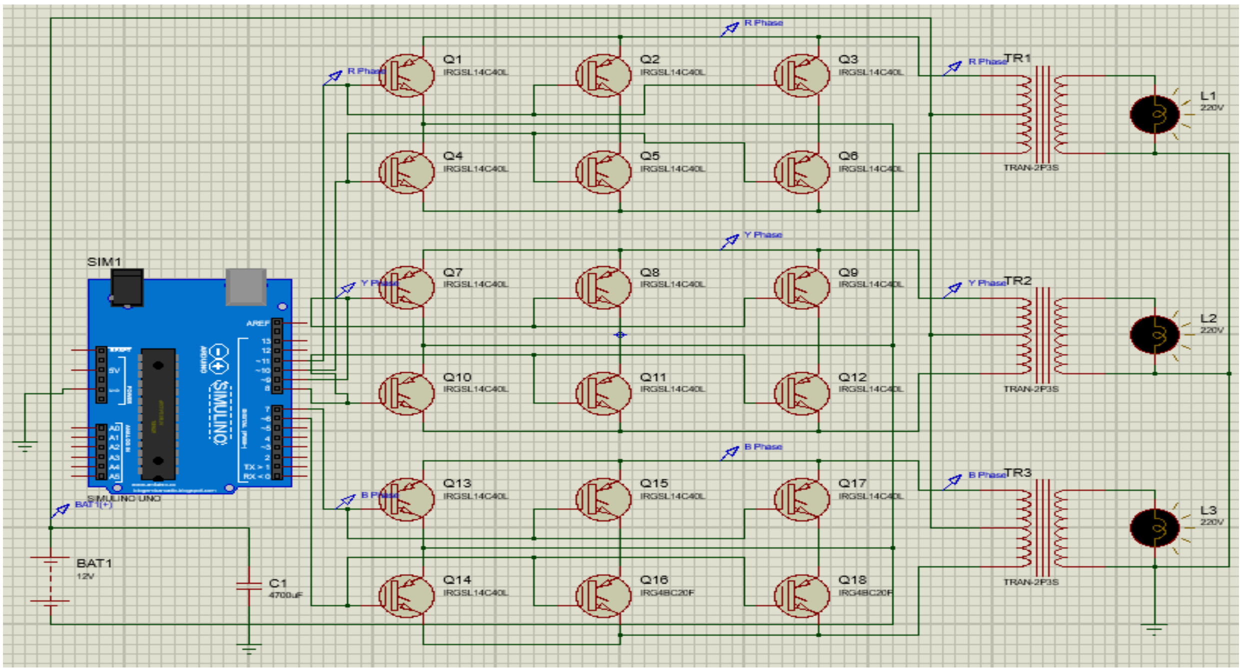
```
  digitalWrite(8, LOW);
  while (var == 0) {
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(11, LOW);
    digitalWrite(10, HIGH);
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(7, HIGH);
    digitalWrite(6, LOW);
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(9, LOW);
    digitalWrite(8, HIGH);
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(11, HIGH);
    digitalWrite(10, LOW);
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(7, LOW);
    digitalWrite(6, HIGH);
    delayMicroseconds(3330); // Adjusted delay to microseconds
    digitalWrite(9, HIGH);
    digitalWrite(8, LOW);
  }
}
```

7. Results

Based on the provided information, here is a paraphrased version:

Simulation runs were conducted using Proteus 8.9 Professional to validate and assess the performance of the newly proposed Arduino-based three-phase inverter employing IGBTs instead of MOSFETs. The subsequent paragraphs detail the outcomes of these simulations. Evaluation covered both operational principles and programmed codes. A simulation snapshot is shown, demonstrating the illumination of three bulbs to confirm successful inversion operations. Transient responses were also analyzed to ensure compliance with design specifications, including the verification of square wave AC outputs with a 120-degree phase shift between each phase.

Software Implementation and Results: The proposed three-phase inverter system was successfully implemented using the components and peripheral devices configured in the Proteus design. The operational status of the deployed system is depicted, with illuminated bulbs validating the functionality of each individual single-phase inverter as per simulation results.



8. Discussion

This study aimed to develop and deploy a three-phase inverter based on Arduino for microgrid applications. The designed inverter system can drive various three-phase household appliances or power tools by providing a 223-volt square wave output with a 120-degree phase difference between phases. While the functionality of the system has been confirmed, it is recognized that sinusoidal signals are typically required for the operation of most three-phase appliances and equipment. Therefore, future development efforts will focus on integrating an output filter to convert the square wave into a sinusoidal wave, enabling compatibility with a broader range of applications.

9. Conclusion

Here's a paraphrased version:

An Arduino-based three-phase inverter system utilizing Insulated Gate Bipolar Transistors (IGBTs) instead of MOSFETs has been designed. This system is suitable for microgrid applications, capable of generating 223V square wave outputs from a 12V battery. Simulation and practical application have extensively validated the system's functionality, affirming its suitability for broad deployment. The Arduino operates on a 12V battery with a dedicated voltage regulator maintaining stable operation at 10V. The inverter comprises three single-phase connections using a total of eighteen IGBTs, which could potentially be reduced to six with more powerful IGBT integration. Each phase of the inverter system has been tested with 60W incandescent bulbs as loads, demonstrating its ability to deliver 386.25V in three-phase operation and 223V in single-phase mode, while meeting the requirement of providing 0.58A current. In summary, the proposed IGBT-based three-phase inverter system offers a reliable and efficient solution for powering three-phase appliances in microgrid setups, ensuring compatibility with diverse industrial applications that demand robust and enduring power supplies.

References

1. Chowdhury et al. (2021) developed an Arduino-based three-phase inverter utilizing power MOSFETs for

microgrid applications. Their study was published in the International Journal of Electrical and Electronic Engineering & Telecommunications, highlighting the system's suitability and functionality in microgrid contexts.

2. Nandurkar and Rajeev (2012) focused on designing and simulating a three-phase inverter tailored for grid-connected photovoltaic systems, achieving a power output of 30KW. This work was published in the journal Power.
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