Faculty of Electrical Engineering and Technology

THE DEVELOPMENT OF AC VOLTAGE CONTROLLER USING MICROCONTROLLER-BASED SOLID STATE RELAY

SITI NUR ADIBAH BINTI ABDUL AZIZ

Bachelor of Electrical Engineering Technology with Honours

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SITI NUR ADIBAH BINTI ABDUL AZIZ

A project report submitted
in partial fulfillment of the requirements for the degree of
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DEDICATION

I appreciate, respect, and sincerely thank my parents for their love, support, encouragement, and sacrifice throughout my life. I would not have been able to get here without sacrifice and support. The greatest thanks go out to my siblings as well, who have always helped me out and given me advice in all I do in life. They have also served as my source of motivation and have always given me their moral, spiritual, emotional, and financial support. I would like to extend my sincere gratitude to all of the lecturers, especially my supervisor, Dr. Mohd Badril Bin Nor Shah, who have helped me learn and improve throughout my research findings and ensured that this Bachelor's Final Project has been completed successfully. I would like to thank all my colleagues who have always been with me throughout this challenging semester and helped me during this project. I hope all their support and encouragement will help me make this project a success.

ABSTRACT

An AC voltage controller is a device that can control the RMS voltage of AC voltage. It has many applications, such as motor speed control, light dimmer and heater control. A solid state relay (SSR) is a type of electronic switching device that is powered by an external voltage (AC or DC). SSRs perform the same job as electromechanical relays, except they have no moving parts and last longer. In this project, an AC voltage controller will be developed by using SSR that will be connected to Arduino microcontroller. The system uses a microcontroller as its control unit, which interfaces with a solid-state relay to control the output of AC voltage. The developed device is tested to AC bulb and AC motor to verify its efficiency. It is found that the device is able to control the speed of AC motor but not suitable to control AC bulb due to flicker problem.

ABSTRAK

Pengawal voltan AC adalah peranti yang boleh mengawal voltan RMS voltan AC. Ia mempunyai banyak aplikasi, seperti kawalan kelajuan motor, pemalar cahaya dan kawalan pemanas. Geganti keadaan pepejal (SSR) adalah sejenis peranti suis elektronik yang dikuasakan oleh voltan luaran (AC atau DC). SSR melakukan kerja yang sama seperti geganti elektromekanik, kecuali mereka tidak mempunyai bahagian yang bergerak dan bertahan lebih lama. Dalam projek ini, pengawal voltan AC akan dibangunkan dengan menggunakan SSR yang akan disambungkan ke pengawalmikro Arduino. Sistem ini menggunakan pengawalmikro sebagai unit kawalan, yang berinteraksi dengan geganti keadaan pepejal untuk mengawal output voltan AC. Peranti yang dibangunkan ini telah diuji kepada lampu AC dan motor AC. Adalah didapati peranti ini boleh mengawal kelajuan AC motor, tetapi tidak sesuai untuk digunakan pada lampu AC kerana masalah berkelip.

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First and foremost, I would like to express my gratitude to my supervisor, Dr. Mohd Badril Bin Nor Shah for his precious guidance, words of wisdom and patient throughout this project.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	-	Percent
π	-	Pi
°	-	Degree
°C	-	Degree Celsius
Ω	-	Ohms
$<$	-	Less than
δ	-	Voltage angle
A	-	Ampere
W	-	Watt

LIST OF ABBREVIATIONS

AC	-	Alternating Current
TRIAC	-	Triode for Alternating Current
SCR	-	Silicon-Controlled Rectifier
IGBT	-	Insulated-Gate Bipolar Transistor
SSR	-	Solid State Relay
DC	-	Direct Current
EMI	-	Electromagnetic Interface
V	-	Voltage
Hz	-	Hertz
IDE	-	Integrated Development Environment
PWM	-	Pulse Width Modulation
RMS	-	Root Mean Square
MOSFET	-	Metal Oxide Silicon Field Effect Transistors
RFI	-	Radio Frequency Interference
PCB	-	Printed Circuit Board
AVR	-	Automatic Voltage Regulator
PIC	-	Peripheral Interface Controller
ZCD	-	Zero Cross Detector
ADC	-	Analogue to Digital Converter
USB	-	Universal Serial Bus
I/O	-	Input/Output
ICSP	-	In-Circuit Serial Programming
RST	-	Reset button
BDP	-	Bachelor’s degree Project
PV	-	Photovoltaic
LVDAC-EMS	-	Electromechanical Systems Simulation Software

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

A fixed AC voltage is converted using thyristors, TRIACs, SCRs, or IGBTs at a fixed frequency and variable voltage by an electronic module known as an AC voltage controller or AC regulator. Similar to an autotransformer, the major uses of an AC voltage controller include starting induction motors, single-phase and three-phase AC drive speed control, lighting control, home and industrial heating, tap-changing transformers, and many other uses. Tap-changing transformers, autotransformers, saturable reactors, and magnetic amplifiers are now being replaced with thyristor-based AC Voltage Controllers due to high efficiency, compact size, control flexibility, and low maintenance requirements. An AC voltage controllers can also be used in closed-loop control systems to regulate the AC voltage magnitude at the desired level.

Solid State Relay (SSR) is a device used for non-contact commutation of power circuits such as heating elements, lighting devices and low power motors. It also permits lower-voltage DC control circuits to regulate high-current AC loads. When an external control signal is applied across the terminals of SSR, it can switch a load on or off like an electromechanical relay. SSR does not have any moving parts such as contacts, armature and springs. Therefore, it does not induce intense electromagnetic interface (EMI) signal, no mechanical maintenance and able to perform fast switching action. SSR provide complete isolation between the control and power circuit by using the electrical and optical features of semiconductors, i.e. photocoupler.

1.2 Addressing Energy Consumption Through AC Voltage Controller

There is growing global concern about energy usage in the development of electrical energy-consuming products. To address this issue, AC voltage controllers are essential for increasing energy efficiency, which directly contributes to the affordability and accessibility of energy for individuals and communities. AC voltage controllers help lower energy bills by optimising voltage levels and minimising energy waste, making energy services more accessible and affordable, especially for low-income households. Energy efficiency and AC voltage controllers both support global efforts to reduce climate change. They aid in limiting global warming and achieving international climate targets by reducing energy use and related greenhouse gas emissions. By minimising the demand for increased power generation capacity, improved voltage regulation lessens the reliance on fossil fuel-based energy sources. Overall, AC voltage controller can be a powerful tool in the fight against energy waste, by precisely matching the voltage requirements of linked equipment, resulting in better overall efficiency.

1.3 Problem Statement

The cost of an inverter can be expensive depending on its power rating, efficiency, and features [1], [2]. Nevertheless, the cost of an inverter can be an important factor in deciding whether or not to use it. TRIACs are bidirectional thyristors that can conduct current in both forward and reverse bias circumstances, making them AC control devices. However, TRIAC might be difficult to design [3], [4]. Since a TRIAC can be triggered in both forward and reverse bias circumstances, a gate trigger circuit must be carefully chosen [3]. The TRIAC's internal structure causes the actual values of latching current, holding current, and gate trigger current to differ significantly in different operating modes, which can make the design process difficult. Hence, SSR is the best way to use it as a switching device.

1.4 Project Objective

The main aim of this project is to develop an Arduino microcontroller-based SSR that is capable of controlling AC voltage, the performance of the device will be compared and analysed with a TRIAC-based AC voltage controller. Specifically, the objectives are as follows:

a) To design an AC voltage controller using microcontroller-based SSR.

b) To develop the hardware prototype of AC voltage controller using microcontroller-based SSR.

c) To analyse the performance of the developed device.

1.5 Scope of Project

The scope of the project is defined as follows:

a) Control of single phase AC voltage.

- The developed device will be connected to single phase 240VAC, 50Hz frequency load.

b) Microcontroller.

- Arduino UNO microcontroller will be used to control the operation of a SSR based on the algorithm of AC voltage control.

c) Software (programming, simulation).

- Arduino IDE software will be used to write a programme for an Arduino microcontroller.
- Proteus software will be used to simulate the designed circuit in this project.

- LVDAC-EMS software will be used for data analysis.

d) Hardware.

- A hardware prototype will be developed to verify the efficiency of the designed circuit.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is a past study from a collection of academic references, such as journal articles and theses, related to a particular research subject or challenge. circles in the scope and context of the project. The researcher will utilise the literature reviews to learn about other people's practises in order to use them as guides for this project. It will allow the researcher to have a better understanding of the topic and to create or innovate in new ways.

2.2 Global or Current Issue of AC Voltage Controller

Energy efficiency is a global issue that is being tackled in numerous industries. Buildings and domestic energy usage, including home heating, cooling, and operating, as well as household electrical use, are under the spotlight since their percentage of world energy use is thought to be between 30% and 40% [5]. Instantaneous water heaters use more energy than necessary since they operate at a set temperature. On the other hand, when operated in closed-loop mode, AC voltage controllers can offer continuous output power adjustment and have improved temperature-regulating capabilities. The study [6] explores the application of such controllers and focuses on how they affect power quality, energy consumption, and temperature regulation. To summarise, the global or current issue of energy efficiency in AC voltage controllers is to build stabilised controllers that optimise AC voltage controller efficiency and reliability.

2.3 Design and Analysis of AC Voltage Controller

AC voltage controllers allow for the modification of the applied alternating voltage to a load. **Figure 2.1** depicts the basic circuit of a single-phase AC voltage controller [7]. It is designed for low-power applications and consists of two anti-parallel thyristors connected between the source and the load. It allows bidirectional full wave symmetric control and, with the addition of a diode, can also deliver a voltage that is half wave asymmetric only in one direction. Additionally, it lowers total costs while raising conduction loss.

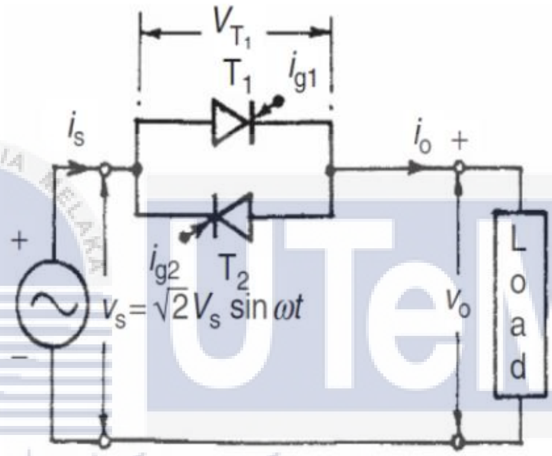

Figure 2.1 AC Voltage Controller [7]

In numerous industrial applications, switching power converters are utilized to convert and distribute energy to the load. PWM signals consist of pulse trains with an output voltage controlling magnitude and fixed frequency. When applied to the gate, the PWM signal changes the turn-on and turn-off intervals of thyristors from one PWM cycle to the next. The PWM signal's frequency must be higher than the modulating signal's frequency.

2.4 Type of AC Voltage Controller

AC voltage controllers, used in induction heating systems, variable speed drives, and grid voltage adjustment, control the output voltage's RMS value. This research analyses harmonic coefficient voltages produced by various voltage and frequency control methods, validating them through simulation and experimental results [8].

2.4.1 Single-Phase AC Voltage Controllers

There are a variety of control methods for regulating the output AC voltage's RMS value.

2.4.1.1 Phase-Angle Control

The voltage control method is the simplest to use; however, due to its slow switching frequency, it has low-frequency harmonics. It describes the output voltage's power quality and comprises two voltage control methods dependent on the number of controlled switching devices.

2.4.1.2 Voltage Regulation with Unipolar Voltage Control Scheme

Due to the load's DC component, this output voltage control method is used in a low power rating load. The output voltage is only controlled for one-half of its cycle, causing an uneven output voltage along the vertical (y) axis. As a result of the switching devices being used at low line frequency, the output has low-frequency harmonics. **Figure 2.2** shows the output voltage in relation to the firing delay and the input voltage, which only regulates the output voltage during positive half-cycle of the input voltage.

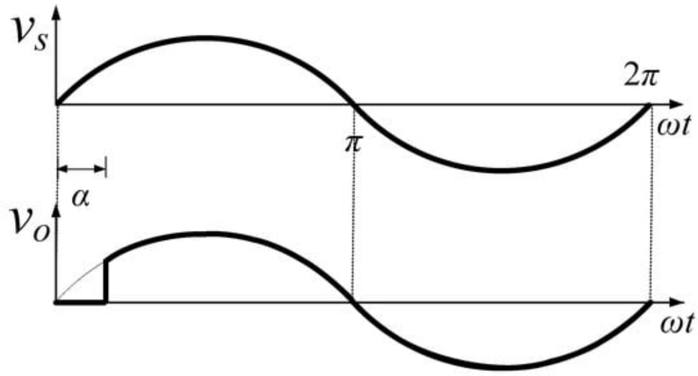

Figure 2.2 Control of the output RMS voltage via unipolar phase-angle control [8]

The input source current develops a DC component due to the DC (average) component of the output voltage, which could lead to core saturation in the linked transformer. A bipolar voltage control scheme is used to solve this problem.

2.4.1.3 Voltage Regulation with Bipolar Voltage Control Scheme

This voltage control system regulates the input voltage by applying two gate pulses in a single cycle. This is accomplished via line commutated thyristor converters, and the output RMS voltage is controlled by firing delay control as shown in **Figure 2.3**. Since the period of the input and output voltage waveforms is equal to 2π, there are no problems with the harmonic coefficient calculation.

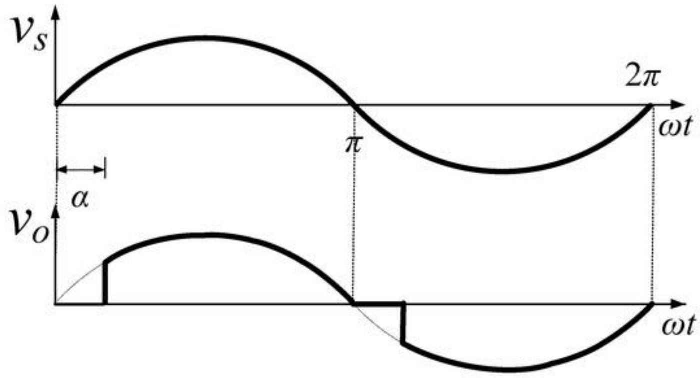

Figure 2.3 Control of the output RMS voltage via bipolar phase-angle control [8]

Due to the waveform's symmetry, all other harmonics are suppressed, leaving just odd harmonics in the output voltage waveform.

2.4.1.4 On-Off Control

This voltage control approach is used to control a load with a relatively long output time constant. For some integer cycles, the input source and load are connected, while for others, it is decoupled. The output voltage's harmonic coefficients are calculated by examining the waveform of the parent input voltage. **Figure 2.4** shows a single on-cycle (k) and five off-cycles [8].

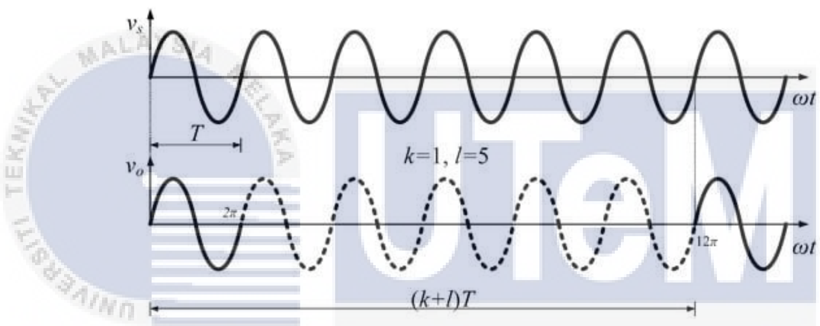

Figure 2.4 Control of the output RMS voltage via on-off cycle control [8]

2.4.1.5 PWM Voltage Control

Due to their low-frequency harmonics, on-off control and phase-angle control have limited applications. As the switching frequency is increased, this method forces the low-frequency harmonics to a higher frequency. The instantaneous output voltage and instantaneous input voltage are identical at ‘dT’ intervals, and at the ‘1 − dT interval is zero. The controlled devices' switching frequencies determine the pulse on and off periods, which are both equal.

The power quality of the output voltage can be investigated analytically using a pulse selective technique as shown in **Figure 2.5**. The instantaneous output voltage decomposes into its parent sinusoidal waveform with a chopping frequency six times the source frequency, resulting in six sinusoidal pulses per cycle of the input voltage.

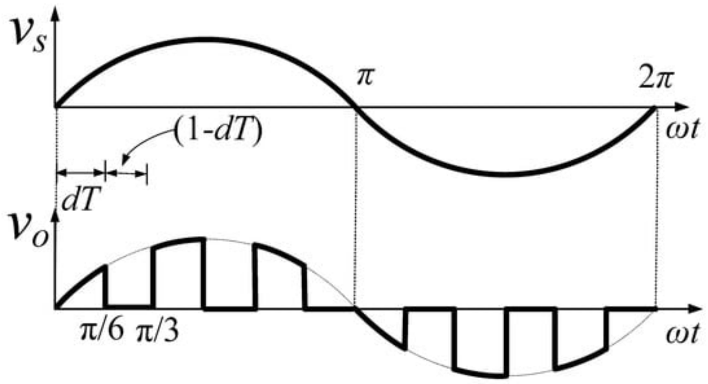

Figure 2.5 Control of the output RMS voltage via the PWM control [8]

2.4.2 Three-Phase AC Voltage Controllers

The heavy-duty three-phase AC motors can also have their speed regulated or start softly with this AC voltage controller. **Figure 2.6** shows the waveform of a three-phase AC voltage controller's output phase voltage with a firing delay of 30° or π/6.

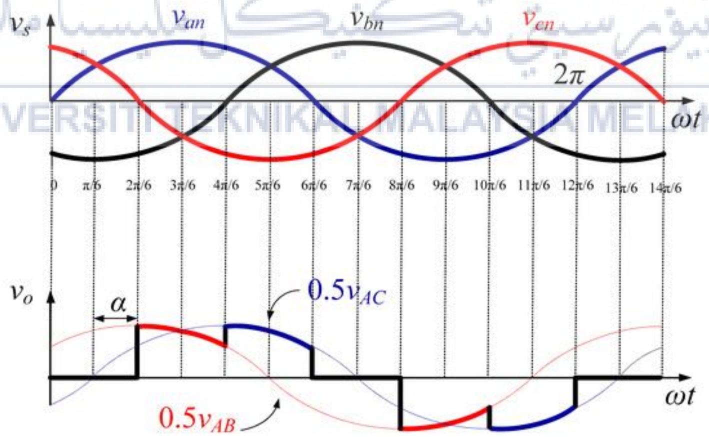

Figure 2.6 Three-phase AC voltage controller output RMS voltage control [8]

2.5 Design of AC Voltage Control using Zero Crossing Detection

An electrical circuit known as a zero cross detector begins operation with the AC charge voltage in the AC process at around 0 volts. The output voltage should start off as a full half-term of the sine wave as the circuit's objective is to start the TRIAC conducting extremely close to the moment when the load voltage reaches 0 volts.

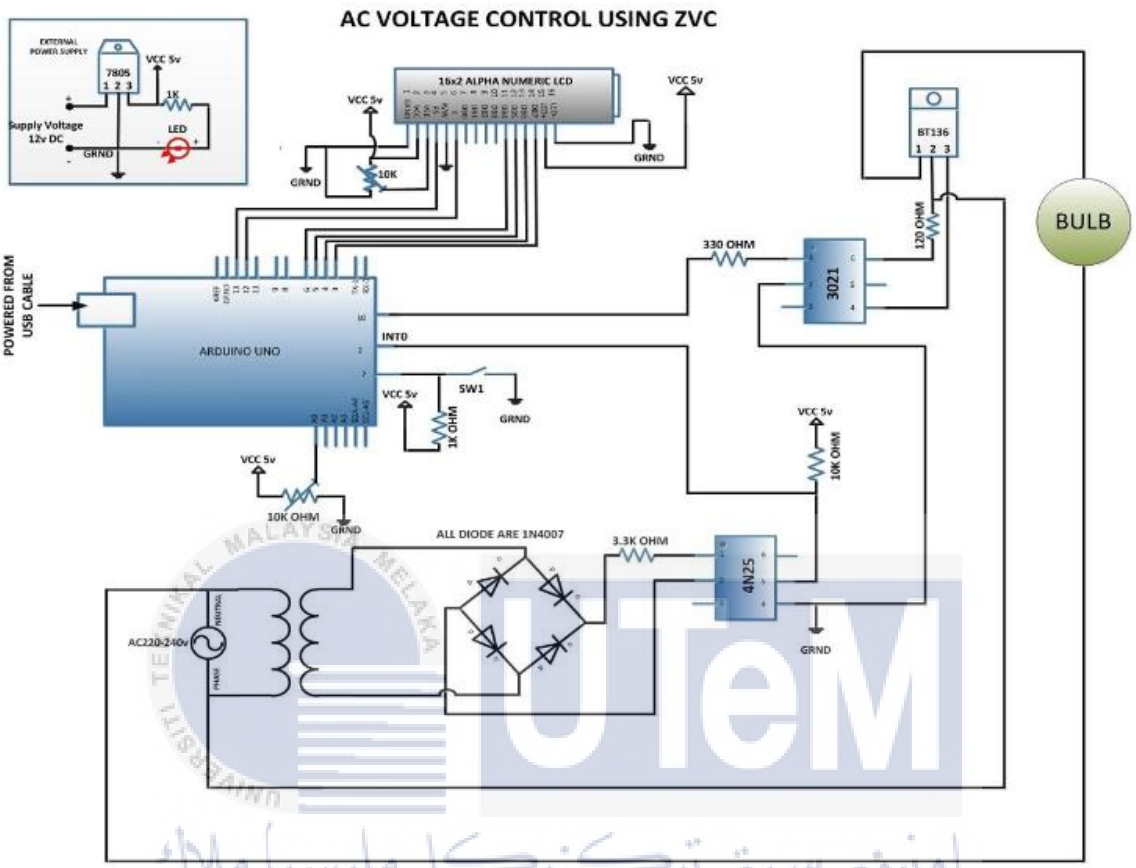

Figure 2.7 Design of AC voltage control using Zero Voltage Crossing Detection [9]

By rectifying the AC voltage with a complete wave rectifier and applying an opt isolator that switches ON and OFF at zero voltage crossings and above, The AC voltage's zero-voltage crossing can be detected. To demonstrate that the microcontroller has zero voltage crossings, this output should be sent to it. To control the AC voltage going to a load, TRIAC should be applied.

By conducting interactive simulations with a microcontroller using software called Proteus, faults in design, component selection, and connection order can be avoided, saving both money and time. When voltage alternates in its direction or when there is a zero-voltage crossing, it is crucial to pay attention to this in order to monitor AC equipment. This is the stage where it alternates courses on the voltage curve.

The Arduino UNO microcontroller-based was developed to improve efficiency. The brightness of the lamp can be controlled using serial port commands in this Arduino project.

2.6 Solid State Relay

SSRs are electrical switches that respond to a very small external voltage applied to their control terminals by turning on or off. In order for the control signal to activate the switch without the use of mechanical elements, SSR requires a solid-state electronic switching device, a sensor, and a coupling mechanism. A variety of switched capacitor cells and power MOSFET switches are switched using SSR [10]. They work very quickly with no sparking and a longer lifespan, are intrinsically compact, and have constant output resistance. The device should be able to function with both AC and DC load currents and not require any external biasing [11].

2.6.1 Solid State Relay SSR-40DA-H

This solid state relay, model SSR-40DA-H [12], has a 4-32V DC input to switch current loads up to 40A and a zero cross trigger control technique where to prevent the occurrence of EMI or RFI, at the zero point of a sine wave, the output will be turned on or off. Ideal for controlling resistive, capacitive, and non-saturated inductive loads. The SSR-40DA-H is renowned for its long service life and high reliability, making it a top choice for various applications. Additionally, its highly reliable and compact design ensures optimal performance in limited spaces. With a focus on user convenience, it is specifically designed to offer maximum simplicity. Moreover, its fast-switching capabilities further enhance its overall efficiency and effectiveness.

2.7 Related Previous Work of AC Voltage Controller

According to [13], the authors present the AC voltage controller based on Arduino using single phase controller techniques by develop a PWM dimmer circuit by combining an IN4007 diode bridge with PWM to adjust the voltage across the bulb (lamp brightness). For the prototype, a step-down transformer, Arduino UNO, PCB main circuit board, 9W LED bulb, bulb holder and switch are used. **Figure 2.8** shows the result of RMS voltage varying at different firing angles and a graph of RMS output voltage vs firing angle in **Figure 2.9**.

Figure 2.8 Result of RMS voltage varying at different firing angle [13]

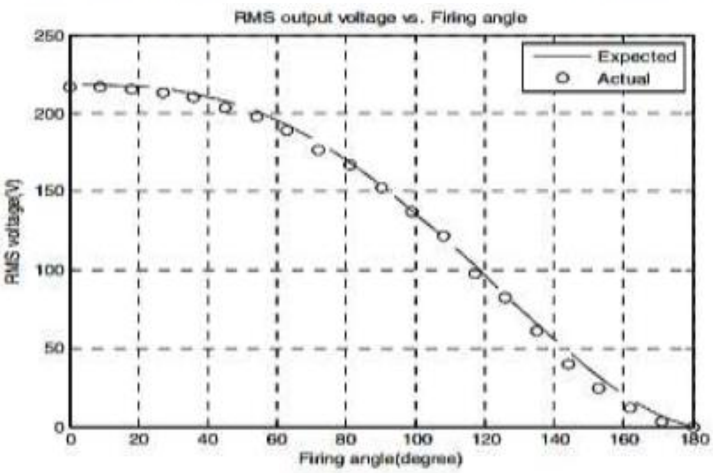

Figure 2.9 RMS output voltage vs firing angle [13]

The research by [14] is about the development of microcontroller-based AC dimming techniques to regulate ambient light levels locally and remotely which will reduce the amount of AC power provided to the load. The proposed system can be applied to a variety of applications, including controlling indoor and outdoor lighting, regulating the amount of light in hotels, train stations, and bus stops, as well as other inductive loads like motors and resistive loads like heaters. **Figure 2.10** shows the block diagram of the developed system.

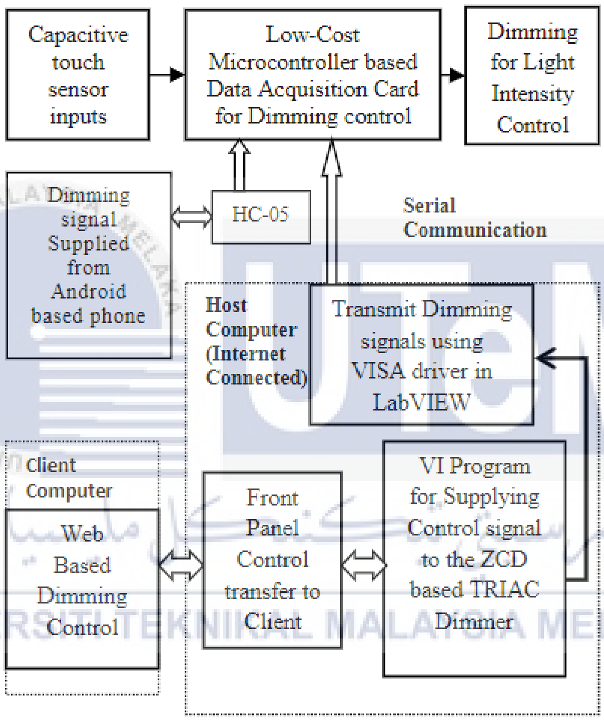

Figure 2.10 System block diagram [14]

There is a study about a prototype of a single-phase AC voltage controller with a microcontroller-based phase angle control that supports soft starting for single-phase induction motors [15]. Using a feedback control system, the output voltage is regulated to maintain the desired fixed RMS value and stabilise the output. The RMS value of the output voltage is measured by a second microcontroller, which sends the results to the primary microcontroller for feedback control. **Figure 2.11** shows the functional block diagram of voltage controller.

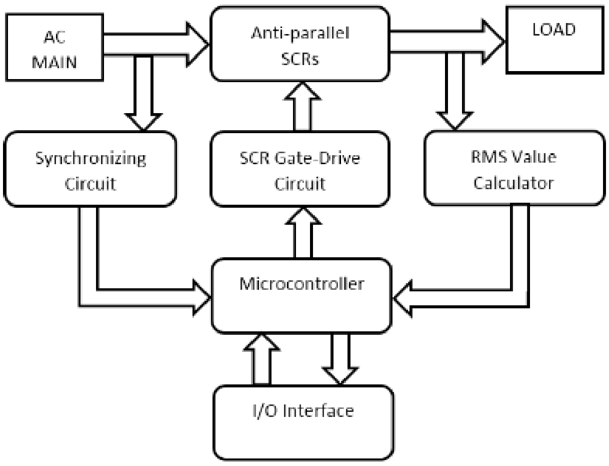

Figure 2.11 Functional block diagram of voltage controller [15]

The work done by [16], focuses on designing and implementing a microcontroller-based single-phase automatic voltage regulator (AVR) using a TRIAC to adjust AC voltage phase. The microcontroller delays the trigger pulse to supply the desired regulator terminal voltage, which is continuously measured and supplied back to the microcontroller through a measuring device. The AVR is intended for domestic heating and lighting controls, introducing a compact AVR, and showcasing the PIC microcontroller's usefulness in power control. It can also be used as a variable resistor in voltage-sensing circuitry. **Figure 2.12** shows the block diagram of microcontroller-based automatic voltage regulator.

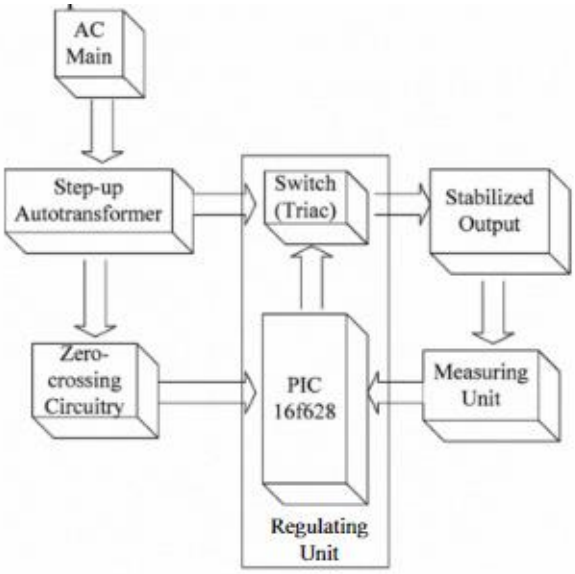

Figure 2.12 Block diagram of microcontroller-based automatic voltage regulator [16]

Lastly, research from journal [17], studied about how to improve presence power control technology and encourage to use Bluetooth-based wireless remote technology to control the AC loads. Therefore, the method to implement the remote AC power control circuit is essential. The whole implemented circuit is shown in **Figure 2.13**.

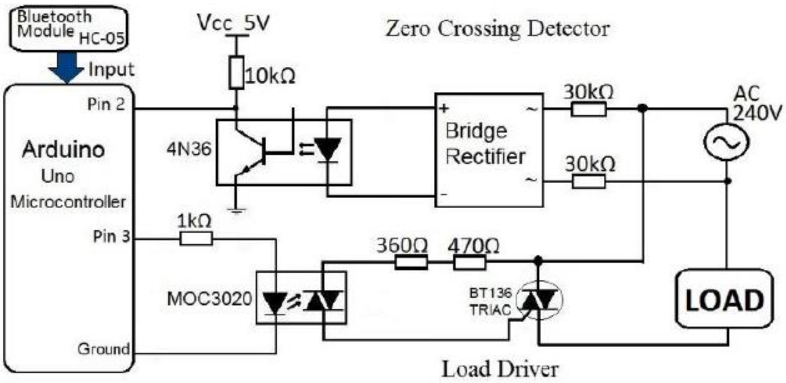

Figure 2.13 Phase Control Technique Circuit Diagram [17]

Table 2.1 Comparison of previous work

NO.	AUTHOR(S)	TITLE	FUNCTIONAL	REMARKS (method & application)
1	R.Swathi, E.Sunaina, M.Ashwini, K.Akhil Reddy (2018)	Implementation of Arduino Based AC Voltage Controller Using Single Phase Controller Techniques	• Design to control brightness of the lamp. • An Arduino UNO microcontroller-based was designed to increase its efficiency.	• Component use: Arduino Uno, IN4007 diode, MCT2E optocoupler and PWM signal
2	Akash Kumar, Fajr, Taznoon Nisar Khajwa, Neeraj Khera (2019)	Microcontroller Based Digital AC Dimming Techniques for Light Intensity Control	• Digitally adjust the firing angle delay of the TRIAC gate from both onsite and remote locations utilizing various approaches that replace the conventional AC dimmer.	• Onsite AC Dimming using Capacitive Touch Sensor • Android based Remote AC Dimming using Bluetooth communication.

3	Arifur Rahman, Nayeem Ansari, Nazneen Ahmed, Kazi Mujibur Rahman and Md. Zahurul Islam (2014)	Development of a Microcontroller-based AC Voltage Controller with Soft Start Capability	• Controls AC voltage efficiently and provides soft start capability for single-phase induction motors.	• Component use: anti-parallel SCR-based voltage controller, gate-drive circuitry for SCR, PWM generation through the microcontroller, phase and frequency detection, RMS value calculation for feedback and input-output interfacing.
4	Nang Kaythi Hlaing, Lwin Lwin 0o (2010)	Microcontroller-Based Single-Phase Automatic Voltage Regulator	• To use it in domestic heating and lighting controls as an adjustable voltage source. • To demonstrate the usefulness of the PIC microcontroller in power control.	• The design is based on the principle of phase control of AC voltage using a TRIAC, where triggering (firing) delay is determined by the PIC microcontroller.

			• It can also be used as a variable resistor in the voltage-sensing circuitry.	
5	Lee Siang Tat, Yiauw Kah Haur (2016)	Remote AC Power Control by Using Microcontroller	• To improve power control technology by controlling from a distance and providing an infinite power control range.	• A TRIAC-based phase control technique for controlling power delivered to AC loads on the Arduino microcontroller. • The AC loads are managed via Bluetooth-based wireless remote technology.

2.8 Summary

By implementing a microcontroller-based solid-state relay (SSR), AC voltage controller will become more efficient and longer operating life. This device can run with either AC or DC loads and has all the built-in benefits of solid-state devices. It also offers good drive-to-load isolation. According to experimental findings, this device can be employed in a variety of low-power applications in place of relays.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, this chapter will cover the methodologies and procedures employed in this project, as well as the hardware components and software needed to accomplish it, with an emphasis on the efficiency of AC voltage controller by using SSR. This project will make use of an Arduino UNO microcontroller as well as software suitable to ensure its success.

3.2 Methodology

In research, challenges such as specialized processes or approaches, analysing information, and so on will certainly arise. The methodology is defined as a family of logic used to study reasoning or as a method of doing something. This will analyse the efficacy of AC voltage controller with a microcontroller-based SSR by calculating time delay.

3.3 Project architecture

A flow chart is a simple graphical representation of a complete project or programme. It displays the steps in a logical order. The flow chart displays the project's progress from start to finish. Pre-development involves research and information gathering, as well as an understanding of all programming languages and functional design. Following the pre-development phase, the first stage of development is to include the data collection procedure into the Arduino coding. During the post-development step, the simulation results are output to hardware and apps for the final stage.

Figure 3.1 displays the project's working system so that the system flow can be better understood.

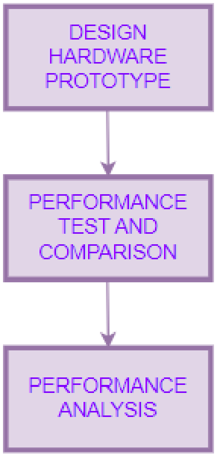

Figure 3.1 Flowchart of project working system.

a) Design hardware prototype

The project will be developed by using zero crossing detector, SSR, and Arduino microcontroller.

b) Performance test and comparison

The project will be tested to an AC load and be compared to TRIAC-based AC voltage controller and connected to the same load. The configuration of the test bed is shown in **Figure 3.2**. A TRIAC-based AC voltage controller will use that is usually found in the market as shown in **Figure 3.3**.

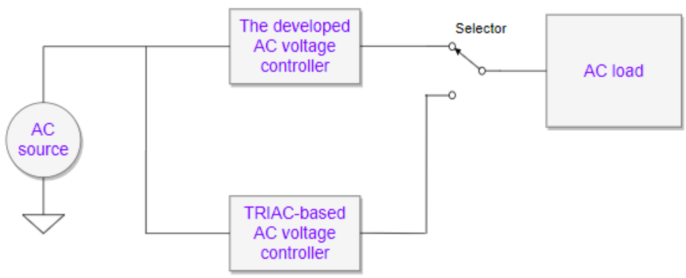

Figure 3.2 The configuration of the test bed

Figure 3.3 A common TRIAC-based voltage controller sold in market.

c) Performance analysis

The efficiency of the developed project will be analysed in term of output power (output voltage and output current).

3.4 System architecture

The most important principle for carrying out this process is the varied voltage output is used for motor speed control, light dimmer, and heater control by adjusting potential resistor value. In addition, a zero cross detector is used as the main source to power this system. It begins operating with an AC load voltage near 0 volts in the AC cycle. This is in relation to SSR. **Figure 3.4** is about this project field diagram.

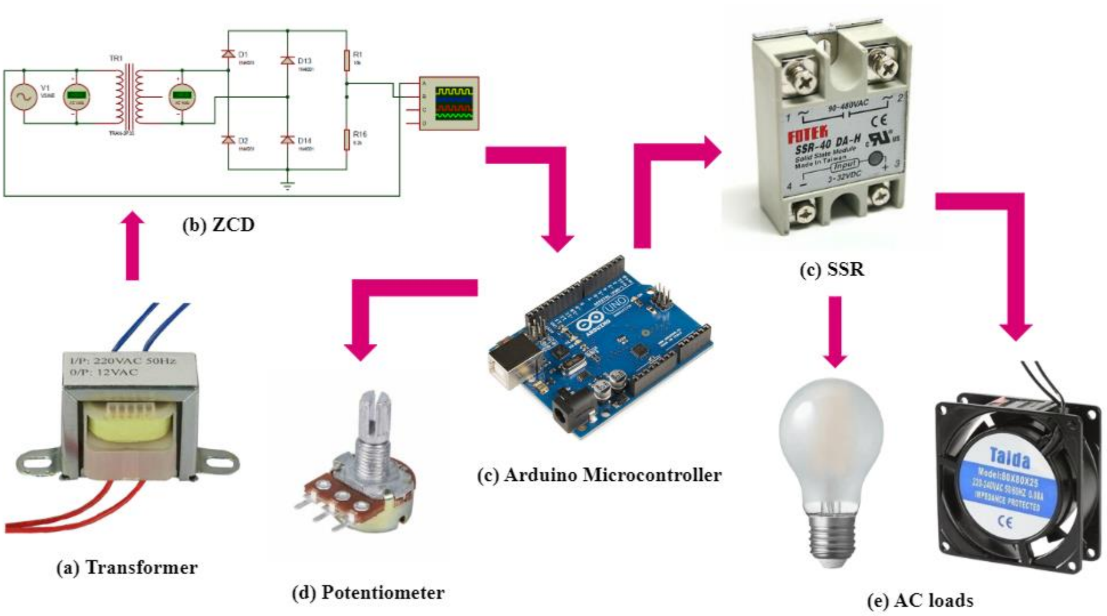

Figure 3.4 Project field diagram

a) Transformer

The transformer is used to step down 240V to 12V AC voltage to deliver signal to zero cross detector circuit.

b) Zero crossing detector

ZCD circuit detects when the sinusoidal supply voltage goes crosses zero. The Arduino microcontroller receives interrupt signals from the pulses produced by the zero cross detector circuit.

c) Arduino microcontroller

Arduino microcontroller will generate firing signal to the SSR based on the signal from ZCD. **Figure 3.5** shows the flowchart of the program of the microcontroller.

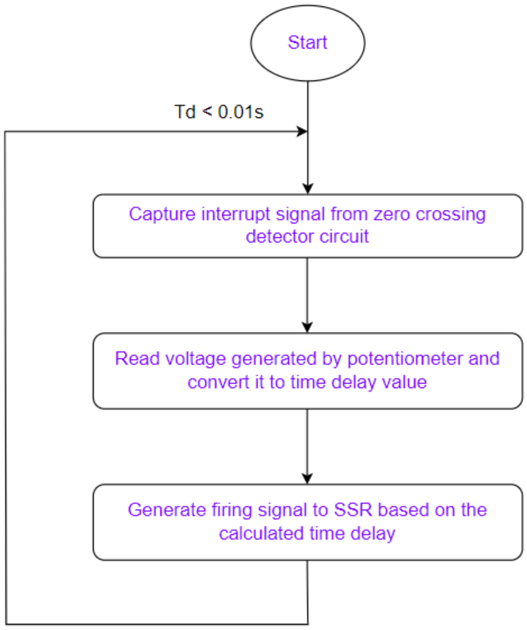

Figure 3.5 Flowchart of the programming of the Arduino microcontroller

d) Potentiometer

To read voltage generated, a potentiometer is used to measure the actual time delay of firing signal, Td as shown as in **Figure 3.6**. The delay time measured is then converted to delay angle using equations as shown:

$$\text{time delay, Td} = \frac{\text{ADC}}{256} \times \frac{1}{2f}$$

where f is the frequency of AC voltage (which is $f = 50$ Hz) and ADC is a value that is converted inside microcontroller from the voltage generated by the potentiometer.

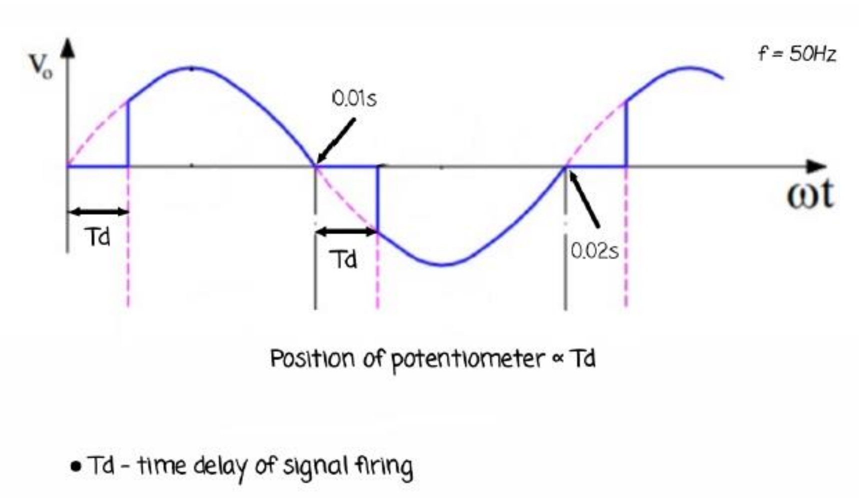

Figure 3.6 Position of potentiometer is directly proportional to Td.

e) AC loads

The power delivered to the AC loads can be adjusted by controlling the time delay between the zero-crossing detection circuit and the firing signal to the SSR.

3.5 Hardware components

Hardware is an important part of any project, especially a prototype model, as it can help us represent all real data and work. If a project just relies on software, such as simulation, it will be unable to obtain actual data or work, as the output of the simulator is dependent on computer or software calculations, which exclude other factors such as environmental factors. The best hardware allows us to study both hardware and software while also improving our skills in areas such as design and modelling.

3.5.1 Arduino UNO board

A microcontroller board called the Arduino UNO is based on the Atmega328. This board, shown in **Figure 3.7**, consists of a power connector, a USB connection, 14 digital I/O pins, six analogue input pins, a 16 MHz ceramic resonator, an ICSP header, and RST button. Furthermore, it requires 5 volts to operate. The Arduino UNO board is used to debug the coding program and execute it in actual hardware to measure current and voltage for each load.

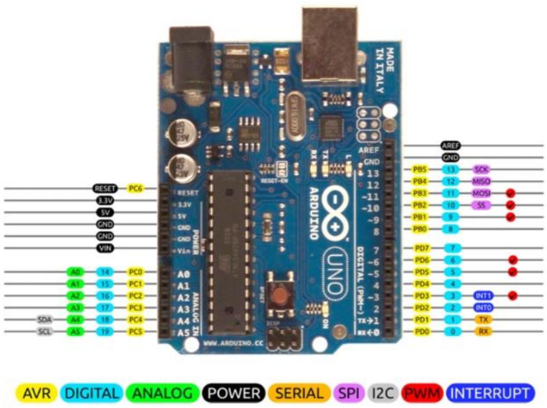

Figure 3.7 Arduino UNO pin configuration [18]

3.5.2 Step down transformer

A step-down transformer is a device that lowers the voltage of an AC power source. It is made up of three parts: a primary winding, a secondary winding, and an iron core. When an AC voltage is given to the primary winding, a fluctuating magnetic field in the iron core generates a voltage in the secondary winding, which is lower than the primary winding.

Figure 3.8 Step down transformer [19]

3.5.3 Solid state relay

SSR is a relay with no moving contacts. In terms of operation, SSR is similar to mechanical relays with moving contacts. In contrast, SSR uses semiconductor switching elements such as thyristors, TRIACs, diodes, and transistors. The design of the SSR is shown in **Figure 3.9**, and the specifications are presented in **Table 3.1**.

Figure 3.9 Solid state relay [20]

Table 3.1 Feature and specification of solid state relay [20]

Type	Terminal Type
Model	SSR-40DA-H
Rated Load Current	40A
Input Data	
Operating Voltage	3~32VDC
Min. ON/OFF Voltage	ON＞2.4V, OFF＜1.0V
Trigger Current	7.5mA / 12V
Control Method	Zero Cross Trigger
Output Data	
Operating Voltage	90~480VAC
Min. Back Voltage	600VAC (Repetitive)
Voltage Drop	1.6V / 25°C
Max. Durated Current	410A
Leakage Current	5.0mA
Response Time	ON＜10ms, OFF＜10ms
General Data	
Dielectric Strength	Over 2.5KVAC / 1min.
Isolation Strength	Over 50MΩ / 500VDC
Operating Temperature	-20°C ~ +80°C
Housing Material	Intensive ABS
Weight	Appr. 105g

3.5.4 Potentiometer

A potentiometer is a simple mechanical device that produces variable resistance when its shaft is spun. By applying voltage to it and having an analogue input on board, it is possible to measure the amount of resistance generated by a potentiometer as an analogue value.

Figure 3.10 Potentiometer

3.5.5 AC loads

In this project, a power electrical bulb 40W and 220/240V AC fan will be used as a test bed to verify the efficiency of the project. If the brightness of the bulb and the speed of the fan can be controlled, it indicates that the developed circuit is functional effectively.

Figure 3.11 40W AC bulb

Figure 3.12 20W AC motor

3.6 Software development

This is an essential software program that helps with the completion of the overall project system. The system cannot be constructed with a connecting circuit and tested for functionality on the built system without this application.

3.6.1 Proteus 8

Proteus 8 is a software suite that allows to simulate, creating, and sketch electrical circuits. This program works with a wide variety of microcontrollers found in a variety of educational contexts. As a result, it may help even novices learn to create electronic circuits.

3.6.2 Arduino IDE

The Arduino IDE is a software program that allows developers to write code in C and C++ using special code structure guidelines. The wiring project is a software library that comes with the Arduino IDE and covers a wide range of common input and output functions. It also connects to Arduino to upload applications and communicate with them. The fact that Proteus is a simulation-based tool also allows for the simulation of Arduino in it.

3.6.3 LVDAC-EMS

The LVDAC-EMS is software developed by the manufacturer for data acquisition and preliminary control functions. LVDAC-EMS features a user-friendly data acquisition and control interface. The curriculum includes student manuals and instructor guides with all the necessary theory taught prior to the hands-on experiments.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the findings and interpretation of the data collected for voltage and current readings. Voltage and current were measured for the AC loads. It is also displayed in the LVDAC-EMS software.

4.2 Results and Analysis

4.2.1 System Functionality

A step-down transformer reduces the 240V AC voltage to 12V AC, which is then delivered signal to signal to a zero cross-detector circuit. The Arduino receives interrupt signals from the pulses produced by the zero cross detector circuit, then reads the voltage generated by the potentiometer and converts it to a time delay value.

Following that, a PWM pulse is applied to the SSR based on the brightness and speed requirements, varying the ON/OFF time of the AC signal and providing a variable output to control the lamp brightness and fan speed. In this case, Arduino is used to generate the PWM pulse, which takes the potentiometer input and outputs the PWM signal to the SSR which then operate the AC bulb and AC fan at the specified brightness and speed. The overall design prototype is shown in **Figure 4.1**.

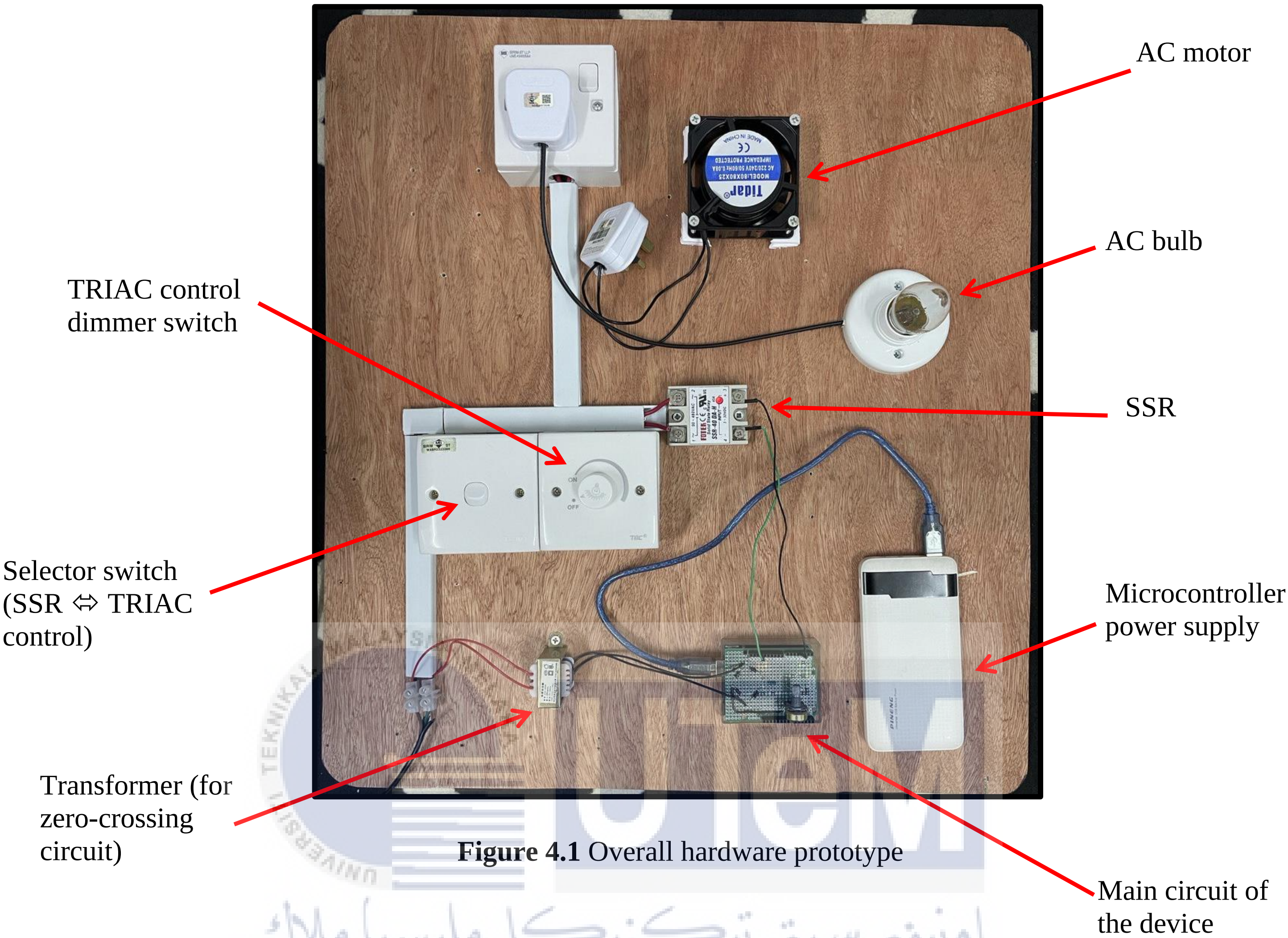

Figure 4.1 Overall hardware prototype

4.3 Performance Analysis

On this part, data analysis is performed using a 40W AC bulb and an 20W AC fan in terms of output power (output voltage and output current) based on the desired duty cycle of PWM signal level by adjusting the potentiometer. The performance of the developed device is then compared to the performance of a TRIAC control dimmer switch that is available in the market. The performance data of the developed device and the TRIAC control dimmer switch are shown in **Table 4.1.**

Table 4.1 Performance data of the developed device tested to 40W bulb.

Duty cycle of PWM (%)	**PWM Level**	**Voltage (V)**	**Current (A)**	**Power (W)**
0	0	0	0	0
20	51	60.0	0.10	6.0*
40	102	133.3	0.12	16.0*
60	153	172.3	0.15	25.8*
80	204	208.7	0.16	33.4
100	255	243.2	0.18	43.8

*Flicker effect

According to **Table 4.1**, the voltage and current reading increased as PWM level increases. The PWM level has a direct influence on the brightness intensity of an AC bulb, resulting in changes in both the output voltage and current. At the low value of duty cycle of PWM signal, it can be seen that bulb is having flicker effect due to the low capability switching frequency of the SSR. The SSR used in this project is only capable of performing switching action less than 100 Hz. The performance of the bulb was also tested by using TRIAC control dimmer switch also it is found that the performance data is almost same to the performance data of Table 4.1, but with no flicker effect.

The device also is tested to the 20W AC fan, and the performance data is shown in Table 4.2. It can be found that developed device can control the speed of AC fan. The fan also is tested to the TRIAC control dimmer switch, and it shows the same performance as illustrated in **Table 4.2.**

Table 4.2 Performance data of the developed device tested to 20W motor.

Desired PWM (%)	PWM Level	Voltage (V)	Current (A)	Power (W)	Speed (RPM)
0	0	0	0	0	0
20	51	87.9	0.01	86.0	510
40	102	130.3	0.04	5.1	1048
60	153	171.2	0.05	8.5	1495
80	204	210.0	0.06	12.3	2074
100	255	243.0	0.08	19.1	2605

From the results shown in Table 4.1 and Table 4.2, it shows that the developed device is not perform well in controlling the bulb intensity since it can cause a flicker effect. However, the device shows the good performance in controlling the speed of AC motor. It is believed that the device also is capable to control a heater for water or air temperature control application, since a heater have almost same time respond to an AC motor.

4.4 Summary

In a nutshell, this developed system can be implemented to control the speed of AC motor or heater, but it is not suitable to control an AC bulb. However, there is room for improvement that can be made for the device in such a way it can control various types of AC load including AC lamp.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Overall, this project has achieved all three objectives using the method defined in Chapter 3. Voltage and current readings can be recorded using LVDAC-EMS software. The developed device has an issue to control the brightness of AC bulb, as in the flicker problem as explained in Section 4.3. However, the device shows a good performance in controlling the speed of AC motor.

The performance of the developed device is compared to a TRIAC control dimmer switch, and it is found there are many improvements should be mode to make the device has same performance or better.

5.2 Project Objectives

5.2.1 To design an AC voltage controller using microcontroller-based SSR.

The first goal was to develop an AC voltage controller using microcontroller-based SSR, which was accomplished by using an Arduino UNO as a microcontroller, zero crossing detector, and SSR.

5.2.2 To develop the hardware prototype of AC voltage controller using microcontroller-based SSR.

The hardware prototype of AC voltage controller using microcontroller-based SSR has been successfully developed. The transformer steps down AC voltage from 240V to 12V, delivering a signal to the zero cross detector circuit. The ZCD circuit detects when sinusoidal supply voltage crosses zero. The Arduino microcontroller receives interrupt signals from the circuit and generates a firing signal to the SSR. A potentiometer measures the time delay of the firing signal, allowing the power delivered to the AC loads to be adjusted. As a result, the data has been recorded in Chapter 4.

5.2.3 To analyse the performance of the developed device.

The efficiency of the developed project has been analysed in term of output power (output voltage and output current). According to the data, as the PWM level increases, voltage and current also increase. The developed device has the same performance as a TRIAC control dimmer switch when controlling AC motor, but the device has a flicker issue when tested to an AC bulb.

5.3 Potential for Commercialization

Throughout the project, AC voltage controller using microcontroller-based solid state relay holds tremendous potential for commercialization in the current market as it could be used in a variety of industries, such as home automation, industrial automation, and power management. Intelligent control based on a microcontroller allows the device to be more adaptable to a variety of circumstances and respond to automation.

5.4 Future Works

For future improvements, AC voltage controller using microcontroller-based solid state relay features could be enhanced as follows:

i) Fully control the circuit by the Android app via Bluetooth connection.
ii) To use fast switching SSR to enable the control of fast respond load such as AC bulb.

iii) To equipped with filter circuit to make the device compatible to EMI regulation.

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APPENDICES

Appendix A Coding

```
#define ZCD 2
#define SSR 3
#define vresistor A0 // variable resistor
int brightness;

void setup()
{
  pinMode(ZCD,INPUT_PULLUP);
  pinMode(SSR, OUTPUT);
  pinMode(vresistor, INPUT);
  attachInterrupt(digitalPinToInterrupt(ZCD), angle, RISING);

  Serial.begin(9600);
}

void loop(){}

void angle(){

  int bright = analogRead(vresistor);
  brightness = map(bright,0,1023,0,255);
  analogWrite(SSR, brightness);

  Serial.print("Dimming Value: ");
  Serial.println(brightness);
```