DESIGN AND IMPLEMENTATION OF A MICROCONTROLLER-BASED AUTOMATIC CHANGEOVER SYSTEM FOR TRANSFORMERS IN POWER STATIONS

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MASTER OF SCIENCE

(Physics)

JOMO KENYATTA UNIVERSITY OF

AGRICULTURE AND TECHNOLOGY

2021

Design and Implementation of a Microcontroller-Based Automatic Changeover System for Transformers in Power Stations

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A Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Master of Science in Physics of the Jomo Kenyatta University of Agriculture and Technology

2021

DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University

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This Thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

I would like to dedicate this work to my mother, Silvia J. Kibet, for the good foundation, prayers, sacrifices and her continued support throughout our lives and in this journey. I would also like to recognize my father in his absentia, the late William Kibet Kisombe for the roots he instilled in me and the mentorship he gave in the course of his life.

ACKNOWLEDGEMENT

First and Foremost, I would like to express my most humble and most sincere gratitude to God Almighty for good health, strength of will and every resource towards the success of this research.

My sincere appreciation go to my supervisors Prof. Mutuku Joseph and Dr. Ominde Calvine of Jomo Kenyatta University of Agriculture and Technology for their continued support during each stage of my research. They gave me a strict yet fatherly guidance and support throughout my research, not excluding their patience, enthusiasm, motivation and immense knowledge.

Thirdly, I wish to acknowledge the opportunity and the financial support that Jomo Kenyatta University of Agriculture and Technology extended to this research and the chance to study this degree in general. At my lowest moments they resurrected my energy. I am grateful to the Physics Department fraternity, who have been with me through this process and their will to guide and evaluate my work through seminars.

Lastly, I wish to extend my gratitude to my dedicated mother and siblings for unwavering trust and encouragement. I appreciate my friends Elphas Khata, Dorothy Mwanzia and Kelvin Lodenyi who have been there with me throughout the study and ever willing to offer a hand when called upon. I am forever grateful for all your contribution to this research.

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LIST OF SYMBOLS

A_0	Open loop voltage gain
B	Magnetic flux of the core
E_1	E.M.F induced on the primary winding
E_2	E.M.F induced in the secondary winding
f	Frequency of the alternating current (AC)
I_2	Current on the secondary side
Is	Relay pickup current setting
K and α	Constant characteristics that vary with relay characteristics
N_2	Number of turns of the secondary winding
P_2	Power on the secondary side
R_1, R_2, R_3, R_4	Resistors 1, 2, 3 and 4
S	Surface area of the core
t	Time in seconds
V_R	Voltage across resistor R
V_{IN}	Input voltage
V_{OUT}	Output Voltage
Φ_2	Magnetic flux induced on the secondary winding
Φ_1	Magnetic flux induced on the primary winding
Φ'_1	E.M.F induced on the primary winding to restore its voltage

LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternating current
ANSI	American National Standards Institute
DC	Direct current
EI	Extremely inverse
EMF	Electromotive Force
IEC	International electro-technical commission
IEEE	Institute of Electrical and Electronics Engineering
KVA	Kilo-volt-ampere
LTI	Long-time inverse
MCU	Microcontroller
MMF	Magneto-motive Force
NC	Normally closed
NO	Normally open
SI	Standard Inverse
TMS	Time multiplier setting
VI	Very inverse

ABSTRACT

Currently, most critical industries in Kenya have employed conventional methods to effect changeover processes from one power source to another for ensuring uninterrupted and efficient supply of power to their plants. However, these methods are subject to many setbacks that include; strenuous operation, time wastage, high probability of fire outbreaks and frequent maintenance which is expensive. This study seeks to provide a solution to these power interruptions by giving automation to the changeover circuit in order to eliminate these setbacks. The circuit incorporates two transformers connected independently to specific loads. Current sensors are connected to the transformers to check for current availability and feed the output to Arduino ATmega microcontroller. A feedback loop is created by connecting the loads to the microcontroller in order to monitor load variations. Using the transformer and load inputs, the microcontroller instructs the relays to switch between the loads according to the specified transformer capacities and availabilities. Load shedding and load sharing are also executed by the microcontroller and the status of the transformers and loads displayed on the LCD display. Two sets of data are then obtained, for the effects of load variations on transformer performance before and after changeover and the other one based on the efficiency of the designed microcontroller based changeover system. The obtained results shows that whenever a load is applied on the secondary side of the transformer, the secondary current increases together with the primary current. It is also found that for two operational transformers, the changeover process does not require any time lapse. A program algorithm is used to achieve load shedding and load sharing through the microcontroller. A Minitab is used to display the outputs of the measured current, voltage, time and resistance. Proteus Ver. 8.6 software was also used to simulate the circuit and the results presented graphically.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

In Kenya, power consumption has relatively increased over the years. A lot of areas have gained access to electricity which has led to vast growth and development. With an increased demand for electricity, industrialization growth has reached higher levels. This has led to the development of schemes that boost the economy of the country and has in turn increased the demand for continuous and uninterrupted power supply. These includes the development of high technology and implementation of complex equipment that are fully dependent on electrical power. To meet these demands, different schemes which essentially need two or more sources of supply to the bus-bar system are required.

It is important to note that having different sources of supply to the grid ensures the continuity of power supplied. This provides an alternative source in case one is at fault or does not meet the supply demand of the consumers. For an efficient system, load shedding and load sharing features in the system ensure that the most critical feeders are catered for when power is insufficient in the line or when there is a fault in any of the transformers. Switching between transformers and loads also prevents transformer failures due to overloading. Both the equipment and methods used to effect the changeover of the supply are exposed to challenges that include inefficiency and cost (Amuzuvi & Addo, 2015).

In major power stations, several three-phase megawatts-transformers are installed. These transformers receive very high alternating currents (AC) and voltages from the generation points. Power which is produced from these transformers require that when voltage is high, current is low. Usually, the voltage is stepped up before being fed to the feeders for distribution which is very crucial in reducing power losses over long distances. For efficient functioning of the transformer, transformer ratings are considered for determining precise measurements of the components; current sensors, capacitors, resisters and relays, together with the parameters affected such as current and resistance. Therefore the presence of any load connected to the secondary coil will either increase or decrease these parameters on both sides of the transformer before and after the changeover takes place.

A feeder, in distribution of power, refers to a group of electric conductors that are connected from a primary distribution point and provide power to several secondary distribution points, branch-circuit points, or a combination of both. In this case, voltage moves from the main transformer into the feeders which then transmit the power to specific areas in the region as directed by the feeders. These transformers are however connected to one another using bus-bars that can be switched on and off and therefore ensuring continuity (Ahmed *et al.,* 2006). The bus-bar system provides links to several transmission circuits in the power station. In case one transformer fails or has an under voltage, the transformers are manually switched on for a specified period of time to enable troubleshooting. It is important to add the aspect of isolation which is done simultaneously with the switching process. The isolation process triggers both load shedding and load sharing processes where crucial loads are connected to the available functional transformer according to demand.

The supply of uninterrupted electricity calls for the introduction of alternative power sources and the automation of power generation techniques (Ahmed *et al*., 2006). Automation of electrical power which mainly involves the use of high technology mostly implies the incorporation of automatic circuit systems that will help in eliminating time wastage, overloading of the electrical equipment and components used through monitoring. The introduction of alternative power sources brings forth the constraints of switching both smoothly and timely between the alternative sources and the mains supply, in case power interruption occurs (Ezema *et al.*, 2012).

In this research, the alternative source in major power stations refer to the subsequent transformers in that power station. The provision of alternative power source in the power stations has no doubt brought relief in the availability of power but not without a supervisory challenge associated with manual operation of the changeover (Obasi *et al.,* 2015). It is therefore important to note that there are two types of changeover systems; manual and automatic changeover systems. The manual changeover system requires continuous attentive manning of the substation or station and therefore interruption of supply for at least some hours is inevitable. In most cases, relays are used to directly detect and isolate the defective transformers manually Obasi *et al.*, 2015). Manual methods are still employed in most industries during the changeover process. However, it is subject to many setbacks including: strenuous operation, time wastage, high probability of fire outbreaks and frequent maintenance which is expensive (Amuzuvi & Addo, 2015).

The automatic changeover system on the other hand carries out the detection, isolation and switching processes automatically. In this research, a voltage sensor is used to detect voltage and compare the voltage levels of the transformer. For quick changeover, transducers and sensors are utilized in the automation process so that human errors and contact are fully eliminated (Uzedhe *et al.*, 2012). As the rate of power interruptions increases, the need to automate the power generation process should be emphasised (Rockis & Mazur, 2001), especially in industries, hospitals and security agencies where an uninterrupted power supply is required. An Automatic transfer switch is very necessary for the operation of these electrical systems because it allows the transfer of loads between power sources without physical intervention (Amadi *et al.*, 2019).

Alternative sources require that whenever one source is faulty or insufficient, then the standby source picks up and provides the needed power, therefore ensuring uninterrupted supply to the consumer. With an automatic changeover system, the changeover occurs instantly. This is because, electrically connected relays and interlocks monitor all the conditions of the changeover (Amadi *et al*., 2019). This package is economical in terms of space, reduced time for system design and troubleshooting and lesser number of failures, ensuring efficient continuous power supply to industries and even households. In current power stations, switch gears have been designed to carry out the changeover.

Switchgears refer to the combination of circuit breakers, electrical switches and fuses. They are used to isolate, control and protect electrical equipment and also used to isolate equipment to allow for troubleshooting and clearing faults in the circuit.

The use of microcontrollers to operate and communicate between different circuits of the substation has become essential for quick fault detection and changing over (Okpala & Ilomuanya, 2016). It can also fulfil data acquisition, equipment control, measurement and parameters adjustment which play an important role in improving the reliability, safety and economic benefits of power grid operation. Furthermore, it can reduce the burden of the dispatchers, comprehend the electric power dispatching automation and modernization, and improve the efficiency and the level of dispatch.

As much as the automatic changeover systems are reliable and efficient, they also suffer setbacks that if not eliminated may cause further damage to the whole power grid. These setbacks include the overloading of transformers after switching. It is important to mention that each transformer in a power station has been assigned specific regions to supply power to. This implies that after the changeover, the alternative transformer will supply to all its specified regions and those of the defective transformer. Therefore, it is almost certain that the alternative transformer may be overloaded due to the high demand of power.

Overloading can be reduced or eliminated by combining the automatic changeover switch and a gradual or sequential loading of the transformer and the switched feeders. Sequential loading refers to the step by step loading of the feeders to ensure stability of the power supply, through the feeders by the overloading of the transformer. The combined function of the automatic changeover system and the sequential loader is critical in areas and industries such as healthcare, banking, security and defence that require uninterrupted power supply for continuous operation. This combination of the automatic changeover and the loader also helps in eliminating the need for manual changeover, extending the efficiency of the transformer, protecting the loads (feeders), and most importantly to enhancing the reliability of power supply.

1.2 Statement of the Problem

Electrical power supply is very essential in Kenya since most of the machines and equipment used are electricity driven. However, the continuous interruption of power supply in this sector due to transformer failures that are caused mainly by overloading, has led to reduced production rates. A lot of time is also wasted during the troubleshooting process. This research uses an experimental method to solve the transformer overloading challenges through the incorporation of load shedding and load sharing of the loads to ensure continuous and uninterrupted supply of power. This study will also provide quick relay switching between the transformers whenever there is a failure to ensure continuity and the loads to ensure all loads are connected at all times through the microcontroller, therefore resulting in an efficient and reliable power system.

1.3 Justification

Industrial plants that are electricity dependent are usually affected directly by the interruption of continuous power supply. Once one of the transformers at the power stations fails, some time is lost between detection and troubleshooting the problem. Even in cases where detection is done in control rooms, the manual switching, and troubleshooting is still not enough since time is a key factor in production rates at the industries. The automatic changeover seeks to solve these problems since no time will be wasted during switching. Automation will bring about efficiency and convenience through immediate problem identification and troubleshooting. The changeover will also ensure uninterrupted electrical power is supplied to the consumers always by switching to the next functional transformer through load shedding and load sharing features.

1.4 Objectives

1.4.1 General objective

To design and develop a microcontroller-based automatic changeover system for continuous supply and distribution of power from power stations.

1.4.2 Specific objectives

1. To evaluate the transformer primary and secondary characteristics with and without load for the development of the changeover system.
2. To measure and analyse load characteristics in relation to current variations of the transformers in the changeover system.
3. To measure the dynamic changes of the input/output current and voltage of the transformer under load shift variations before and after changeover through the designed microcontroller system.

CHAPTER TWO

LITERATURE REVIEW

Power failure or outage over the years has led to the development and evolvement of changeover systems from manual to automatic systems. It is important to note that the introduction of automatic changeover systems was done to reduce the shortcomings of the manual changeover systems. These inventions have introduced various techniques of switching loads between power sources from mechanical, electrical and electro-mechanical methods. This includes the use of relays and the advanced technologies of microcontrollers. This chapter focuses on the literature of advancements made over the years on changeover systems and their operations.

2.1 Changeover system

Frequent interruptions of electric power supply have brought about the introduction of standby generators mostly in developing countries (Amuzuvi & Addo, 2015). Most changeover systems in power stations are manually operated and require constant monitoring in case failure occurs. When power transfer is required from one transformer to another or from one phase to another during transformer overload, the system must respond in the shortest time possible to ensure continuity of supply Manual changeover systems employ the use of relays that are manually switched from one source to another. However, for these manual changeover systems efficiency and cost remain a challenge. If the process of changeover between the two power supply sources is manual, human error may occur causing electrocution/electric shock, machine damage as well as increased downtime that consequently introduces massive losses (Rockis & Mazur, 2001).

Manual methods are still employed in most industries during the changeover process. However, it is subject to many setbacks including: strenuous operation, time wastage, probability of fire outbreaks and frequent maintenance which is expensive (Amuzuvi & Addo, 2015). Over the years, manual switching has evolved in many areas of the changeover system for transformers. This includes the isolation circuit breakers and the switching gears in general. In a substation, when the transformers malfunction, the circuit breakers, which are mostly in high voltage and high current, switches trip to isolate the transformers from the outgoing and incoming lines.

Reliable and timely switching between two or more power sources has become the focus in providing continuous and uninterrupted power supply. This has led to inventions of advanced technologies that counter these challenges. Inventions on load switching systems between two sources by use of two electromechanical relays has been a wide area of research. However, the reliability of eletromechanical relay contacts is greatly affected (Zhang *et al.*, 2019). This is because of the mechanical sliding manner of the contact spring components. In this case, automation of changeover systems not only refers to the switching system but also the detection, protection and distribution stages of the substation (Zhang *et al*., 2019).

Interfacing power sources to loads using microcontrollers has proved to be the most reliable method in recent changeover research, whether it is between generators and main utilities, between phases or even main power sources such as transformers. An automatic phase selector and gen-set changeover system using a microcontroller was designed to ensure safe operation of appliances, optimal performance of systems, reliability and continuity in utility power supply (Ofualagba & Udoha, 2017). The changeover occurred between the three phases with regard to the load requirement in case of failure of one of the phases. The microcontroller which is the logic centre of this circuit senses the three phases through a step-down network and the changeover is effected without delay (Ofualagba & Udoha, 2017). However, their design work was limited to specific loads and utilities and covered a small network.

In 2018, an automatic transfer switch that switches between a utility source and a generator for two buildings was designed (Hasanah *et al.*, 2018). Although a microcontroller was used to effect the changeover, time delay was experienced after switching to allow the gen-set to pick up. Another disadvantage of this system was that it required human intervention during refuelling of the generator (Hasanah *et al*., 2018).

This research study proposes the use of a microcontroller to implement the automatic transfer of power supply between two or more transformers in a power station or substation for efficient change over. Since all the transformers are operational and working in parallel with their specific loads, no downtime is experienced and therefore quick changeover is effected. It also aims to enhance reliability of power supply through the inclusion of prioritization of loads that will help reduce the overloading of the transformer. That is, whenever one of the transformer’s capacity is exceeded, then the loads are shared among the available transformers in the setup or are shed accordingly. This will ensure that areas and regions with critical operations will be considered first.

2.2 Theoretical considerations

2.2.1 Relay switching mechanism in a changeover circuit and its characteristics

Alternative power sources require that an effective switching system is incorporated to provide for continuous power supply. Over the years, relays have played a major role in this. This includes the electromechanical and mechanical relays which are electronically energized. However, these relays have succumbed to arcing and mechanical strain that hinder any changeover system from effective performance. Therefore, in any domestic or commercial power supply system with a three-phase connection, it is recommended that an automatic changeover be installed to supply an uninterrupted power to critical loads in case one phase fails (Himadri & Sayan, 2016). For the power substations, relays are crucial in switching between the transformers during both the isolation process and the prioritization of feeders.

Relays are classified mainly based on their characteristics, operation mechanism, logic or the actuating parameter. Based on relay characteristics, we consider an over current relay whose actuating parameter is current. The current coil is activated when the current flowing in the circuit exceeds the intended current. Depending on operating time, over current relays can be classified into three; instantaneous over current relay, definite time over current relay and inverse time over current relay. Instantaneous over current relays operates as soon as the current in the coil gets higher than the pickup setting current. However, the time delay is not intentionally applied. Its operation time is in the order of milliseconds. Definite time over current relays have a time delay set immediately the pickup current is exceeded. Inverse time over current relay, on the other hand, has the tripping time tied to the input current. In other words, the higher the input current the shorter the tripping time and therefore time and current are inverse. Its advantage is that for very high currents, much shorter tripping times can be obtained without risk to the protection selectivity (Juan & Edward, 2004).

According to the International Electrotechnical Commission (IEC) 60255 characteristics, four standard current time characteristics are defined. They are, the Standard inverse (SI), Very inverse (VI), Extremely inverse (EI) and Long-time inverse (LTI) (McFadyen, 2012). SI refers to the case where there is a relatively small change in time per unit of change of current. These relays are used in utilities and industrial circuits. Very Inverse characteristic is where the inverse occurs over a great range and tends to definite time after saturation. They are mostly employed on long sub-transmission lines and feeders. EI refers to when the core saturation occurs at a very late stage and are suitable for transformer and cable protection. On the other hand, long-time inverse characteristic relay picks latest when the current exceeds the setting value. The relay tripping time for all the characteristics can be calculated using

$$t = \frac{K}{\left(\frac{I}{I_S}\right)^{\alpha} - 1} \times TMS \qquad \text{2.1}$$

Where; t is tripping time in seconds, I is the actual secondary current in amperes, I_s is the relay pick-up current setting and TMS is time multiplier setting. K and α characteristics are constants that vary depending on the characteristic being used.

Table 2.1: The values of characteristics K and α for the characteristics SI, VI, EI and LTI (McFadyen, 2012)

Characteristic	A	K
Standard Inverse	0.02	0.14
Very Inverse	1	13.5
Extremely Inverse	2	80
Long-time Inverse	1	120

However, the values of K and α vary differently depending on the standards being considered, that is either the American National Standards Institute (ANSI) or the Institute of Electrical and Electronics Engineers (IEEE). When current is varied over time, the relay characteristics vary differently. However, all the characteristics form decreasing curves when plotted in a graph as shown in Figure 2.1.

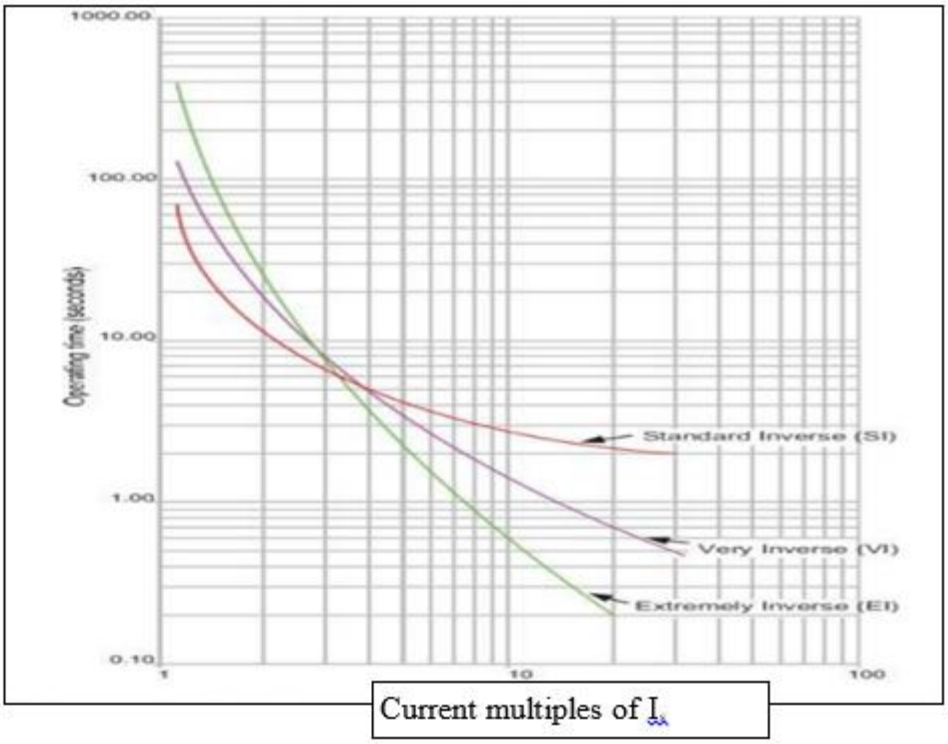


Figure 2.1: Graph of Current against time for relay characteristics at TMS=1.0 (McFadyen, 2012)

Inverse time relay characteristic curves above indicate the speed of operation in seconds with regard to the input current. Standard inverse, very inverse and extremely inverse characteristics are the most commonly used. The constants, α and K determine the slope of the relay characteristic. Therefore, given the delay characteristics, for a specific time dial setting and pick up current settings, the relay tripping time can be obtained (Juan & Edward, 2004). It is noted that the extreme inverse (EI) curve is steeper followed by the very inverse (VI) then the standard inverse (SI) curve.

2.2.2 The input voltage/current detection process involved in the changeover circuit

When transformers are fully operational (without malfunctions), current/voltage is stepped down as directed. This implies that voltage/current is present in the substation grid system. It is important to note that, depending on the load demand and the status of the transfer, the voltage/current value may vary from the expected value. A detection mechanism is therefore necessary. In 1983, William and Ralph invented a system for switching loads between two or more power sources when an interruption of power to one load occurs. It involves the transfer of load from one AC power source to another. It includes a power source monitor sensor whose output signal triggers the contacts to either open or close to isolate one faulty power source and connect to the alternative power source. The contact arrangement may include an automatic transfer switch which is very key during switching. An Automatic transfer switch is very necessary for the operation of electrical systems as it allows the transfer of loads between power sources without physical intervention (Amadi *et al.*, 2019).

A voltage comparator is used in this context to detect overvoltage or under voltage. The comparator stage is used to sense when the public power supply voltage has dropped below a certain pre-set level (Atser & Roy, 2014). When the transformer produces an A.C current less than the expected value, the comparator will compare this value with a set reference voltage value. To calculate the voltage drop across each resistor, the equation

$$V_R = \frac{R_2}{R_1+R_2} V \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.2$$

is used where V_R is the voltage drop across resistor R, R_2 is the resistance of resistor R_2, R_1 is the resistance of resistor R_1 and V is the supplied voltage as shown in figure 2.2

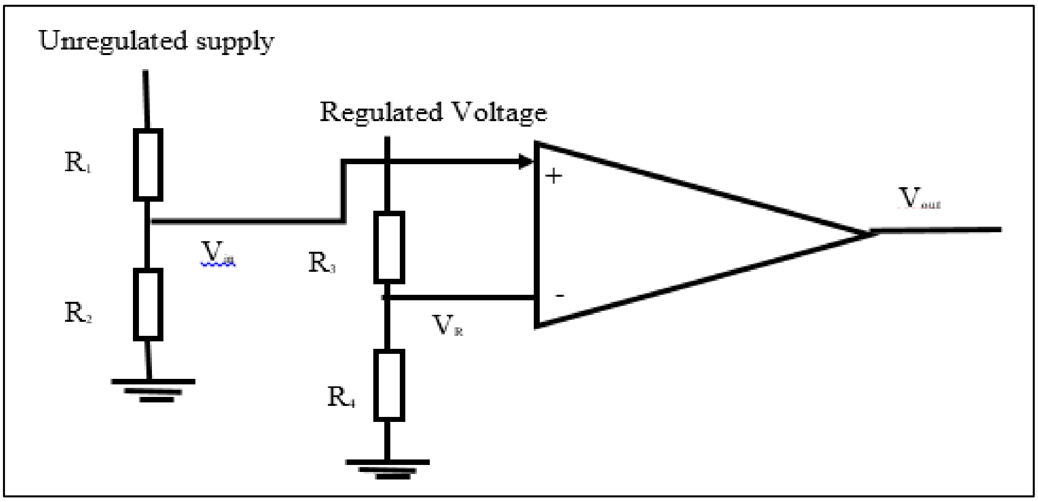


Figure 2.2: Comparator Voltage Level Detector

Where, unregulated voltage refers to the AC voltage from the transformer and the regulated voltage is the set reference voltage for the comparator.

Voltage across all the resistors is calculated using equation 2.1. The output voltage V_{OUT} of the comparator will be calculated using

$$V_{out} = A_0 V_{in} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.3$$

Where A_0 is the open loop voltage gain of the operational amplifier which is usually not less than 20000.

Consequently, the equation

$$V_{in} = V^{+} - V^{-} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

will be used to calculate the input voltage. V^+ and V^- are the voltages at the non-inverting and inverting terminals respectively.

As the input voltage drops below the reference voltage, the comparator gives a lower output voltage which will changeover the relay. When the input voltage goes above the reference voltage, a higher output is given by the comparator causing the relay to switch the power supply (Atser & Roy, 2014).

Automatic changeover systems require that the detection and isolation processes are carried out smoothly and timely to allow for switching. They are referred to as the switching gears and play a major role in transformer protection. The circuit breaker is the main part of the switch gear. It is a protective device designed to open an electrical circuit automatically thereby preventing any harm or damage to equipment and personnel. Unlike a normal switch, a circuit breaker also operates automatically in the event of a fault, or when a line or feeder overloads.

The output voltage of the voltage comparator is fed to a microcontroller which instructs the relays to isolate and break the circuits. The microcontroller communicates with all the components in the circuit as well as centralizing all operations of the changeover system. In 1991, the automatic power failure and auxiliary generator control was invented *(United states of America Patent No. US5268850A, 1991).* Detectors were used to sense power at the distribution socket and at the generator outlet socket. On the other hand, a microcontroller responded to the sensed power outage at the distribution socket therefore starting the auxiliary generator and consequently connecting the controlled socket to the generator outlet socket and vice versa.

2.2.3 Automation and load shedding process of the changeover circuit

The need for continuous and uninterrupted power supply has greatly increased due to the introduction of new technological advancements. This also implies that the technology employed in changeover systems has also advanced. To gain reliability through substation automation, the performance of electrical protection is increased, advance disturbances monitored, and the recording capabilities enabled (Joji *et al.*, 2017). The system monitors and controls the circuit breakers on site to achieve data acquisition, measurement, parameter adjustment, and various signal alarms through digital equipment and sensors. Therefore, real-time status of currents, voltage, pressures, temperatures and contacts is observed and recorded with time. The use of microcontrollers to operate and communicate between different circuits of the substation has become essential for quick fault detection and changing over (Joji *et al.*, 2017). The controller executes the required action as it receives the corresponding input digital signals from the input interface (Okpala & Ilomuanya, 2016).

Power stations and substations with more than one transformer of high capacity normally incorporate changeover systems in case of power interruptions. When a fault causing interruption in the electrical power grid of medium voltage occurs, it is the protection device, existing in the substation, which goes into action and leave the medium voltage grid without electricity until the fault is located and corrected. Therefore the need for alternative transformer. To ensure transformer protection during the changeover process, oil level monitoring, temperature changes and voltage and current that may cause transformer overloading must be checked frequently. Parallel connection of a master and slave transformer is made to provide the surplus power needed in the grid (Abhishek *et al.*, 2017).

Smart phase change over system with an AT89C2 microcontroller was designed by Christian to check the availability of any live phase and connect a load automatically to the live phase (Christian, 2012). When one transformer fails in the substation, the voltage detector senses the voltage difference and its input fed to the microcontroller. From this point, the microcontroller takes over the whole operation by signalling the relays both at the isolation stage and when giving outputs to the feeders.

When high electricity demand growth is not matched by the growth in generating capacity, energy deficit problem cannot be avoided (Syadli *et al.,* 2016). A proper scheduling program must have a clear periodic schedule, fixed outage hours, fairly distributed and alternated among consumers and most importantly solve energy deficit problem (Syadli *et al*., 2016). To carter for overloading after switching, prioritization of feeders is necessary. This function is referred to as load shedding and is included in the software of the microcontroller. Load-shedding provides for reducing and restoring several circuits within the area, which represent loads of different priority, with loads being removed and restored, regarding their priority. Therefore, the changeover circuit should have three main functions, that is, to detect, isolate and prioritize loads.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

For the circuit modelling and setup, both simple and complex components have been used. The simple components included led bulbs, connecting wires, capacitors, resistors and diodes among others. Relays, current/voltage sensors and ATmega256 module microcontroller which played the major roles in the switch were also added in the circuit. Several measurement meters are used to monitor and measure variable as they changed throughout the experiment. They include an ohmmeter, multimeter and a temperature sensing device.

3.2 Methodology

3.2.1 Working Principle

The working principle of the automatic microcontroller based changeover system is shown in Figure 3.1.

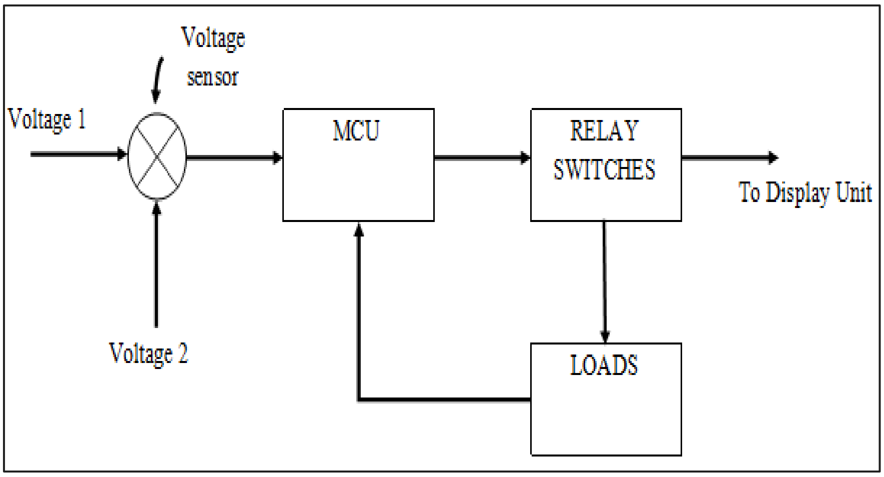


Figure 3.1: The control circuit diagram of the changeover system

It starts with the detection of voltage/current from the two transformers using a voltage/ current sensor circuit. The output of the voltage comparator/sensor is fed to the microcontroller unit (MCU) that gives the instruction to the relay switches to either isolate the defective transformer or not to isolate it. If there is presence of current from both transformers, the microcontroller will instruct the respective relays to either open or close the loads. Current variations will be recorded as they occur. If no voltage is input to the microcontroller, it will imply that the transformer did not have any input and therefore will show a cause for failure. This system also includes a feedback mechanism that monitors and records load current values to determine if the transformers can support the demand. In which case, current sensors from the loads are connected as inputs to the microcontroller. The main materials used in the system are voltage sensor circuit, transformers, relays, the arduino module and loads.

3.2.2 Voltage Sensor Circuit

The voltage sensor circuit is required for constant monitoring of input current and voltages from the transformers must be done. The circuit setup is as shown in figure 3.2.

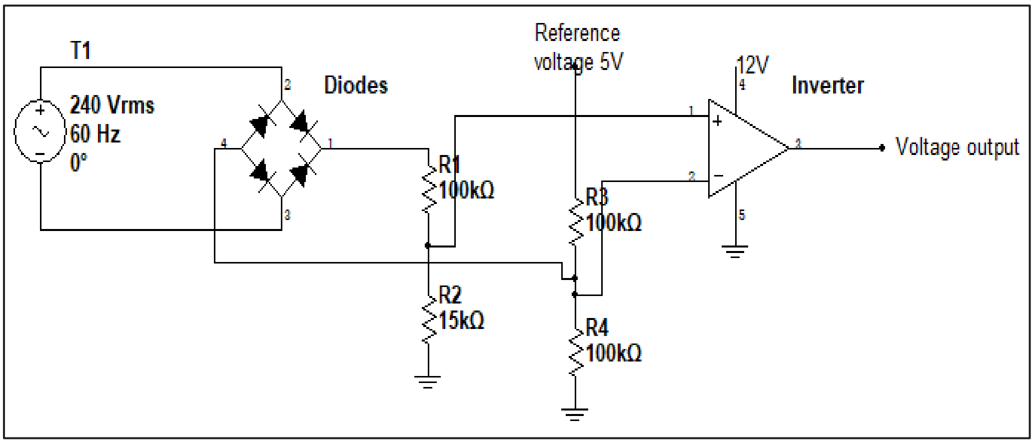


Figure 3.2: Voltage detector circuit using an IC comparator

The voltage detection circuit includes resistors, a full-wave bridge rectifier and an IC comparator. The mains line is connected through two resistors to the positive pin of the IC and a reference voltage of 5V connected to the negative pin. To calculate the voltage across, $R_{2,}$ the equation

$$V_{R2} = \frac{R2}{R1+R2} V^{+} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

is used where V_{R2} is the voltage across R_2, V^+ is the unregulated voltage, R1=100 kΩ and R2=15 kΩ.

The output voltage of the rectifier was calculated using

$$Vo = \frac{2\times\sqrt{2}\times Vrms}{\pi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

3.2.3 Transformer Test

The transformer test circuit is shown in Figure 3.3.

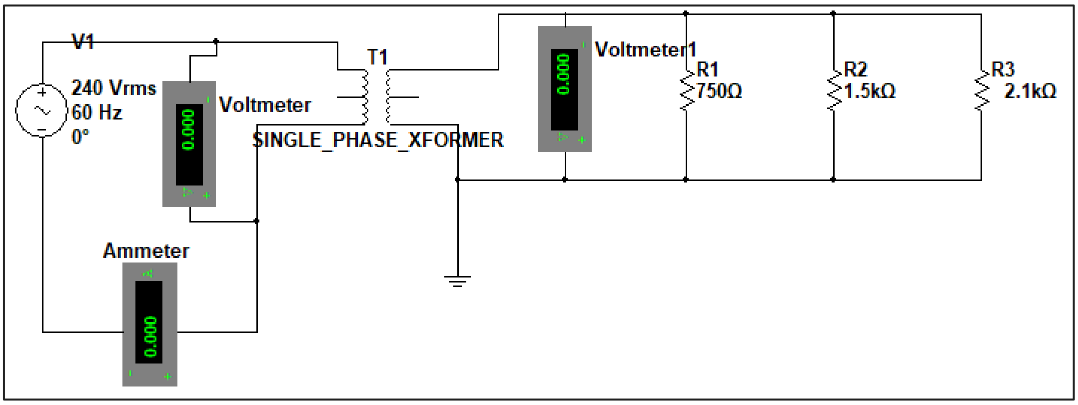


Figure 3.3: A single-phase transformer circuit for monitoring transformer current and voltage characteristics.

This circuit is important for evaluating transformer performance and current capacities that are essential before connecting high loads. It involves voltage and current variations with time when the changeover system is under load shift. Two 240 V/12 V AC transformers are connected in separate breadboards together with the rectification and regulation circuit. Simple loads of 750 Ω, 1500 Ω and 2100 Ω were then connected in parallel. Voltmeters XMM2 and XMM3 were connected in parallel to the transformer and an ammeter XMM1 in series to measure primary and secondary voltage and current of the transformer respectively.

3.2.4 Relay Array Module

In the system, four loads are connected each having its own relay. Since two transformers act as sources for all the four loads, then each load is collected to each transformer via an independent relay. An 8 channel 5 V relay module was used to connect to all eight terminals of the loads. It is used to drive high voltage using low voltages using the arduino microcontroller. Each relay has a normally closed (NC) contact and a normally opened (NO) contact. An electromagnetic effect is created each time current is connected to the coil. With current present, the normally open contact is closed to switch the load on. When current is withdrawn, it de-energizes and the moving contact closes the normally closed to switch off the load.

3.2.5 Design of the Automatic Changeover Circuit

The automatic changeover circuit required two 240 V/12 VAC transformers connected in parallel. Four loads of different capacities are also connected in the circuit, with each transformer being allocated two loads as per their load capacity as shown in Figure 3.4.

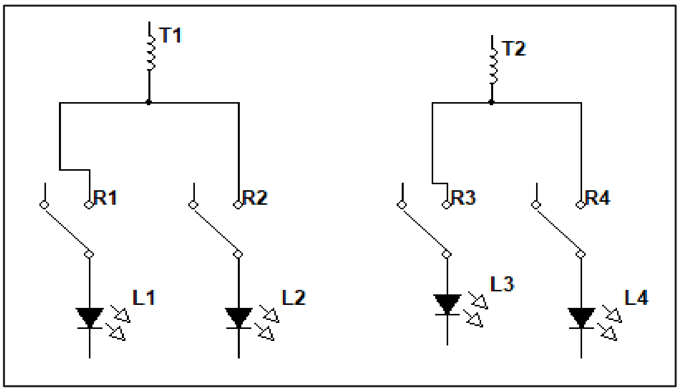


Figure 3.4: Line to load connection through relay switching

Relays R1 and R2 are used to control the loads from transformer T1, while relays R3 and R4 are used to control loads for transformer T2. When there is no current from both transformers, all the relays remain at the normally closed. When both T1 and T2 have current, relays R1, R2, R3 and R4 move the contact to the normally open and the LEDs for loads L1, L2, L3 and L4 light consecutively. When only T1 has current, then only relays R1 and R2 remain at the NO. To effect load shedding feature, each load is connected to each transformer through independent relays. Therefore if only T1 has current, then the relays open and closed accordingly to switch on the prioritized loads.

3.2.6 Design of the Control system

ATmega2560 Arduino microcontroller was used to implement automation in the changeover system. It contains 16 analogue input/output pins and 54 digital input/output pins. The block diagram showing the operation of the control circuit is at shown in Figure 3.5.

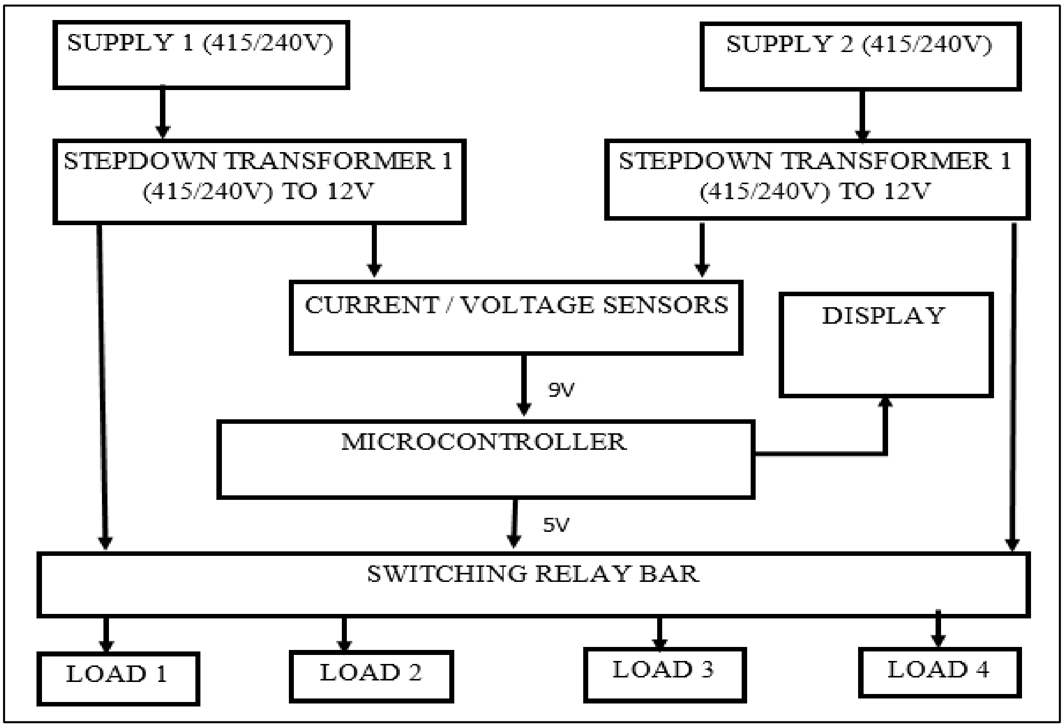


Figure 3.5: Block diagram of the microcontroller based changeover system

Using the Arduino software, C programming language was used to write the program into the microcontroller in order to run the hardware of the system. In addition, the system provides for load shedding and load sharing features, such that, when one of the transformers fails, the respective loads are connected to the existing functional transformer with priority; according to urgency and demand. The microcontroller continuously compares load currents to the transformer input currents. Therefore, whenever the load exceeds the allocated transformer load capacity, the microcontroller instructs the relays to close or open in order to shed/isolate that particular load. The LCD display will show the status of the connected transformers together with the current demand of each load connected in the system.

CHAPTER FOUR

RESULTS AND ANALYSIS

This chapter presents and discusses the results obtained during the experiment. Data was collected for when the system was normally operational. This refers to when all the transformers were connected and working properly and when the system was faulty, that is, when either one of the transformers had failed.

4.1 System primary and secondary Circuit Testing Results

This section presents results for current and voltage of the primary and secondary windings of the transformer when load is connected and when load is not connected.

4.1.1 Current and voltage readings of the transformer without load

Since the changeover system is designed to prevent transformer overloading and allowing for effective switching and load shedding solutions, it was important to test the transformer characteristics both in ideal situations and abnormal situations. The transformers were connected to the mains and voltage and current values were recorded in steps of 30 seconds for 210 seconds for both the primary and secondary sides. In the first case, loads were not connected to the secondary side and the results recorded in Tables 4.1 and 4.2.

Table 4.1: Voltage and current readings at the primary winding with time

Time, t (s)	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**
Voltage, V (V)	252	252	252	252	252	252	252	252
Current, I (mA)	36.4	36.2	36	36.2	36.5	36.5	36	36

Table 4.2: Voltage and current readings at the secondary winding with time

Time, t (s)	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**
Voltage, V (V)	14	14	14	14	14	14	14	14
Current, I (mA)	1.8	1.8	1.7	1.8	1.7	1.7	1.8	1.8

Voltage readings on the primary and secondary side remained constant at 252 V and 14V respectively throughout the experiment. However, current readings changed slightly with time. The graph of current against time and voltage against time for the primary side was plotted on the same graph as shown in Figure 4.1 while the graph of current against time and voltage against time was plotted on a graph as shown in Figure 4.2.

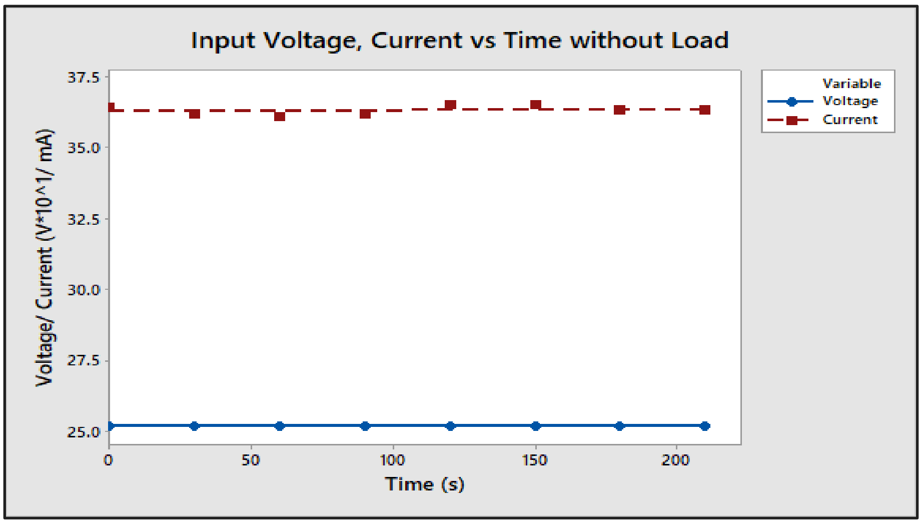


Figure 4.1: Graph of voltage and current against time for the primary side when the loads are not connected.

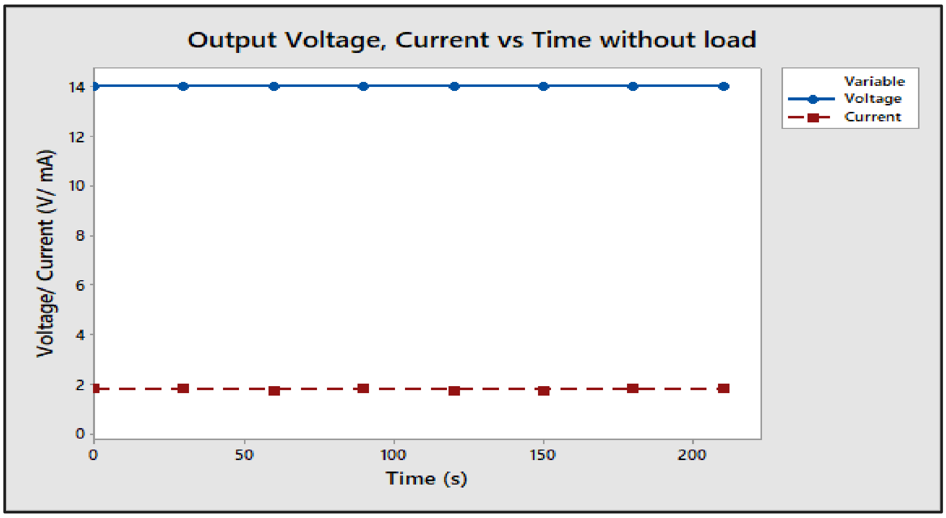


Figure 4.2: A graph of voltage and current against time for the secondary side when no load is connected.

It can be observed from the graphs that, when no load is connected, voltage remains constant on both the primary and secondary sides while both input and output ac currents vary slightly forming a best line of fit horizontal to the time axis. Current on the secondary loop is not expected to be present since the loop is open. However, because of the primary loop which has the no-load current (transformer excitation current), it establishes a magnetic field inducing current in the secondary coil. In addition, because of the high coil impedance of the transformer, the no-load current magnetizing current ends up being low, therefore low primary and secondary currents are recorded.

4.1.2 Current and voltage readings of the transformer with load shift

Testing transformer characteristics when loads are introduced was carried out using simple loads of 750 Ω, 1500 Ω and 2100 Ω for both the primary and secondary sides of the transformer. The results are as shown in tables 4.3 and 4.4 respectively.

Table 4.3: Voltage and Current primary readings with time

Time (s)		0	30	60	90	120	150	180	210
Voltage (V)		252	252	252	252	252	252	252	252
Current (mA)	750Ω	39.8	39.9	39.8	40.2	40.1	40.4	40	40.1
	1500Ω	40.6	40.9	41.1	41.3	40.7	40.6	40.2	40.1
	2100Ω	41.3	41.6	41.8	41.6	42.1	41.2	39.9	38.2

Table 4.4: Voltage and Current secondary readings with time

Time (s)		0	30	60	90	120	150	180	210
Voltage (V)		14	14	14	14	14	14	14	14
Current (mA)	750Ω	2.5	2.4	2.4	2.4	2.3	2.3	2.3	2.4
	1500Ω	3.1	2.9	2.7	2.9	2.8	2.7	2.9	2.5
	2100Ω	3.2	3.1	3.4	2.8	3.5	2.9	2.5	2.2

Tables 4.3 and 4.4 show voltage and current measurements with time, of the primary and secondary sides of the transformer, respectively. Each load was connected independently and the current was measured and recorded at an interval of 30 seconds for a period of 210 seconds. The independent load connections were done to monitor current variations when low and high loads were present in the circuit.

On the other hand, voltage readings on both the secondary and primary side of the transformer remained constant throughout the experiment, that is, 14 V and 252 V respectively. When load is connected on the secondary side of the transformer, voltage remains constant since the load and the winding impedance have little or no interference on the secondary voltage. Since the secondary voltage depends on the primary voltage, the primary voltage remains constant.

From the e.m.f equation of the transformer, the induced voltage on the secondary side is given by

$$E_2 = 4.44 \times f \times S \times B \times N_2 \qquad (4.1)$$

Where f is the frequency of the ac current, N_2 is the number of turns of the secondary winding, S is the surface area of the core and B is the magnetic flux. Also, S*B gives the maximum flux of the core. 4.44 is a constant calculated from the maximum magnetic flux peak and the form factor (1.11 for a sinusoidal variation).

Therefore, power transferred from the primary side to the secondary side is given by

$$P_2 = E_2 \times I_2 \qquad (4.2)$$

But since power is determined by load to give

$$P_2 = I^2 \times R \qquad (4.3)$$

From equation 4.3, when the transformer is on load condition, current I_2 flows through the secondary winding. This current then induces the magneto-motive force N_2I_2 on the secondary winding. According to Lenz's Law, N_2I_2 sets up a magnetic flux, Φ_2 on the secondary winding which opposes magnetic flux, Φ_1 from the primary winding. Because of the opposition, the resultant magnetic flux of the transformer decreases which in turn reduces the induced e.m.f E_1, (induced voltage on the primary winding). The strength of voltage on the primary winding V_1 becomes more than the induced voltage E_1 therefore drawing an additional primary current I'_1 from the main supply. I'_1 is used to restore the original magnetic flux by inducing a magneto-motive force N_1I_1 to set up flux Φ'_1 which is in the same direction as Φ_1 core and therefore cancelling flux Φ_2. So when the original magnetic flux is restored the strength of V_1 becomes equal to E_1.

Figure 4.3 shows current variations with time for the primary side as recorded in Table 4.3. When 750 Ω load was connected in the circuit, very little change in current was recorded compared to when 2100 Ω load was connected. The higher load consumed more current. Additionally, very high current variation was observed; from a minimum of 2.2 mA and a maximum of 42.1 mA. The fluctuations however decreased when the load was reduced to 1500 Ω and then further reduced at 750 Ω.

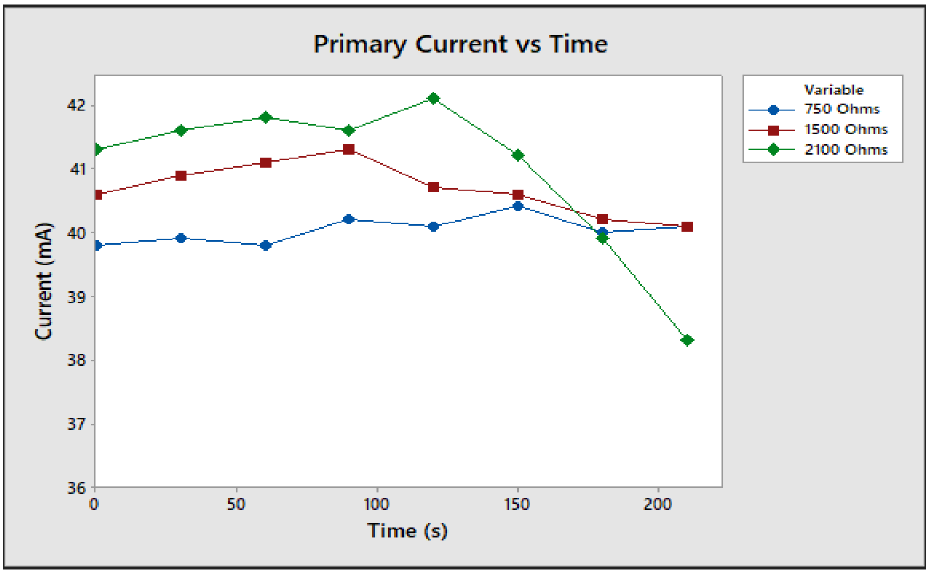


Figure 4.3: Graph of primary current with time for 750 Ω, 1500 Ω and 2100 Ω loads

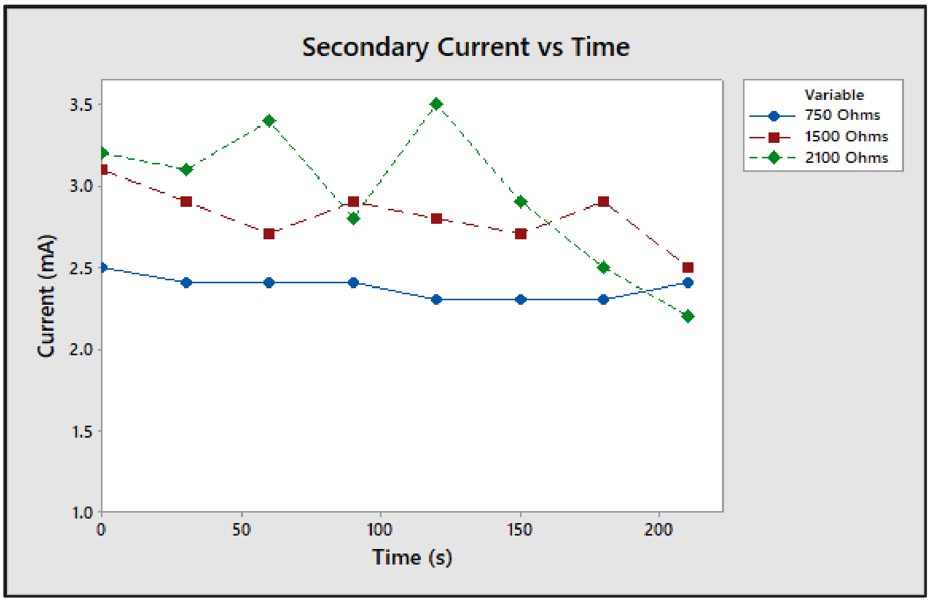


Figure 4.4: Graph of secondary current with time for 750 Ω, 1500 Ω and 2100 Ω loads

On the secondary side of the transformer, it similar observations were made with regard to the primary side. Current varied less at low loads and high when higher loads were connected. Current varied between 2.2 mA and 3.5 mA for the highest load and between 2.3 mA and 2.5 mA for the lowest load.

When load was connected to the circuit, current increased on the primary side to transfer energy to the load connected. This in turn caused an increase in the input current so as to balance the current generated by the secondary side, that is, the current to the load. Therefore, when and if load is infinitely increased, then current on primary side increases as the secondary current increases simultaneously.

4.2 Results during Manual Changeover

To further analyze transformer characteristics in a changeover system, various loads were introduced in the circuit and the results recorded in Table 4.5 to Table 12. The LCD values recorded represented the load values as expressed in the algorithm used for the simulation.

4.2,1 Current and Voltage readings with Load shift

Table 4.5: Apparent current, Resistance and LCD readings for the changeover circuit when both transformers are normally functional and the loads are within the transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.2	53.9	1	17	ON	L1
0.13	44.8	1	5	ON	L2
0.11	49.3	2	12	ON	L3
0.18	51.1	2	16	ON	L4

From Table 4.5, all the bulbs were observed lighting in the circuit. The two transformers were also observed working properly with transformer 1 supplying L1 and L2 and transformer 2 supplying L3 and L4. These observations implied that the load capacity of the transformers were not exceeded and therefore remaining stable throughout. In this case, changeover was not necessary since all conditions were met.

Table 4.6: Current, Resistance and LCD readings for the changeover circuit when both transformers are normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.2	56.4	X	17	OFF	L1
0.15	50.7	1	15	ON	L2
0.16	54.2	2	16	ON	L3
0.12	48.9	2	13	ON	L4

Table 4.7: Load current, Resistance and LCD readings for the changeover circuit when both transformers are normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.18	54.1	X	16	OFF	L1
0.21	58	1	19	ON	L2
0.25	61.3	2	20	ON	L3
0.19	54.4	X	17	OFF	L4

Table 4.8: Resistance, LCD and Apparent current readings for the changeover circuit when both transformers are normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.11	47.6	1	17	ON	L1
0.34	72.2	X	5	OFF	L2
0.09	45.3	2	12	ON	L3
0.15	52.5	2	16	ON	L4

The results in Table 4.6, 4.7 and 4.8 showed several bulbs OFF. This was because loads L1, L2, L3 and L4 had shifted in either of the conditions causing load shedding and load sharing to occur. Based on the prioritization criteria in the program, L2 is first in demand followed by L3, L1 and finally L4. In Table 4.6, the total load for transformer 1 exceeded its capacity. The microcontroller opened the relay to L1 in order to distribute the remaining load to L2, L3 and L4 in that order. These observations implied that the load capacity of transformer 1 was not sufficient to supply to the remaining load.

In Table 4.6 and 4.8, total loads exceeded the total capacity of the two transformers and therefore only distributing to the loads with the highest demands, L2 and L3. In addition to high loads, it was recorded in Table 4.8 that the highest demanding load was off regardless of its priority. This condition was created in situations where L2 was critical and had to be shut off so as to supply to the remaining Loads that met there conditions.

Table 4.9: Apparent current, Resistance and LCD readings for the changeover circuit when only one transformer is normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.2	54.7	X	17	OFF	L1
0.19	52.1	2	16	ON	L2
0.12	49.1	2	12	ON	L3
0.15	52.3	X	16	OFF	L4

Table 4.10: Resistance, Current and LCD readings for the changeover circuit when only one transformer is normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	Resistance, R (Ω)	Transformer	LCD values	Bulb	Loads
0.08	45.1	2	10	ON	L1
0.13	49.4	2	12	ON	L2
0.14	51.1	X	13	OFF	L3
0.05	44.4	2	6	ON	L4

Table 4.11: Apparent current, Resistance and LCD readings for the changeover circuit when only one transformer is normally functional and the loads exceed transformer capacity range.

Apparent Current, I (mA)	**Resistance, R (Ω)**	**Transformer**	**LCD values**	**Bulb**	**Loads**
0.27	62.7	X	20	OFF	L1
0.295	66.3	2	24	ON	L2
0.32	70.8	X	27	OFF	L3
0.2	57.9	X	18	OFF	L4

Changeover systems that have only one supply are at risk. This is because they are exposed to overloading, overheating and eventually system breakdowns. In such cases, the available current cannot sustain the connected loads and therefore quick system maintenance must be made. In Table 4.9, 4.10 and 4.11, transformer 1 records no current in the line. Transformer 2 on the other hand can only support half of the load depending on the load demands of L1, L2, L3 and L4.

In the first case, only L2 and L3 have their bulbs lighting since they are the first in the prioritization criteria. In Table 11, all the loads are supplied except L3 because the total load from L1, L2 and L4 was within the available transformer capacity. In Table 4.9, it can be shown that only the highest Load in demand is supplied with the rest being shut down.

From the results in Table 4.5 to 4.11, it was determined that for a transformer changeover system, the current demand from the transformer increased with increase in load as illustrated in Figure 4.5.

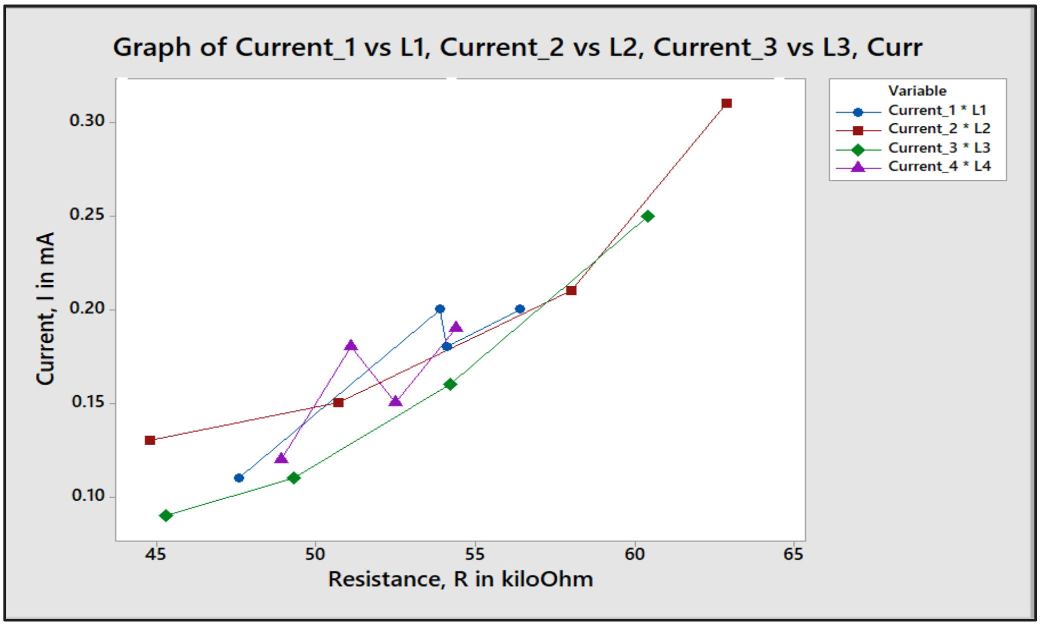


Figure 4.5: Graph of resistance, R against current, I for loads L1, L2, L3 and L4

4.3 System simulation Using PROTEUS

The Simulation of the microcontroller based changeover system was done using PROTEUS ver. 8.6 as shown in the circuit in Figure 4.6. Two input currents, I1 from transformer 1 and I2 from transformer 2 were fed to the microcontroller through the current sensor. Four input currents from L1, L2, L3 and L4 were also fed into the microcontroller to provide a feedback loop to the system. The algorithm used in the program was based on continuous comparison of the input currents from the two transformers and the currents consumed by the loads. The 8 channel and 2 channel relay modules were connected to the loads from the microcontroller to effect the switching instructions between the loads. The relays were also used as isolators in case one transformer was faulty or when a load had to be shed. The LCD display was connected to the microcontroller to show the real time status of transformer 1 and transformer 2 and load currents of L1, L2, L3 and L4 equivalents to the transformer capacity specified in the program.

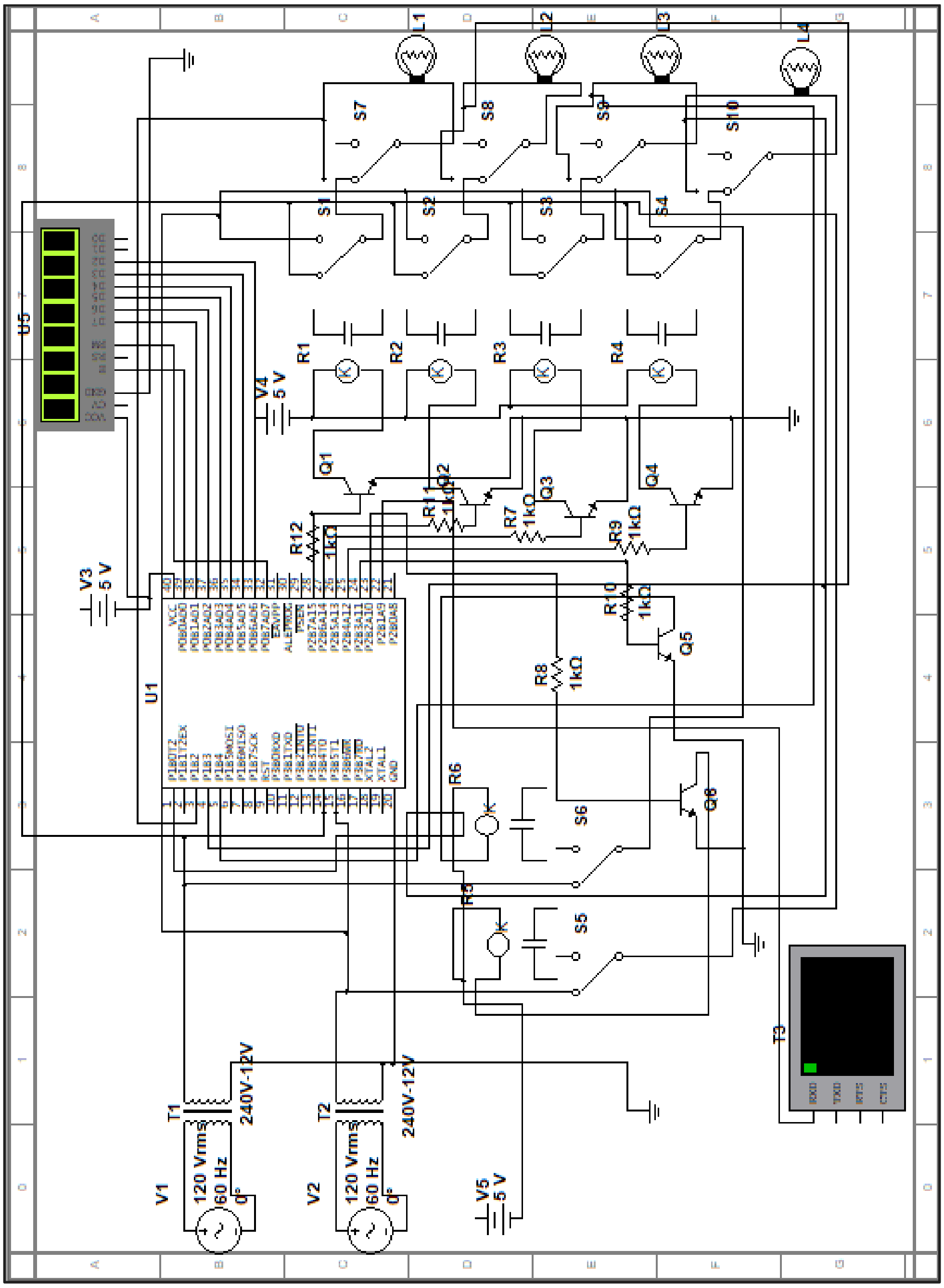


Figure 4.6: Simulation circuit diagram of the microcontroller based changeover system

4.4 The testing Results and Discussions

For the full implementation of the system, Figure 4.7 was used to illustrate the flow of the entire circuit. T1L1, T2L1, T1L2, T2L2, T1L3, T2L3, T1L4 and T2L4 represented relays 1 to 8 respectively with all the transformers connected through the relays to loads 1 to 4 as shown in Figure 4.7.

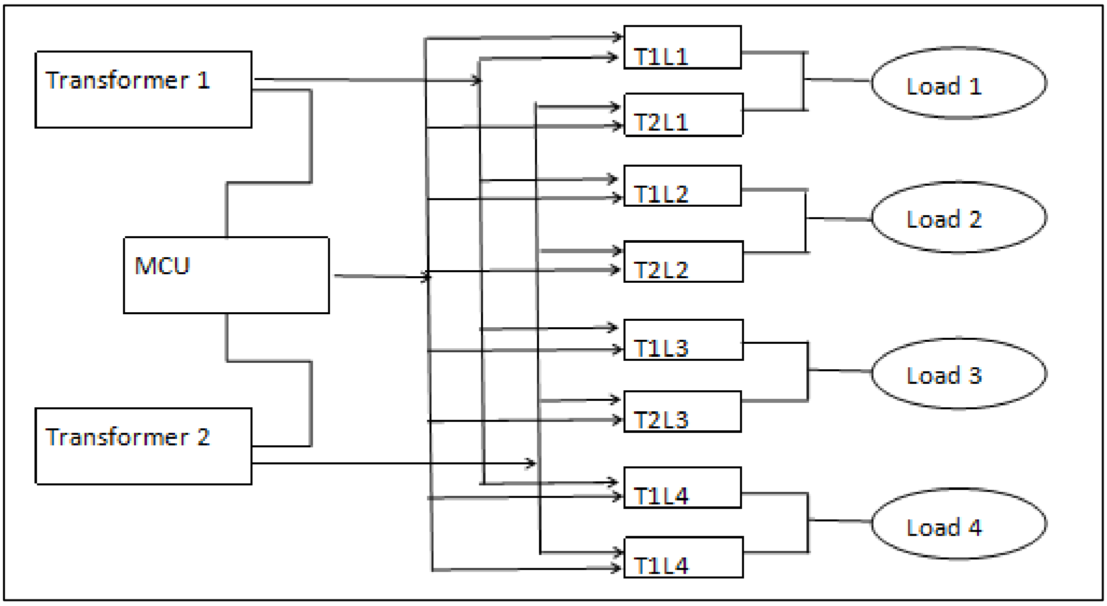


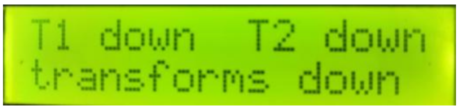
Figure 4.7: Block diagram of the testing microcontroller system

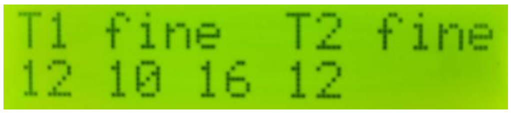
The microcontroller constantly compared the inputs from the transformer and the loads and instructed Relays 1 to 8 on which loads to close and open. This system ensured that, whenever there was a power interruption either due to failures of transformer 1 or 2, all the loads remained ON. The status of the transformers, relays and loads was observed and recorded as in Table 4.12.

Table 4.12: Automatic changeover results for transformers 1 and 2 and loads L1, L2, L3 and L4

Status of Transformers		Relays								Loads			
T1	**T2**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**L1**	**L2**	**L3**	**L4**
ON	ON	ON	OFF	ON	OFF	OFF	ON	OFF	ON	ON	ON	ON	ON
OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	ON	ON	ON	ON
ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	ON	ON	ON
OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON

For effective transformer changeover, load shedding and load sharing features included in the changeover ensured that only the loads within the specified transformer capacity in the algorithm were switched on. The display showed the status of the transformers and the loads L1, L2, L3 and L4 during the changeover process as in Figure 4.8 and 4.9, that is, which transformer between 1 and 2 was active and which loads were switched on. Since the load prioritization criteria followed L2, L3, L1 and L4 consecutively, load shedding and sharing was effected and active loads shown on the display.

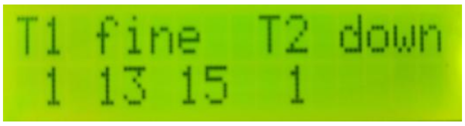




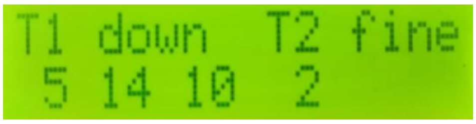
(a) (b)

Figure 4.8: LCD Display showing the status of transformer 1 and 2 when both have failed and when both are working properly together with the load values of L1, L2, L3 and L4.

Figure 4.8 (a) shows the case when both transformer T1 and T2 and down and Figure 4.8 (b) shows the case when both transformers are functional.



(a)



(b)

Figure 4.9: LCD display of the status of T1 and T2 when one transformer has failed and the respective active loads.

The experiment was purposed to verify the capability of the designed system to switch over the supply source of the loads from Transformer 1 to transformer 2 and vice-versa. Figure 4.9 (a) shows the case when transformer T2 was down while T1 was fine and only loads L1, L2 and L3 being active. This is because, when one of the transformers failed, the remaining loads were distributed to the remaining active transformer which could supply a specific load capacity. In this case, the prioritization criteria dictated that L2 then L3 then L2 then L4 be connected in that order. Figure 4.9 (b) shows when transformer T1 was down while T2 was fine. In the case where all transformers were functional and the loads exceeded the transformer capacity, the prioritization criteria was also implemented to effect load shedding and load sharing which in turn prevented transformer overloading.

The switching time of the changeover system was very negligible making the system efficient. This is because no down time was needed for either of the transformers during the changeover since the AC current/voltage was of the same frequency.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The need for continuous and uninterrupted power supply to consumers has become one of the leading demands in Kenya currently. In order to efficiently connect and supply power, efforts have been made to create and establish more power stations and substations so as to reach more consumers. With these projects in hand, the challenge to provide uninterrupted power is posed and therefore, the limitations that arise from the current conventional methods employed can be improved through this research. From the designed automatic changeover system for transformers, both high voltage and low voltage power stations can adopt this system depending on the nature of the loads required by the various sectors and consumers. Many variables are affected in the event a load is introduced in the transformer network, for instance, the frequency of the current, transformer voltage, temperature of the transformer and the current in the system. Load mainly affects the current in the transformer network in that, any increase in the load increases the current and vice versa. These variations may in turn cause voltage and frequency instability leading to an unstable system. With the implementation of this microcontroller based changeover system, any increase or decrease of current is detected before supplying to the consumers using the current sensors. The available current is then distributed among the existing loads through the AC relays ensuring supply continuity throughout and at the same time preventing transformer overloading challenges.

5.2 Recommendations for further research

This research focused mainly on power supply and therefore the results are important to power distribution and technological stakeholders in the energy industry for smart grid developments and designs. The assumption made in this study is that the transformers used in the stations are similar in terms of ratings. The assumption was adopted for the purpose of designing a quick automatic changeover system that did not require time lapse. However, based on the assumptions made in this study, transformer parameters and ratings vary from transformer to transformer. The methodology used required that all the transformers be similar in capacity and rating so that current and voltage characteristics are not interfered with during the changeover. This also eliminated the need for time delay during the changeover process. Further research should be carried out for dissimilar transformers to eliminate time lapse and develop other mechanisms to efficiently switch between transformers.

Additionally, due to scaling factors, in the case of wider areas, further experimental designs are recommended using microcontrollers.

REFERENCES

Abhishek, H., Vinayaka, S., Vani, H., Sudha, H., & Kumar, P., (2017). Effective Load Sharing of Distribution Transformers with Safety Cut-off Using GSM Technology. *Journal for Research in Applied Science & Engineering Technology*, 5356-5368.

Ahmed, M., Mohamed, A., & Agusiobo, O., (2006). Development of a Single Phase Automatic Changeover Switch. *Au Journal Of Technicial Report* , *8*(17), 68-74.

Amadi, A., Umeogamba, A., Ogbuka, C., Nwosu, C.,Chinaeke, O., & Odo, M., (2019). A 5KVA Automatic Transfer Switch with Overload, Short Circuit Protection and Generator Stop Functions. *2019 Ieee 1st International Conference On Mechatronics, Automation And Cyber-Physical Computer System*, 69-81.

Amuzuvi, C., & Addo, E., (2015). A Microcontroller-Based Automatic Transfer Switching System for a Standby Electric Generator. *Ghana Mining Journal*, 2:18-36.

Atser A. & Roy G. (2014). Design and Implementation of a 3-Phase Automatic Power Change-Over Switch. *American Journal Of Engineering Research (Ajer)*, *3*(9), 7-14.

Christian, M. (2012). Smart Change Over System with AT89C52 Microcontroller. *Iosr Journal Of Electrical And Electronics Engineering*, *22*(3), 31-34.

Ezema, L., Peter, B., Harris, O., & Power, E., (2012). Design of Automatic Change Over Switch with Generator Control Mechanism. *Natural Anf Applied Sciences* , *36*, 125-130.

Hasanah, R. Soeprapto, S., & Adi, P., (2018). Arduino-based Automatic Transfer Switch for Domestic Emergency Power Generator-Set. *Advanced*

Information Management, Communicates, Electronic and Automation Control Conference, 742-746.

Himadri, S. & Sayan, D., (2016). Design of Automatic Phase Selector from any Available Three Phase with the Use of Logic Gate and Relay Driver. *International Journal Of Innovations In Engineering And Technology, 7*(12), 91-104.

Joji, J., Christy, P., Akhil, A., Justin, J., & Koilraj, A., (2017). Substation Automation System for Energy Monitoring and Control Using SCADA. *International Journal of Recent Trends in Engineering and Research*, 980-994.

Juan, M., & Edward, J., (2004). *Protection of Electricity Distribution Networks, 2nd Edition.* London, United Kingdom: The Institution of Engineering and Technology Publishers, *1*(2), 66-68.

Obasi, C., Olufemi, B., John, J., Victor, O., & Ubadike, C., (2015). Design and Implementation of Microcontroller Based Programmable Power Changeover . *Computer Engineering And Intelligent Systems* , *11*(23), 38-50.

Ofualagba, G., & Udoha E., (2017). Design and Simulation of Automatic Phase Selector and Changeover Switch for 3-Phase Supply. *International Journal of Novel Research in Electrical and Mechanical Engineering, 4*(2), 28-35.

Okpala, U., & Ilomuanya, U., (2016). Implementation of the Designed Automatic Changeover System for the Department of Physics. *International Journal of New Technology and Research*, *2*(4), 130-136.

Osaretin C., Ibhadode E., & Igbinovia, S., (2016). Design and Implementation of Automatic Changeover Switch (With Step Loading) for Renewable Energy Systems. *Int. J. Renew. Energ and Environ*, *34*(6), 179-192.

Rockis, C., & Mazur, A. (2001). *Electrical Motor Controls.* New York: American Technical Publisher, *3*(2), 138-163.

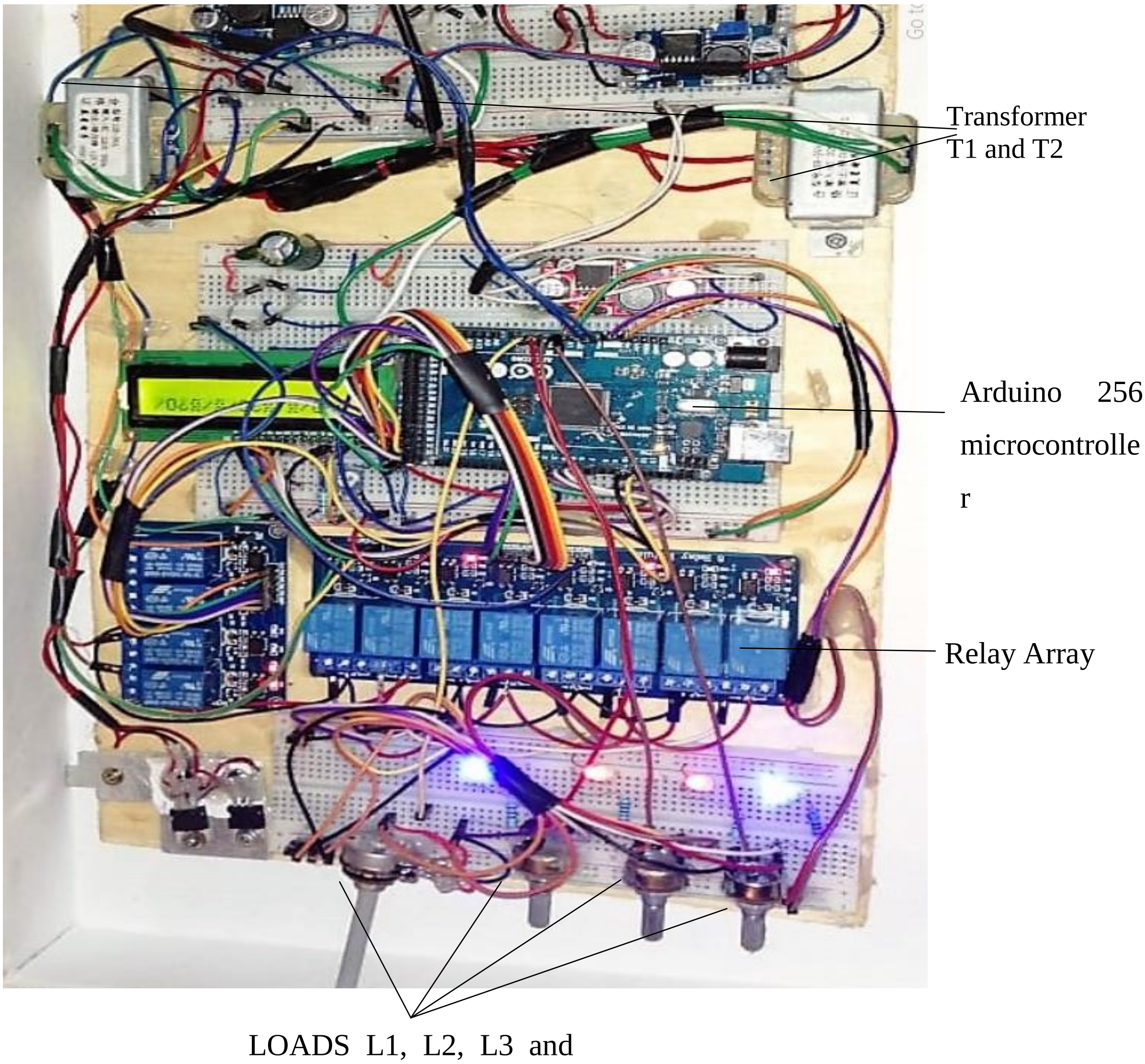
Syadli, H. Abdullah, M., Hassan, M., Hussin, F., & Faridiansyah, I., (2016). An improved load shedding scheduling strategy for solving power supply defisit. *Jurnal Teknologi (Science and Technology)*, *7,* 5-7.

Uzedhe, G., Ekene, M., & Chukwubuikem, M., (2012). A Cost Effective Approach to Implementing Changeover Systems. *Academic Research International*, *14*(2), 62-72

Zhang, C., Ren, W., & Wang, T., (2019). Modeling and Experimental Verification of Contact Sliding Behavior for Flexible Spring Components within Electromechanical Relays. *Ieee Transactions On Components, Packaging And Manufacturing Technology*, 78-96.

APPENDICES

Appendix I: The designed changeover system plate



Appendix II: Program code

```
float T1_overload , T2_overload , T1_load , T2_load , L1 , L2 , L3 , L4, RL1
, RL2 , RL3 , RL4;

boolean T1shutdown , T2shutdown , T1overload, T2overload , UL11 , UL12
, UL21 , UL22 , UL31 , UL32 , UL41 , UL42;

floatT_max_load = 30;

int T1 = 2;

int T2 = 3;

int L1T1 = 4;

int L1T2 = 5;

int L2T1 = 6;

int L2T2 = 7;

int L3T1 = 8;

int L3T2 = 9;

int L4T1 = 10;

int L4T2 = 11;

void setup() {

Serial.begin(9600);

delay(100);
```

```
int x;

for (x = 2 ; x < 12 ; x++) {

pinMode(x, OUTPUT);

digitalWrite(x, LOW);

  }



digitalWrite(T1, HIGH);

digitalWrite(T2, HIGH);

  T1_overload = T2_overload = T1_load = T2_load = L1 = L2 = L3 = L4 = 0;

  T1shutdown = T2shutdown = T1overload = T2overload =  false;

load(1, 0, 1, 0, 0, 1, 0, 1);

}

void loop() {

if (T1shutdown) {

load(0, 0, 0, 0, 0, 1, 0, 1);

  }

if (T2shutdown) {

load(1, 0, 1, 0, 0, 0, 0, 0);

  }
```

```
  T1_overload = map(analogRead(A0), 0, 1023, 0, 40);

  T2_overload = map(analogRead(A1), 0, 1023, 0, 40);

  RL1 = map(analogRead(A2), 0, 1023, 0, 100);

  RL2 = map(analogRead(A3), 0, 1023, 0, 100);

  RL3 = map(analogRead(A4), 0, 1023, 0, 100);

  RL4 = map(analogRead(A5), 0, 1023, 0, 100);

  L1 = RL1;

  L2 = RL2;

  L3 = RL3;

  L4 = RL4;

Serial.println(String(RL1) + " " + String(RL2) + " " + String(RL3) + " " + String(RL4));

if (L1 >= T_max_load&& L2 >= T_max_load&& L3 >= T_max_load&& L4 >= T_max_load) {

return;

  }

checkoverload();

switchloads();

checkoverloadagain();

upload();
```

```
delay(100);

}

void load(boolean L11, boolean L12, boolean L21, boolean L22, boolean L31, boolean L32, boolean L41, boolean L42) {

  UL11 = L11;

  UL12 = L12;

  UL21 = L21;

  UL22 = L22;

  UL31 = L31;

  UL32 = L32;

  UL41 = L41;

  UL42 = L42;

}

void upload() {

digitalWrite(L1T1, UL11);

digitalWrite(L1T2, UL12);

digitalWrite(L2T1, UL21);

digitalWrite(L2T2, UL22);

digitalWrite(L3T1, UL31);

digitalWrite(L3T2, UL32);
```

```
digitalWrite(L4T1, UL41);

digitalWrite(L4T2, UL42);

}

voidcheckoverload() {

if (RL1 >= T_max_load) {

    L1=0;

  }

if (RL2 >= T_max_load) {

    L2=0;

  }

if (RL3 >= T_max_load) {;

    L3=0;

  }

if (RL4 >= T_max_load) {

    L4=0;

  }

}

voidcheckoverloadagain() {

if (RL1 >= T_max_load) {
```

```
    UL11 = false;
    UL12 = false;
  }
if (RL2 >= T_max_load) {
    UL21 = false;
    UL22 = false;
  }
if (RL3 >= T_max_load) {
    UL31 = false;
    UL32 = false;
  }
if (RL4 >= T_max_load) {
    UL41 = false;
    UL42 = false;
  }
}
voidswitchloads(){
  T1_load = L1 + L2;
  T2_load = L3 + L4;
```

```
if (T1_load <T_max_load&& T2_load <T_max_load) {
load(1, 0, 1, 0, 0, 1, 0, 1);
  }
else if ((L1 + L3) <T_max_load&& (L2 + L4) <T_max_load) {
load(0, 1, 1, 0, 0, 1, 1, 0);
  }
else if ((L1 + L4) <T_max_load&& (L2 + L3) <T_max_load) {
load(0, 1, 1, 0, 1, 0, 0, 1);
  }
else if (L2 <T_max_load&& (L1 + L3 + L4) <T_max_load) {
load(0, 1, 1, 0, 0, 1, 0, 1);
  }
else if (L1 <T_max_load&& (L2 + L3 + L4) <T_max_load) {
load(1, 0, 0, 1, 0, 1, 0, 1);
  }
else if (L3 <T_max_load&& (L1 + L2 + L4) <T_max_load) {
load(1, 0, 1, 0, 0, 1, 1, 0);
  }
else if (L4 <T_max_load&& (L1 + L2 + L3) <T_max_load) {
```

```
load(1, 0, 1, 0, 1, 0, 0, 1);

  }

else if ((L1 + L2) >= T_max_load&& L1 > L2 && L1 <T_max_load&& (L2
+ L3) <T_max_load) {

load(1, 0, 0, 1, 0, 1, 0, 0);

  }

else if ((L1 + L2) >= T_max_load&& L1 > L2 && L1 <T_max_load&& (L2
+ L3) >= T_max_load&& (L3 + L4) <T_max_load) {

load(0, 0, 1, 0, 0, 1, 0, 1);

  }

else if ((L1 + L2) >= T_max_load&& L1 > L2 && L1 <T_max_load&& (L1
+ L3) <T_max_load) {

load(0, 1, 1, 0, 0, 1, 0, 0);

  }

else if ((L1 + L2) >= T_max_load&& L1 > L2 && L1 <T_max_load&& (L1
+ L3) >= T_max_load&& (L3 + L4) <T_max_load) {

load(0, 0, 1, 0, 0, 1, 0, 1);

  }

else if ((L1 + L2) >= T_max_load&& L2 >= L1 && L2 <T_max_load&&
(L1 + L3) <T_max_load) {

load(0, 1, 1, 0, 0, 1, 0, 0);
```

```
}

else if ((L1 + L2) >= T_max_load&& L2 >= L1 && L2 <T_max_load&& (L1 + L3) >= T_max_load&& (L3 + L4) <T_max_load) {

load(0, 0, 1, 0, 0, 1, 0, 1);

}

else if ((L3 + L4) >= T_max_load&& L4 > L3 && (L1 + L2) <T_max_load) {

load(1, 0, 1, 0, 0, 1, 0, 0);

}

else if ((L3 + L4) >= T_max_load&& L3 >= L4 && L3 <T_max_load&& (L1 + L2) <T_max_load) {

load(1, 0, 1, 0, 0, 1, 0, 0);

}

/*

else if ((L1 + L2) >= T_max_load&& (L3 + L4) >= T_max_load&& L2 <T_max_load&& (L1 + L4) <T_max_load) {

load(0, 1, 1, 0, 0, 0, 0, 1);

}

else if ((L1 + L2) >= T_max_load&& (L3 + L4) >= T_max_load&& L2 <T_max_load&& L1  <T_max_load) {

load(0, 1, 1, 0, 0, 0, 0, 0);
```

```
}

else if ((L1 + L2) >= T_max_load&& (L3 + L4) >= T_max_load&& L3 <T_max_load&& (L1 + L4) <T_max_load) {

load(1, 0, 0, 0, 0, 1, 1, 0);

}

else if ((L1 + L2) >= T_max_load&& (L3 + L4) >= T_max_load&& L3 <T_max_load&& L1 <T_max_load) {

load(1, 0, 0, 0, 0, 1, 0, 0);

}

*/

else if ((L1 + L2) >= T_max_load&& (L3 + L4) >= T_max_load&& L2 <T_max_load&& L3 <T_max_load) {

load(0, 0, 1, 0, 0, 1, 0, 0);

}
```

Appendix III: Paper Published