TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF ELECTRICAL ENGINEERING

A FINAL YEAR PROJECT REPORT
ON

"DESIGN AND FABRICATION OF SOLID-STATE ON-LOAD TAP CHANGER"

(A Project Report submitted in partial fulfilment of the requirements for the Bachelor's Degree in Electrical Engineering)

EE755

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APRIL 28, 2023

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ACKNOWLEDGEMENT

First and foremost, we would like to express our sincere gratitude to our Supervisor Dr. Prof. Nava Raj Karki and Ass. Prof. Mohammad Badrudoza for their guidance, motivation and continuous support in our project. We could not have imagined a better advisor and mentor. We would like to express our deepest regards to the Head of Electrical Engineering Department for valuable and kind support during the project. Our sincere thanks go to all the Professors and Lecturers in the department for their precious suggestions and lead throughout the project duration. Last but not the least, we would like to thank all the staff of the department and our friends for their cooperation and support.

We are thankful to the authors of various research papers we cited to reach to the current stage of the project. Any sort of suggestions or criticism will be highly appreciated and acknowledged.

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ABSTRACT

In the recent time, the continuous, uninterrupted and fast power supply along with high efficiency is one of the major concerns in the field of power system. It is necessary that our system should react quick to increase and decrease in heavy as well as light load. The on-load tap changers have become one of the important parts of transformer in order to regulate the constant output voltage without disconnecting the load.

The purpose of this project is to design the most convenient type of tap-changing system that omits all the disadvantage of the present type of tap changing. It focuses on how current tap changing system is working, what are the problems associated with it and hence how can we replace them by using modern tools, devices, systems and methods. Earlier mechanical type on-load tap changers were in use which had major shortcomings like arcing, slow response time, high maintenance and service costs. And these get even worse in the case distribution transformers which are manually operated that too after disconnection of load and hence do not provide dynamic control over output voltage and require constant human intervention. Due to these flaws of the mechanical type, solid-state (electronic) tap changers were introduced.

Electronic OLTCs are even more effective these days due to advent of power semiconductor devices like IGBT, triac, etc. that have led to improved operating characteristics like no arcing, fast switching and lower losses along with lower implementation costs and high controllability. This makes it even more favourable for replacement of mechanical tap changers available in distribution transformers. We have used power electronic components like Optocoupler and Triac as a switching device and control them by sending switching signal from microcontroller. Generally, Load vary in practical system and tap changers are used in HV side of transformer but for implementing hardware we have kept Tap-Changer in low voltage side and vary input voltage. We have used two centre-tapped transformer and implement three switching configurations so as to satisfy the working principle of On-load Tap Changer.

The constant output voltage in the desired range is achieved with continuous change in input power supply. When the input supply is decreased, the output voltage reaches the minimum range where the tap is changed and output voltage get increased to maximum limit value of output voltage and similarly if the input supply is increased, the output voltage will reach the maximum limit, thus changing the tap and reducing output voltage to minimum limit.

This project introduces the most efficient method of tap-changing system by replacing old, bulky, manually operating and late reacting system of tap-changing. The newly introduced system is easy in designing, small in size, arc free, quick responsive, automatic, easy to handle and economical for investing, operating and maintaining. Thus, in this report implementation of such EOLTC is presented with micro- controller-based control strategy providing higher degree of flexibility in modifying the control algorithms.

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LIST OF ABBREVIATIONS

A/D=Analog to Digital

ac = alternating current

D/A=Digital to Analog

dc = direct current

ELOTC = Electronic OLTC

HV = High Voltage

IGBT = Insulated Gate Bipolar Transistor

LV = Low Voltage

OLTC = On-Load Tap Changer

PWM=Pulse Width Modulation

SCR = Silicon controlled rectifier

CHAPTER ONE
INTRODUCTION

1.1 Background

With the growing urbanization and industrialization, the energy demand is increasing rapidly. The substations of previously installed capacity are facing difficulties in meeting instantaneous demand due to increase in load. This increased in the load on the secondary side of the transformer is called overloading of the transformer. This increase in load decreases the terminal voltage of the transformer and the current in both the side increases.

As there is overloading in the transformer, it causes overheating, and eventually thermal degradation of the insulation, reducing its life. Thus, it is necessary to protect the transformer from overloading for healthy operation of the system.

A tap changer is an integral part of transformers that enables the selection of variable turn ratios in specific increments. Its purpose is to adjust the turn ratio on the primary side of the transformer in response to load changes occurring on the secondary side. By doing so, the tap changer ensures that the rated output voltage remains consistent on the secondary side, thus safeguarding the transformer from potential consequences arising from overloading.

Based upon the way we use them, there are two types of tap changer i.e., Off-load tap changer and On-load tap changer. Off-Load tap changer are used when load is not supplied meanwhile On-load tap changer are used when the load is supplied continuously. On the other hand, on the way of designing the tap changer, they are categorized as Mechanical tap changer and electronic tap changer. Electronic tap changer is constructed using different solid-state switches like SCR, IGBT with their own principle of operation and Mechanical tap changer are constructed using mechanical moving parts with the different principle of operation than those of electronic tap changer.

Owing to the different facts like efficiency, cost, principle of operation and various factors, Electronic On-load tap changer (EOLTC) also known as solid state on-load tap changer is considered as the best of all and it was the reason behind for us opting to design and fabricate Electronic On load Tap Changer.

1.2 Problem statement

An essential concern in safeguarding transformers is the significant expense associated with their replacement and the considerable duration of power outages resulting from the failure of a large transformer. The main problem that the transformer faces is the abnormal increase and decrease in the load at the consumer end. This led to voltage fluctuation on distribution network. Also, line to ground fault on any feeder causes voltage sag to occur on parallel feeders that might affect power quality. This voltage fluctuation on the distribution network might affect voltage sensitive loads. Also, the current increases beyond limitation with decrease in terminal voltage. So, the terminal voltage across of the transformer needs to be somewhat constant. Because increase in current causes more I2R losses which leads to poor efficiency of transformer. Similarly, voltage swell leads to decrease in current. This may cause insulation failures. Thus, tap changer is used for overall improvement of power stability.

The transformers with the off-load tap changer are used widely in the distribution network, but they do not satisfy the requirement of dynamic voltage regulation at the consumer end. That’s why on-load tap changer is much preferred for voltage regulating over offload tap changer.

The stability of the voltage was affected by the working of the OLTC. The transformer is often equipped with a more sophisticated and costly on-load tap changing mechanism. Recently, solid state on-load tap changer has been presented to eliminate the OLTC limitations and drawbacks.

1.3 Objective

The major objectives of our project are as follows:

- To demonstrate the working of tap changer.
- To design and hardware fabricate Solid State On-load Tap Changer.

1.4 Scope and limitations of project

The proposed system has some scopes and limitations:

➢ **Scopes**

- Applicable at distribution level to regulate the consumer voltage without constant monitoring and manual intervention.

- Applicable in Power Transformers for regulation of LV side voltage with minimal losses and fast switching.
- Multiple voltage levels using low number of switches which is not possible in mechanical OLTC.
- This will improve overall power system stability.

➢ **Limitations**

- One of the major problems of electronic tap-changer is its cost.
- Complex circuitry and control strategy.

1.5 Report Organization

This project consists of following chapters:

- This project constitutes five chapters including the current chapter. This chapter explains about the different types of tap-changers and needs of electronic onload tap-changer to overcome the deficiency of current type tap-changer. Also, it covers statement of problem, objective of this project along with scopes and limitations.
- Chapter two provides a literature review on literature review on theory and articles or publications from IEEE conferences or transactions as well as books from the major publishers. The main intention behind it is to find available information and results from other researches.
- Chapter three explains the methodology for modelling of electronic onload tap-changer, working of voltage sensor, working of analog to digital converter using Arduino and the design of snubber circuit for protection.
- Chapter four presents the simulation and hardware result and discussion regarding the controlling of tap-changing phenomenon and its performance in different cases.
- Chapter five conclude the result and present the future work that can be done.

CHAPTER TWO
LITERATURE REVIEW

2.1 Journal review

B. Kommey et al. [1] have proposed and tested a system for on-load tap changing on single phase power transformers with solid state devices. Compared to other on-load tap changing systems it is more effective, accurate, and cost effective, eliminates arcing, contact wear since there are no movable parts, reduces maintenance cost, improves switching time, system safety, and stability.

Jawad Faiz et al. [2] put forward some common differences between the working of mechanical and electronic on-load tap changer. The paper explains with complete simulation on MATLAB.

Josemar de Oliveira Quevedo, and groups [3] have presented their theory on design of electronic on-load tap changer for distribution transformer which helps in Automatic Voltage Regulation. When it is submerged with communication features, the system allows the remotely control of the voltage levels and controlling of the grid variables. It provides revenue control, loadshedding, power dispatch control for DG applications, among others. These Characteristics are expected improvements for actual and smart grid distribution systems.

N.Nagalakshmi, T.Thivagar et al. [4] explain in their research about electronic tap changer with five tapping switches by the use of TRIAC to control voltage deviation and measurement of current to reduce over voltage problem, and steady the entire system without affecting in excess of voltage problem.

G.R. Chandra Mouli et al. [6] explain Power electronic OLTC transformers can be constructed using old-type two-winding transformers or auto transformers. The cost and stuff required for the OLTC relies mainly on the following five factors:

1. OLTC is constructed using a two-winding transformer or an autotransformer
2. Nominal voltage rating and current rating of the windings of transformer.
3. Taps number/semiconductor switches.
4. Nominal voltage and current rating of the semiconductor type switches.
5. Fault states in the network, control and protection.

V. S. Bugade et al. [10] explain the drawbacks of mechanical tap changer and introduce Automatic Voltage Control on-load (AVCL) type tap changer for upholding constant output voltage. Using of AVCL system on primary side will give the fast response, removing arcing issues, remove wear and tear, decrease of losses, maintains equipment safety and man kinds.

A. Ismail, h. Alsuwaidi et al. [11] explain IGBT based OLTC and non-linear hysteresis control algorithm which setups the commutation of the taps without unnecessary short circuit operation of the taps. It shows ability of designed system to present accurate voltage regulation at end user side and adroitness of designed system to fix voltage sag and swell in maximum period of one cycle.

2.2 Theory

2.2.1 Microcontroller

A microcontroller is a compact integrated circuit designed to govern a specific operation in a system. Microcontrollers are often low-powered devices which takes input from the sensors or input ports and sends signals to different components in the device. These devices are often small and low cost due to which the system can be made compact and economical. Moreover, the use of microcontrollers increases the flexibility of the system as they are fully programmable. Among various microcontrollers available in the market like ATMEGA8, ATMEGA16, ATMEGA32, we can use either of these for our project.

Fig. 2.1 shows a typical internal structure of the microcontroller including data and address buses that interface microprocessor with I/O devices and memory and to ease these interactions, microcontroller is provided with peripherals, timers, serial I/O and A/D converters. Due to these features, microcontroller can be considered as an independent entity on itself with all the required components to drive it.

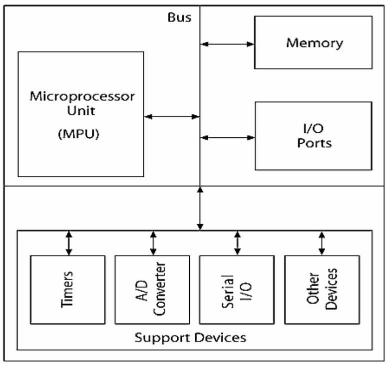


Fig. 2.1: Internal configuration of microcontroller [12]

2.2.2 On-Load Tap Changer (OLTC)

The transformer containing the tap setting which is changed without being disconnected from main supply is called On-Load Tap Changing Transformer. Taps are changed according to change in load in order to maintain constant output voltage. OLTC is equipped with special characteristic that tap position is changed without interrupting the main circuit supply. Generally, tapping is placed at the HV winding of transformer because the current in HV side is less so that low-cost insulation and small tapping lead can be used. With the change in load, voltage of the system is changed and in order to maintain constant output voltage tap changing is done. Generally, transformers are equipped with OLTC in HV side.

The OLTC is placed in oil filled compartment which is either remotely or locally controlled. There is provision of disconnecting handle in case of emergency. While the tap is changed from one portion to other, arcing occurs due to short circuit between two adjacent tapping. Thus, to minimize the Short-circuited current, impedance which may be resistance or centre tapped reactance is used.

For simulation centre-tapped transformer (tran2P3S) is used as 3 tap changers.

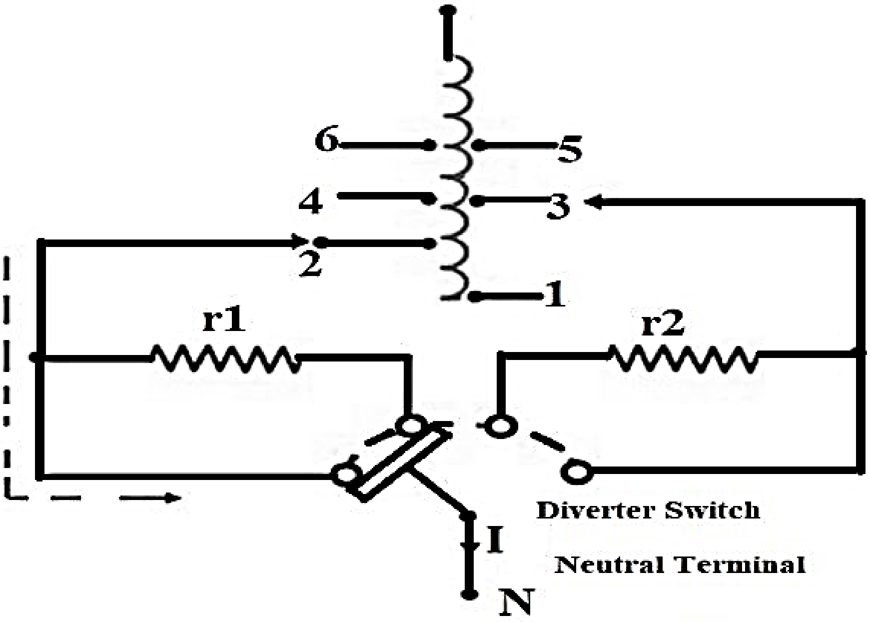


Fig. 2.2: Mechanical on-load tap changer [13]

Fig. 2.2 shows a schematic of a conventional on load tap changer with different taps drawn from the windings of the transformer in an alternate fashion such that the diverter switch can choose between the simultaneous taps just by to-and-fro motion with just a control mechanism attached to it. And these switch diverters are provided with either resistors or reactors so as to control the circulating current while switching from one tap to another and hence reducing losses and transients.

2.2.3 Triac

A Triac which is also called bidirectional switch is three terminal AC switch which conducts when applied gate signal is positive or negative. Thus, it is used as a switch in our OLTC circuit.

When the applied gate voltage is higher than breakover voltage, triac is turned on. On the other hand, if the gate signal is applied for 35 micro second, it turns on. Similarly, Gate triggering method is used to turn it on for applied voltage being less than breakover voltage.

Fig. 2.3 shows a schematic of Triac which can considered as back-to-back connected power transistors that conducts the ac current with common gate such that both of them can be controlled via same gate signal.

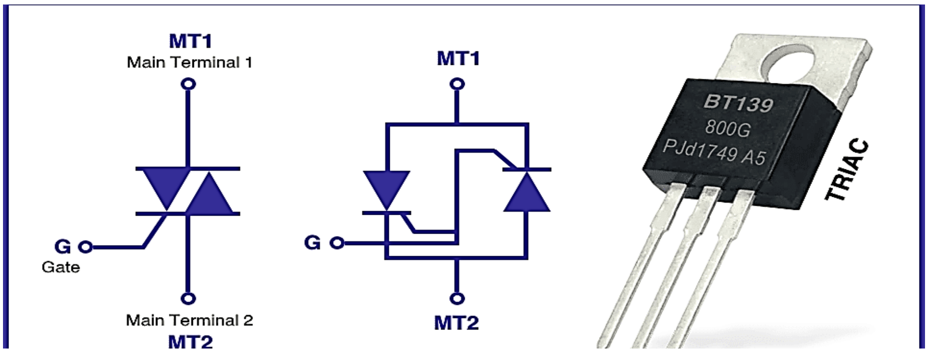


Fig. 2.3: Triac [14]

Fig. 2.4 is the switching characteristics of the Triac and as can be seen in the fig 2.4 Triac in both the regions i.e., conducts the ac current. In both of the regions, it has both conducting state and blocking state, and once the current exceeds the latching current or its gate receives gate signal, the Triac becomes conductive and the voltage drop between the main terminal and gate reduces significantly.

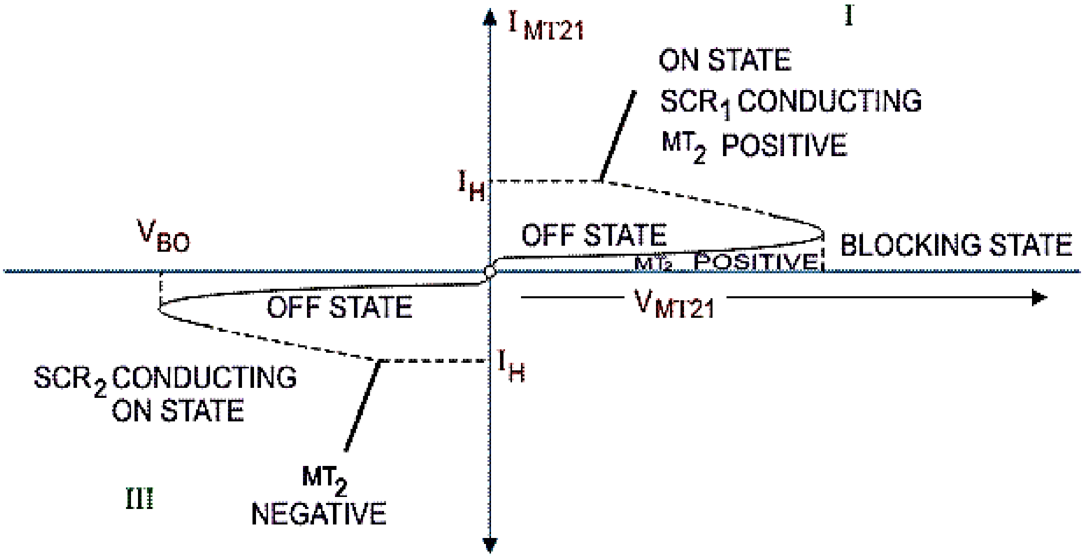


Fig. 2.4: V-I Characteristics of Triac [15]

2.2.4 di/dt Protection

Thyristor needs small amount of time in order to spread the current uniformly throughout the junction. If rise in anode current is very fast compared to spread velocity, a localized hot spot is created where heating occurs due to high density and the device may fail due to excessive temperature. To limit this eddy inductance is used as shown in Fig.

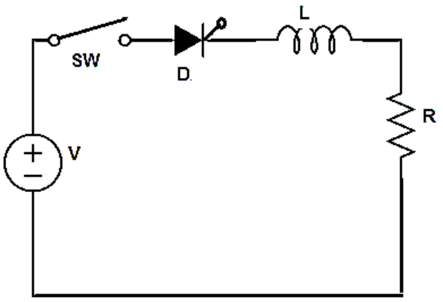


Fig. 2.5: di/dt protection [16]

From the fig 2.5, when SW switch is closed and the SCR is turned on by supplying gate pulse, then the voltage equation of circuit becomes

$$V = R * i + L\frac{di}{dt} \text{……………………………………………………..……….(2.1)}$$

Solving the above equation, the anode current becomes,

$$i = \left(\frac{V}{R}\right)\left[1 - e^{-\frac{t}{\tau}}\right] \text{…………………………………………………..…..…..….(2.2)}$$

where $\tau = \frac{L}{R}$ ………………………………………………………..……..….(2.3)

Differentiating the equation 2.2 w.r.t time, we get

$$\frac{di}{dt} = \left(\frac{V}{L}\right) e^{-\frac{t}{\tau}} \tag{2.4}$$

di/dt will be maximum just after the start of SCR conduction. Suppose the instant of maximum di/dt be at time t = 0. Then, the maximum value of di/dt can be written as,

$$\left(\frac{di}{dt}\right)_{max} = \frac{V}{L} \tag{2.5}$$

But S is the maximum permissible value of di/dt of SCR, so

$$\left(\frac{di}{dt}\right)_{max} \leq S$$

$$\left(\frac{V}{L}\right) \leq S$$

$$L \geq \left(\frac{S}{V}\right) \tag{2.6}$$

Thus, (S/V) is the minimum value of inductance where S is the permissible value of di/dt and V is the voltage of voltage source. If AC voltage source is used instead of DC, then peak AC voltage V_m should replace V in the expression of L.

2.2.5 dv/dt protection

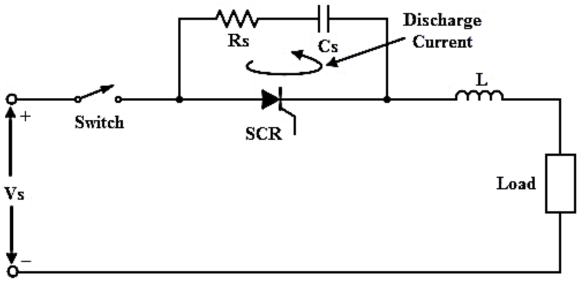


Fig. 2.6: dv/dt protection [17]

From the fig 2.6, If switch is closed at time t = 0, a step voltage will be applied across the SCR and dv/dt across the SCR may be high enough to turn on the device. Such a method of turning on the device. Such a method of turning on the device may be destructive. The dv/dt can be limited by connecting a snubber circuit as shown in fig 2.7. The voltage across the thyristor will rise exponentially and dv/dt can be turned on approximately as follows: -

$$\frac{dv}{dt} = \frac{0.632vs}{R_S C_S} \quad \text{......(2.7)}$$

The value of Rs is from the discharge current

$$Rs = \frac{Vs}{I_{scr}} \quad \text{......(2.8)}$$

The snubber circuit consists of a resistance R and a capacitor C in series placed in parallel with a SCR. When applied voltage is negative, commutation occurs and forward current becomes zero. But current flows as a result of sweeping of charge carriers at external junction due to inductance. The flowing current continues until it reaches peak and then falls to zero quickly which results in voltage spike having value of L(di/dt). When switch is closed, a sudden voltage is seen across SCR but when thyristor is opened, capacitor C work as a short circuit and voltage across SCR becomes zero. As the time goes on Capacitor C get charged at a very slow rated limit dv/dt at the rating of device. Thus, the capacitor protects the SCR against high voltages and high dv/dt. From above discussion we can conclude simply a Capacitor C is enough to protect the SCR against dv/dt false triggering.

2.2.6 Optocoupler

An optocoupler is a power electronic component which uses light to transfer electrical signal between two isolated circuits. It protects LV DC system from HV AC system. The available optocoupler can withstand 10KV of input to output voltages and voltage transients with speed up to 25kv/us.

Fig. 2.7 shows a schematic of the opto-coupler used in this project that consists both photo diode and photo transistor in same IC and, once the photo diode in the DC side of the circuit is triggered by external gate signal which in turn fires the photo transistor making it conductive in the AC side of the circuit and hence enables us to control the HV AC side with LV DC signal.

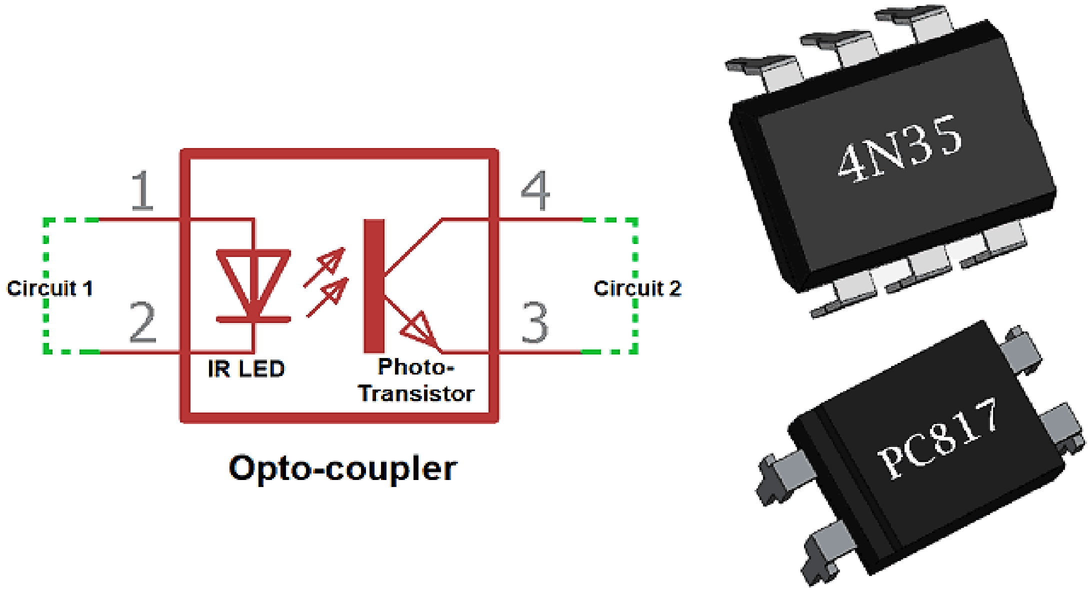


Fig. 2.7: Internal structure of optocoupler [18]

2.2.7 Voltage Sensor

Voltage sensors are wireless tools capable of being affixed to various assets, machinery, or equipment to enable continuous monitoring. Their primary function is to constantly observe voltage data, which can serve as an indicator of potential problems. An excessively low voltage reading may suggest an impending issue, while excessively high voltage levels can pose a threat to other assets. Once predefined thresholds are surpassed, immediate alerts are transmitted to a centralized computer system. These sensors operate by detecting magnetic fields, measuring magnetic flux, as well as determining the direction and strength of specific magnetic fields between two components. Additionally, they are capable of detecting electromagnetic fields, which enables them to monitor the intensity of these waves in critical assets. Moreover, voltage sensors can measure contact voltage. By leveraging this information, maintenance teams can acquire a comprehensive understanding of their equipment and assets.

CHAPTER THREE

METHODOLOGY

3.1 Overview

Following is the block diagram of our proposed system

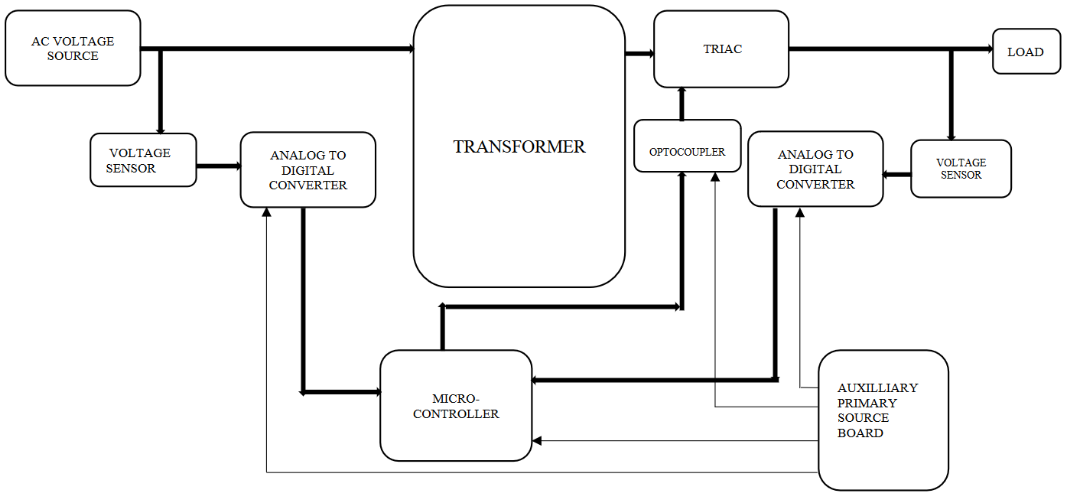


Fig. 3.1: Proposed EOLTC System

In the block diagram fig. 3.1, analog voltage sensed by voltage sensor is then digitalized by the Analog to Digital Converter which is then processed by microcontroller into actual value of voltage. Microcontroller then compares this sensed value of voltage with the reference voltage. If the sensed voltage is beyond the limit set by reference voltages, then appropriate command to change tap position is given to the optocoupler-triac firing circuit. Appropriate optocoupler then fires the triac associate with it acting as power electronic switch. This process is shown in flowchart given in fig 3.2.

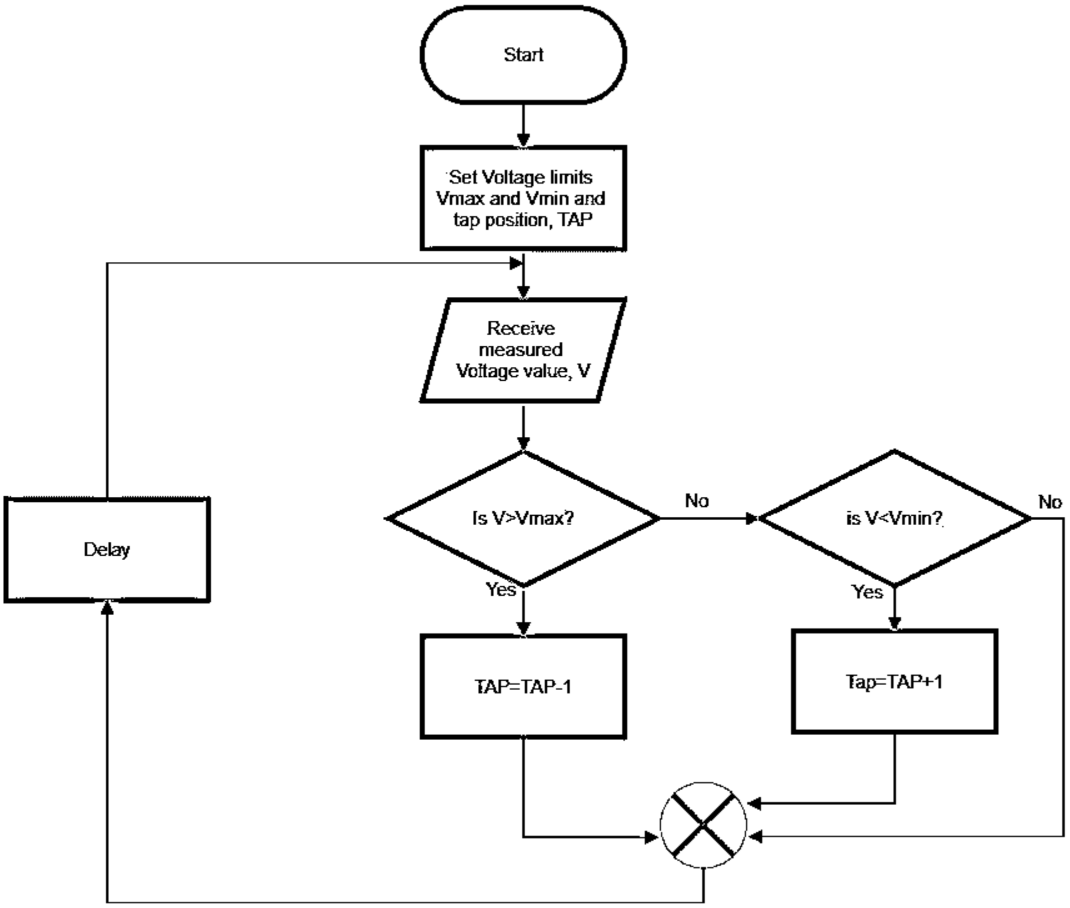


Fig. 3.2: Flowchart of Proposed System

3.2 Voltage sensor circuit

Voltage sensors are used in the system to inspect the primary and secondary voltage. Voltage sensing of ac system is not as straightforward as that of dc system. Various methods can be used to approximate the ac voltage, such as:

3.2.1 Root Mean Square (RMS) method:

Square root of mean of sum of squares of instantaneous volage taken in every few intervals which is a fraction of time period. The smaller the sample interval and larger the number of instantaneous voltages squared and summed, the more accurate value of voltage is obtained.

$$V_{rms} = \sqrt{\frac{\sum_{i=1}^{n} v_i^2}{n}} \quad \text{……………………………..…………..….(3.1)}$$

3.2.2 The peak voltage method:

Largest value of instantaneous voltage within a time period gives peak ac voltage. This method to determine ac rms voltage is less accurate even if the voltage measurement interval used is very small as it measures false peak voltage during voltage spike or noise.

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} \qquad (3.2)$$

The relationship between the input voltage and the ADC output of ZMPT101B is measured manually.

3.3 Analog to Digital Converter (A/D converter)

The sensed current and voltage are in analog form which is changed into digital form with the help of analog to digital converter. This is incorporated inside the microcontroller used. The digital signal processed by the microcontroller which into the equivalent value of voltage then it sends the required instructions for the tap changer to change its tapping to maintain the rated output terminal voltage.

3.4 EOLTC Module

The signal from the microprocessor is received in the optocoupler where the photoelectric effect activates the optocoupler which sends the gate signal to the triac such that respective triac is closed and respective turn ratio is maintained to produce rated output terminal voltage. The EOLTC module with tap changer at primary side is shown in fig. 3.3.

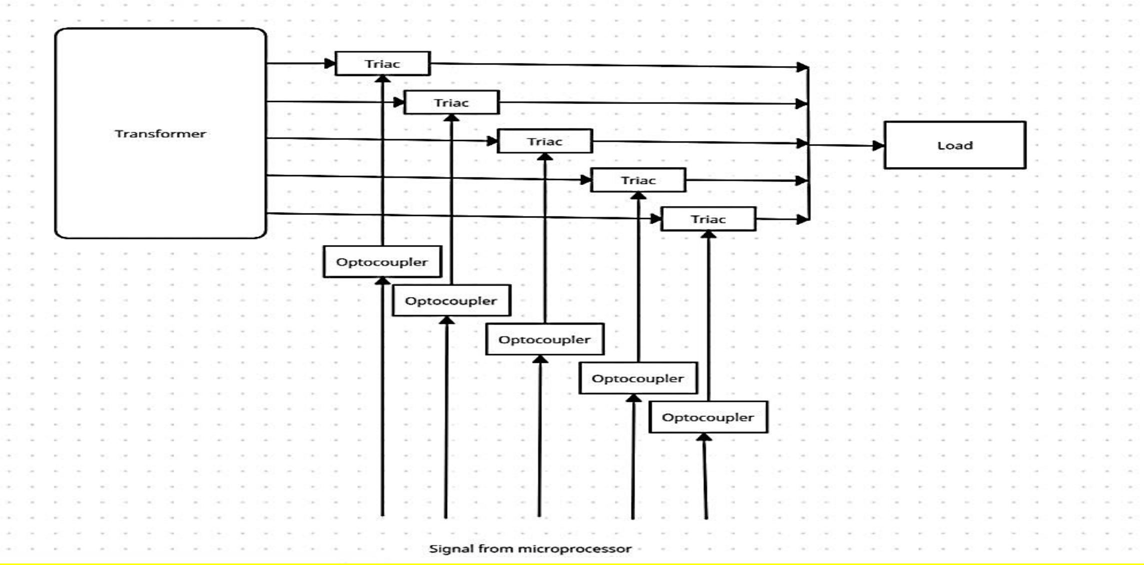


Fig. 3.3: EOLTC Module

From fig 3.3, we see that signal from the microcontroller is fed to the optocoupler one at a time, the optocoupler being conducted will give a gate signal for respective triac to fire where each triac is associated with different number of tapping such that favourable tapping position can be chosen to give the constant output voltage to the load.

3.5 Snubber Circuit

With the use of opto-isolator, use of infrared led and photo triac can rapidly raise problems like, electrical fast transients (EFT) withstanding. Thus, in order to deal with this problem snubber circuit is used. Although the snubber circuit contains few circuits, the calculation of value of capacitor and resistor is complicated and very time consuming to achieve.

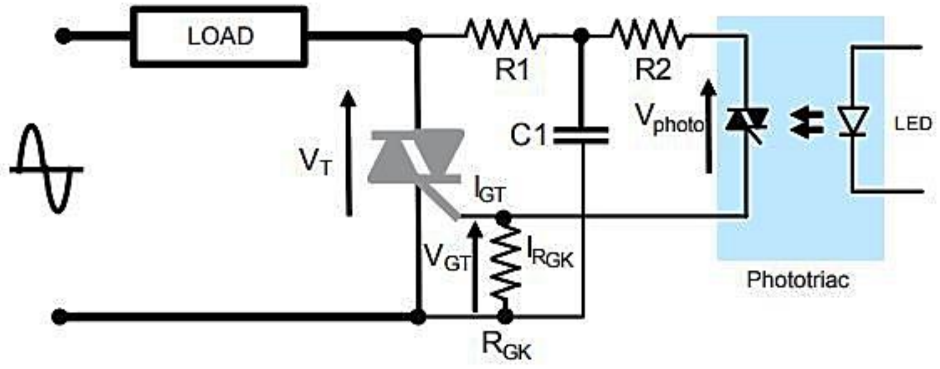


Fig. 3.4: Snubber Circuit

For the calculation of R_1, R_2, C_1 and R_{GK},

Given,

$$VT = (R1 + R2) * I + V_{photo} + V_{GT} \tag{3.3}$$

$$V_{GT} = R_{GK} * I_{RGK} \tag{3.4}$$

$$I = I_{GT} + I_{RGK} \tag{3.5}$$

From (3.3), (3.4) and (3.5),

$$V_T = (R_1 + R_2) * I_{GT} + \left[\left(\frac{R_1 + R_2}{R_{GK}}\right) + 1\right] * V_{GT} + V_{photo} \tag{3.6}$$

And also,

$$R_2 = \frac{V_{line(peak)}}{I_{surge}} \tag{3.7}$$

Again,

$$\frac{dV_{c1(max)}}{dt} = \frac{V_{line(peak)}}{R_1 * C_1} \quad \text{……………………………………………….……….……….}(3.8)$$

For BT 136,

we have,

$I_{GT} = 10mA$

$V_{GT} = 1.5V$

$I_{surge} = 4A$

$dv/dt = 250\ V/u\ sec$ for worst case

So, we get,

$R1 = 100\ ohms$

$R2 = 50\ ohms$

$C1 = 23.5nF$

3.6 Switching Circuit Configuration

The configuration of the tap winding used in this project has multiple taps in winding with each tap representing different turn ratio. These taps can be either provided in high voltage side or low voltage side of transformer each having their own merits and demerits. High voltage magnitude on high voltage side causes more stress on switching device whereas high current on low voltage side causes component heating. The selection of tapping location of EOLTC whether in high voltage side or low voltage side is the compromise between these two cases. However, shell type transformer does not give much of a choice in this regard since high voltage tapping is easier to construct in this type of transformer.

Faiz and Siahkolah [9] introduce various switching configurations to realize large number of taps with limited number of switching devices. This involves adding and subtracting step voltages of each tap with various combinations to realize wider tapping range. In our project we used low voltage simple multitap configuration with three tapping provided on low voltage side.

CHAPTER FOUR
RESULT AND DISCUSSION

4.1 Software Simulation

We designed 3-tap transformer with secondary tapping on simulation software and controlled the tapping with microcontroller based on change in secondary voltage with change of load. Fig 4.1 clearly shows the simulation circuit done on proteus. For this purpose, we used 2 single tap transformers (TRANS2P3S) to achieve 3 taps in secondary side. We use zero crossing opto-coupler triacpredriver (MOC3031M) and Z0405MF triac.

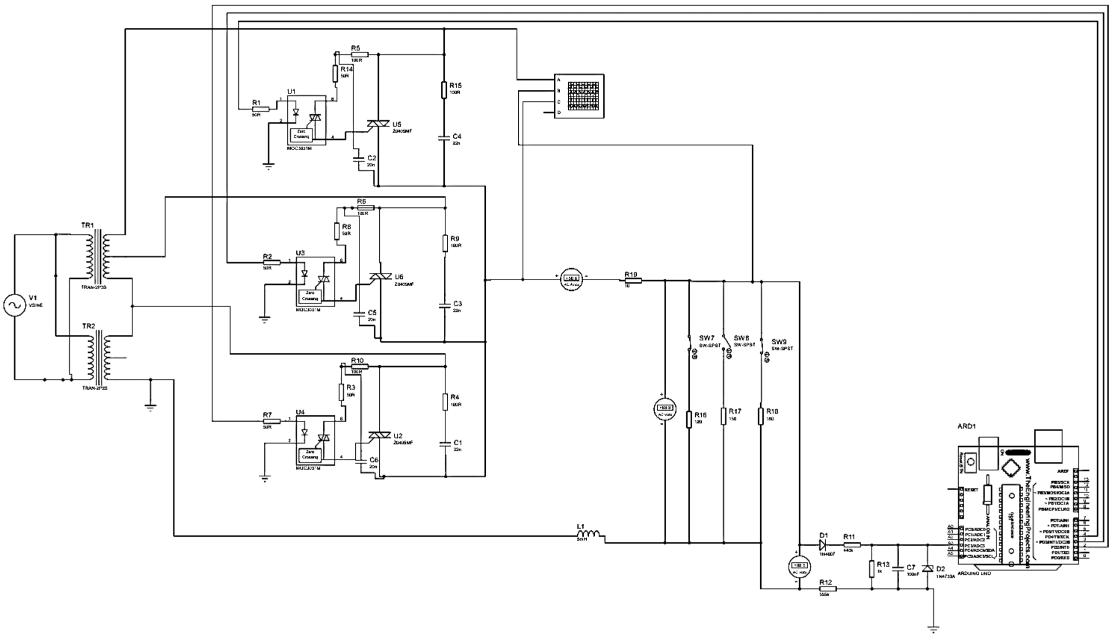


Fig. 4.1: EOLTC simulation

Fig. 4.2 shows the simulation result. The result clearly shows that initially (say at first tap) voltage remains constant until load changes. Whenever load is varied (increases) or supply voltage decreases, voltage of LV side decreases and is sensed by voltage sensing circuit which is fed to controller. From where a control signal is sent to MOC3031 to switch into appropriate tap and thus voltage stabilizes. With the increases in load, terminal voltage decreases and finally stabilizes with the operation of tap. The waveform from oscilloscope clearly shows the stabilization of voltage after load voltage variation.

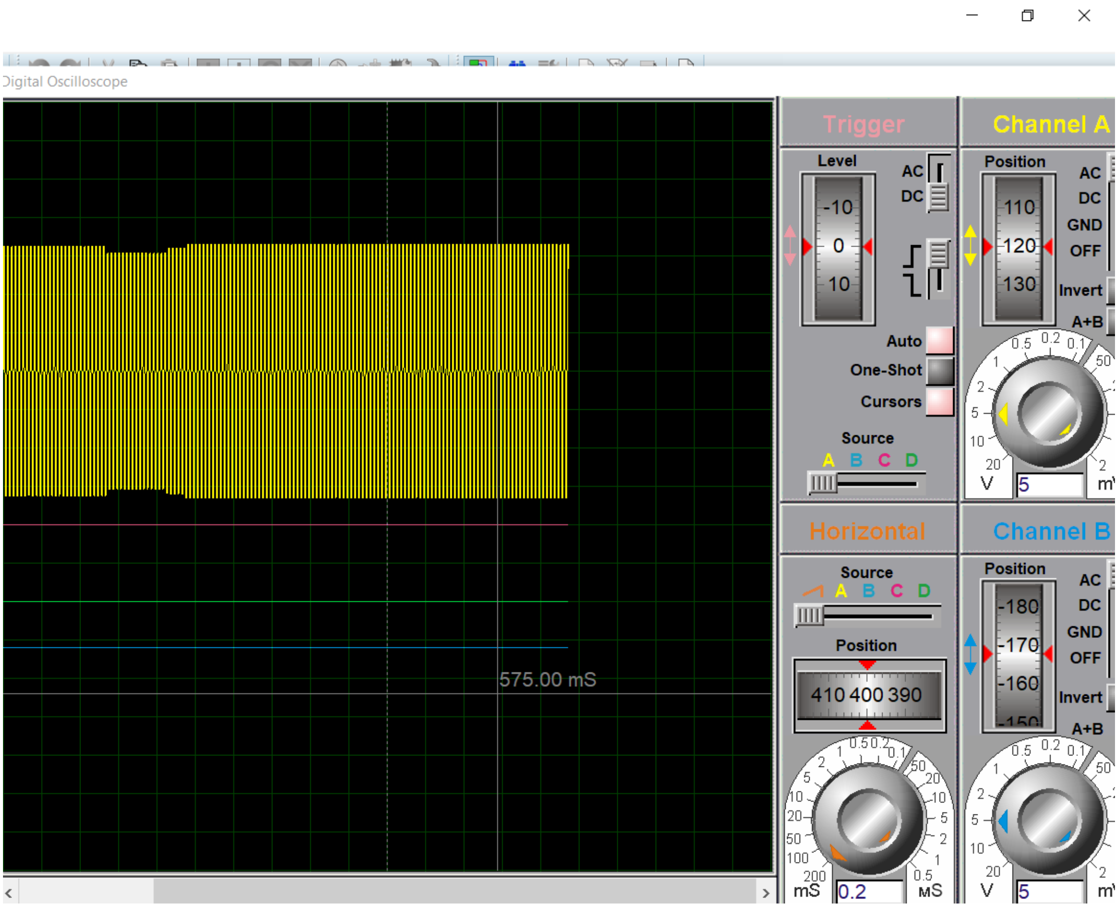


Fig. 4.2: Voltage regulation with EOLTC

4.2 Hardware Implementation

We designed 3-tap transformer with tapping on secondary side based on 220/24V and 220/12V centre tapped transformers and connected three taps with optocoupler-triac firing circuit. For testing of our fabricated EOLTC we use varying voltage source of lab for varying supply to input side and accordingly observe the output voltage and hence the change in tap. We used MOC3021 optocoupler, BT136 triac and ZMPT101B voltage sensor for hardware implementation.

Table 4.1: Tap position with normal I/O voltage

End to end	220/24 and 220/12=36V	Tap 0
End to centre tap	220/24 and 220/12=30V	Tap 1
End to nearest tap	220/24 and 220/12=24V	Tap 2

Fig 4.3 is the schematic diagram of hardware implementation. Unlikely to simulation circuit we use two center tap transformers for three tap configurations i.e., end to end, end to center and end to nearest tap. LEDs were used as load , MOC3021 optocoupler ,BT136 as triac and Arduino uno as microcontroller.

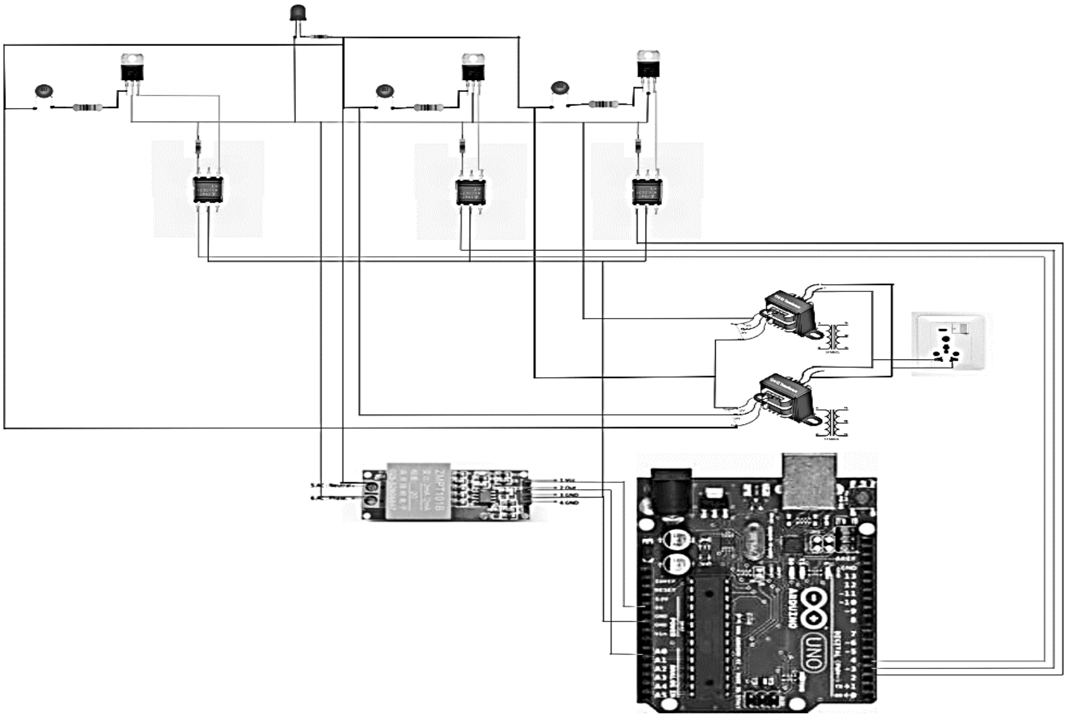


Fig. 4.3: Circuit diagram of work done

Fig 4.4 is hardware circuit successfully tested in a lab. For this purpose, we supplied variable voltage to input side of transformer as per table 4.1. During testing of circuit, we find the result and waveform very similar to our expected output.

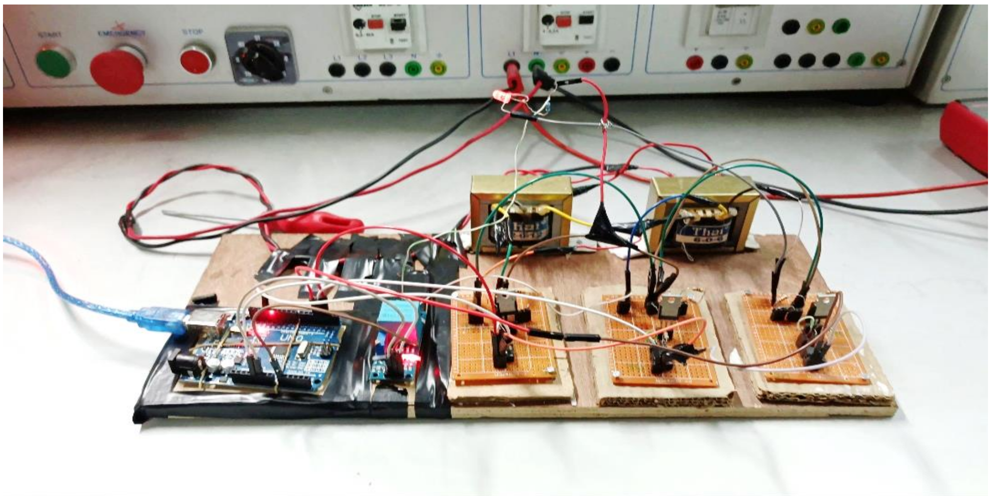


Fig. 4.4: Hardware implementation of 3-tap transformer

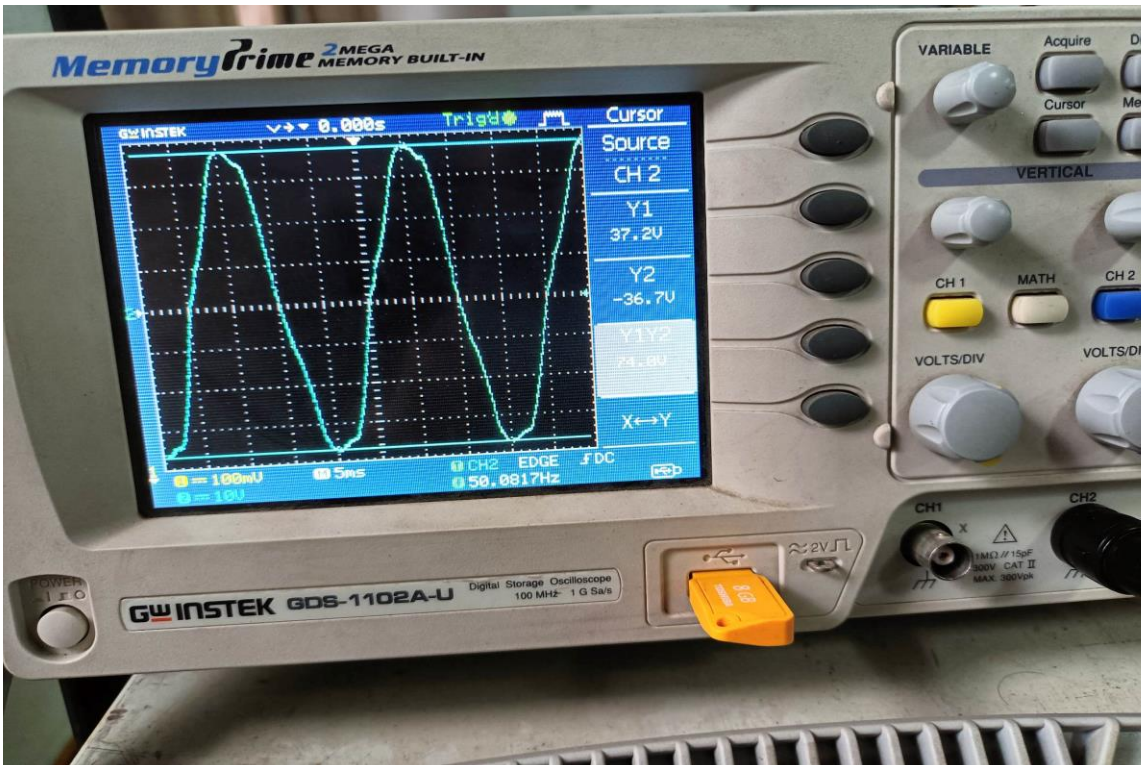
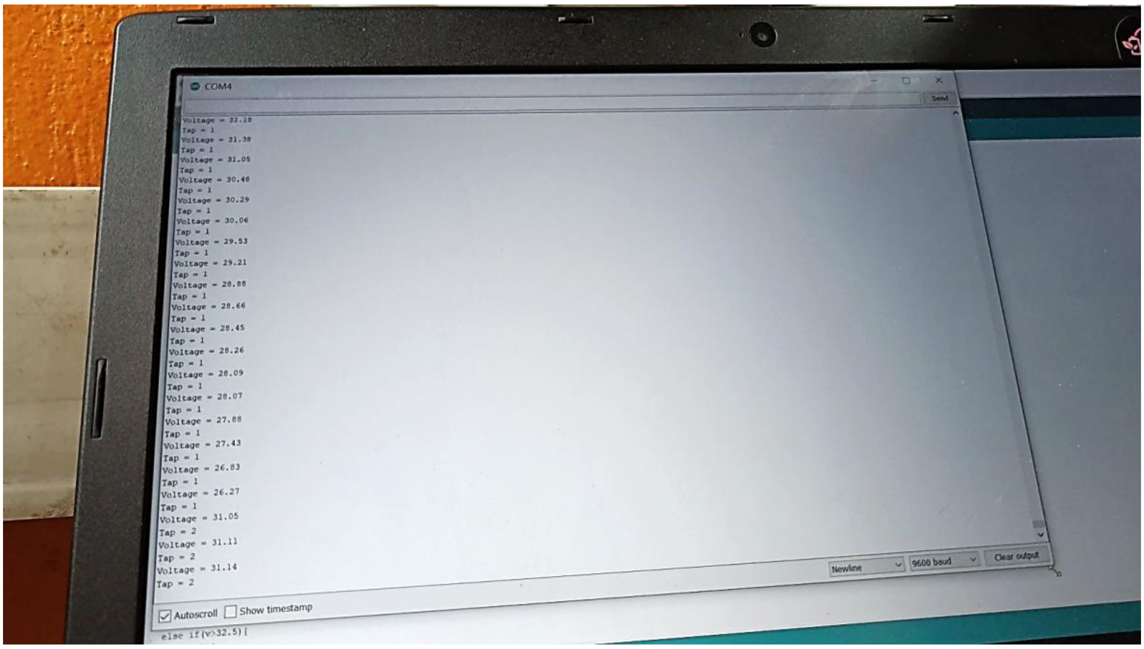


Fig. 4.5: Waveform from Oscilloscope



```
Voltage = 32.18
Tap = 1
Voltage = 31.38
Tap = 1
Voltage = 31.05
Tap = 1
Voltage = 30.48
Tap = 1
Voltage = 30.29
Tap = 1
Voltage = 30.06
Tap = 1
Voltage = 29.53
Tap = 1
Voltage = 29.21
Tap = 1
Voltage = 28.88
Tap = 1
Voltage = 28.66
Tap = 1
Voltage = 28.45
Tap = 1
Voltage = 28.26
Tap = 1
Voltage = 28.09
Tap = 1
Voltage = 28.07
Tap = 1
Voltage = 27.88
Tap = 1
Voltage = 27.43
Tap = 1
Voltage = 26.83
Tap = 1
Voltage = 26.27
Tap = 1
Voltage = 31.05
Tap = 2
Voltage = 31.11
Tap = 2
Voltage = 31.14
Tap = 2
```

```
else if(v>32.5){
```

Fig. 4.6: Tap Position

Fig 4.6 is the observed tap position at different voltage level. Microprocessor is programmed to change tap when measured value of voltage exceeds the specified (reference) voltage. Each change in tap corresponds to 6V change in voltage at 220V primary at no load. We tested our hardware with supplying variable primary side voltage to change secondary side voltage which if exceed the specified value changes tap position accordingly changing the turn ratio between primary and secondary side hence adjusts the secondary side voltage within specified range. The range is carefully selected such that the changed tap position does not make the secondary side voltage go beyond the another extreme of the specified limit which can cause the tap position to swing between those two positions. If it happens not only the output voltage keeps fluctuating but may harm the switching component. Table 4.2 shows the result obtained when changing input voltage with change in output voltage with corresponding tap transition.

Table 4.2: Observed Tap position with I/O voltage

Input voltage(V)	Output Voltage(V) Change	Tap transition
Decreased to 187V	26V-31V	1-2
Increased to 196V	32.5V-27V	2-1
Increased to 240V	32.5V-27V	1-0
Decreased to 234V	26V-31V	0-1

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The major shortcomings of the mechanical OLTC like arcing, slow action and high wear and tear leads to the transition into the electronic OLTC which outshines the mechanical counterparts in all these departments making it a better choice. And for its practical implementation and demonstration, we implemented a Triac based E-OLTC with 3 taps in the steps of 6V in the secondary side of centre-tapped transformer. This enabled us to keep the output voltage almost constant within specified limit of 26.5V to 32.5V despite the changing input provided on the primary side of the transformer without manual intervention and need to disconnect the load. Hence, satisfying the principle of OLTC, we were able to design and fabricate, a Triac based OLTC fulfilling our objective.

5.2 Recommendation

Despite our best of the efforts, we were unable to fabricate ready-to-use model of EOLTC for the distribution transformers. Also, some additional features can be added to it convenience. So, some recommendations for future to do the same are listed below.

- Use of HV switches to withstand the voltages in the primary of distribution transformer
- Use of IOT devices for remote monitoring and manual over-ride of the EOLTC
- Integration with reactive power compensator for better performance in voltage regulation

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APPENDIX: A

Specifications of Components used

Arduino Uno

- Used as microcontroller
- Inbuilt A/D and D/A convertor
- Based on Atmega328P
- 14 digital I/O pins (6 of which can be used as PWM outputs)
- 6 analog inputs
- A16 MHz ceramic resonator
- USB connections, a power jack, an ICSP header and a reset button

ZMPT 101B

- Uses : Voltage sensor
- Rated input current : 2mA
- Rated output current : 2mA
- Linear Range : 0 ~ 1000V, 0 ~ 10mA
- Isolated withstand voltage : 4000V
- Turn ratio : 1000:1000
- Measurement accuracy class : 0.2
- Linearity : 0.1%
- Rated burden : <= 200 ohms
- Operating frequency : 50Hz
- DC control resistance : 110 @ 20 degree celcius

MOC 3021

- Uses : Optocoupler/ Opto-triac
- Forward Current : 50 mA
- Forward Voltage : 1.15 V

- Hold Current : 250 µA
- Isolation Voltage : 5 kV
- Max Input Current : 50 mA
- Max Input Voltage : 1.5 V
- Max Operating Temperature : 100 °C
- Max Output Current : 100 mA
- Max Power Dissipation : 330 mW
- Min Operating Temperature : -40 °C
- Nominal Input Voltage : 1.15 V
- Output Voltage : 400 V
- Power Dissipation : 330 mW
- Reverse Breakdown Voltage : 6 V
- Turn-On Delay Time : 20 µs

BT 136

- Uses : Used as triac
- Triac Type Logic : Sensitive Gate
- Configuration : Single
- Voltage - Off State : 600V
- Current - On State ($It_{(RMS)(Max)}$) : 4A
- Voltage - Gate Trigger ($V_{gt(Max)}$) : 1.5V
- Current - Gate Trigger ($I_{gt(Max)}$) : 10mA
- Current - Hold (Ih_{Max}) : 15mA
- Current - Non Rep. Surge 50, 60Hz (It_{sm}) : 25A, 27A

APPENDIX: B

Arduino Code:

```
int tap[] = {2,3,4};
 int t=0;
 void setup(void) {
  Serial.begin(9600);
  pinMode(tap[0], OUTPUT);
  pinMode(tap[1], OUTPUT);
  pinMode(tap[2], OUTPUT);
  digitalWrite(tap[0], HIGH);
// get rms voltage
float get_rms() {
  float rms_v = 0;
  for(int i = 0; i < 2000; i++) {
    float r = analogRead(A0);  // read from analog channel 0 (A0)
    rms_v = rms_v + sq(r-512);
    delayMicroseconds(200);
  }
  return sqrt(rms_v/2000/5.44);
}

// main loop
void loop() {

  char buf[10];
  float v = get_rms();
```

```
Serial.print ("Voltage = ");
Serial.println(v);
Serial.print ("Tap = ");
Serial.println(t);
if(v<26.5){
  if(t<2){
     t=t+1;
     digitalWrite(tap[t], HIGH);
     delay(100);
     digitalWrite(tap[t-1], LOW);
  }

}
else if(v>32.5){
  if(t>0){
    t=t-1;
    digitalWrite(tap[t], HIGH);
    delay(100);
    digitalWrite(tap[t+1], LOW);
  }

}
else{
  }
```

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