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A THREE-PHASE INVERTER FOR MICROGRID SYSTEMS BASED ON THE ARDUINO PLATFORM AND UTILIZING POWER MOSFETS

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Abstract — Power production from sustainable energy based microgrids has been promoted due to worries about climate change and the rapid depletion of fossil fuel supplies. Finally, a three-phase inverter based on the Arduino platform and using MOSFETs is developed to transform direct current (DC) into three-phase alternating current (AC), which is essential for microgrid systems and sustainable-powered homes. Using pulse width modulation (PWM) signals at the gates of three stages of power MOSFETs controlled by an Arduino Uno, the system is intended to create 223V square signals at each phase from a 12V battery. In a power MOSFET, the inversion process is carried out independently for each of the three single-phase connections by use of a total of eighteen transistors, six for each stage. The system is configured to create pulse width modulation (PWM) signals with a phase shift of 120 degrees between each phase using an Arduino Uno. The amplification is achieved by coupling three step-up transformers to the outputs of MOSFET stages. Using a 60W incandescent bulb at each phase as a load, the system produces 386.25V of voltage for the three-phase line, which delivers 0.58A of current. Proteus handles the electrical circuit design and simulation, while the Arduino IDE is used to write the programming programs.The proposed system is tested and validated in a real-world setting.

Index Terms—Arduino Uno R3, MOSFET, PWM, Three-phase Inverter, Microgrid, Renewable Energy, Proteus

INTRODUCTION

In this era of quickly developing technology and broad electrical use, power generation and management have become more complex challenges. As carbon dioxide (CO_2) emission rules become stricter across the world, traditional ways of producing and controlling power will become unsustainable [1, 2]. That's why plenty of people have been exploring for replacements for our current electricity infrastructure [3]-[5]. As more and more people rely on electrical power, the strain on the power system increases, leading to issues like voltage swings.

power outages caused by problems with the grid or supplies. One promising result of this trend is the microgrid system [6], which has the potential to solve many of the problems plaguing conventional grids. This is because renewable energy power distribution systems have advanced rapidly in recent years in response to rising energy demands and increased interest in environmentally friendly technologies. Microgrids, seen in Figure 1, consist of distributed generators (DGs), energy storage devices, and regulated loads, and can function either independently or in conjunction with the larger power grid. Microgrids have promise as highly reliable and financially sustainable power systems [2] due to their environmental friendliness, efficiency, and system resilience.

Fig. 1. A typical microgrid system [7], [8].

Microgrids have a far lower initial investment cost than traditional major power grids, and they can provide dependable energy supply to a large number of rural inhabitants. Microgrids improve electricity quality by reducing voltage swings and can significantly reduce operational costs while still meeting customer demand. Features like conservation voltage regulation (CVR) and four-quadrant inverter operation seen in contemporary microgrids offer the potential for even more optimization of energy use. To lower the high power demand and the high cost of electricity during the peak consumption time, the microgrid can receive contributions from all homes with renewable energy sources. Microgrids have several potential benefits for utilities, including the reduction of transmission and distribution bottlenecks, the optimization of grid assets, and the postponement of expensive infrastructure improvements [2]. Microgrids may incorporate a wide variety of micro-sources, such as photovoltaic and solar panels, wind generators, micro-turbines, biomass, geothermal, steam and gas turbines, fuel cells, and internal combustion engines that use reciprocating pistons. Energy capacitors (super-capacitors), flywheels, and batteries are all viable options for microgrids to store energy for later use. Microgrid storage devices not only keep the balance of supply and demand in check [2], but they also store energy generated from renewable sources. Since DC electricity is what energy storage systems store, an inversion system is required for use with AC appliances and machinery in homes and businesses.

An inverter is a device that changes direct current (DC) power into alternating current (AC) electricity while maintaining the correct voltage and frequency [9], [10]. An inverter's output can be configured to any number of phases. In practice, however, single-phase and three-phase inverters predominate [12]. Depending on their design, three-phase inverters can either be a bridge inverter or a series of three single-phase inverters. This publication employs Method Two of its construction. Inverter topologies may be broken down into two categories: current source inverters (CSI) and voltage source inverters (VSI) [13]. If you have a DC power source and want to generate AC power at a different frequency, you'll need a variable frequency alternating current (AC) generator, or VSI. The three most common types of VSIs are square-wave inverters, pulse-width modulated (PWM), and single-phase voltage-cancelling. The design for a Pulse-width Modulated Visible Spectrum Interceptor is presented here [12, 14]. A basic three-phase inverter is shown in the diagram.

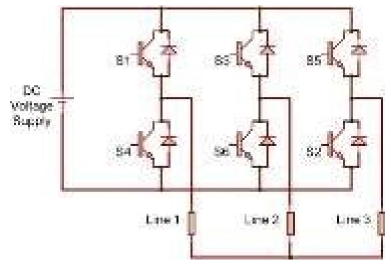

Fig. 2. A basic voltage source three-phase Inverter [9].

Pulse width modulation (PWM) is used by switching devices to create the illusion of continuously changing analog signals. This method has a very high electrical efficiency [15]. Most commonly, designers will utilize one of three PWM techniques: single-pulse modulation, multiple-pulse modulation, or sinusoidal pulse-width modulation [14]. Several methods exist for using pulse width modulation (PWM) in an inverter to produce an AC signal that closely resembles a pure sine wave. Instead than the inverter dictating the size of the output, the input voltage does [14]. The output voltage of the inverter can be set at a constant or varying frequency. To get a variable output voltage while the DC input voltage is fixed, an inverter's frequency is often altered by pulse width modulation (PWM). The output of an inverter is an alternating waveform, which is not necessarily a perfect sine wave. However, there are a few ways in which the inverter's output waveform may be made more sinusoidal [12]. PWM algorithms can be used in both single- and three-phase inverters. To achieve the required electrical efficiency [9], [14], the modulation must be carried out simultaneously for each phase with angular displacements of 120 degrees, 150 degrees, 180 degrees, etc., unless the induction motor is a three-phase induction motor. This method uses MOSFETs and a 120-degree phase shift with Single-pulse Modulation.

Pulse-width-modulated (PWM) signals can be generated using a wide variety of components, including op-amps, 555 timers, microcontrollers, and Arduino. Arduino may be looked of as a microcontroller since it is an open-source platform that makes use of a microcontroller chip. Using sensors and other input methods, Arduino allows users to create interactive electrical devices at minimal cost and with ease of usage [16]. In this example, an Arduino Uno R3 is used to do the required function.

This article explains how a three-phase inverter, which converts a direct current (DC) signal to an alternating current (AC) signal over three lines, was conceptualized, designed, and prototyped. The inverter creates 223V square signals at each line while maintaining a phase displacement of 120 degrees using a 12V battery and three stages of 18 power MOSFETs operated by pulse width modulation (PWM).

This paper's remaining sections are organized as follows. In Section II, we sketch the block diagram of the system along with the required components and peripheral devices. Section III details the hardware design and electronic circuitry of the system. In Section IV, we cover how to program an Arduino Uno R3. Section V presents the results of the effort. Section VI wraps up the study, and Section VII outlines where the authors want to take the topic in the future.

I. MATERIALS & METHODS

The designed inverter involves an Arduino Uno as the brain of the system and to produce PWM signals, Power MOSFETs to create AC signals, and center-tapped step- up transformers to amplify the output. As per the focus of paper, a brief explanation of Arduino Uno R3 (Fig. 3) and Power MOSFETs (IRF Z44N) are provided below, followed by a detailed list of system components, and the system block diagram.

Fig. 3. Arduino Uno R3 with pin-outs.

A. Arduino Uno R3

Arduino is an open-source platform based on a single-board microcontroller that was designed to make it easier to conduct multidisciplinary research through the formulation and execution of procedures based on electronics. Arduino's hardware is an 8-bit Atmel AVR microcontroller with on-board I/O capability, while the software is made up of a programming language (C) and a boot loader [17], [18].

The ATmega328 microprocessor is the basis of the Arduino Uno, one of the several Arduino series. It has a reset button, a power jack, a USB port, an ICSP header, a 16 MHz crystal oscillator, and 14 digital I/O pins (6 of which may be used as PWM outputs). The DC input voltage range used by the Arduino Uno board is 6–20 volts [18], [16], [19]. This paper's work is conducted with the most recent version of the Arduino Uno series, the Arduino Uno R3. The Arduino Uno R3 has all the functionality of earlier Arduino Uno boards, and more, thanks to its usage of an ATmega16U2 (USB-to-Serial converter) instead of an 8U2 or FTDI. memory and faster transfer rates.

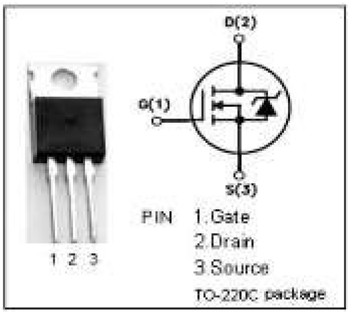

Fig. 4. IRF Z44N pin-outs [20].

TABLE I: COMPONENTS AND PERIPHERAL DEVICES

Devices	*Reference / Name*	*ID / Specification*
Battery	BATTERY	12V
Arduino	Arduino Uno R3	ATmega328P based
Capacitor	C1	4700uF, 50V
MOSFET	Q1, Q2, Q3, …, Q18	IRF Z44N (V_{DS}=55V max, I_D=49A max, $\pm V_{GS}$=20V max, $V_{GS(TO)}$=2V min)
Transformer	Transformer 1 to 3	Primary 12V, Secondary 220V
Lamp (as load)	Lamp 1 to 3	60W, 220V

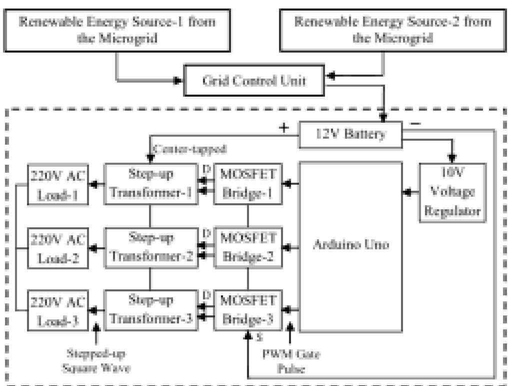

Fig. 5. Block diagram of the designed three-phase inverter system.

B. Power MOSFETs (IRF Z44N)

In the 1970s, the first field-effect transistor was developed, leading to the subsequent development of the Power MOSFET (Metal Oxide Semiconductor Field Effect Transistor). Once the preferred technology in most power electronics applications, BJTs (Bipolar Power Junction Transistors) have been mostly replaced by power MOSFETs. Power MOSFETs are now the go-to power device because of their quick switching, low gate-drive power, and high parallelism [21]. You'll find them in things like audio and radio frequency circuits, motor control circuits, and high-frequency inverters. In this investigation, a fast-switching IRF Z44N Power MOSFET (Fig. 4) is used because of its low on resistance of 0.032, high drain current of 49A at 25°C, and low source-drain voltage of 55V. Components and Supplemental Tools
Table I lists everything that must be purchased separately from the Arduino Uno and Power MOSFETs.

Type D Block Diagram of a System
A block diagram is the most effective tool to quickly gain an overarching understanding of a system. The block diagram in Fig. 5 is a useful tool for quickly grasping the architecture of the system under investigation. The DC power from the battery and the microgrid or renewable energy source are converted to AC power by each of the three legs in the diagram. Each leg has a stage of power MOSFETs and a step-up Transformer that work separately to perform the inversion and amplification procedures.
This is the fundamental concept upon which the method or system is based: DC electricity from the battery is transformed into AC via the MOSFET step. Since the MOSFETs are acting as switches, their gate pulses are controlled by pulse width modulation (PWM) signals from the Arduino. Input direct current (DC) power is converted to output alternating current (AC) by the MOSFETs, which are turned on and off by gate pulses. The MOSFET stages' output signals are configured to be 120 degrees out of phase with one another on the Arduino. Finally, step-up transformers are used to amplify the alternating signals at the output of the MOSFET stages so that they can drive 220V loads. It is anticipated that the secondary winding of the transformers would produce square waves.
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II. ELECTRONIC CIRCUIT / HARDWARE DESIGN

As mentioned above, a three-phase inverter can be built by inverting three single-phase connections separately, as long as they have a certain phase displacement among them [12]. The three-phase inverter in Fig. 6 is designed with 120 degrees phase displacementwith PWM applied to each phase separately by the Arduino

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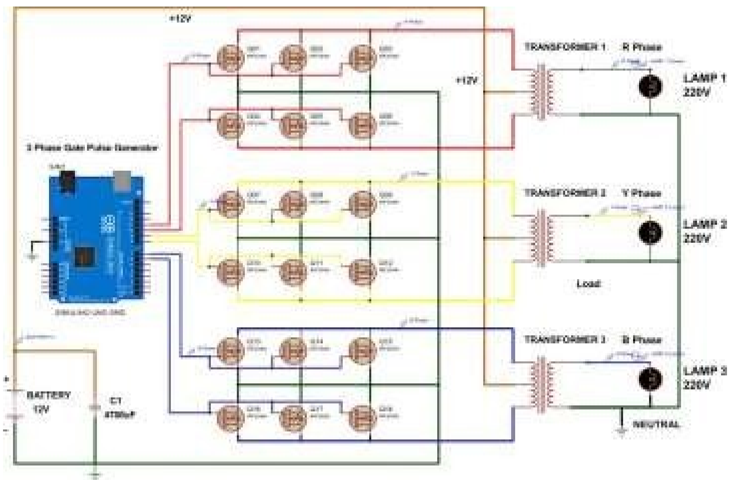


Fig. 6. The whole schematic of the Arduino-based three-phase inverter.

Each leg in Fig. 6 symbolizes a single-phase connection, and the six power MOSFETs (nMOS) on each leg are connected to the Arduino so that they may switch to accomplish the inversion. The ideal number of MOSFETs is determined by the power requirements. The suggested work utilizes 6 MOSFETs in parallel because to the relatively low power rating of the MOSFET type used in the implementation (IRF Z44N). A center-tapped step-up transformer with MOSFET outputs in each leg boosts the 12V input to 223V.
Fig. 6 uses color to clearly depict the interconnections between the various circuit components, such as the batteries, Arduino, MOSFETs, and transformers. To simulate the operation of a three-phase system, we use three 220V light bulbs as loads. The drain of the MOSFET bridge is connected to the positive terminal of the battery, while the other two wires of the transformer are connected to the gate and source of the bridge. The negative battery connection is connected to the source of all three MOSFET bridges, and the gate of each bridge is connected to the digital output (PWM) of an Arduino. Each transformer generates EMF to cancel out the EMF from the battery in response to gate pulses from an Arduino, switching MOSFETs to convert DC current to AC current. There is a 'Y' configuration between the transformers and the loads, with

the main and secondary impedances of the transformers set to 5.7mH and 1000 correspondingly. Schematic Capture in Proteus 8.9 Professional is used to construct the electrical circuit.

III. Arduino Programming

The Arduino board provides a platform for writing software for microcontroller-based electronics. An Atmel ATmega328P microprocessor is utilized in an Arduino Uno R3. Therefore, an Arduino's functioning is tied to code that conforms to the standard characteristics of Atmega programming [22, 23]. PIN 6–11 of the Arduino are used as output pins [24] to create the PWM signal that is sent into the three MOSFET bridges during the inversion operation, resulting in a 120° phase shift. The programming codes are written using the Arduino IDE. The real code is listed in Table II.

TABLE II. Programming Code of the Inversion System

```
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);
delay(6.67);
digitalWrite(9, HIGH);
digitalWrite(8, LOW);
while(var==0){
delay(3.33);
digitalWrite(11, LOW);
digitalWrite(10, HIGH);
delay(3.33);
digitalWrite(7, HIGH);
digitalWrite(6, LOW);
delay(3.34);
digitalWrite(9, LOW);
digitalWrite(8, HIGH);
delay(3.33);
digitalWrite(11, HIGH);
digitalWrite(10, LOW);
delay(3.33);
digitalWrite(7, LOW);
digitalWrite(6, HIGH);
delay(3.34);
digitalWrite(9, HIGH);
digitalWrite(8, LOW);
}
}
```

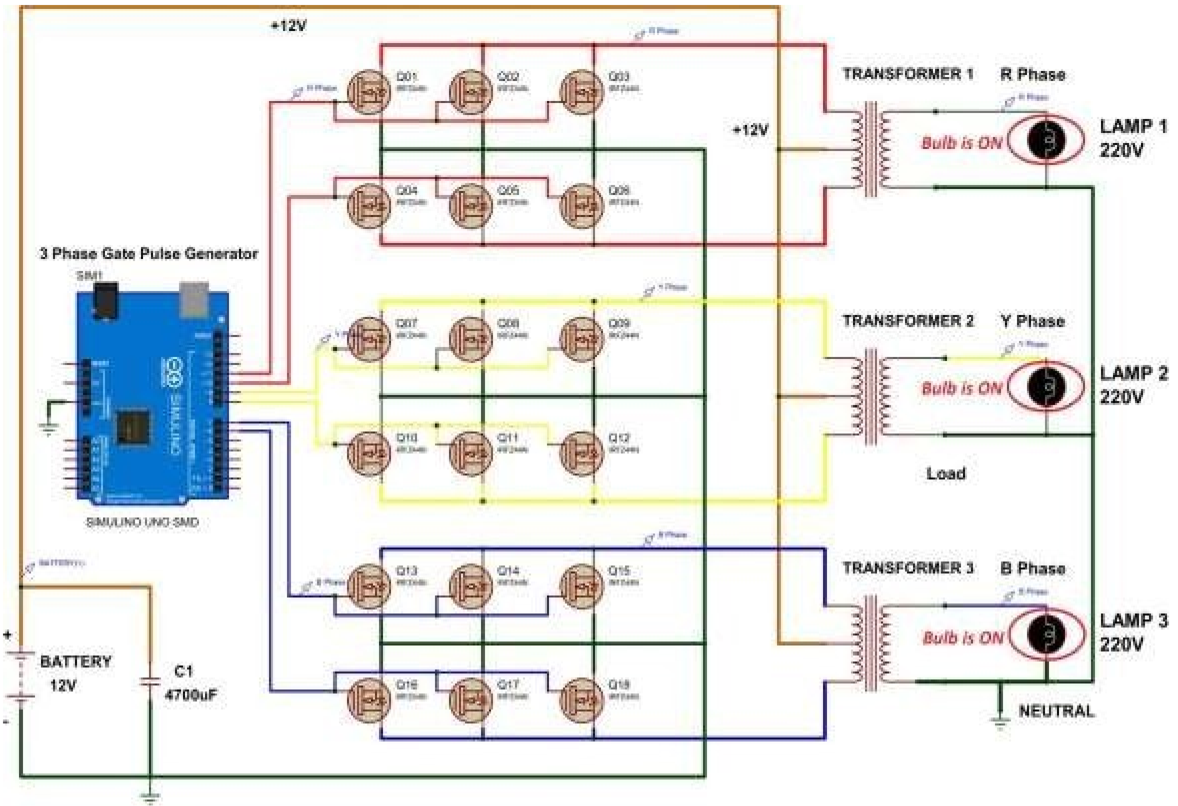


Fig. 7. Operational simulation result of the three-phase inverter.

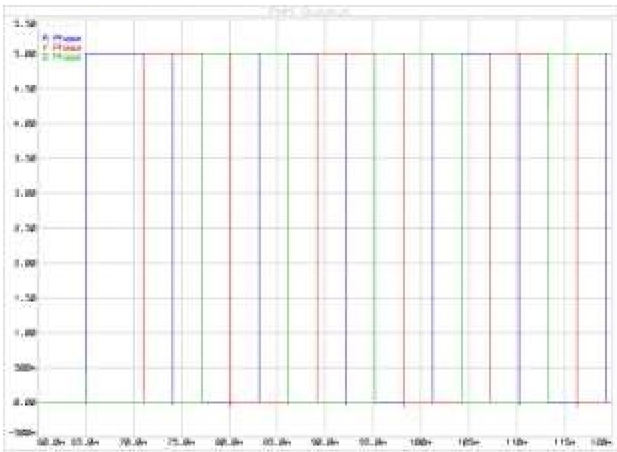


Fig. 8. PWM voltages from Arduino with 120°phase displacement.

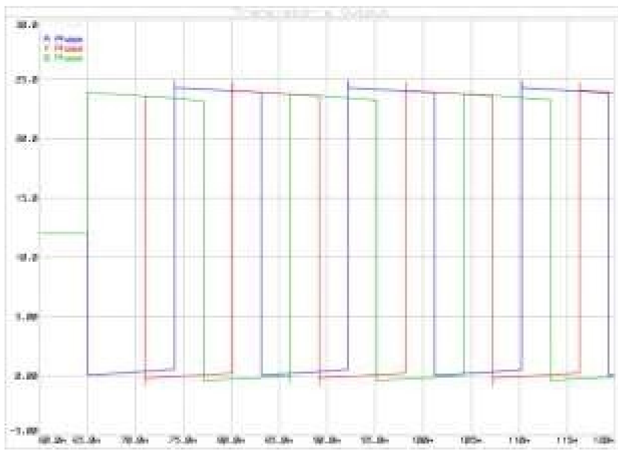


Fig. 9. Output voltages at the three stages of transistors.

IV. Results and Discussion

A. Simulation Results

To verify and investigate the operation of the system, the designed system is simulated in Proteus 8.9 Professional. The results are verified according to the written program codes and their working principle, which satisfy the expected outcome. The screenshot of the simulation that represents the operational analysis is provided in Fig. 7, which shows the 3 (three) lamps/bulbsare illuminating justifying the individual inversion processes are working.

Besides operational analysis, the transient responses of the system are also checked and verified in Proteus to make sure the signals response is as per the design. The

obtained results are shown in Fig. 8 through Fig. 13, justifying the transistors are making square (AC) waves from DC input keeping 120 degrees phase displacement among the individual three phases. The resultant current- voltage parameters obtained from the Proteus simulation are provided in Table III.

Table III. Resultant Current-Voltage Parameters

Parameters / Phase	Single-phase	Three-phase
Voltage	223 V	223 V × = 386.25 V
Current	0.58 A	0.58 A

$\sqrt{3}$

Apparent Power	75 VA	75 VA × 3 = 225 VA
Active Power/ Load Power	60 VA	60 VA × 3 = 180 VA
Power Factor	60 VA ÷ 75 VA = 0.8	180 VA ÷ 225 VA = 0.8

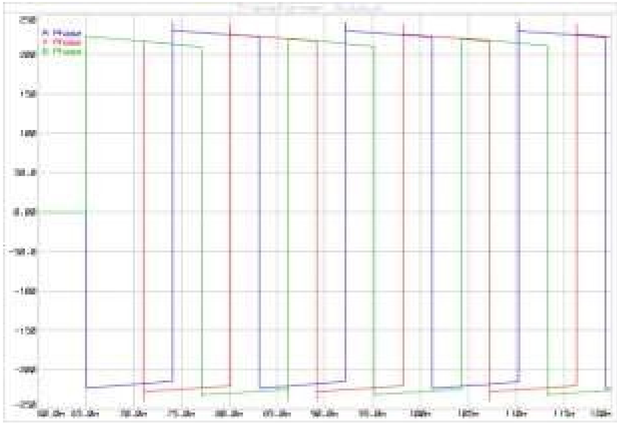


Fig. 10. Converted AC voltages at the outputs of three transformers.

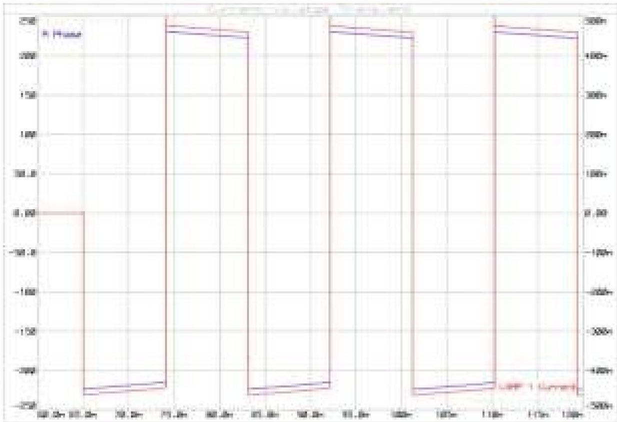
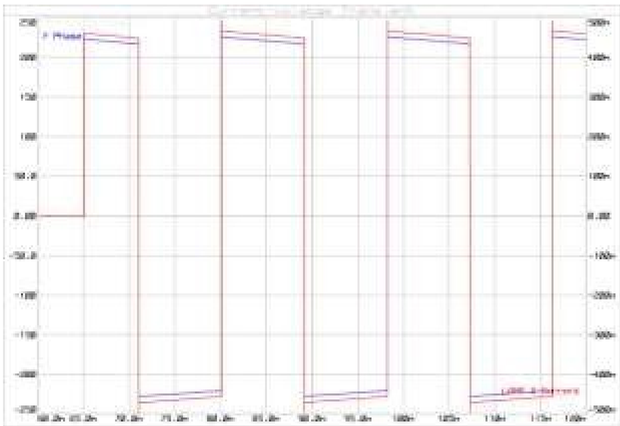


Fig. 11. Voltage vs current transient response at Phase-R.



B. Implementation/Prototype & Results

The designed three-phase inverter system is practicallyimplemented with the components and peripheral devices as per the Proteus design, which is shown in Fig. 14. Fig.
15 represents the implemented system ON condition, where the illuminating bulbs are justifying that each single-phase inverters are working as designed and simulated.

Fig. 14. Practical setup of the designed three-phase inverter.

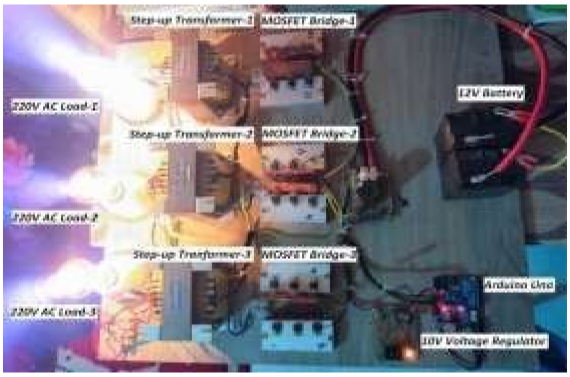


Fig. 15. Practical implementation of the designed three-phase inverter inits ON condition.
Fig. 12. Voltage vs current transient response at Phase-Y.

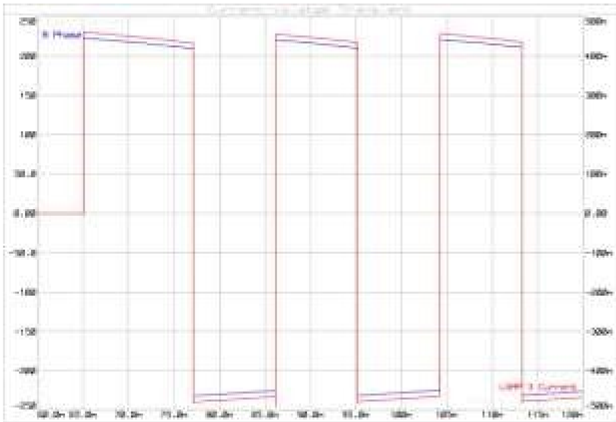


Fig. 13. Voltage vs current transient response at Phase-B.

C. Discussion

Several research projects [25]-[41] have been conducted on this issue or ones like it. Specifically, the fundamental principle is presented well mathematically in [34], where a three-phase inverter based on an 8051 microcontroller is designed with 6 (six) MOSFETs using PWM technique and achieved close to pure sinusoidal signal; however, hardware implementation is not shown, results are inadequate, and the maximum output voltage is not provided. Although mathematical modeling is provided for the PIC microcontroller-based three-phase inverter designed and built in [40], the output electrical characteristics are unsatisfactory due to the inverter's slightly noisy sinusoidal signal. With a maximum line voltage of 230V, a transformerless single-phase inverter is constructed in [30] using 4 (four) MOSFETs to produce a nearly pure sinusoidal signal through the use of the SPWM modulation method. The hardware implementation is still incomplete, though. A single-phase inverter, made using 4 (four) MOSFETs and operated by an Arduino Uno, is detailed in detail in [27] and [28].Modulation method using SPWM (and SHE in [27]). While the essential concepts are well-illustrated and mathematically-described in [27], the system's output electrical characteristics are inadequate, and the maximum output voltage is not specified. provided. With a maximum line voltage of 230V, the system described in [28], which there are no readily available programming instructions for, and got practically a clean sinusoidal signal out of it. In [26] and [35], we see how to construct an efficient single-phase inverter based on an Arduino Uno and 2 (two) MOSFETs. No circuit diagram, programming instructions, or simulation were provided, despite the fact that the method described in [26] got very close to obtaining a pure sinusoidal signal. The modulation process is not explained, and the output has subpar electrical properties. However, the output transient reactions and observed output electrical characteristics are missing from the system described in [35], despite the fact that PWM was used in the system. A MOSFET-based, Arduino Nano-based single-phase inverter using SPWM modulation is constructed in [33] and [39], yielding a sinusoidal signal with some noise. Although [33] does a good job of presenting the findings of no-load and with-load testing as well as efficiency estimates, it falls short in its explanation of hardware implementation and its provision of extensive programming codes. Using 8 (eight) MOSFETs, the system described in [33] was able to generate a maximum line voltage of 230V. [39] says their system can handle up to 220V of line power, however they don't provide entire circuit and programming codes or samples of hardware implementation.

In this study, we present the research and development of an Arduino-based three-phase inverter for usage in microgrids. The stated inverter system generates a 223V square wave output as maximum line voltage, with 120 degrees phase displacement among each phase, which may power a wide variety of three-phase domestic appliances or industrial power equipment. All aspects of the system—its design, implementation, and performance—have been validated. In-field researchers and students will benefit greatly from the complete circuit diagram, source code, and other documentation of the design process. electrical parameters, etc. The offered work in this paper including its applicability is summarized in Fig. 16

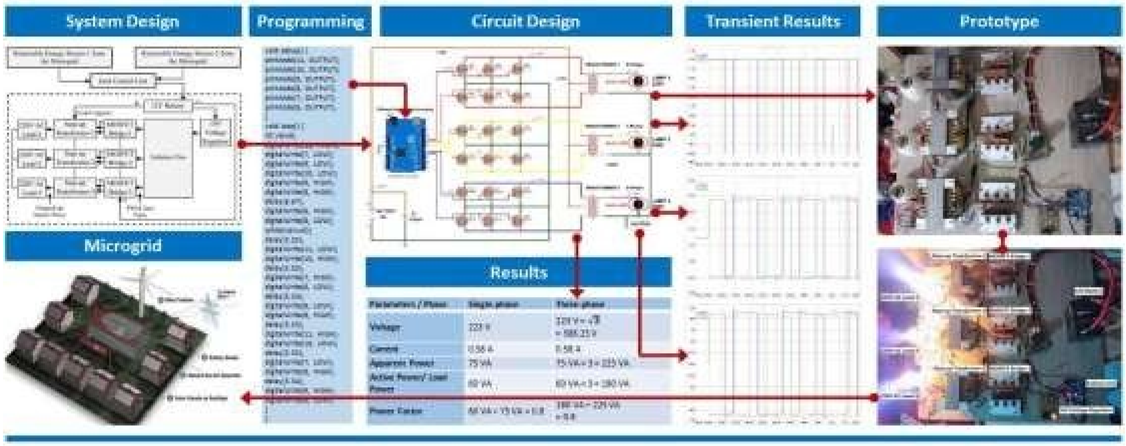


Fig. 16. A visual summary of the work done in this paper.

V. Conclusion

An Arduino, power MOSFET, and 12V battery may be transformed into 223V square signals suitable for a three-phase converter. All of the tests that were conducted on the system confirmed that it could work in a microgrid environment. Not only does the built system undergo theoretical planning and testing, but it also operates as expected. A 12V battery powers the inversion process, while a voltage regulator keeps the Arduino powered at 10V. Adding high-powered MOSFETs may cut the number of power MOSFETs necessary for the inversion process from 18 across three independent single-phase connections down to 6. A 60W incandescent bulb loads all three phases, resulting in 386.25V, 223V, and 0.58A, correspondingly. Since the majority of electrical equipment need three-phase connections, the proposed inverter might find usage in a microgrid, a sustainably powered home, or a small industrial site.

SURVEYING THE FUTURE

There is, as with any technological endeavor, space for growth and improvement in the work detailed in this paper. Altering the Arduino program to provide sinusoidal output without a filter is a further path to explore. Finally, the power management system between the various sources would be completed by developing the Grid Control Unit according to the block diagram in Fig. 5.INTERESTS IN CONFLICT

The authors of this publication certify that they have no financial or personal stakes in the outcomes of this study.

WORKS BY THE AUTHORS

Saroar Hossain and Niloy Kumar Das, who both answered to Imran Chowdhury, did the bulk of the real job. Taslim Ahmed and Mohammad Mahmudul Hasan looked through the blueprints and prototypes and provided helpful feedback and insight. All writers have read and approved Imran Chowdhury's draft of the work.

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