UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

ARDUINO CONTROLLED AC VOLTAGE REGULATOR

MASTER THESIS

Alhasan Ali Jasim AL-JUBOORI
1406030037

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

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Alhasan Ali Jasim AL-JUBOORI, having student number …**1406030037**... and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of jury, the presentation of the thesis prepared with the title of: ''**ARDUINO CONTROLLED AC VOLTAGE REGULATOR**''

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Thesis Defense Date: 23.05.2017

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

I hereby declare that all information in the study I presented as my Master's Thesis, called; **ARDUINO CONTROLLED AC VOLTAGE REGULATOR** has been presented in accordance with the academic rules and ethical conduct. I also declare and clarify with my honor that I have fully cited and referenced all the sources I made use of in the present study.

23.05.2017

Alhasan Ali Jasim AL-JUBOORI

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For My Grandmother's Memory

First of all, I thank Allah for helping me to complete this thesis.

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May, 2017 **Alhasan Ali Jasim AL-JUBOORI**

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LIST OF ABBREVIATIONS

AC	: Alternating Current
AVR	: Automatic Voltage Regulator
BJT	: Bipolar Junction Transistor
CPLD	: Complex Programmable Logic Device
CSA	: Canadian Standards Association
DC	: Direct Current
DIP	: Dual-In-line Packages
EM	: Electromechanical
EMF	: Electromotive Force
EMI	: Electromagnetic Interference
FACTS	: Flexible AC Transmission System
GTO	: Gate Turnoff Thyristor
IDE	: Integrated Development Environment
IGBT	: Insulated Gate Bipolar Transistor
I/O	: Input/Output
IMU	: Internal Measurement Unit
IRED	: Infrared-Emitting Diode
LCD	: Liquid Crystal Display
LDR	: Light Dependent Resistor
MEMS	: Micro-Electro-Mechanical Systems
Np	: Number of turns in the primary coil
Ns	: Number of turns in the secondary coil
Np/Ns	: Turns Ratio
PAVR	: Programmable Automatic Voltage Regulator
PDB	: Power Development Board
PSCAD/EMTDC	: Power System Computer Aided Design /Electromagnetic Transients including DC

PWM : Pulse Width Modulation

SCR : Silicon Controlled Rectifier

SDP : Semi-Definite Program

SIP : Single-In-line Packages

SSR : Solid-State Relay

SSVR : Static Series Voltage Regulator

SVC : Static VAR Compensator

TCR : Thyristor Controlled Reactor

TCVR : Thyristor Controlled Voltage Regulator

TRIAC : TRIode for Alternating Current

VAC : Volts of Alternating Current

VAR : Volt-Ampere Reactive

VHSIC : Very High Speed Integrated Circuit

VHDL : VHSIC Hardware Description Language

VLSI : Very-Large-Scale Integration

Vp : Primary Voltage

Vs : Secondary Voltage

Φ : Magnetic Flux through One Turn of the Coil

Vo : Output Voltage

Vi : Input Voltage

B : Magnetic Flux Density

A : Cross Sectional Area

ABSTRACT

ARDUINO CONTROLLED AC VOLTAGE REGULATOR

AL-JUBOORI, Alhasan
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Supervisor: Prof. Dr. Doğan ÇALIKOĞLU
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The thesis study is to investigate a way to design an AC voltage regulator to obtain a constant voltage in the case of change of the source voltage. Several methods are used to achieve this target. The most popular method is by using a transformer with multiple taps to get a constant voltage according to turn ratio of the transformer. Turns ratio is used to control the output voltage according to the selected tap which can be selected by many methods. One of these methods using a relay that consists of losses and noise. In order to avoid these problems a solid-state relay can also be used, which will be controlled by an Arduino to improve the performance of the system. The use of an Arduino provides flexible, efficient, and fast control. Solid-state relays which consist of a triac also are used in this study to reduce the losses and noise in the device instead of mechanical relays which have disadvantages compared with SSR.

Keywords: ACVR4T, Arduino, Solid-State Relay (SSR), Transformer, Triac.

ÖZET

ARDUINO İLE KONTROL EDİLEN AC VOLTAJ REGÜLATÖRÜ

AL-JUBOORI, Alhasan
Yüksek Lisans, Elektrik ve Elektronik Mühendisliği
TezDanışmanı: Prof. Dr. Doğan ÇALIKOĞLU
Mayıs-2017, 63 sayfa

Tez çalışması, kaynak geriliminin değiştirilmesi durumunda sabit bir voltaj elde etmek için bir AC voltaj regülatörü tasarlamanın bir yolunu araştırmaktır. Bu amacı gerçekleştirmek için bir kaç yöntem kullanılmaktadır. En yaygın yöntem, trafonun sarma oranına göre sabit bir gerilim elde etmek için çoklu kademeli bir transformatör kullanmaktır. Sarma oranı, seçilen kademeye göre çıkış voltajını kontrol etmekte kullanılır. Kademeler, bir çok yöntem kullanılarak seçilebilir. Bu yöntemlerden biri kayıp ve gürültüyü içeren bir röle kullanmaktır. Ayrıca, sistem performansını artırmak için Arduino ile kontrol edilen yarı iletken bir anahtar da kullanılabilir. Arduino kullanımı esnek, verimli ve hızlı bir kontrol sağlar. Bu çalışmada, triyaktan oluşan bir katı hal röleleri de, SSR'ye kıyasla dezavantajlı olan mekanik röleler yerine kayıp ve gürültüyü azaltmak için kullanılmaktadır.

Anahtar Kelimeler: ACVR4T, Arduino, Katı Hal Rölesi (SSR), Transformatör, Triyak.

CHAPTER ONE

INTRODUCTION

1.1 Presentation of the Work

In this work, a regulator called ACVR4T (AC Voltage Regulator with a 4-Tap Transformer) is designed and implemented to supply 220 V_{AC}. The maximum output power is 1100W.

A multi-tap transformer is used for this purpose with the use of Arduino whose control the switching of the tap. In order to reduce losses and noise while increasing the life-time of the device, solid-state relays are used rather than mechanical relays. The aim of use the Arduino is to provide a flexible, efficient, and fast control.

There are several problems of voltage regulation in the electrical power brought to homes in some of area. This leads to damage most of electrical appliances where the electricity is used in these homes and other areas.

The best solution to the regulation of voltage problem can be found by choosing the best way to control this voltage with the best usage of technology. Therefore, in this study, a highly efficient voltage regulator has been made to avoid high or low voltage problems.

The electrical appliances connected to it will work more efficient by using such a regulator and thus they will protect the harms due to increasing or decreasing in the voltage levels.

1.2 Main Component Used in the Study

Several materials are used in this study work to complete the experimental work. To control the solid-state relays in ACVR4T, a new method is used which is completely different than those used usually. The aim of using this method is for faster time and more efficient performance. The control through the use of Arduino is the most important issue of this study.

1.3 Literature Review

1.3.1 Introduction

The voltage regulators are the general characteristics for many circuits. It is used to secure a constant and stable voltage that is supplied to ticklish electronics. Its wise and elegant operation use to stabilize the output to the desired level is typical for many analog circuits. These voltage regulators are the components used to achieve steady and reliable voltage. It takes the input voltage and creates a controlled output voltage ignoring the input voltage at either constant level of voltage level and/or alterable level by choosing the correct external components. This level of output voltage automatic regulation is treated by different feedback techniques. Example of that is a simple one such as zener diode, whilst the others that involve complex feedback topologies used to enhance efficiency, execution, accuracy, as well as add other features such as voltage output increase above voltage input in the voltage regulator.

1.3.2 Studies

Several studies have been done to improve the voltage regulation. Below is a literature review to some of these studies that provides a glimpse into progress the scientific community has made, and which by the end contribute in improving the current state.

An optimal way to establish the position of the tap for the voltage regulation transformers in the distribution systems has been studied and analyzed by Robbins et. al. [1]. In this work, the problem is cast as a rank-constrained Semi-Definite Program (SDP), where transformer tap ratios are apprehended by: first introduce the secondary side of virtual bus per adaptor, and second by compel the values that those virtual bus voltages be in the tap positions limit. Then one obtains a problem of convex Semi-Definite Program by restful the no convex rank1 constraint in the formulation of SDP rank constrained. The ratio between the primary and secondary side bus and virtual bus voltage are used in determine the tap positions that comes from the best solution of the relaxed Semi-Definite Program and approximate it to the nearest discrete tap values. In this work, a distributed algorithm is proposed based on the Alternating Direction Method of Multipliers (ADMM) and for efficient solve of the relaxed Semi-Definite Program (SDP).

Different case studies are presented for single phase as well as three phase distribution systems to explain the effectiveness of Alternating Direction Method of Multipliers based algorithm distributed, as well as, to liken its results with the methods of centralized solution. It demonstrated how this method is applicable via numerical method examples including the single phase and three phase test systems [2]. The above work demonstrated the how this method is applicable by numerical examples that involve single phase and three phase check systems. The suggested future work is to comprise the convergence improving to the distributed ADMM-based algorithm, as well intend to stratify this approach of distributed optimization to a scheme for a system of tracking control of wide voltage tracking.

Zhang et. al. [3] study on the problem of regulating the voltage in the distribution of power networks with profound penetration of energy resources distributed, such as the based generation renewable, and the capable of storage loads. In this work, the study is taken as an optimization program, aiming to minimize the network losses that are subject to constraints on the magnitude of bus voltage, active and inter active limits of power injections, and transmission line thermal losses and limits. Enough conditions are provided on which can solve the optimization problem through its relaxation convex. The data used from existent networks showed that these adequate conditions are predicted to be convinced by almost all networks. To solve the problem, an efficient distributed algorithm is provided. The algorithm keeps to a communication topology that is described by a graph that is same as those stated in the electrical topology network. The algorithm operation that includes its robustness vs. communication link failure, across different case studies of 5, 34 and 123 distribution systems bus power which is also illustrated.

The consumption of electric energy continuously increases due to the rapid technological progress, but this is not applicable for the case of transmission systems because of the difficulties of building of new lines from both environmental and political reasons, so, the systems are driven nearer to their limits leads to critical situations and overcrowding which by the end endangering the security of the system. The devices of power flow control such as Flexible AC Transmission

Systems (FACTS) give the chance to affect the power for both voltages and flow and as a result enhance the system security and through the resolve of congestions and then improve the voltage profile. Static VAR compensator plays a significant role in the last few years in the area of voltage regulation in AC transmission systems. Vishwakarma and Sahu [4] studied and analyzed the efficient of three phase voltage regulation of AC transmission lines by using a fixed Volt-Ampere Reactive compensator.

This work will cover the design of Static Voltage-Ampere Reactive compensator and its implementation for effective three phase voltage regulation in AC transmission lines in MATLAB Simulink platform. The algorithm of Vishwakarma and Sahu [4] work shows an efficient solution to this problem and provides an efficient voltage regulation. It also showed that the algorithm developed is stiff against the fluctuations of random voltage in the transmission line.

The design and implementation of an AVR with a highly precise and reliable hysteresis has been studied [5]. In this work, the alternating power is provided by Power Development Board (PDB) in Bangladesh. It is undergoing a variation from time to time; this is in addition to the rural areas that provide voltage remains smaller than those stated. This leads to a massive threat to the advanced electronic devices such as TVs, computers, refrigerators etc. For these reasons, the input voltage should remain in an acceptable pre-specified limit in rural and urban areas.

The lacks to the precisions of available current systems and the oscillating problem between two different output voltages create high flow at the output that may damage the electronic devices and units. The research above mention treats both introduced and shortcomings in 215-237 V_{AC} of tolerable range by the use of several taps. During changing from one level to the other a hysteresis has been introduced and thus the oscillation is prevented. This design maintains to regulate the variation of alternating current input of 150-273 V_{AC} to the range of tolerable of 215-237 V_{AC} alternating current output. A new automatic voltage regulator can make by adding many taps at the secondary side of the auto-transformer and relays. This can regulate the range of input voltage of 80V_{AC}-350V_{AC} to a stable output voltage of 220V_{AC}.

Fixed voltage regulator can be defined as the electronic device that can regulates change in voltages in a specific approach to protect the apparatus by eliminating any transients in the sharing set of connections. It is a good number appropriate for 24-hour permanent progression operations where collapse due to fluctuations consequences in serious economic losses and smashup of equipment.

In today's circumstances, low power consumption and low cost are the main features of any voltage system design. So, to meet the over necessities, Sharma and Gupta [6] have planned a Very-Large-Scale Integration (VLSI) based fuzzy logic static voltage regulation system using low-cost Complex Programmable Logic Device (CPLD) with low consumption. This type of voltage regulators has many industrialized uses where 24-hour electricity is essential and where power cut or voltage fluctuation may reason critical losses. The incorporation of complete logic into a single chip CPLD reduces the cost of the system. It also reduces the design area and definitely it will additional reduce the power consumption. The mainframe and other peripherals will be replaced by a single chip CPLD. VHSIC Hardware Description Language (VHDL) programming will be used for making CPLD device because it can port to any device so as to facilitate mass production. The board is by default programmed with a *.jam file, which contains CPLD board diagnostic system. This can be used to test all the peripherals that are on the board with CPLD. The work shows that this type of voltage regulators has many industrialized uses and would be very fruitful where 24-hour electricity is essential and where power cut or voltage fluctuation may reason critical losses.

The improving of voltage level using a Static VAR Compensator (SVC) has been studied by [7]. This study demonstrates the prospect the Flexible Alternating Current Transmission System (FACTS) controller’s applications, such as the SVC and enhances the voltage regulation performance through the use of latest technology switching devices in the transmission system of electronic power under the control of voltage and power flow. Economically, the static VAR compensators are highly used in electrical transmission systems in order to enhance the post-disturbance voltages recovery that can cause instability to the system used. Static VAR Compensator acts as system improvements through the controlling of power sources shunt reactive, for both inductive and capacitive, with advanced technology power electronic switches.

The above investigation presents that new transmission fixed voltage reactive compensator can successfully and efficiently have used in the systems of power transmission to treat the poor dynamic execution and voltage regulation problems that happen in a transmission system of 115 KV and 230 KV. Static Volt Amperes Reactive Compensator transmission and other Flexible AC Transmission System controller remains to be used with more frequency due to its advantage that makes the network reliable and guides to an open access structure. Because Static VAR Compensators is a proven Flexible AC Transmission System, the utilities will continue to use Static VAR Compensators because of its ability to resolve the problems of voltage regulation and stability. This is in addition of its environment friendly alternative to the high cost and unpopular installation of new transmission lines. Voltage control analysis and its dynamic performance will still the most important process used to identify system problems as well as to present and demonstrate the validation activity for the potential of possible solutions. For this reason, the continuous advancement and progress in system and device modeling will assure more over that suggested solutions are achieved by highly management with steady confidence and trust.

The level system of voltage changes due to a change in the load and the decrease in the voltage of the load leads to an increase in the demand for a reactive power that it may cause a further reject in the bus voltage if it is not met by the power system. Eventually, this decline causes a progressive and fast decline to the voltage at that position. This may have an effect of cascading on neighboring areas which may leads to voltage collapse.

In the work of Bhaskar [8], Flexible AC Transmission System controller such as Static Volt Amperes Reactive Compensators and thyristor Controlled Voltage Regulators are applied to stay the voltage within its limits. Static Volt Amperes Reactive Compensator is either provided or extracts the reactive power and the thyristor Controlled Voltage Regulators will inject chains of voltage at the end of load end to avoid the breakdown in voltage. Fine change in reactive power is possibly gained due to the control of thyristors firing angle. Static Volt Amperes Reactive Compensators and thyristor Controlled Voltage Regulators are developed and examined by the test systems of Institute of Electrical and Electronics Engineers (IEEE), and the outputs are given.

Using Simulink technique of MATLAB, both SVC and TCVR are simulated. The two mentioned devices enhance voltage profile, as well as, both of them (SVC and TCVR) are used at the end of the load end to keep the voltage within the specific level.

Static Volt Amperes Reactive Compensator (SVC) is connected with the load and thyristor Controlled Voltage Regulators (TCVR) in parallel gives a series injection. TCVR will act for slight voltage variation, while SVC acts for large voltage variations to increase the voltage level to the required value.

Ramakrishna et. al. [9] demonstrated the applications possibility for the controllers of Flexible Alternating Current Transmission System (FACTS), as the Static Volt Amperes Reactive Compensator through the use of updated technology of power electronic switches in the transmission system area of electric power. Its use was with the voltage and flow of power controlling to improve the voltage regulation. The use of SVC is to control the voltage level at a certain bus with the potential of add extra damping control. This will damp the oscillations effectively in the power system as SSR, and inter-area as well power oscillations. Static VAR Compensators acts to improve the system by controlling the power sources of shunt reactive for inductive and capacitive, with high technology power devices of electronic switches. This study demonstrates the solving of the poor dynamic performance problem as well voltage regulation problems in a transmission system of 115 kV and 230 kV using Static VAR Compensators.

Hoque [10] suggests the design and implementation of a highly accurate and convenient hysteresis and defense of anomaly of Programmable Automatic Voltage Regulator (PAVR). There is a shortage in the accuracy of the current system as well suffer from the oscillating problem between 2 output voltage, which lead to a surge at the output that may harm the electronic devices. To prevent this, there is a need to steadiness the power voltage and decrease the rate of output wave of unchangeable power voltage to the devices during the load changes. This needs to maintain a constant voltage and fast reaction against the prompt change of input voltage and load. The work defines the shortcomings and introduces a new system in the tolerable and substantial stable of $220V_{AC}$ with '4.5% output accuracy for any deviation of input supply voltage within 100-340 V_{AC}. To control the whole system automatically a microcontroller is used with some protection devices were to detect the fault and the circuit implementation in this system are simple and flexible than conventional analog control circuitry. A simulation for both circuit and program has been accomplished for establishing better performance.

The protection against the excessively high and low voltage and current is confirmed and found crucial for the sophisticated electrical and electronic equipment. It is mentionable that the PAVR is very much cheap than other systems because of having a microcontroller in place of discrete electronic components and simple protection units. Therefore, the circuit design and implementation are very much easy, flexible and the efficiency of this system is good enough as well. According to market comparison study, the commercially available AVR has 3-4 stabilization steps of input variable voltage as the output having large value stable within a particular range which is not ultimate design to have accurate output. For the above work [10], the way has been taking over to make the system that obtaining an output which is accurate within input large variation. This is due to the design of the master transformer that has several taps in the side of transformer secondary winding, which maintains slight differences in the turn between the two adjacent taps. PAVR is applied to all electrical and electronics equipment especially in communications and precision instruments of manufactories.

It is clear that, from above design and the comparison with some other common existing AVR systems that the proposed proprietary PAVR in this work performs better than any other existing systems. Because it is mainly programmable that can be programmed as the demand maintaining proper precision and sufficient hysteresis over a wide range of input variation.

The modeling of SSVR in the calculations of flow of load flow for a static voltage reparations and decrease of loss has been introduced [11]. A precise SSVR model used in the calculations of load flow is presented. Phasor diagram method is used to derive, discuss analytically and mathematically the device rating and the direction of the desired injection of reactive power to recover the voltage to the required value (1p.u.). Modeling of Static Series Voltage Regulator in its max classification of injection reactive power is derived due to its changes when reaches to the maximum capacity. The suggested method validity is calculated using 2 systems with standard distribution that consist 33 and 69 nodes respectively. The best position of Static Series Voltage Regulator is determined separately for the problems of loss reduction and under voltage mitigation in the distribution systems. The results of this work present that the capability of SSVR in the compensation of voltage and the reduction of loss is minimized when the rating is limited for its reactive power. The results also show the soundness of the suggested model for SSVR in large distribution systems.

Nwoho [12] study and analyze the improvement of stabilize the voltage using Static Volt Ampere Power Systems Compensator. In this work, Nwoho demonstrated the effects of SVC on the stability of voltage stability of a power system. The Static

Volt Ampere Compensator (SVC) functional structure built with a TCR and its model are presented. The model is setup on act the controller as impedance that varies with the TCR firing angle. A Computer Aided Design /Electromagnetic Transients Power System that includes direct current (PSCAD/EMTDC) is used to do the studied simulations and the results in detail are displayed to access the execution and implementation of Static Volt Ampere Compensator on the stability of system voltage. The simulations carried out in this work assured that SVC could supply quick acting to support the voltage that is necessary to avoid the reduction possibility in voltage as well as collapse in voltage at the bus to which it is connected.

The improvement of power quality using Pulse Width Modulation (PWM) voltage regulator is studied [13]. In this work, stress has been placed to the present scenario of power quality in each grid. By using more of nonlinear electrical loads rather than linear loads, the efficiency increased with reducing the power requirements. This leads to degrades in the quality of power for the whole system. The quality of power is basically calculated by the magnitude of frequency and voltage in the system. To improve the quality of the system, voltage regulators, filters, etc. is used. A PIC16F877A microcontroller voltage regulator is used and presented in this work. It works on the concepts of Pulse Width Modulation voltage regulator which is called a “smart circuit”. The mentioned circuit provides a good automated regulation and without consumes much power. The only major obstacle is the presence of harmonics in the output, therefore any modification or enhancement in the circuit is needed from this point of view.

1.3.3 Arduino Microcontroller and Related Studies

According to Massimo Banzi [14], Arduino is regarded as an open source physical computing program, which is based on a simple I/O board and an evolution environment that carry out the language of processing.

Advancement in science and technology has led to the popularity of digital displays (bill boards) for advertisement and public enlightenment as opposed to manually painted bill boards. One advantage of such digital displays is the flexibility of changing the contents without necessarily removing the board. This is made possible mainly through the use of a microcontroller programmed to control the characters displayed on the screen.

Okomba et. al. [15] discusses the design and prototype implementation of an Arduino microcontroller based Liquid Crystal Display (LCD) system that uses a Light Dependent Resistor (LDR). The Arduino microcontroller is a microprocessor embedded circuit board with an open source software development environment that allows easy development of microcontroller based devices. It allows for the development of micro-controlled systems that can be adapted to particular needs. The Arduino microcontroller was connected (hard-wired) to the pins of an LCD programmed to display a list of names continuously but one at a time. The developed system was tested and found to meet the required specifications. The aim of the work is to provide a keypad programmed to allow manipulation of the characters displayed on the screen. Further hardware can be added to the prototyped circuit such as real time clocks and thermometers thereby permit the Liquid Crystal Display (LCD) to show the present temperature and time. The simplicity of their design and easiness of interface permit to use an LCD screens in several projects on a large and small scale. Finally, this design enables the manipulation of the LCD using the Light Dependent resistor as a tool whose voltage variation depends on the light intensity. The plans are also exploring the use of a bigger LCD with suitable hardware to manipulate and display graphics in addition to the characters.

The use of Arduino for tangible human-computer interaction is studied and analyzed [16]. The Arduino prototyping program has been used in this project. A Femtoduino, an ultra-small Arduino compatible board is also developed.

Varesano work was with electronics, Arduino, Micro-Electro-Mechanical Systems (MEMS) sensors, orientation sensing algorithms, and 3D computer graphics to make a prototype of a tangible user interface named Palla. In this work, some of the theoretical and experimental issues of designing a tangible user interface prototype with the focus on orientation sensing have been discovered. The work gives an extensive knowledge on the Arduino such as provides a preface to electronics area that is useful for the reader. It describes the program of Arduino electronics prototyping and provides an explanation of previous works in using Arduino, both from an electronic and programming point of view. It is also introducing Micro-Electro-Mechanical Systems, gyroscopes, accelerometers, magnetometers and the sensors used. This is in addition to explain the orientation sensing problem from a mathematical point of view; describes Free Internal Measurement Unit (IMU), a 9 degrees of measurement IMU developed during the work. Depict Palla, and introduces Femtoduino, and finally developing an ultra-small Arduino compatible board for usage in size constrained Arduino prototyping.

Panyayong et. al. [17] presents a design and implementation of low cost 6.35 kVA AC-voltage stabilizer using an Arduino-Atmega2560 microcontroller. The power meter integrates circuit (ADE7763) and 8 tabs 6.35 kVA step-up transformer are the cooperative components that operated with microcontroller system. The voltage and current signal are captured by voltage and current sensors then delivered to the microcontroller. After the Arduino microcontroller computed data, the microcontroller generates a control signal to control a power for TRIode for Alternating Currents (TRIACs). The function of power TRIACs is to select proper tap of the transformer that matches the required output voltage. This proposed system has an ability to compute watt-hour units and can calculate usage electrical cost in real time. All electrical data of the system are shown on a 20x4 monochrome LCD character display. The experimental results of this work show that the proposed system can stabilize 40.01% maximum at line input voltage 160.7 Volts of Alternating Current (VAC) and output voltage 225.0 V_{AC}. The proposed system is capable of maintaining the system voltage within the normal operating range between 160-220 V_{AC}. The disadvantage of this proposed system is that it is operated as a step-up voltage only. This problem can be solved by choosing multi-tap step-up/ step-down power transformers. In the future, power transformer circuits may be replacing with a power electronic system in order to reduce weight. In the proposed system, the weight is heavy because it contains an iron-core transformer.

The microcontroller-based embedded system has an important role in web control system application. Most of the modern manufacturing and processing industries need to monitor the environment physical data like temperature, intensity, humidity etc. through a combination of hardware and software. Sundaresan and Durai [18] presents a way to build a low-cost customizable prototype for the web application for server room monitor and appliances control based on Microcontroller and Wiznet W5100 ethernet chip through Arduino ethernet shield. The temperature and intensity data can read through the sensor and monitor through LCD, Mobile or Desktop. Based on temperature, the appliances (like. Cooler, Fan, AC, Bulb) can be controlled from the webpage. More than one appliance at a time can also control and stores the temperature and intensity data in the database. The past data of temperature and intensity after plotting the graph can also analyze. The system can be used in this work for safety purposes to help the employee, people works in industries and home owners. The system also can control by mobile, tab, laptop, desktop etc. with Wi-Fi range. According to this program, more than one equipment and operate specific appliance can have included.

The power meter Arduino, which is wireless based is a noninvasive current household power meter with a MATLAB interface is studied and analyzed [19]. Split core current transformers are used in the current measurements. The data is transmitted through a connection of 802.11b across the wireless router of the home to the base station and interface of MATLAB. The objective of the work is to supply a clear image of a current usage of homes, and estimate the consumption of power from the provided data. The projects also specify which equipment turns on/off through the analysis of new data. The aim of providing such data is to enhance and reduce the use of the power.

The system was consisting of transducers, and its rectifier circuitry, main Arduino board, WiShield add-on board, as well as base computer station. The project software built on Arduino board on the computer base station. Current from the two wires is measured carrying currents to the main power panel, sampled by the Arduino board, which was sent as a UDP packet to the base station computer across Wi-Fi network. The software of the base station is analyzed the packet and transforms the raw of A/D conversion into the present data, where it can be used to show the usage of the current to the user or to assessment the real power for the user display. The latest data rate obtained from project embedded side to the base station is 20 Hz, with 4.75 mA r.m.s current measurement resolution. Small changes in the visible house current are allowed for this resolution during the data test. The data of current measurement gives an approximate error of 4.96% when it is compared with consumer grade Wattmeter during the measurement of a purely resistive load that consumes 180 Watt.

The above project is of a precious practice in test, implementation, design, and system testing that contains several components of software and hardware. Using project of open source for a central section as Internet Protocol pile in the project is assumed at first to be a large consumption in the design time but finished up completely accelerated the wireless part of the embedded system design. Much time is obtainable for the circuit of present measurement, which has the ability to go through different designs before one reach to an acceptable one.

1.4 Thesis Outline

This thesis is outlined as follows:

Chapter 1 offers a general introduction and a background to voltage regulations and the Arduino, which is useful for the reader. Chapter 2 describes the main structure of ACVR4T, transformers, solid-state relays, and Arduino that have been used. Chapter 3 provides a description of the methodology of the multi-tap transformer and the system operation. Chapter 4 demonstrates the experimental work and the difference between the mathematical calculation and experimental work. Chapter 5 gives the conclusions of the thesis and the recommendations for the future work.

CHAPTER TWO

THE MAIN STRUCTURE OF ACVR4T

2.1 Introduction

The advance in the technology of power electronics is highly driven by the consecutive release of power switches gate-controlled [20]. It is started with the Bipolar Junction Transistors (BJTs) power switches, then by MOSFETs and Insulated Gate Bipolar Transistors (IGBTs) ones. These power switches have progressively more applications and power ratings that were predominated formerly by the use of Silicon Controlled Rectifiers (SCRs) and Gate Turnoff Thyristors (GTOs). The new switches availability has likely made it to narrow industrial size of alternating current adjustable speed that drives by an order of magnitude across the last twenty years reducing the kilowatt cost to the half [21].

In this study, we tried to keep-up the evolution of electronics and made a voltage regulator consist of a special transformer that contains a specific number of turns that is calculated based on the mathematical forms. This is in addition to the use of the best types of switches in order to reduce the loss and noise and controlled them by the use of Arduino.

In this chapter, each material and how it works will be explained in detail to make it easier for the reader to understand the principle work for each part in ACVR4T later to understand how ACVR4T works.

2.2 Transformer

The electrical power transformer is a fixed device that transfers the electrical energy from one circuit to the other without any direct electrical connection through the help of mutual induction between two windings. It also transforms the power from one circuit to another without any change in its frequency, probably in different level of voltage [22].

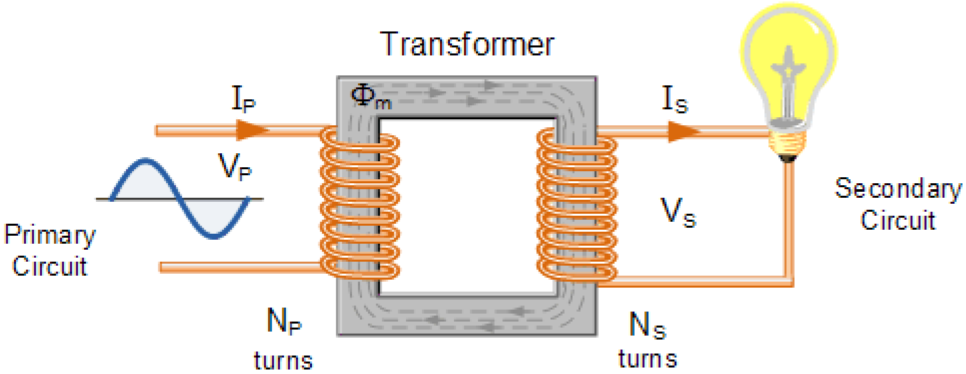

Figure 2.1: Single phase voltage transformer [23]

Since 1830s, transformers represent the major component in electrical and electronic circuits. Although there are new technologies in electronic circuits that have reduced the transformers needs, but it is still essential in several applications [24].

2.3 Types of Transformers

Transformers are classified in several ways, depending on its number of turns and its construction. The types of transformer can be classified based on the following:

1- Numbers of turns
2- Construction
3- Type of service
4- Power utility
5- Winding design

2.3.1 Transformers Based on Number of Turns

Power transformers are constructed based on one of following two types of turns, which are:

1- Step-down Transformer

A step-down transformer has less number of turns on the secondary coil than those for the primary coils. The induced voltage across the secondary coil is smaller than the applied voltage across the primary coil. In other words, the voltage is “stepped-down”.

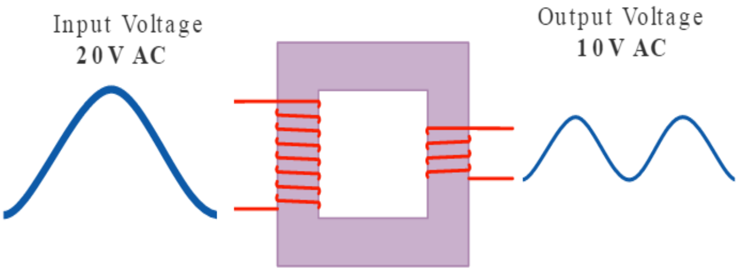

Figure 2.2 : Step-down transformer [25].

2- Step-up Transformer

A step-up transformer has more number of turns on the secondary coil than those for the primary coils. The induced voltage across the secondary coil is higher than the applied voltage across the primary coil. In other words, the voltage is “stepped-up”.

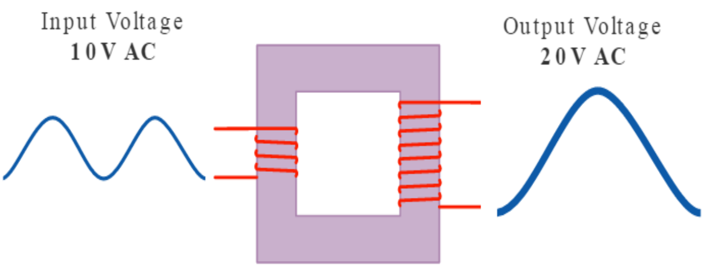

Figure 2.3 : Step-up transformer [25].

2.3.2 Transformers Based on Construction

Power transformers are constructed based on one of following two types of cores, which are [26]:

1- Core Type Transformer

This type of power transformer is built on one of two types of cores. One construction type consists of a simple rectangular laminated piece of steel with the transformer windings wrapped around two sides of the rectangle. This construction type is known as core form (Figure 2.4).

The core type transformer features can be explained as follows: the winding is positioned on two core limbs; only one magnetic flux path; better cooling due to larger surface exposure to atmosphere; and very useful in case of large size low voltage. This is in addition to the following features: less output due to losses; the winding is surrounded the major part of the core; less mechanical protection to the coil; having two limbs; and easy to repair and maintain.

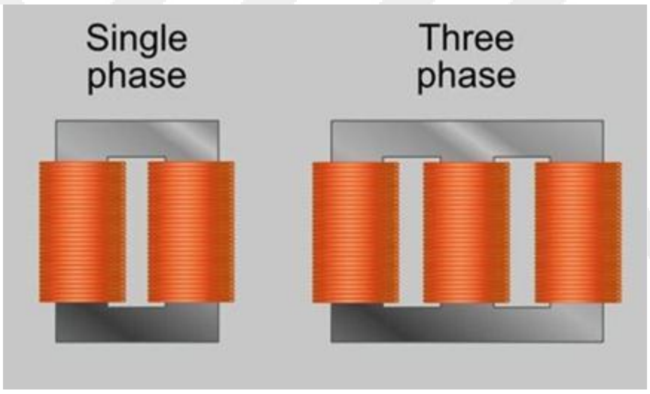

Figure 2.4 : Core type transformer [26].

2- Shell Type Transformer

Shell type transformer is the most common in the applications of Low voltage such as the transformers used in electronic circuits and power electronic converters etc. Typically, the shell from large power transformers use more core electrical steel and are more flexible to short-circuit in the transmission systems and are quite used in industrial applications. The primary and secondary are on one leg which is surrounded by the core with shell-formed transformers (Figure 2.5).

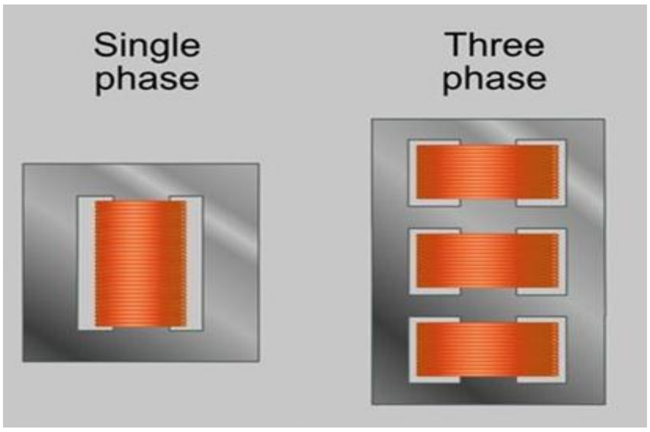

Figure 2.5 : Shell type transformer [26]

2.3.3 Transformers Based on Type of Service

Power transformers are constructed based on one of the two following types of the transformer [27]:

1- Distribution Transformer

The transformer distribution is used for distribution of electric energy at small voltage (lower than 33kV) for the industrial purposes and 440-220 V_{AC} for the domestic purposes. These features of this type of transformers is that it is of a small size, work at low efficiency (50-70%), easy installation, small magnetic losses & it is not always completely loaded.

2- Power Transformer

This type of transformer is used for heavy load transmission, and at a higher voltage (higher than 33kV) and 100% efficiency. Power transformer is also of large size and larger than those for the distribution transformer. It is of high insulation level and generally used in generating station and transmission substation.

2.3.4 Transformers Based on Power Utility

According to the power utility, the power transformers are constructed on one of the two following types [28], which are:

1- Single Phase Transformer

This type of transformer is made to work on a single-phase supply of alternating current and is almost used in low power applications such as residential lighting, heating and air conditioning, etc. It can be connected in parallel or series based on the requirements of the load.

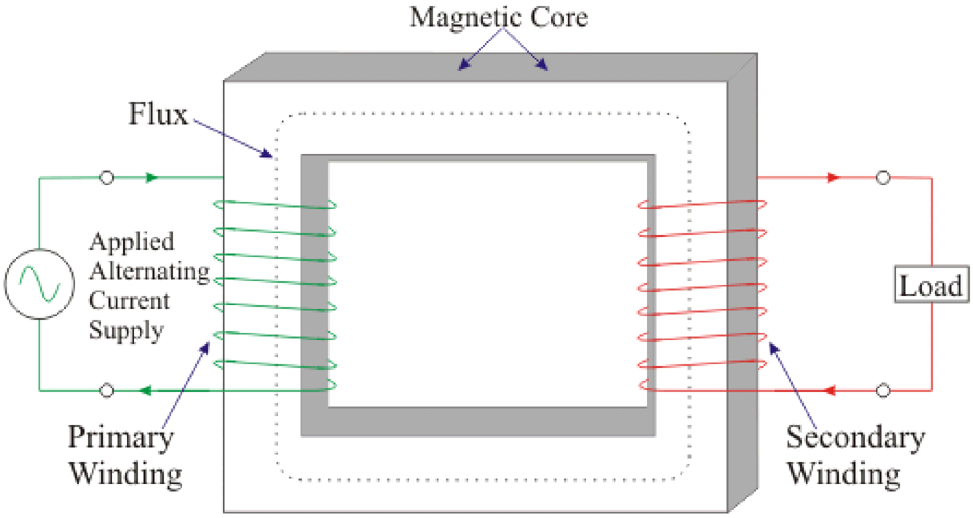

Figure 2.6 : Single phase transformer [29].

A single-phase transformer contains 2 windings on a same iron core. If one of the winding is connected to an alternating current voltage, an alternative magnetic field is set on the iron core. This field coupled with the secondary winding produces an electromotive force in it. As a result, this electromotive force drives the current to pass to the load circuit.

2- Three Phase Transformer

Three-phase transformer is constructed and designed particularly for particular voltages mostly voltages of higher values. It has 3 windings types as it includes primary and secondary windings as for the three phases.

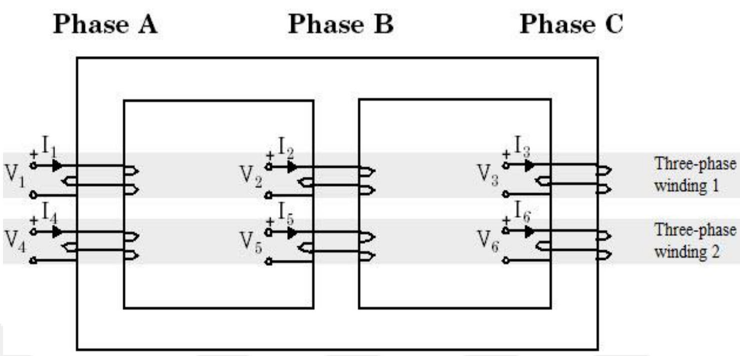

Figure 2.7 : Three-phase transformer [28].

These windings can be connected the form of delta or wye (Star). The primary and secondary windings of transformer can be combined as delta- delta, wye- delta, delta-wye, and wye-wye. This combination depends on its use. For example, in distribution side, delta to star is used in connections transformers.

2.3.5 Transformers Based on Winding Design

According to the winding design, the power transformers are constructed on one of the two following types [28], which are:

1- Isolation Transformer

Isolation Transformer is the transformers with primary and secondary windings (input and output) isolated from each other, and it is recognized as isolation transformers. Input and out power is isolated electrically for this construction, by a dielectric insulation barrier.

This transformer transfers electricity power without frequency from one circuit to another circuit without frequency changes, and it is also consisting of primary and secondary winding. The primary winding is linked with the main circuit and the secondary winding to the desired load circuit. An Isolated transformer can be defined as a transformer of primary and secondary windings that isolated from each other [28].

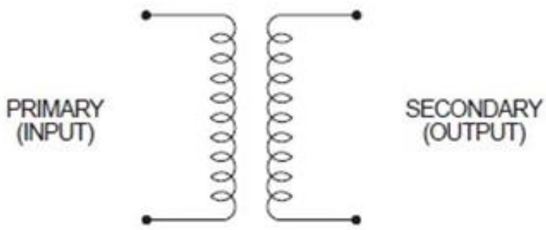

Figure 2.8 : Isolation transformer [28].

2- Auto-Transformer:

The primary and secondary in autotransformer joint the common winding. Always, secondary voltage has a terminal that is combined with the primary. Voltage step up or step down is obtained by a tap from measuring the winding from the common end. Example for that is a 50% of the winding secondary tap will make half of the input voltage.

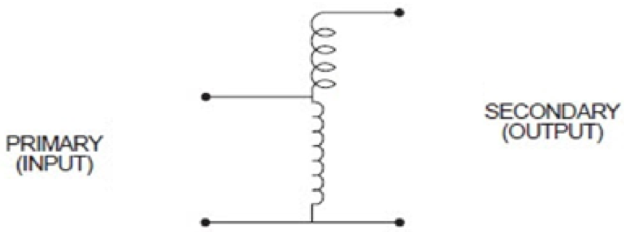

Figure 2.9 : Auto-transformer [28].

An autotransformer contains of only one winding, a works of as a secondary winding is part of it. It is cheaper, lighter as well as smaller than those for the double winding transformer. It also has smaller leakage reactance, higher efficiency, best power quality and fewer needs of copper. So, it’s advantageous comparing with the conventional one is that it does not supply any electrical isolation from the mains to the load as well it is of high prone to faults. Auto transformer is also used in voltage step down or step up by combining the windings in different arrangements.

2.4 Main Parts of Transformer Construction

The three major constructional parts of the transformer are:

1. **Transformer of Primary Winding:** this type of transformer results in a magnetic flux when it is linked with source of electric.
2. **Transformer of Magnetic Core:** the magnetic flux supplied by the primary winding that will move across the small path of reluctance, combined with secondary winding and thus originate a locked magnetic circuit.
3. **Transformer of Secondary Winding:** the flux supplied by primary winding, will move across the core, and then connected with secondary winding. These winding wounds on core itself giving the required transformer output.

2.4.1 Transformer Winding

Winding manufacturing and design practices for distribution transformers of power has concentrate on the differences between coils, layer windings and rectangular core that is generally used in making distribution transformers, disc and helical windings and circular core designs, which is normal in transformation of power.

2.4.2 Transformer Winding Design

The most important requirements of transformer winding are [30]:

1. The winding should be economically efficient in both of initial cost, with a view to the market availability of copper, and the transformer in service efficiency.
2. The conditions of heating the windings should meet standard requirements, since the exit from these requirements towards permitting higher temperature that will completely and drastically minimize the transformer service life.
3. The winding should be mechanically steady comparing to the forces appearing due to occurring of the sudden short circuit of the transformer.
4. The winding should have the prerequisite electrical strength comparing to high voltages.

2.5 Principle Work of Transformers

A transformer is equipment that transforms the electrical energy from one circuit to another across inductive coupled conductors, and the transformer's coils regarded, and it is regards as a power converter. Current changes in the primary winding originate a magnetic flux that is varying in the core of transformer and thus changing the magnetic field across the *secondary* winding. The magnetic field variation stimulates a varying Electromotive Force (EMF), or voltage, in secondary winding. This influence is named as the inductive coupling.

When the load is linked with the secondary winding, a current will flow in this winding and there will be a transfer of electrical energy from the primary circuit to the load through the transformer. The secondary winding induced voltage (*V*s) is related to the primary voltage (*V*p) in the ideal transformer and can be given by the number of turns ratio in the secondary (*N*s) to the number of turns in the primary (*N*p) [31].

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \tag{2.1}$$

By choosing a proper ratio of turns, the transformer can alternate the current voltage to be step-up by making *N*s higher than *N*p, or step-down by making *N*s lower than *N*p. The windings are the coils wound around a ferromagnetic core, air-core transformers being a notable exception.

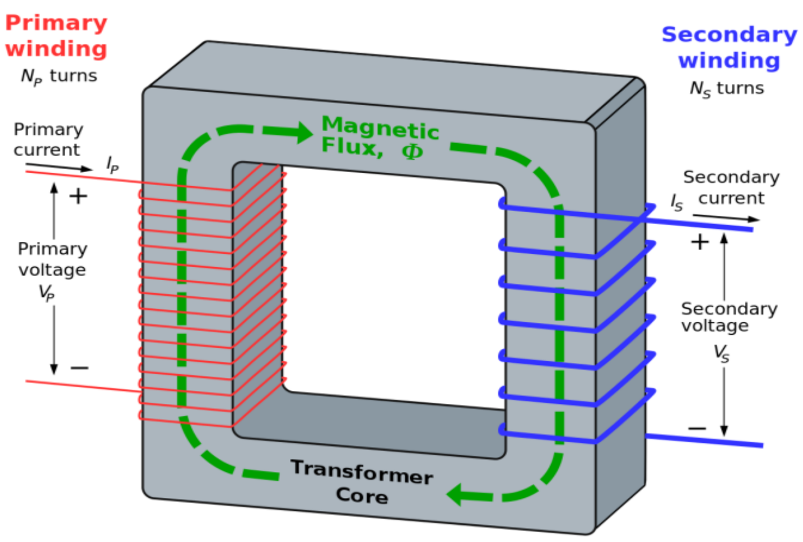

Figure 2.10 : Transformer inductive coupling showing the varying of current in the primary winding and the varying of the magnetic field through the secondary winding [31].

The induced voltage through the secondary coil can be calculated from Faraday's induction law, as follows:

$$V_s = N_s \frac{d\emptyset}{dt} \tag{2.2}$$

Where Vs is the secondary winding induced voltage, Ns is the number of turns in the secondary coil, and Φ is the magnetic flux through the coil of one turn.

If the coil turns are positioned perpendicularly to the magnetic field lines, the flux is the output of density of magnetic flux B as well the area A through which it cuts. The area is fixed, being equal to transformer core cross sectional, whereas the magnetic field change with time according to the primary excitation. Since the same magnetic flux flow across the primary and secondary coils in an ideal transformer, the immediate voltage through the primary winding can be written as.

$$V_p = N_p \frac{d\emptyset}{dt} \tag{2.3}$$

Taking the ratio of equations (2.2) and (2.3) for V_s and V_p gives the base equation of step up or step down the voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \tag{2.4}$$

Np/Ns is recognizing as the turns ratio and is the functional features of primary for any transformer.

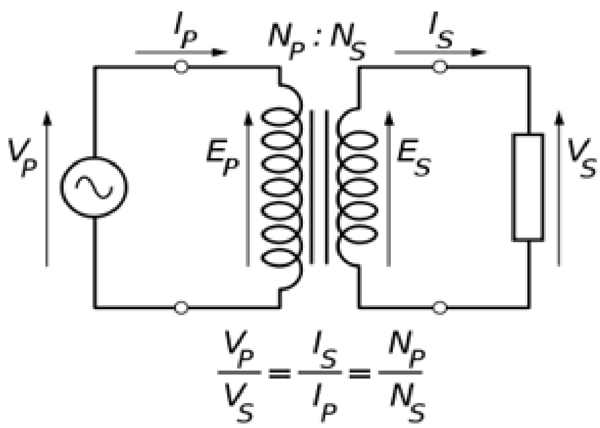

Figure 2.11 : Transformer primary functional characteristic showing the turn's ratio Np/Ns [31].

During the passes of electrical current across a long, hollow coil of wire we have a strong magnetic field inside the coil and a weak field at the outside. The magnetic field line pattern moves across the coil spread out from the end, and then goes around the outside at the other end.

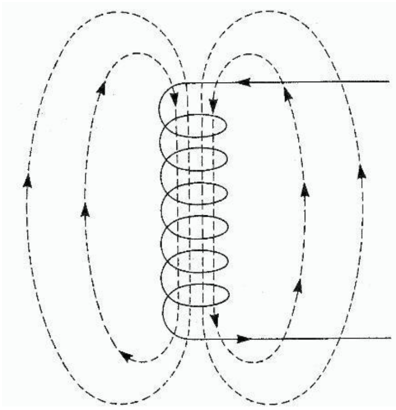

Figure 2.12 : Pattern of the magnetic field when an electric current move across the long, coil of wire.

These ones you draw with a pencil are not real links. They are the lines that we consider it similar to those in the sketch, to show magnetic field pattern: It is not real lines such as those you draw with a pencil. It is the lines that we believe, as in the sketch, to illustrate the pattern of magnetic field. It is the direction that a sample of iron is magnetized by the field. For a strongest field, the lines are mostly closely and crowded. For hollow coil, the lines form complete rings. In case of iron core in the coil, it becomes magnetized and makes the field much stronger in the 'on" current.

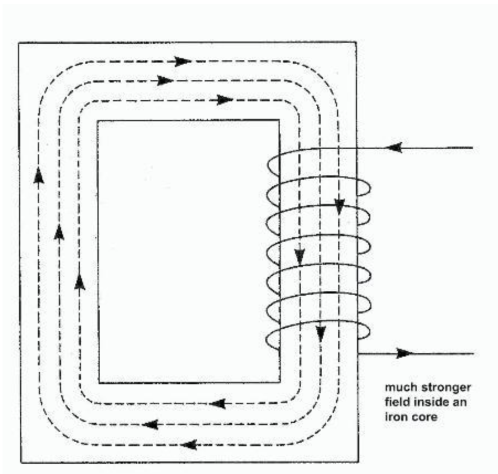

Figure 2.13 : Pattern of the magnetic field for passing the electric current across a hollow coil of wire.

The transformer iron core is generally a complete ring with 2 coils wound on it. One of them joint to a source of electrical power and is named the primary coil and the other provides the power to the load and named as the secondary coil. The current magnetization in the primary coil moves round whole way the ring. Both of secondary and primary coils can be anywhere wound on the ring due to the carry of iron to the magnetization changes from one coil to other. There is no electrical connection between the two coils; however, they are connected by the magnetic field in the iron core.

There will be no effect in secondary in case of steady current in the primary, but if the primary current is changed so there will be a secondary effect one. Changing of current in the primary one

Current variations in the primary stimulate an Electromotive Force in the secondary one. There will be a current flow when secondary is linked to the circuit.

The iron core is a crude secondary itself and the primary current variations stimulate small circular voltages inside core. The stimulated voltage would drive the wasteful secondary currents in it if conductor iron core is solid. That is the core is manufacture of very fine sheets clamped with each other's, with facing to each coated sheet to make it a poor conductor. The sheets rims can be visible by visualize at rims of transformer core.

2.6 Multi Tapped Transformer

Transformers may contain several taps to maximize or minimize the voltage. Each tap either add or deduct windings to the transformer. A mutual transformer has 2 windings, which are the primary and the secondary one. These are usually electrically-isolated from each other, with secondary voltage stimulated across mutual induction.

A multiple winding transformer can also be defined as the transformer which has more than one primary or secondary windings connected with each other in a specific arrangement to supply the needed levels of output voltage or to drive a number of loads at the output. This can be indicated as a one transformer special characteristic, as transformers are fully many-sided devices and normally several advanced operations needs to be completed with it instead of driving just one output from a single primary coil.

A Multi-Tap Transformer is either a step-up or step-down transformer that has several taps on either primary or secondary winding. A Multi-Tap Transformer gives a reliability in the requirements of your input and output voltage.

Multi-Tap Transformers are used in the element applications heating. The heating elements resistance increases with age which results in minimizing the current across the heating element. To retrieve back the current of heating element current to its original value, the applied voltage to this heating element must be enlarged. Multi-tap transformer combinations supply an additional tap to recover the change.

Multi-tap transformers can also use in retrieve the changes of input power voltages to a customer facility. Input power to the equipment changes as a result of load conditions as well as the vicinity of the usefulness power to the customer facility and many other causes. This leads to an input voltage mismatched with a customer facility. The wiring arrangement of multi-tap transformer can be able to supply with necessary taps to recover the input voltages changes.

2.6.1 Principle Work of Multi Tap Transformer

There is no difference between the master operation of a multiple winding transformer and the ordinary one. The calculations of currents, turns ratio, primary and secondary voltages showed similar results. The only point needs to pay much awareness to the polarities of voltage for each winding coil, and the dot convention that marks winding polarities whether it is positive or negative when connect them together.

A multi coil transformer or multi winding transformer are other names of multiple winding transformers. All of them consist of additional of one primary or secondary coil on a common laminating core. Multi winding, and multi-phase transformer maybe a single or three phase transformers, and its operation is same.

One of these transformers is used to provide different small levels of voltage for various electronic circuit components.

An ideal use of different winding transformers is in the power supplies and triac switching converters, thus a transformer can have several secondary windings and each of it is electrically isolated from each other’s and looks as it is just isolated electrically from the primary. After that the secondary coils yields a voltage that is related to its coil turns number [32].

2.6.2 Advantages of Multi-Tap Transformer

A multi-tap transformer is a voltage regulator designed to keep fixed level of voltage. It can be mainly used to adjust one or more direct or alternating current depending on its design. The most important multi tap transformer advantages are:

1- It helps to obtain a constant voltage in case of the change voltage source where the transformer output voltage changed. The voltage output is already designed for the ordinary transformers.
2- It helps to have different voltage levels where we can have more than 2 outputs within different voltage levels. But only one output can get from the ordinary transformer.

2.7 Solid-State Relay (SSR)

SSR is electronic circuit that consist a circuit with signal level trigger connected to a semiconductor power switch, either as a transistor or a thyristor. These products are tested and packed in factory instead of some circuits on a circuit board. Figure 2.14 shows a solid-state relay block diagram that can switch alternating currents. It has three functional sections:

1. An optocoupler that contains light emit diode and a photo-transistor
2. A zero voltage detector or trigger circuit
3. A solid-state load that switch the device, which is either transistor or thyristor.

In the block diagram, a triac serves as the load switching device. A solid-state rely is differs from an electromechanical (EM) relay in its structure and operation, but both of them supply power gain.

The six advantages that solid-state relays offer over electromechanical relays are:

1. Higher accuracy and longer life.
2. Better matching with circuit logic level.

3. Large speed switching.

4. Higher resist to shocking and vibration.

5. No contacts that can defection or gabble to delay the response time.

6. No bent from contact opening that can produce EMI or pose fire or hazard explosion.

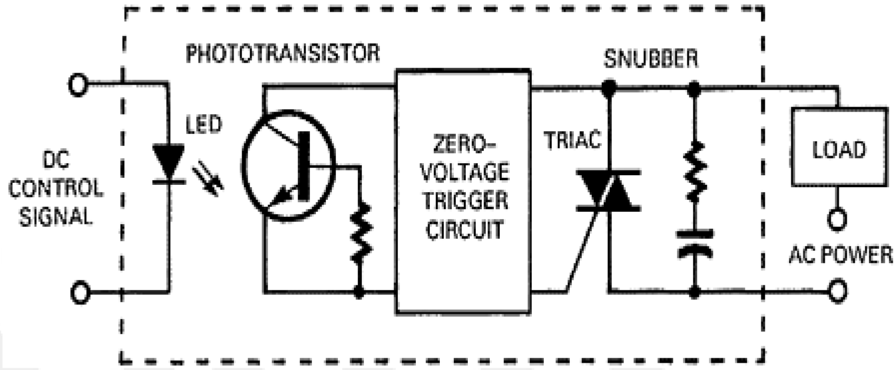

Figure 2.14 : Solid-State Relay (SSR).

The drawbacks to solid-state relays are their large cost than electromagnetic relays with similar ratings and the need that power is provided to them.

Solid-state relays are suitable for AC switching needs either to reverse parallel back to back SCRs or electrically equal triac (Figure 2.14). However, power bipolar or MOSFET transistors can switch direct current.

The classification of solid-state relays is based on its input circuit or way of getting I/O isolation. True solid-state relays attain electrical isolation between its input and output circuits with optocouplers, but hybrid solid-state relay using reed relays or transformers.

2.7.1 Optocoupled Alternating Current Solid-State Relays

An optocoupled alternating current solid-state relays is a solid-state relay that consists of optocoupler. It can be controlled by alternating or direct current input signals that are applied to its terminals. An Infrared Emitting Diode (IRED) conducts, convey the optical signal to a correspondent photo detector that provides the input/output isolation. The photo detector can be a photodiode, phototransistor, or photocell. The output of the signal from the photo detector excites the device output to switch the load current.

2.7.2 Reed-Relay Coupled AC SSRs

A reed-relay coupled alternating current solid-state relays AC SSR is a hybrid SSR that proposed most of the true solid-state relays advantages except those for I/O isolation, which is get from a reed-switch capsule. The signal of input control is applied to the coil that includes reed switch and induced magnetic field through the reed contacts. This actuates the circuitry that triggers the solid-state device to switch the load current.

2.7.3 Transformer Coupled AC SSRs

A transformer-coupled alternating current solid-state relays AC SSR is a hybrid SSR that proposed most of the true solid-state relays advantages except those for I/O isolation, which is get from a transformer. The signal of input control is used for primary winding of a small transformer, as well as, to the output from the secondary winding actuates the circuit that triggers the solid-state device to switch the load current.

2.8 Power Solid-State Relays

An alternating current power SSR is capable of treating higher currents than the typical ones. These solid-state relays have the same arrangement. The load is normally switched by two back to back controlled silicon rectifiers or a triac rated for 2 to 75 A.

Zero voltage trigger circuit confirms that the silicon controlled rectifiers or triac will only be triggered when alternating current voltage passes the zero reference in either negative or positive direction. This decreases the impact of surge currents when switching to load. High currents can get from the tungsten filament shining lamp and capacitive loads switching. The tungsten lamp cold resistance is smaller than ten percent of its illuminated resistance. If the solid-state relay is turned at the voltage value not at zero crossing, the larger immediate load current drawn by the lamp load may damage the solid-state relay.

Once the silicon controlled rectifiers or a triac triggered, it will not end the conducting till its load current reaches to zero. A snubber bypass voltage transients is a capacitor and resistor in series and it is usually happened with inductive loads when the voltage and current are out of phase. Most of factory made general purposes alternating current solid-state relays have triacs rated to 10 A at 120 to 240 V, but dual silicon controlled rectifiers are able of switching the alternating current power loads higher than 40 kW.

The major technical considerations in the specifications of alternating current solid-state relays are:

1. Voltage isolation
2. Range of operating temperature
3. Range of Control signal
4. Release and must-operate voltages
5. Input current

Approved factory-made power solid-state relays hold the labels showing a UL confession and the approval of Canadian Standards Association CSA.

2.8.1 Direct Current Solid-State Relays

A direct current solid-state relay is an optically coupled device that usually has a MOSFET power as an output switch. Some direct current solid-state relays contain optoisolators that consist of an IRED matched to a photovoltaic cell array. The array voltage turns on a MOSFET bi-directional output switch, allowing it to control the alternating and direct currents of either polarity. DC SSRs can be obtained in a wide range of package styles, through the DIPs and SIPs, but there is no standardization package. Some low-power direct current solid-state relays have replaced reed relays for analog communications switching [33].

2.9 Arduino

Arduino is an open source program that is used in constructing the electronics projects. Arduino contains a microcontroller which is physical programmable circuit board, software, and IDE that works on the computer. It is used to write and upload the code of the computer to the physical board. The computer hardware contains a board that is open source hardware designed around 8bit Atmel automatic voltage regulator microcontroller or a 32-bit Atmel ARM. The on-board microcontroller chip preprogrammed is a boot loader that permits the programs uploading programs to the microcontroller memory without needs to a chip programmer.

The Arduino program has become quite common even for those who are just beginning with electronics, and for good reason. Unlike most prior programmed circuit boards, the Arduino didn’t need a hardware piece to load new code onto the board, and you can easily use a USB cable. This is in addition that Arduino integrated development environment uses a simplified C++ version, which is easy to learn to program. Lastly, Arduino gives a standard form factor that breaks out the microcontroller functions into a more accessible package [34].

2.9.1 Types of Arduino Boards

The types of Arduino boards are:

1. Arduino Uno (R3)
2. Lily Pad Arduino Board.
3. RedBoard Arduino Board.
4. Arduino Mega (R3) Board.
5. Arduino Leonardo Board.
6. Arduino Shields.

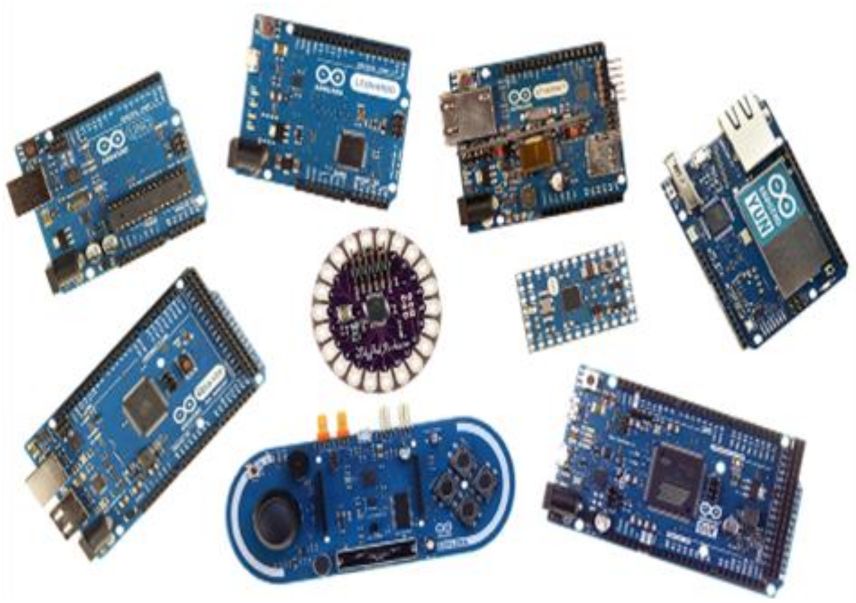

Figure 2.15 : Types of Arduino Boards

2.9.2 Arduino UNO

The Arduino Uno is a microcontroller board that is based on the ATmega328 (Figure 2.16). It contains 14 digital I/O pins, 6 of them can be used as outputs of pulse width modulation. This is in addition to 6 analog inputs, 16 MHz crystal oscillator, ICSP header, power jack, USB connection, and a reset button. Arduino Uno consists all what is needs to aid the microcontroller; merely connect it with a USB computer cable or power it with AC to DC adapter or battery to start with.

The Arduino Uno is different from any other previous boards; it didn’t use the FTDI USB to serial driver chip. It lineaments Atmega8U2 programmed as a USB to serial converter [35].

In Italian "Uno" is called so to point the release of upcoming of Arduino 1.0. Version 1 and Uno is regarded as an indication of Arduino for moving ahead. The latest in the chain of a USB Arduino boards is the Uno, and it is reference model for its program when compared with old versions.

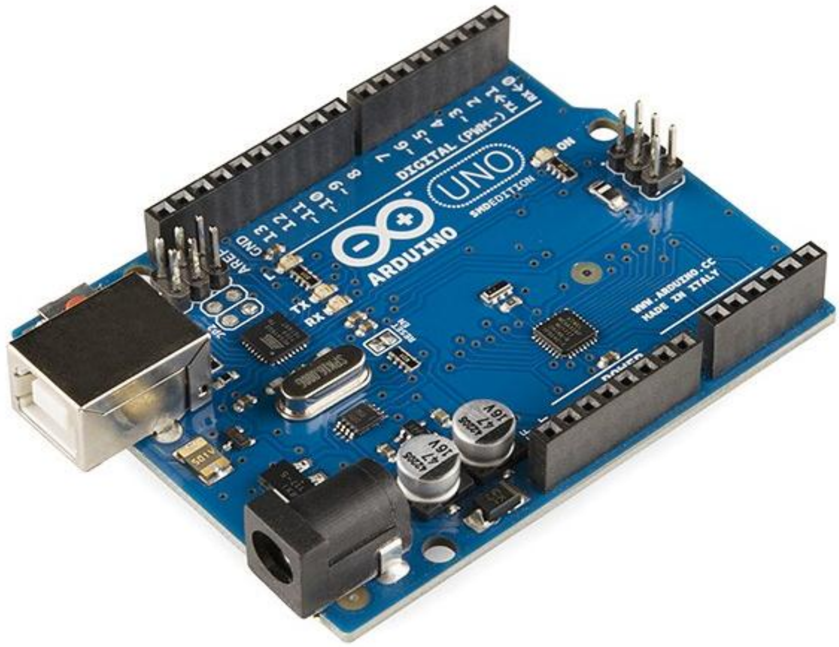

Figure 2.16 : Arduino Uno [36].

The Arduino Uno can be used and work through the connection of USB or with using of external power supply. The source of power is automatically chosen. The external non-USB power can come from AC to DC adapter or from battery. The adapter is plugging with 2.1mm center-positive plug to the jack power board. A battery leads can be inserted in the pin headers of ground (GND) and Vin of power connector. The board can work on outer provide of 6 - 20 V. If the supply is lower than 7V, the 5V pin may provide less than 5 volts then the board may be unstable. The voltage regulator heats up if using larger than 12V and this may lead to the board damage. The best recommended range is between 7 - 12 V [35, 37].

The power pins are as follows:

1. $\boldsymbol{V_{IN}}$ is the input voltage of Arduino board when using external power source as reluctant to five volts from the USB connection or any adjustable power source. Voltage is provided as well across this pin, or, if voltage is providing through the power jack, access it across this pin.
2. **5V** is the regulated power supply used to provide the microcontroller and other parts on the board with the power. This come from either a VIN across on-board regulator, or provided by a USB or other regulated supplying 5V.
3. **3V3** is a supply of 3.3 V that produced by on board regulator. The draw of maximum current is 50 mA.

4. **GND** Ground pins.

The Arduino Uno has a poly fuse reset that maintains the USB ports for computers safe from the short and over current. All computers have its own protection but the fuse provide more protective layer. For example, applying higher than 500 mA to USB port will automatically break the connection by the fuse till removing the short or overload.

2.10 How to Use the Arduino

Arduino can sense the environment at conditions by receiving the input from different sensors and influence on its surrounding by controlling lights, motors, and other actuators. Arduino programming based on wiring and its development environment is used in programming the microcontroller board. Arduino projects have different uses, it can be stand alone or connect it with software working on a computer, for example Flash or Processing [35].

CHAPTER THREE

THE DETAILED DESIGN OF ACVR4T

3.1 Overview

This study has been done to obtain a voltage with specific range (212-228) V_{AC} by using tapped-transformer of four taps, solid-state relay and Arduino controller to control the selected tap. The ACVR4T is designed to avoid the varying voltage problem which is distributed to the consumers from the grid. This can be done by installing the system at the consumer point and as a result this system will act as a protection to the electrical instruments and will limit the voltage delivered to the electrical devices. In this work, the transformer has been analyzed and designed according to the previous studies that have been discussed earlier in chapter two. Solid-State Relay (SSR) has been used instead the mechanical relay which has a high current and delay in switching time while the SSR has a higher response and less current. Controlling the switching is also done by using Arduino microcontroller.

The explanation of the detailed design is given in the following sections and photographic views of ACVR4T are given in the appendix.

3.2 Block Diagram

The block diagram in Figure 3.1 illustrates the general idea and design of the system.

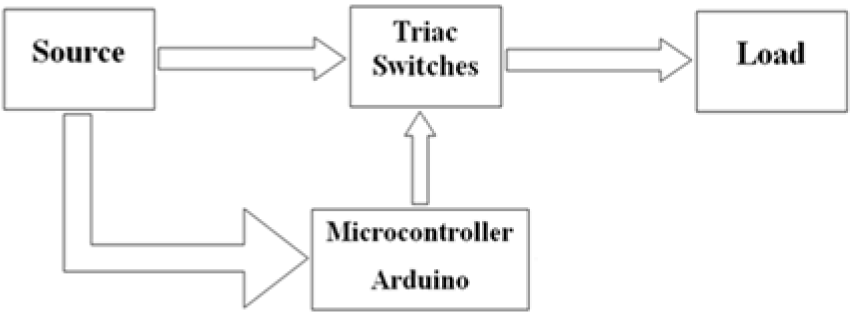

Figure 3.1 : System design block diagram

The ACVR4T has been tested in the laboratory to check that the output voltage within the range that the system work with (182-242) V_{AC}. There are five SSRs, the first one is connected directly to the source and controlled by the Arduino. If the voltage source is under or over the operating range the switch will be in open state to prevent supplying voltage out of the range. The other four SSRs are connected to the tapped transformer and controlled by the Arduino, which will specify which switch will be on closed state according to the source voltage and the required output voltage. There is no any possibility of having two switches in closed state.

3.3 System Operation

Figure 3.2 shows the power side of the system. The voltage supplier is connected to the system through a miniature circuit breaker which is used as a switch to protect the system from high currents.

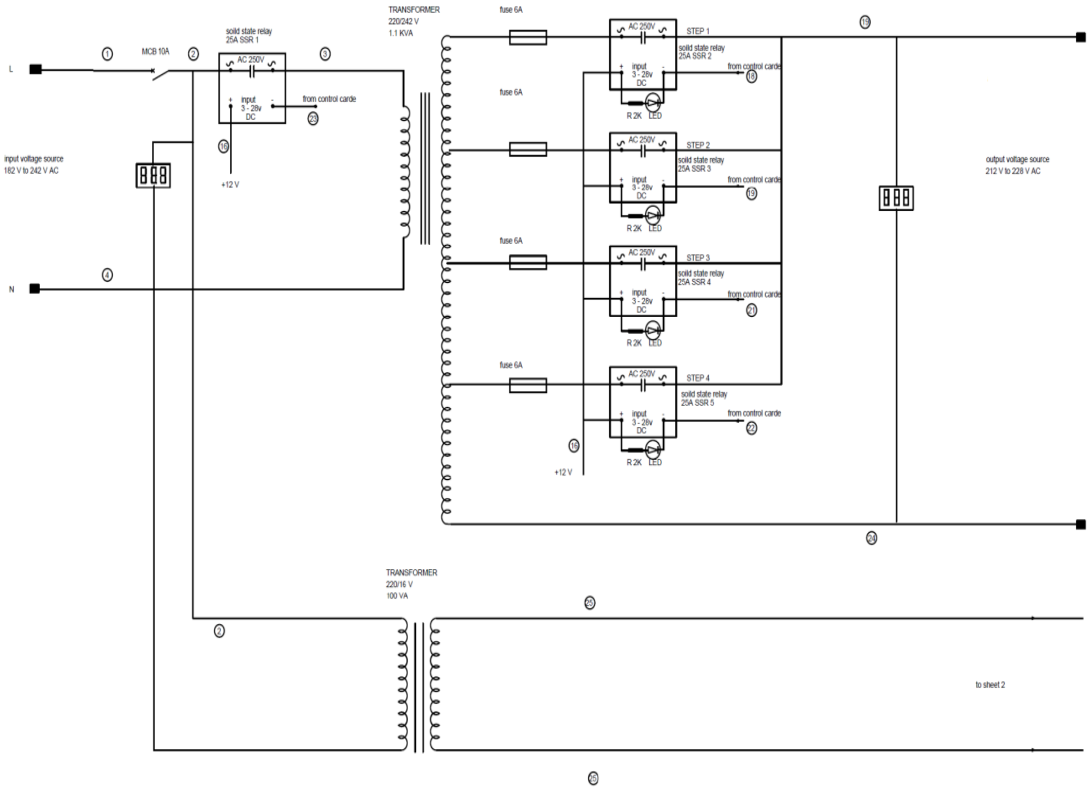

Figure 3.2 : System power side.

After the MCB, the line wire is connected to a SSR which supply the tapped transformer and connected to a step-down transformer supplies the controlling circuit. The SSR input is connected to the 12V output of the rectifier and the other terminal is connected to the ground through a transistor which is controlled by the Arduino. This SSR is used to protect the system from the voltages under (182$V_{\mathbf{AC}}$) and over (242$V_{\mathbf{AC}}$). The step-down transformer transforms the voltage with a transformation ratio of 220/16 V is connected to electronic circuit that regulates the voltage from 16V to 12V. Also, we used a bridge rectifier and capacitor to obtain a smooth DC voltage. A diode is used as shown in figure 3.3 to prevent backward currents.

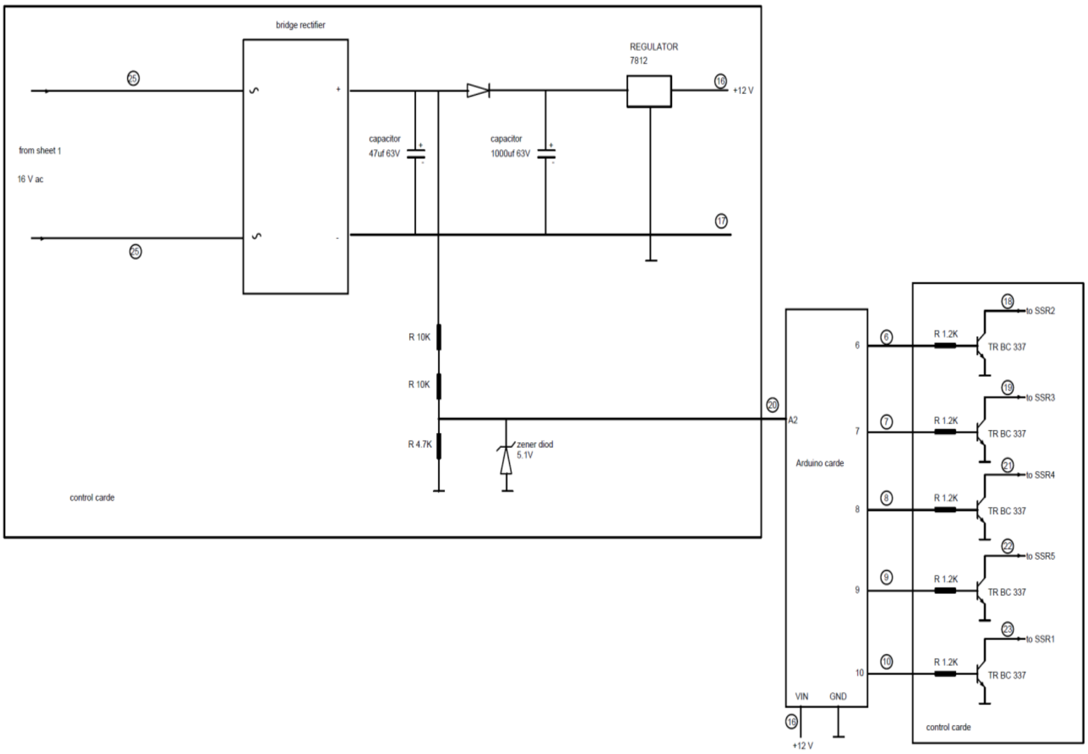

Figure 3.3 : System control side.

Regulator model 7812 is used to regulate and ensure that the supplied voltage to the Arduino is 12 V. A voltage divider circuit is linked to the rectified voltage and the circuit output is linked to a zener diode for voltage protection and to the pin A2 of the Arduino to measure the voltage source using a built-in analog to digital converter feature in the Arduino.

The measured voltage of the source is then compared with the multi statements to check if it's within the operation voltage range. If the voltage is within the range, the Arduino will generate a signal to turn on a transistor that connects the first SSR ground pin to the ground of the circuit. Following that, the trigger circuit of the SSR will trig the SSR to be in the close state. The Arduino will check which statement fits the required voltage for the input and generate a signal to trig the transistor that is connected to the SSR which is connected to the responsible tap of the transformer. If the input voltage varied, there is a need to change the selected tap transformer. The Arduino will read the input voltage and change the selected tap with a permeability of 1 V_{AC} when the input voltage goes under the specified lower limit of the range for a specific tap, and 500 ms of delay upon changing from tap to another.

3.3.1 Voltage Divider Calculations

The input voltage which read by the Arduino is calculated according to the tap as follows:

At V=182V_{AC}

Secondary voltage for control transformer 220/16 V

$\frac{220}{16}=\frac{182}{V2} \rightarrow V2 = \frac{182x16}{220}$

$V2 = 13.23V$

The DC voltage after bridge rectifier = $A_{A.C}$ x 1.414 Where: 1.414 = $\sqrt{2}$

DC voltage = 13.23 x 1.414 = 18.71 V

$V_{DIVIDER}$= A2 = 18.71 x $\frac{4.7}{4.7+10+10}$ = 3.56V

At V=197V_{AC}

Secondary voltage for control transformer 220/16 V

$\frac{220}{16}=\frac{197}{V2} \rightarrow V2 = \frac{197x16}{220}$

$V2 = 14.32\,V$

The DC voltage after bridge rectifier = $A_{A.C}$ x 1.414

DC voltage = 14.32 x 1.414 = 20.25V

$V_{DIVIDER}$= A2 = 20.25 x $\frac{4.7}{4.7+10+10}$ = 3.85V

At V=212V_{AC}

Secondary voltage for control transformer 220/16 V

$\frac{220}{16}=\frac{212}{V2} \rightarrow V2 = \frac{212x16}{220}$

$V2 = 15.41V$

The DC voltage after bridge rectifier = $A_{A.C}$x 1.414

DC voltage = 15.41 x 1.414 = 21.79V

$V_{DIVIDER}$= A2 = 21.79 x $\frac{4.7}{4.7+10+10}$ = 4.14V

At V=227V_{AC}

Secondary voltage for control transformer 220/16 V

$\frac{220}{16}$=$\frac{227}{V2}$ $\rightarrow V2 = \frac{227x16}{220}$

$V2 = 16.5V$

The DC voltage after bridge rectifier = $A_{A.C}$ x 1.414

DC voltage = 16.5 x 1.4 = 23.33V

$V_{DIVIDER}$= A2 = 23.33 x $\frac{4.7}{4.7+10+10}$ = 4.44V

At V=242V_{AC}

Secondary voltage for control transformer 220/16 V

$\frac{220}{16}$=$\frac{242}{V2}$ $\rightarrow V2 = \frac{242x16}{220}$

$V2 = 17.6V$

The DC voltage after bridge rectifier =$A_{A.C}$ x 1.414

DC voltage = 17.6 x 1.414 = 24.89V

$V_{DIVIDER}$= A2 = 24.89 x $\frac{4.7}{4.7+10+10}$ = 4.73V

3.4 Operation State

3.4.1 Under Voltage State

For source voltage, less than 182V_{AC}, the SSR that responsible and connected to the source voltage will be open and no power flow to the transformer.

3.4.2 Over Voltage State

For source voltage, greater than 242V_{AC}, the SSR that responsible and connected to the source voltage will be open and no power flow to the transformer.

3.4.3 Normal Operation State

If the source voltage is within the operation range (182-242) V_{AC} the SSR that connected to the source voltage will be closed and a comparison loop will be made inside the Arduino to decide which SSR that connected to the proper tap of the tapped transformer by comparing the source voltage with different clauses and if the statement fits the requirements the Arduino will generate signal to the transistor and close the SSR that is should be closed.

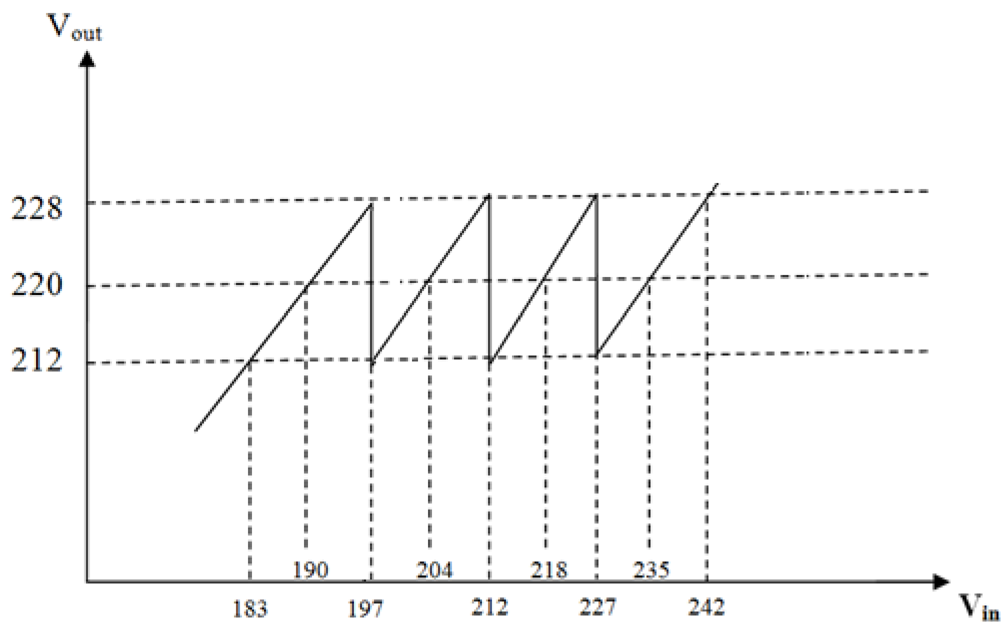

Figure 3.4 : Output voltage range.

3.5 Mathematical Calculations

3.5.1 Transformer Components Calculations

$$\frac{N_2}{N_1} = \frac{V_2}{V_1} \tag{3.1}$$

Transformer Ratio

$$\frac{V_o}{V_i} = \frac{V_2}{V_1} \tag{3.2}$$

But the Power = VI

Power = 220 x 5 = 1100 VA

$$Wire\ Diameter = \sqrt{IK} \tag{3.3}$$

Where K= 0.56 (Copper Constant)

$$Wire\ Diameter = \sqrt{0.5\ x\ 0.56} = 1.25\ mm$$

$$\boldsymbol{E}r.m.s. = 4.44\ fN\emptyset_{max} \tag{3.4}$$

And

$$\emptyset_{max} = BA \tag{3.5}$$

Where *B* is the magnetic flux density

From equations 3.4 and 3.5 above

$$\boldsymbol{E}r.m.s. = 4.44\ fNBA \tag{3.6}$$

From equation 3.6, N can be written as:

$$N = \frac{\boldsymbol{E}r.m.s.}{4.44\ fBA} \tag{3.7}$$

Where **Magnetic Flux Density** equal**:**

If Power Transformer < 1 kW =1

If Power Transformer from 1-5 kW =1.05

If Power Transformer from 3-5 kW =1.1

If Power Transformer > 5 kW =2

$$N = \frac{1}{4.44\ x\ 50\ x\ 1.05\ x\ A} \tag{3.8}$$

In the case study of this work, A equal to 48 cm^2

To find the actual area used for the coil, A = 48 x 0.9 = 43.2 cm^2 and equation 3.9 can be written as follows:

$$N = \frac{1}{4.44\ x\ 50\ x\ 1.05\ x\ 43.2\ x\ 10^{-4}} = 0.993\,\frac{Turn}{V} \tag{3.9}$$

The above value can be approximated to 1 turn/V

Note that $N_{primary}$ = 242 Turn

$N_{secondary}$ = 228 Turn $(Tap\ 4)$

$$N_{secondary}\ (Tap\ 3) = \frac{212}{242} = 0.876$$

The difference between Tap 4 and Tap 3 = 227-212 = 15$V_{\mathbf{AC}}$

$$N\ Tap(3) = \frac{15}{0.876} = 17.123$$

Which can be approximated to 17 Turn

$$N_{secondary}\ (Tap\ 2) = \frac{197}{242} = 0.814$$

The difference in voltage between Tap (3) and Tap (2) = 212-197 = 15$V_{\mathbf{AC}}$

$$N\ Tap(2) = \frac{15}{0.814} = 18.428$$

Which can be approximated to 18 Turn

$$N_{secondary}\ (Tap\ 1) = \frac{182}{242} = 0.752$$

The difference in voltage between Tap (2) and Tap (1) = 197-182 = 15$V_{\mathbf{AC}}$

$$N\ Tap(1) = \frac{15}{0.752} = 19.946$$

Which can be approximated to 20 Turn

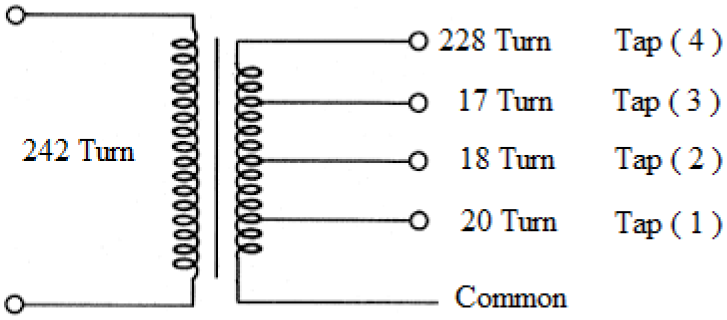

Figure 3.5 : Number of turns for each tap.

3.5.2 Output Voltage Calculations

Case Input Voltage (182-196) V_{AC}

The ratio for Tap (1) = $\frac{228+17+18+20}{242}$ = 1.16

Where V_{in} is the range voltage for tap (1) 182 → 196 V_{AC}

$$V_{oAC} = 1.16xV_{in}$$

Case Input Voltage (197-211) V_{AC}

The ratio for Tap (2) = $\frac{228+17+18}{242}$ = 1.08

Where V_{in} is the range voltage for tap (2) 197 → 211 V_{AC}

$$V_{oAC} = 1.08xV_{in}$$

Case Input Voltage (212-226) V_{AC}

The ratio for Tap (3) = $\frac{228+17}{242}$ = 1.01

Where V_{in} is the range voltage for tap (3) 212 → 226 V_{AC}

$$V_{oAC} = 1.01xV_{in}$$

Case Input Voltage (227-242) $V_{\mathbf{AC}}$

The ratio for Tap (4) = $\frac{228}{242}$ = 0.94

Where V_{in} is the range voltage for tap (4) 227 → 242 $V_{\mathbf{AC}}$

$$V_{o\mathbf{AC}} = 0.94xV_{in}$$

3.6 Test the Experimental Work

We have tested the project using two variable resistors to achieve different cases.

Case I: In this case, a variable resistor has been connected in parallel with the output terminal of the transformer. We noticed the transformer was working in correct operation.

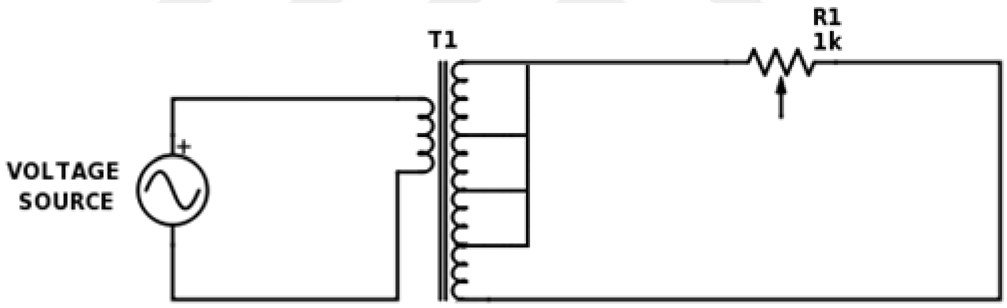

Figure 3.6 : Case I circuit.

Case II: In this case, one variable resistor has been connected in series with the source to get a variable input voltage to check the transforming ratio for each tap, and another resistor has been connected in parallel with the output terminal of the transformer.

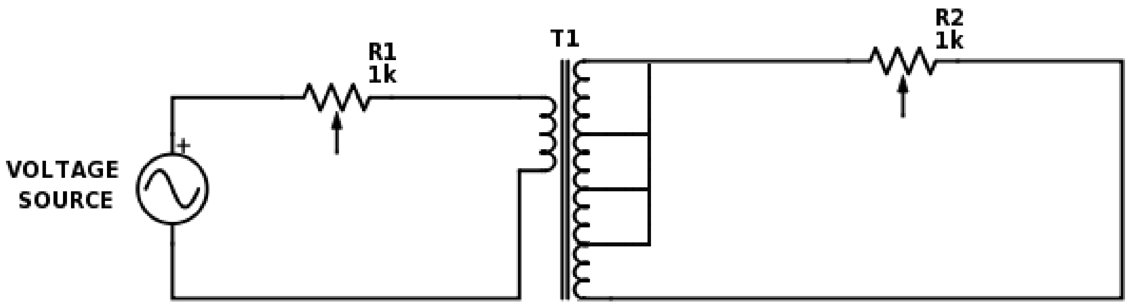

Figure 3.7 : Case II circuit.

Case III: In this case, two resistors have been connected in parallel with the output terminals of the transformer to increase the load.

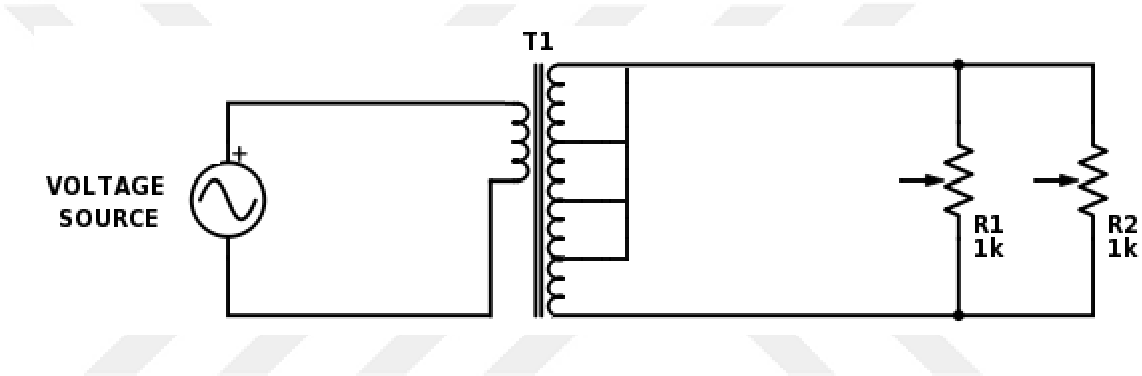

Figure 3.8 : Case III circuit.

CHAPTER FOUR

EXPERIMENTAL RESULTS

4.1 The Results

The tables below show the results that have been obtained from the laboratory work. Table 4.1 shows the results that have been obtained from the mathematical calculations and experimental work without using the load.

Table 4-1 : Comparing between mathematical calculations and experimental work without using the load.

No. Tap	Mathematical Result		Experimental Result (Without Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap 1	182	211.12	182	209.84
	183	212.28	183	210.99
	184	213.44	184	212.15
	185	214.60	185	213.30
	186	215.76	186	214.45
	187	216.92	187	215.60
	188	218.08	188	216.76
	189	219.24	189	217.91
	190	220.40	190	219.07
	191	221.56	191	220.22
	192	222.72	192	221.37
	193	223.88	193	222.52
	194	225.04	194	223.68

No. Tap	Mathematical Result		Experimental Result (Without Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap 1	195	226.20	195	224.83
	196	227.36	196	225.98
Tap2	197	212.76	197	210.39
	198	213.84	198	211.46
	199	214.92	199	212.53
	200	216.00	200	213.60
	201	217.08	201	214.66
	202	218.16	202	215.73
	203	219.24	203	216.80
	204	220.32	204	217.87
	205	221.40	205	218.94
	206	222.48	206	220.00
	207	223.56	207	221.07
	208	224.64	208	222.14
	209	225.72	209	223.21
	210	226.80	210	224.28
	211	227.88	211	225.34
Tap3	212	214.12	212	210.30
	213	215.13	213	211.29
	214	216.14	214	212.28
	215	217.15	215	213.28
	216	218.16	216	214.27
	217	219.17	217	215.26
	218	220.18	218	216.25
	219	221.19	219	217.24
	220	222.20	220	218.24
	221	223.21	221	219.23
	222	224.22	222	220.22

No. Tap	Mathematical Result		Experimental Result (Without Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap3	223	225.23	223	221.21
	224	226.24	224	222.20
	225	227.25	225	223.20
	226	228.26	226	224.19
Tap4	227	213.38	227	212.92
	228	214.32	228	213.86
	229	215.26	229	214.80
	230	216.20	230	215.74
	231	217.14	231	216.67
	232	218.08	232	217.61
	233	219.02	233	218.55
	234	219.96	234	219.49
	235	220.90	235	220.43
	236	221.84	236	221.36
	237	222.78	237	222.30
	238	223.72	238	223.24
	239	224.66	239	224.18
	240	225.60	240	225.12
	241	226.54	241	226.05
	242	227.48	242	226.99

Table 4.2 below shows the results that have been obtained from the mathematical calculations and experimental work with using the load of value of 2A approximately.

Table 4-2 : Comparing between mathematical calculations and experimental work with using the load.

No. Tap	Mathematical Result		Experimental Result (With Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap 1	182	211.12	182	209.30
	183	212.28	183	210.45
	184	213.44	184	211.60
	185	214.60	185	212.75
	186	215.76	186	213.90
	187	216.92	187	215.05
	188	218.08	188	216.20
	189	219.24	189	217.35
	190	220.40	190	218.50
	191	221.56	191	219.65
	192	222.72	192	220.80
	193	223.88	193	221.95
	194	225.04	194	223.10
	195	226.20	195	224.25
	196	227.36	196	225.40
Tap2	197	212.76	197	210.79
	198	213.84	198	211.86
	199	214.92	199	212.93
	200	216.00	200	214.00
	201	217.08	201	215.07
	202	218.16	202	216.14
	203	219.24	203	217.21
	204	220.32	204	218.28
	205	221.40	205	219.35
	206	222.48	206	220.42
	207	223.56	207	221.49
	208	224.64	208	222.56

No. Tap	Mathematical Result		Experimental Result (With Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap2	209	225.72	209	223.63
	210	226.80	210	224.70
	211	227.88	211	225.77
Tap3	212	214.12	212	209.88
	213	215.13	213	210.87
	214	216.14	214	211.86
	215	217.15	215	212.85
	216	218.16	216	213.84
	217	219.17	217	214.83
	218	220.18	218	215.82
	219	221.19	219	216.81
	220	222.20	220	217.80
	221	223.21	221	218.79
	222	224.22	222	219.78
	223	225.23	223	220.77
	224	226.24	224	221.76
	225	227.25	225	222.75
	226	228.26	226	223.74
Tap4	227	213.38	227	211.11
	228	214.32	228	212.04
	229	215.26	229	212.97
	230	216.20	230	213.90
	231	217.14	231	214.83
	232	218.08	232	215.76
	233	219.02	233	216.69
	234	219.96	234	217.62
	235	220.90	235	218.55
	236	221.84	236	219.48

No. Tap	Mathematical Result		Experimental Result (With Load)	
	V_{inAC}	V_{outAC}	V_{inAC}	V_{outAC}
Tap4	237	222.78	237	220.41
	238	223.72	238	221.34
	239	224.66	239	222.27
	240	225.60	240	223.20
	241	226.54	241	224.13
	242	227.48	242	225.06

The following figures (4.1 – 4.3) present the results of voltage output range for the mathematical result, experimental result without the use load, and experimental result with the use of load.

Figure 4.1 shows the relation between the input voltage and the output voltage which is obtained from mathematical calculations with ratio 1.16 for Tap (1), and1.08 for Tap (2), and 1.01 for Tap (3), and 0.94 for Tap (4). We can notice that when the voltage goes down and reaches the lower limit of each tap it will have a permeability of 1 V_{AC} then it will change the selected tap to the previous one.

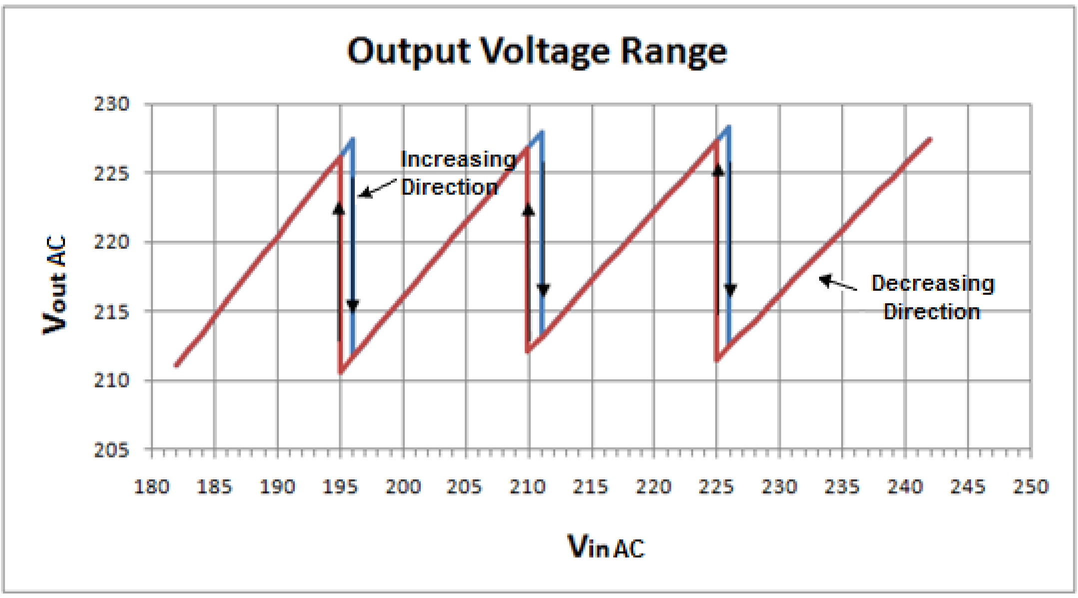

Figure 4.1 : Output voltage range obtained from mathematical calculations

Figure 4.2 shows the relation between the input voltage and the output voltage which is obtained from experimental results from the laboratory in no load case with ratio 1.153 for Tap (1), and 1.068 for Tap (2), and 0.992 for Tap (3), and 0.938 for Tap (4). Also, we can notice that when the voltage goes down and reaches the lower limit of each tap it will have a permeability of 1 V_{AC} then it will change the selected tap to the previous one.

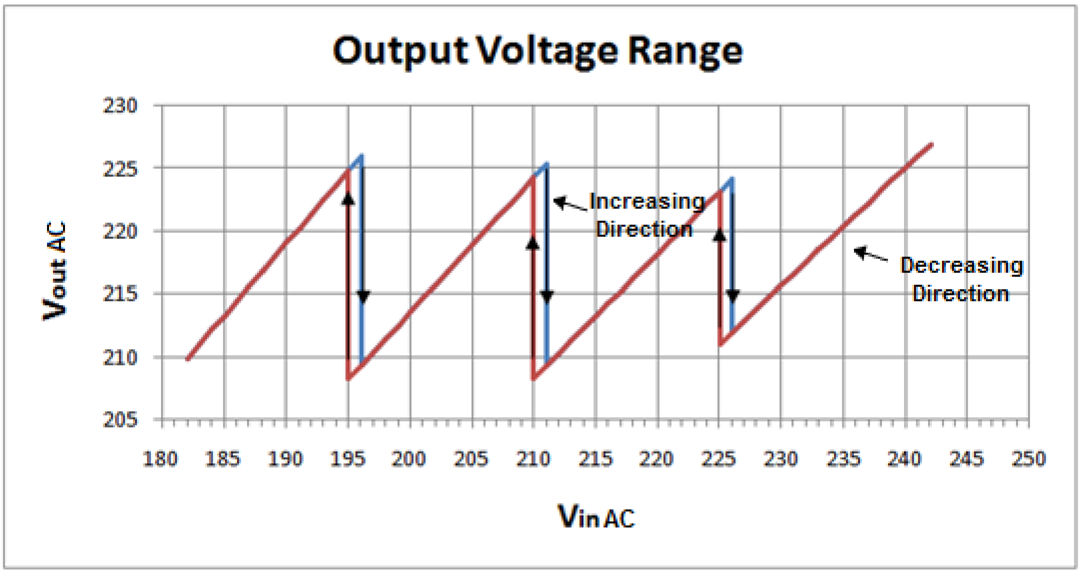

Figure 4.2 : Output voltage range obtained from experimental work without the use of load.

Figure 4.3 shows the relation between the input voltage and the output voltage which is obtained from experimental results from the laboratory in load case around two amperes with ratio 1.15 for Tap (1), and 1.07 for Tap (2), and 0.99 for Tap (3), and 0.93 for Tap (4). Also, we can notice that when the voltage goes down and reaches the lower limit of each tap it will have a permeability of 1 V_{AC} then it will change the selected tap to the previous one.

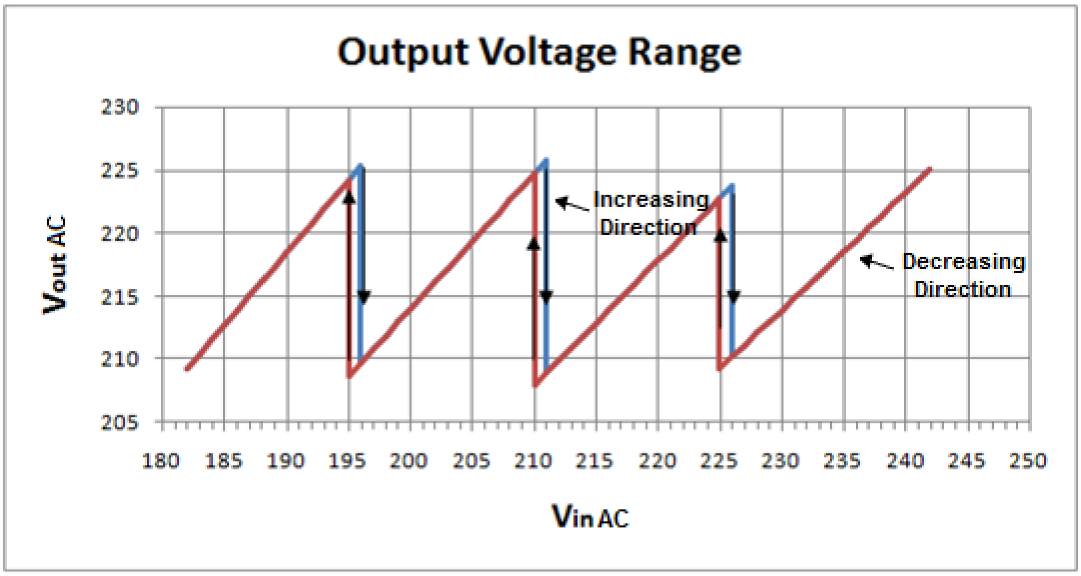

Figure 4.3 : Output voltage range obtained from experimental work with the use of load.

If we compare the results which we get it from ACVR4T with another research where there are many researchers that have worked on this topic one of them " Design and Implementation of an Automatic Voltage Regulator with a Great Precision and Proper Hysteresis " [5] with output voltage range 215-237 V_{AC} by using 8 taps. Figure 4.4 shows the relation between the input voltage and the output voltage which is obtained from this study.

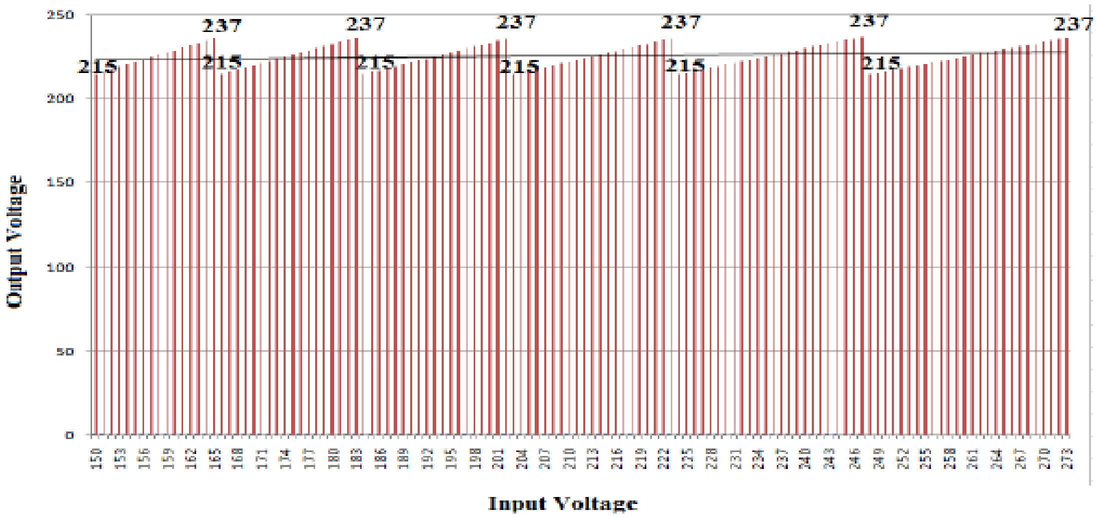

Figure 4.4 : Output voltage range [5]

We can see the output range changes 22 V_{AC} but by using ACVR4T the change in the output voltage range is 16 V_{AC}. Also, in this research non-programable controlling circuit is used which consists of comparators and logic gates. If one of these components goes down or failed will result in fault in the circuit and the circuit may stop supplying the load. In the switching part of the circuit, mechanical relays are used in this research which has a disadvantage compared to SSR. However, in ACVR4T we can notice that when the voltage goes down and reaches the lower limit of each tap it will have a permeability of 1 V_{AC} then it will change the selected tap to the previous one with 500 ms of delay upon changing from tap to another and this cannot be seen in the other research.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

5.1 Conclusion

In this thesis, a device called ACVR4T consists of four taps is used. Each tap has different number of turns that regulates the variable input voltage which varies from 182 to 242 V_{AC} to provide an output of 212 to 228 V_{AC}. ACVR4T has been designed and implemented according to the calculations that are discussed in the thesis chapters above with a new controlling method by using an Arduino.

This control method provides more flexibility where the Arduino can be working with many programs like C++ or MATLAB or etc. and we can be programmed as we want by writing its code. Also, the Arduino is fast controlling since it uses less components to control the required switch while in non-programable controlling circuit more components are required to get the same result which will take more time and less accuracy. Through these benefits, we can say that the device will work highly efficient. Solid-state relays are also used instead of relays. This leads the electrical circuit to achieve switching with less losses and noise.

5.2 Recommendations for Future Studies

As mentioned above, ACVR4T has been designed and implemented with four taps to get output voltage with range 212 to 228 V_{AC} controlled by using the Arduino.

It is recommended in future study to study the optimum number of taps to get the output voltage with the range closer to 220 V_{AC}.

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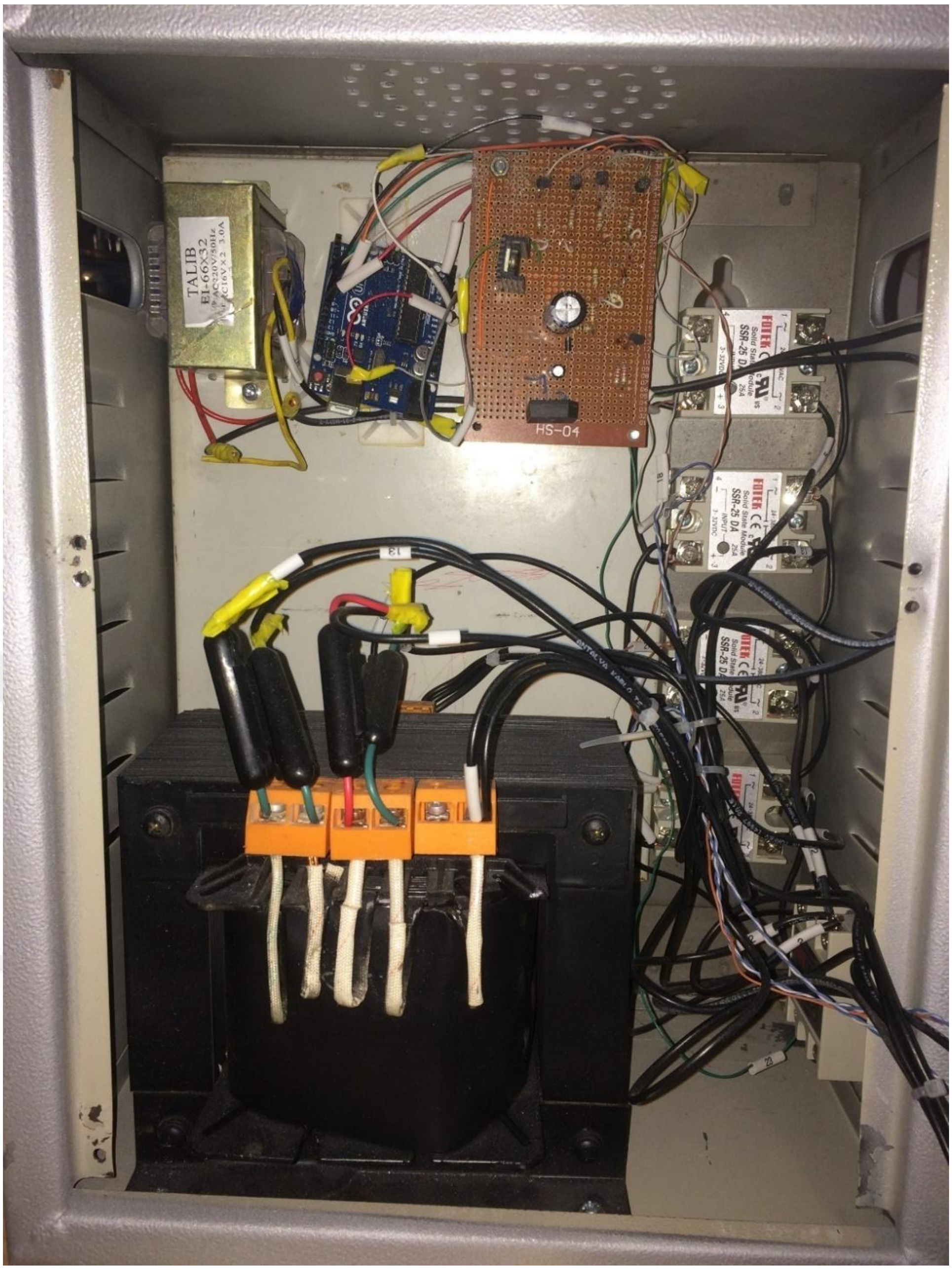
APPENDIX

THE PICTURES OF ACVR4T

Appendix 1 : Front View



Appendix 2 : Inside View