KATHMANDU UNIVERSITY

SCHOOL OF ENGINEERING

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

FINAL PROJECT REPORT

RELAY BASED AUTOMATIC VOLTAGE STABILIZER

A **Third-year final project report** submitted in partial fulfillment of the requirements for the degree of

Bachelor of Engineering

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CERTIFICATION

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ON

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ABSTRACT

With the increasing power demand, it has become one of the biggest challenges to provide a stable and uninterrupted voltage supply to the consumers under various load conditions. The fluctuation in voltage values results in low performance and eventually damages the electrical appliances used. To fix this problem, an Automatic Voltage Stabilizer (AVS) is needed for households and industries. A voltage stabilizer is an electrical appliance that is designed to deliver a constant voltage to a load at its output terminals regardless of the changes in the input or incoming supply voltage. It protects the equipment or machine against over-voltage, under-voltage, and other voltage surges. A voltage stabilizer is also called an Automatic Voltage Stabilizer. It is responsible for correcting the AC voltage of the electrical power supply to provide a stable and secure power supply to equipment, allowing for a stable voltage and protecting the equipment from most of the problems of the mains. The project aims to make a relay-based Automatic Voltage Stabilizer. The control circuit consists of an autotransformer, relays, voltage comparators, microcontroller, demultiplexers, current, and voltage sensing units, flash ADC, and signal conditioning circuit. The system also consists of a display that displays the input voltage and output voltage in an instant. The control circuit operates within the fluctuation range of 190V to 260V. The power rating of this Automatic Voltage Stabilizer is 1kVA. This single-phase Automatic Voltage Stabilizer gives the output voltage of 220V with a sensitivity of ±1%. If the input voltage is lower than 180V and higher than 260V, the system automatically shuts down preventing the damage that could be caused to the system and the load. The system thus designed and fabricated could stabilize household electrical usage and prevent domestic appliances from being damaged. The primary focus of the system is to stabilize the voltage for domestic purposes.

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CHAPTER I INTRODUCTION

1.1. Background

Voltage is the most important parameter in an electrical power system. It is necessary to maintain a constant voltage at the output as it is the driving force that energies the current through the conductor. Loose or corroded connections within households or powerlines, and improper fabrication of wires generally result in voltage fluctuation. From natural causes including thunder, lightning, and fallen trees to technical problems like the use of multiple sensitive gadgets, sudden change in load results in voltage variation. A low capacity transmitter for power transmission is another major cause of voltage variation [1]. Voltage fluctuation in the electrical system results in the short life of the electrical equipment.

The automatic Voltage stabilizer plays an important role in all loads from the resistive, inductive, and capacitive loads. The basic work of a Voltage Stabilizer is to carry out two necessary functions i.e. Buck and Boost function. Buck and Boost function is nothing but the regulation of a constant voltage from over voltage and under voltage circumstances. This Buck and Boost function may be carried out manually with the help of selector switches or automatically with the help of additional electronic circuits. During Overvoltage circumstances, the Buck function does the necessary reduction of voltage intensity. Similarly, during under-voltage circumstances, the Boost function increases the voltage intensity. The idea of both the functions as a whole is to maintain the same voltage output [2]. The different ways the voltage is stabilized automatically include using servos, relays, tap changing method, and differential power mode Insulated Gate Bipolar Transistor (IGBT) PWM. The voltage is automatically stabilized based on the input voltage in the transformer and is controlled by a microcontroller. Voltage Stabilizers can be single-phase or three-phase as required.

1.2. Motivation

Voltage fluctuation can be a reason for the inefficient and improper performance of electrical appliances and systems in households and industries. The fluctuating power supply is the major cause of damage to electrical components in any machine and device. The efficient and optimal utilization of electronic appliances establishes a need for an electrical circuit that can provide a regulated voltage out of the unregulated one. Voltage regulation is the number of voltage changes between the no-load voltage and the full load voltage. Thus, voltage stability is a prominent factor in the safety and optimal performance of electrical appliances. A voltage stabilizer prevents any device from unpredicted damage due to voltage fluctuations and improper voltage supply. So, there is an absolute need for the stabilized voltage for the optimal performance of any electrical appliance.

1.3. Problem Description

Voltage fluctuations are systemic variations of the voltage envelope of random voltage changes, the magnitude of which does not normally exceed specified voltage ranges. The usual no-load voltage is 220V but when connected to a load, the voltage drops below 200V. As most electrical appliances are designed to operate with maximum efficiency with a better performance which requires a maintained power rating during operation. With the household and domestic loads turned on, there is a net increase in the resistive load causing a current drop and resulting voltage fluctuation. Excessive dropping is due to increased resistance in a circuit, typically caused by an increased load, or energy used to power electric lights, in the form of extra connections, components, or high-resistance conductors [3].
Some significantly important effects can be observed as a result of over-voltage and under-voltage. Over-voltage results in permanent damage to the connected device, damage to winding and insulation, unnecessary disruption in the load, overheating, and degradation in the lifetime of the device. Similarly, under-voltage leads to equipment malfunction, lower efficiency of the devices, and low performance of the device [4].

The solution to the problem of fluctuation in the voltage lies in the design of an electronic circuit that monitors the main supply and takes a decision on its own to initiate the switching action that will eventually lead to the load seeing a voltage within the acceptable normal range. [5] Voltage stabilizers are electronic appliances designed to deliver a constant voltage to a load at its output terminals regardless of the changes in the input or incoming supply voltage. [6]

1.4. Objectives

The project "Automatic Voltage Stabilizer" is inclined with the following objectives:

i. Study the voltage fluctuation, causes, and impacts on the electrical appliances.
ii. Understand the design and working mechanism of the auto-transformer, voltage stabilizer, and relay-based transformer tapping.
iii. Design a voltage stabilizer and program to automatically stabilize the unstable voltage.

1.5. Methodology

The project aims to design and fabricate an automatic voltage stabilizer. For the design and fabrication of the project, different stages are covered from literature survey to proteus simulation, breadboard testing, and final fabrication of the project in matrix. The project proceeds with the sensing of the input ac signal with a potential transformer based voltage sensing technique. The output of the sensing is sent to the Arduino microcontroller after signal conditioning. The Arduino is programmed to provide 4 multiplexed digital outputs which act as input to a DEMUX. The output of DEMUX triggers the relay with the help of the relay driver circuit. The relay is connected to different taps of the transformer and stabilized voltage is achieved with the tap changing. The input and output voltage are displayed using a seven-segment display and a 16*2 LCD display.

1.6. Limitations

The project is limited to some of the features. Some of the limitations are enlisted below:

i. There is a chance of the presence of wear on the mechanical parts of the relay.
ii. Presence of wear and tear in the fabricated transformer resulting minor vibration and humming sound.
iii. Overload capacity is low.

1.7. Organization of the report

The report comprises various chapters to integrate the details of the project. The chapters include an introduction, technology and literature survey, methodology, study cases, accomplishments, future works, and conclusion. The introduction section provides a brief introduction to the voltage fluctuation and explains the problems caused. The impacts of unstabilized voltage have been briefly discussed to establish the need for voltage stabilizers in a real-world scenario.

The technology and Literature survey provide in-depth insight into the causes of voltage fluctuations and their effects on various aspects of appliance performance and efficiency. Various voltage stabilization techniques are discussed and the working mechanism of a voltage stabilizer has been discussed.

The following section of the methodology provides a detailed description of the system overview and a general block diagram of the automatic voltage stabilizer. The circuit of the project has been presented and the completion percentage of the project is also discussed.

The calculations on the design of the transformers and calculation of the signal conditioning have been discussed in the study cases and then the project has been concluded with a slight insight on the task accomplished and the task remaining.

1.8. Summary

Voltage stabilization has been a serious concern regarding the longevity of electrical appliances for residential use and industrial application. The voltage drops from 220V to below 200V when any kind of load either resistive, inductive, or capacitive load causes a significant impact on the overall performance and life of the appliances. Unpredicted fluctuation in the voltage causes unexpected equipment malfunction and lower efficiency of the devices. The voltage fluctuation establishes a need for voltage stabilization for the efficient performance of the appliances and constant voltage supply as it is the driving force of any appliance. Voltage stabilizers are the devices that stabilize the fluctuated input voltage and provide a constant output voltage. The project aims to design and fabricate a relay-based voltage stabilizer that stabilizes the voltage based on the tap changing mechanism of the auto-transformer with the help of multiple relays.

CHAPTER II TECHNOLOGY AND LITERATURE SURVEY

Voltage Stability is an extreme issue in control frameworks, which consistently achieve working points of confinement forced by monetary and ecological conditions. At whatever point there are an adjustment in the stack the framework voltage level changes. With the drop-in voltage level, the responsive power request increments. Most of the gadgets and devices associated with our day-to-day activities require a smooth and steady flow of electric supply. However, a variety of factors can hamper the stability of power. One of the most important issues is voltage fluctuation. As a safety measure and the project intends to design an automatic voltage stabilizer, it is important to investigate the root cause of the voltage fluctuation.

2.1. Causes of voltage variation

2.1.1. Poor Supply of Electricity

Poor supply of electricity includes problems in the supply side of the electricity which may be loose connections, damaged wires, and even connection problems in the transmission lines. Additionally, a low capacity transmitter to transfer the power from the main supply can also cause the improper flow of electricity. On the other hand, faulty appliances tend to draw more current than usual which could lead to voltage fluctuations in homes and industries [1].

2.1.2. Natural Causes

Natural factors such as thunder, lightning, fallen trees, and heavy rains tend to be the cause obstruction in the transmission lines Similarly, the animals and birds in the power cable also cause problems in the transmission. The accidental dip in the voltage level leads to power surges and thus results in huge damage to electrical gadgets. [1]

2.1.3. Wiring Issues

Improper wiring is a major cause leading to irregular electric supply and voltage fluctuations. Poor fabrication of electric wire, heating, damages caused due to insets and pets cause grounding and excessive leakage of the electricity. This results in a poor supply of electricity and un-stabilized voltage.

2.1.4. Interference

Power fluctuation is also resulted due to the connection of multiple sensitive gadgets and appliances. Appliances such as iron, hairdryers, electric ovens, etc. can cause a power surge to the circuit when they are operating. This issue is identified from the flickering of the lights and the poor performance of appliances. This is known as interference [1]. Voltage stabilizers tend to be a proper solution for such scenarios.

Voltage stabilizers have become mandatory for electrical equipment in homes, offices, and industries; they help to protect the electrical equipment and machine from over and other voltage surges. Voltage stabilizers provide a constant voltage at their output terminals regardless of the changes in the input or incoming voltages. There are different techniques and arrangements to deal with and facilitate voltage control and stabilization. Manually operated voltage stabilizers generally boost or buck the voltage and are generally built with electromechanical relays to give the output voltage within the desired range [7].

2.2. Types of Voltage Stabilizers

With the advancement and automation, voltage stabilizers nowadays are controlled by a microcontroller and thus are automatic. Various techniques for voltage stabilization have been identified. The voltage stabilizers are generally electromagnetic, relay type, and servo voltage stabilizers.

2.2.1. Electromagnetic Voltage stabilizers

Electromagnetic voltage stabilizers stabilize the voltage based on the variation of the magnetic flux in the core of the transformer. The flux changes are made by changing the magnetic permeability of the core gap. Thus, special cores with gaps are used. In some cases, additional windings are also used for the control of the semiconductor circuits. In stabilizers with additional windings, a change in the magnetic flux created by these windings leads to a change in the total flux in the core.
The circuits with the semiconductor devices used as the control element characterize the speed of the electromagnetic voltage stabilization. The stabilizers are observed to provide a smooth voltage regulation, high accuracy in stabilization, and high speed of work. On the other hand, the system lacks mechanical movements and provides a wide range of temperatures. But, the system can only work on a limited load capacity and small stabilization range [8].

2.2.2. Relay Type of voltage stabilizers

Relay-based voltage stabilizers consist of a set of relays beside the transformer, a rectifier circuit, a controller unit, and other minor components. The electronic circuit compares the output voltage with a reference value provided by a built-in reference voltage source or a microcontroller that controls the operating voltage. Whenever the voltage rises or falls, the control circuit switches the corresponding relay to connect the desired tapping to the output voltage [7]. The tapping either step-ups the voltage when the voltage falls or steps down the voltage when the voltage rises.

Relay-based voltage stabilizers are observed to change the voltage with an accuracy of ±10 % [7] and are generally preferred for low rating appliances in homes, offices, and industries. The relay provides a wide temperature range for the operation and operates at zero loads [8].

2.2.3. Servo based voltage stabilizers

In the case of servo-based voltage stabilizers, a phase of the buck-boost transformer primary is connected to the fixed tap of the autotransformer and another one connects with a moving arm which is controlled by the servo motor. Apart from the buck-boost transformer, the servo stabilizer gets connected in the series of incoming voltage. These voltage stabilizers are observed to provide greater accuracy for around ±1% in voltage variation ranging up to around ±50 % [7].

Servo voltage stabilizers are most popular for low rating appliances used in homes, offices, and industries to provide correct voltage for protecting equipment and their desired performance. Servo stabilizers can be single-phase or three phases as required and are oil-cooled or air-cooled. In some cases, the booster transformer is operated by regulating an autotransformer mounted on the servo drift shaft [8].

Studies provide the accuracy of servo voltage stabilizer far better than relay type voltage stabilizer. Servo type of voltage stabilizers is observed to provide a wide range of voltage stabilization with greater accuracy. Relay type voltage stabilizers provide a set of relays connected with the transformer for changing the tap while the servo-based voltage stabilizer comprises the buck-boost transformer connected with a fixed tap. Comparing the tentative cost, the relay-based voltage stabilizer is cheaper than the servo-based stabilizers as the cost of the servo is more than the relay. As relay-based voltage stabilizers don't provide a better resolution ability, they are not much preferred for higher ratings while servo-based are preferred for higher ratings than 1kVA.

In an AC circuit, the voltage and current waveforms are sinusoidal so their amplitudes are constantly changing over time. Since we know that power is voltage times the current (P = V*I), maximum power will occur when the two voltage and current waveforms are lined up with each other. That is, their peaks and zero crossover points occur at the same time. When this happens the two waveforms are said to be "in phase" [9].

Power factor is defined as the ratio of real power (P) to apparent power (S) and is generally expressed as either a decimal value, for example, 0.95, or as a percentage: 95%. Power factor defines the phase angle between the current and voltage waveforms, where I and V are the magnitudes of RMS values of the current and voltage. Note that it does not matter whether the phase angle is the difference between the current for the voltage or the voltage to the current. The mathematical relationship is given as:

$$\text{P.F.} = \frac{\text{Real Power}}{\text{Apparent Power}} = \frac{P}{S} = \frac{VI\cos\beta}{VI} = \cos\beta$$

Then the cosine of the resulting angle between the current and voltage is the power factor.

2.3. Voltage Sensing Methodologies

The input voltage needs to be sensed for the variation in the tapping of the relay for the stabilized output voltage. There are several techniques for sensing the input voltage which include potential transformers-based voltage sensing, and differential amplifier-based voltage sensing.

2.3.1. Potential Transformer

In this case of voltage sensing, a potential transformer is used to step down the primary voltage and secondary voltage to lower the secondary potential output voltage. This transformer step down the voltage to a safe limit value which can be easily measured by ordinary low voltage instrument like a voltmeter, wattmeter and watt-hour meters, etc. [10]

2.3.2. Differential Amplifier based voltage measurement

A differential amplifier is used to amplify the voltage from two voltage levels. In the case of ac voltage measurement, two voltages, one from the positive terminal about the neutral and another negative from the neutral are used. The difference amplifier method is more economical than the potential transformer when the voltage to be sensed is less than 400V.

The large resistance in the circuit doesn't allow high voltage to appear across the op-amp. The capacitors in the circuit are used to filter harmonics from the input voltage and provide protection to the microcontroller from the harmonics. [11]

The project comprises of rectifier circuit with a step-down transformer for the ac voltage sensing purposes. The step-down transformer converts the high AC voltage into a small voltage of around 0-12 volts. The small AC voltage is turned to DC voltage by a rectifier circuit and then conditioned within the range of 5 volts DC to be fed into the microcontroller. The microcontroller is programmed accordingly to trigger the relay switch.

Autotransformer is the major component for the tap changing. The output and input circuits are connected as a single continuous winding. The output and the supply voltages are not isolated from each other and this transformer helps in the lowering and raising of the voltage. Unlike other transformers, autotransformers likely consume less conductive material and are better at saving iron material as power is not being transferred to the output electromagnetically and the core material handles less power. [12] The primary and the secondary winding of the automatic transformer are linked both electrically and magnetically.

Autotransformers are mostly used for the adjustment of the line voltage to either change its value or to keep it constant. An autotransformer can be designed to be cheaper for the same VA rating [13].

The display of the input voltage and output voltage can be done by various methods. Some feasible and cheap methods include the display using LCD and seven-segment display. LCD generally uses controller I2C for communication with the liquid crystal. However, the project looks forward to integrating seven segment display for the display of the input voltage and the output voltage. Seven segment displays are simple and effective for the display of numeric values and information specifically voltage reading in the scenario of the project.

Seven segment displays are made up of LEDs combined such that they can be used to display numbers and letters. As their name implies, they are made of seven LEDs plus an additional LED for a dot. Led dot matrix displays, on the other hand, are made up of LEDs in a square matrix form to indicate a letter, number, or symbol [14]. There are several different types of LEDs based on the environment, application, display color, and segmentation. Seven segments are LED displays designed to screen numerals only. These LEDs are not designed to show any letters. With the seven different LED segments, a numeral with digits from 0-9 is presented. 7 is the minimum number of segments in any LED display

Arduino UNO is the commonly used board that is also known as classic Arduino. This board has 14-digital I/O pins, where 6- pins can be used as PWM, 6-analog inputs, a reset button, a power jack, a USB connection, and more. This board can receive and send information over the internet with the help of Arduino shields [15].

CHAPTER III METHODOLOGY

The project overview has been described in the following sections.

3.1. System Overview

The overall block of the project has been designed and studied for convenience in simulation and further fabrication. The overview of the project is can be studied by the following block in figure 1.

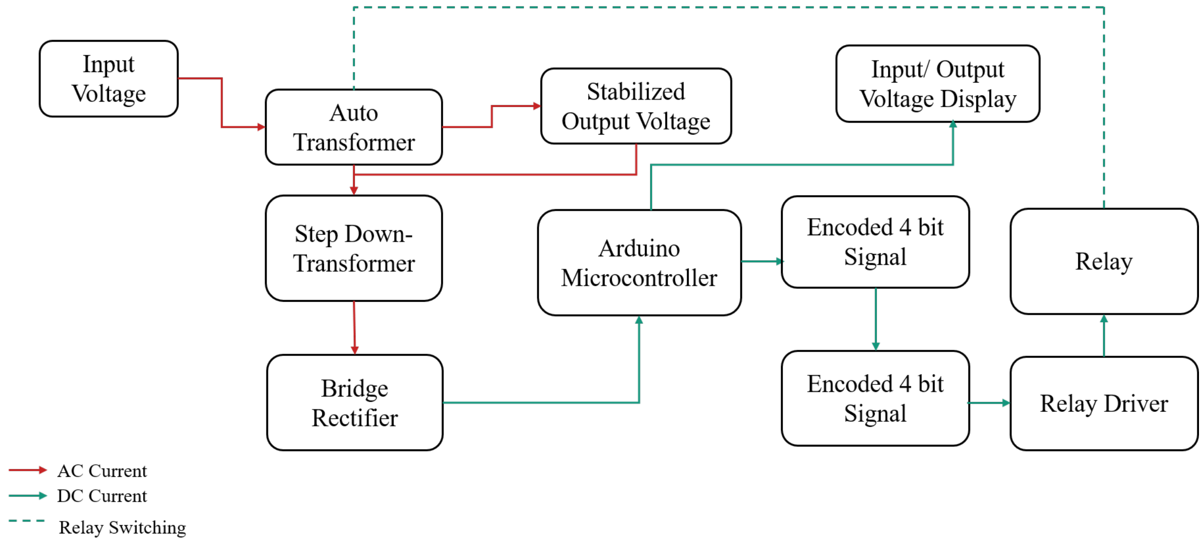


Figure 1: Block Diagram

3.2. Project Description

The project can be understood through the following steps.

I. The input voltage from the step-down transformer is sent to the rectifier-based voltage sensing.
II. The output from the voltage sensing is signal conditioned within the range of 5 volts making it suitable to be fed into the microcontroller.
III. The microcontroller is programmed accordingly to calibrate the input voltage from the sensed voltage. Similarly, the microcontroller is also programmed to control the relay.
IV. The microcontroller provides four outputs in the form of logic high and logic low signals. The four encoded outputs from the Arduino microcontroller are used to switch the relays.
V. The output from the microcontroller is then sent to a 4X16 demultiplexer which is then given to the relay driver.
VI. The relay driver operates the relay in low signal input.
VII. The relay then changes the taping of the transformer to get stabilized voltage.
VIII. The transformer then gives the stabilized output voltage to the load.
IX. The input and output voltage are displayed using the seven-segment display and LCD Display.

3.3. Summary

The project comprises four parts: AC voltage sensing, Relay logic, Display, and the design of the transformer. The source voltage is stepped down with the help of a transformer and rectified into a DC signal. The DC signal is conditioned within the desirable range that can be fed into the microcontroller. The capacitor is used to filter the harmonics and for the protection of the circuit. The signal in the microcontroller is calibrated to identify the input voltage based on the signal fed into it. The microcontroller is programmed to provide an encoded signal as output. The coded decimals trigger the specific relay after being decoded by a demultiplexer. Then, the tapping of the relay is performed in the set of relays to achieve the perfect number of turns and good voltage stabilization. The encode Seven segment display and LCD is interfaced with the Arduino to display the input and output voltage.

CHAPTER IV SYSTEM DESIGN

The project has been designed in multiple parts from the design of autotransformer, ac sensing techniques, and tap changing methodologies.

4.1. Design of Auto-Transformer

The EMF equation given by Faraday's Law of Electromagnetic Induction is:

$$E = N \frac{d\varphi}{dt} \ldots\ldots\ldots\ldots\ldots(1)$$

Where N is the total number of turns of the transformer, φ is the flux through each turn which changes by time *dt* and E is the induced EMF.

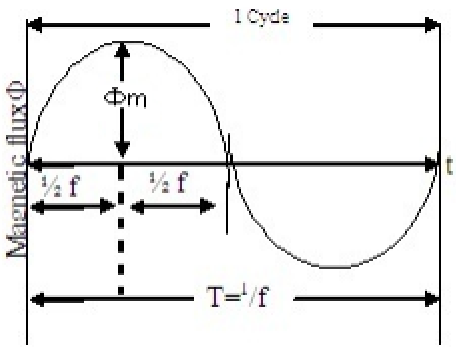


Figure 2: Sinusoidal Flux Variation

As shown in the figure above, flux changes from zero to maximum value φ_m in a quarter of a cycle (1/4f), so the average rate of change in flux is given by,

$$\text{Average rate of change in flux} = \frac{\varphi_m}{\frac{1}{4}.f}$$

$$= \frac{\varphi_m}{1} \div \frac{1}{4}.f \ldots\ldots\ldots\ldots(2)$$

$$= \frac{\varphi_m}{1} \times \frac{4f}{1}$$

$$= 4f\varphi_m \; T\emptyset\lambda \ldots\ldots\ldots(3)$$

$$\text{Average EMF per turn} = 4f\varphi_m \text{ volts}\ldots\ldots\ldots(4)$$

Where,

f = Frequency of AC input in Hertz

φ_m = Maximum flux in core

$= B_m \times A$

B_m = Magnetic flux density

A= Area of transformer

For a sinusoidal flux variation, rms value of induced emf ,

$$E_{rms} = 1.11 \times Average \text{ value}$$
$$= 1.11 \times 4f\varphi_m$$
$$= 4.44f\varphi_m ....(5)$$

Induced EMF in primary winding is given by,

$$E_1 = Induced \text{ emf per turn*No.of primary windings}$$
$$= 4.44f\varphi_m \times N_1$$
$$= 4.44N_1 f\varphi_m ....(6)$$

Where, N_1 = No. of primary windings

$$E_1 = 4.44fN_1 B_m A...........(7)$$

Similarly, the rms value of EMF induced in secondary winding which has N_2 number of turns is given by,

$$E_2 = 4.44f\varphi_m \times N_2$$
$$= 4.44N_2 f\varphi_m$$
$$= 4.44N_2 fB_m A............(8)$$

Where, N_2= No. of secondary windings

Therefore, it is seen that;

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\varphi_m$$

which implies that EMF per turn is the same in both windings. In an ideal transformer under no-load condition, V1 = E1 and V2 = E2.

Transformer Design Specifications:

Power Rating= 1kVA

Input Voltage= 180V to 260V

Output Voltage= 220V±5%

Frequency= 50Hz

Type= Single Phase Core type

Cooling scheme= Air cooled

Core cross-section: square

i. Current Density: Ranges from 2-3A/mm^2 for continuously operated power devices.
ii. Weighting factor K ranges from 0.7 – to 0.8 for a single-phase core type transformer.

In the design, the values taken were:

σ = 2.33A/mm^2, K = 0.72, stacking factor= 0.96.

Magnetic Circuit Core Design:

4.1.1. Voltage per Turn (V_t):

The output equation of a transformer is given as P= E*I*10^{-3} (KVA) ....(9)

Where,

$$E = 4.44fN\varphi_m................(10)$$

$$I = \frac{\varphi_m}{\lambda N}..................(11)$$

Therefore,

$$P = 4.44fN\varphi_m \times \frac{\varphi_m}{\gamma N} \times 10^{-3}$$

or, $$P = \frac{4.44fN(\varphi_m)^2}{\gamma N} \times 10^{-3}.....................(12)$$

or, $$(\varphi_m)^2 = \frac{P.\gamma}{4.44f} \times 10^3............................(13)$$

∴, $$\varphi_m = \sqrt{P} \times \sqrt{\frac{\gamma}{4.44f} \times 10^3}........................(14)$$

But the voltage per turn, $V_t = \frac{E}{N} = 4.44f\varphi..........(15)$

Substituting the value φ_m in equation (15), we get,

$$V_t = 4.44f\sqrt{\frac{\gamma}{4.44f} \times 10^3} \times \sqrt{P}..............(16)$$

$$= \sqrt{4.44f\gamma \times 10^3} \times \sqrt{P}......................(17)$$

$$= K\sqrt{P}...(18)$$

Where, K= $\sqrt{4.44f\gamma \times 10^3}$, f is supply frequency in hertz, P is the electrical rating of transformer in KVA, φ_m is maximum flux circulating in the core in weber, γ is the ratio of magnetic loading to electric loading (a constant), E is the impressed voltage in volts, I is the current in amperes and K is weighting factor.

Now, to calculate V_t,

$$V_t = 0.72\sqrt{1} = 0.72.............(19)$$

4.1.2. Calculation of Magnetic Flux in the Transformer:

From equation (15), we know that,

$$V_t = 4.44f\varphi_m$$

Then,

$$0.72 = 4.44 \times 50 \times \varphi_m$$

$$\text{or, } \varphi_m = \frac{0.72}{4.44 \times 50}$$

$$\text{or, } \varphi_m = 3.243 \times 10^{-3}$$

$$\therefore, \varphi_m = 0.003243 \text{ Wb}$$

4.1.3. Cross-Sectional Area (Ai):

The calculated cross-sectional Area of the transformer is found to be 3621mm^2.

4.1.4. Calculation of Magnetic Field Strength of Transformer:

We know that,

$$\varphi_m = B_m \times A$$

$$\text{or, } B_m = \frac{\varphi_m}{A}$$

$$\text{or, } B_m = \frac{0.003243}{3621 \times 10^{-3}}$$

$$\therefore, B_m = 8.9 \times 10^{-4}\ T$$

4.1.5. Net Window Area (Aw):

The calculated Net Window Area of the Transformer is found to be 1900mm^2.

4.1.6. Electric Circuit (Winding) Design:

i. Number of turns of primary windings N_{p}:

The expression for voltage per turn is given by, $V_t = \frac{E}{N}$

Where N is the number of turns and E is the induced voltage.

Therefore, $N_p = \frac{E}{V_t}$ ....(20)

E is 220V for the primary circuit, $N_p = \frac{220}{0.72}$

$= 305$ turns

ii. Number of turns of secondary windings (tapings) N_s:

The secondary windings consist of many tapings, each outputting voltages but within the range of 220V ±5%.

$$N_{s\,min} = \frac{209}{0.72}$$

$$= 290.2\ turns \approx 291 \text{ turns}$$

$$N_{s\,max} = \frac{231}{0.72}$$

$$= 320.8\ turns \approx 321 \text{ turns}$$

For maximum controlled input voltage of 260V, the voltage per turn becomes, $V_t = \frac{260}{305}$

$= 0.85$ V/turns

For a minimum controlled input voltage of 180V, the voltage per turn becomes,

$$V_t = \frac{180}{305}$$

$$= 0.59 \text{ V/turns}$$

The permissible maximum voltage is 231V, so the secondary turns become, $= \frac{231}{0.85}$

$= 271.7 \approx 272$ turns

The permissible minimum voltage is 209V, so the secondary turns become

$$= \frac{209}{0.59}$$

$= 354.2 \approx 355$ turns

iii. Current Requirements:

Primary winding current is obtained from the relation P=VI

Therefore, I_1= P/V = 1000/220 = 4.545A

Secondary winding current is obtained from, $I_1 N_1 = I_2 N_2$

$$\text{or, } I_2 = \frac{I_1 N_1}{N_2}$$

$$\text{or, } I_2 = \frac{4.545 \times 305}{355}$$

$$\therefore, I_2 = 3.904A$$

iv. Determination of Conductor Sizes:

Current Density, $\sigma = \frac{I}{A}$

Where, $\sigma = 2.33\text{A/mm}^2$

$$A = \frac{\pi d^2}{4}$$

This implies that,

$$\sigma = \frac{I}{\frac{\pi d^2}{4}} \quad \ldots\ldots\ldots\ldots\ldots(21)$$

For primary windings, using equation (21),

$$\text{or, } 2.33 \times \frac{\pi d^2}{4} = 4.545$$
$$\text{or, } d^2 = 2.483$$
$$\text{or, } d = \sqrt{2},483$$
$$\therefore, d = 1.575\text{mm}$$

Therefore, the standard wire gauge (SWG) for primary windings is 16.5 SWG.

Now, for secondary windings, again using equation (21), we get,

$$\text{or, } 2.33 \times \frac{\pi d^2}{4} = 3.904$$
$$\text{or, } d^2 = 2.133$$
$$\text{or, } d = \sqrt{2.133}$$
$$\therefore, d = 1.46\text{mm}$$

Therefore, the standard wire gauge (SWG) for secondary windings is 16.5 SWG.

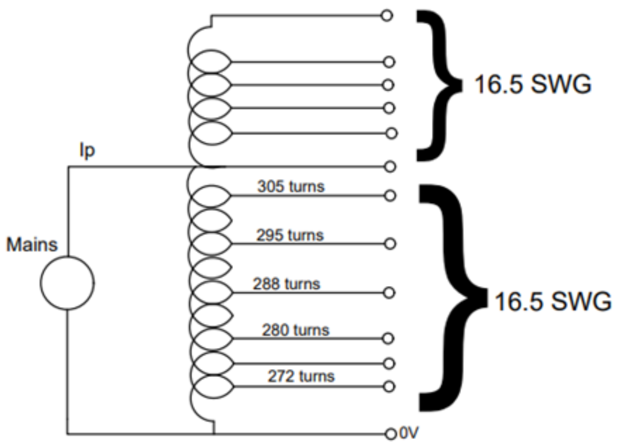


Figure 3: Transformer Coil Layout

Summary

Thus, a mathematical design of an autotransformer of rating 1.0 kVA is completed. The input voltage fluctuation from 190V to 260V AC is considered a reference parameter and the output voltage is anticipated to be 220V, 50Hz. Single-phase core type transformer has been considered for design with a total number of 355 turns. The current in the primary winding is calculated to be 4.45 Amps and in secondary windings is calculated to be 3.90 Amps. The primary winding coil diameter and the secondary windings coil diameter are calculated to be 1.575mm and 1.46 mm respectively (16.5 SWG).

4.2. AC Voltage Sensing

Differential Amplifier based voltage sensing has also been studied and simulated for the idea generation regarding AC voltage sensing. Differential Amplifier-based sensing has been found quite complex in simulation than potential transformer-based voltage sensing. The BCD code variation with the variation of input voltage through Arduino has been visualized in proteus simulation. The variation can be observed in figure 4. The physical project doesn't include the integration of this technique due to the complexity.

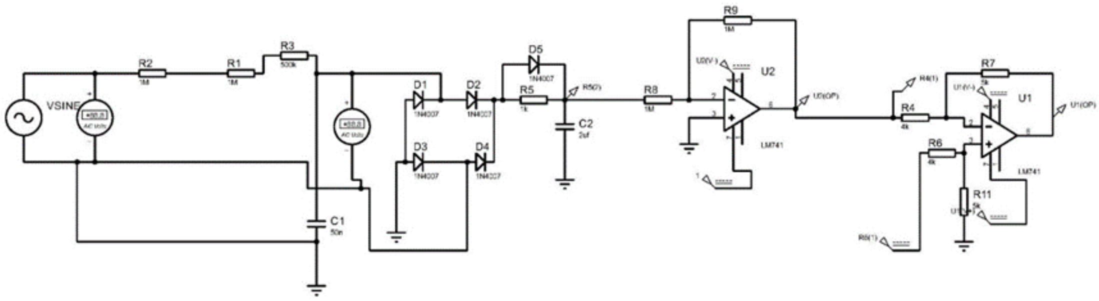


Figure 4: Differential Amplifier based sensing

The project implements rectifier-based voltage measurement for AC voltage measurement purposes. The simulation log uses a transformer for stepping the input voltage down and a potentiometer is integrated to condition the signal in the range that can be fed into the microcontroller. Capacitors have been used in the circuit to filter the harmonics from the input voltage. The signal conditioned DC voltage is fed to the microcontroller which is programmed for tapping the relay. The simulation of the circuit is provided in figure 5.

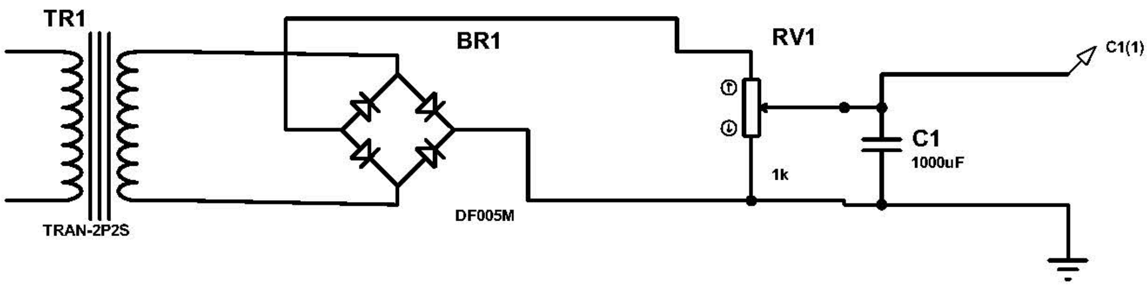


Figure 5:Transformer based voltage sensing

The table for the various voltage signals obtained at different input voltage at different tapping is presented.s

Table 1: Input Voltage sensing

Tapping Number	Input Voltage	Signal Conditioned Voltage
1	190V	2.87V
2	194V	2.96V
3	198V	3.03V
4	202V	3.09V
5	206V	3.17V
6	210V	3.25V
7	216V	3.35V
8	220V	3.41V
9	226V	3.52V
10	231V	3.60V
11	235V	3.67V
12	239V	3.75V
13	245V	3.83V
14	250V	3.93V

Summary

Transformer-based voltage sensing has been simulated and implemented for the AC voltage measurement purpose. An LCD is connected with the Arduino in simulation to get the voltage sensing display. Transformer-based voltage sensing has been implemented in the circuit to sense the input voltage to the system and also to sense the output voltage from the transformer after changing the tap using the relay.

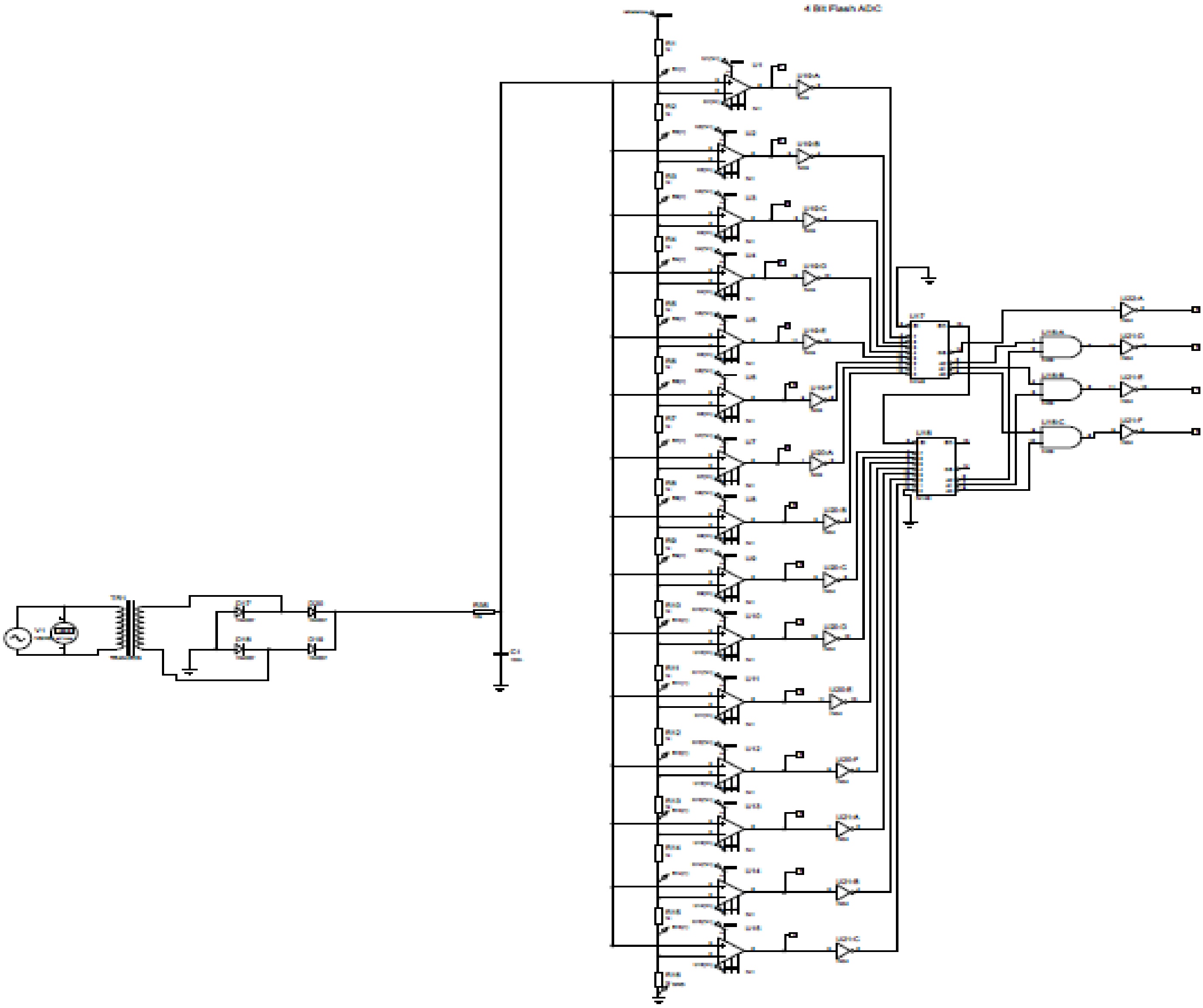


Figure 6: Transformer based Voltage Sensing and flash ADC simulation

Flash ADC and Encoder for BCD Output

Flash Analog to Digital converter has been studied for the operation in the circuit. The reference voltage had been taken and the analog to digital converter is simulated to generate a series of binary coded. The outputs from the 16 operational amplifiers have been fed into the two 8x3 encoders to get 16*4 binary output. The circuit is shown in figure 7. The binary coded decimals are yet to be analyzed for the triggering of the relay. The sets of code and approximate voltage are calculated and presented.

The Required equation is:

$$v_{out} = \frac{R_{out}}{R_1 + R_2 + R_3 + \ldots\ldots + R_N} \times V_{in} \ldots\ldots\ldots\ldots\ldots\ldots \text{(23)}$$

The above equation gives the table below:

Input voltage(V)	D0	D1	D2	D3
0	0	0	0	0
0.312	0	0	0	1
0.624	0	0	1	0
0.936	0	0	1	1
1.248	0	1	0	0
1.560	0	1	0	1
1.872	0	1	1	0
2.184	0	1	1	1
2.497	1	0	0	0
2.809	1	0	0	1
3.121	1	0	1	0
3.434	1	0	1	1
3.747	1	1	0	0
4.06	1	1	0	1
4.37	1	1	1	0
4.68	1	1	1	1

Figure 7: Voltage Distribution and Binary Coded Decimal

Note: A not gate is used in the output of op-amp for convenience in simulation.

Summary

For the encoded signal generation, flash ADC had been identified. The flash ADC is signaled by the AC Voltage sensing part to generate a series of 4-bit codes. The code is generated by the voltage variation obtained from equation 23. The code is to be manipulated by the microcontroller for the relay logic. The four-bit code generation can be visualized by the simulation in figure 7. The breadboard testing of 4-bit flash ADC has been completed on the breadboard. The Flash ADC circuit hasn't been integrated into the final circuit of the system due to the complexity and the encoding of the signal achieved from the microcontroller.

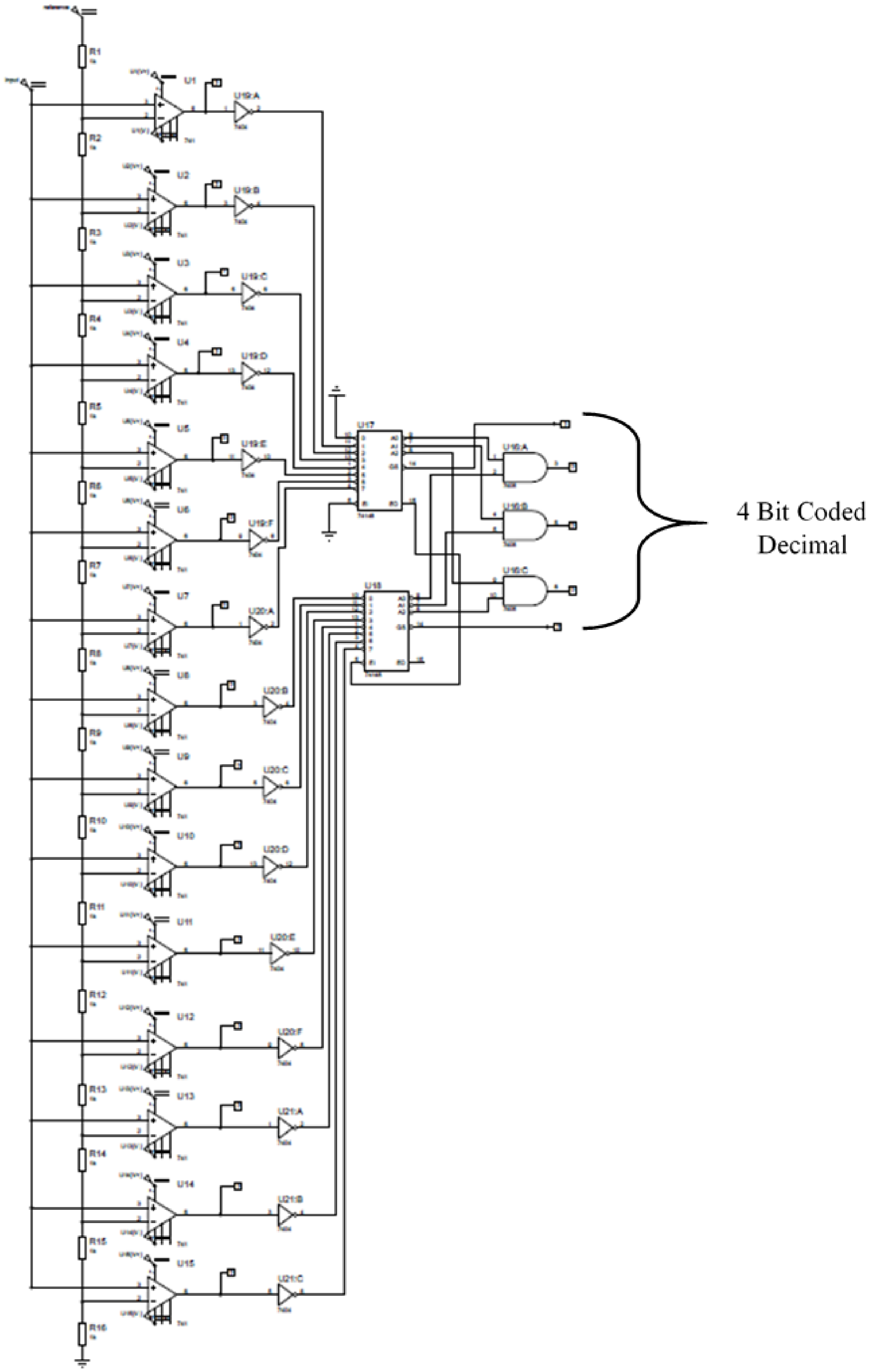


Figure 8: Four Bit Binary Coded Decimal Simulation

4.3. Relay Logic

The control of the relay to control the tapping of the autotransformer is the major part of the system. Many relays are controlled to step up the voltage and step down the voltage when the voltage variation is observed. The microcontroller is programmed to identify the input signal from the input AC signal. Referencing the input signal, the microcontroller identifies whether the voltage has to be stepped up or stepped down. The microcontroller then generates a series of coded decimals in the form of logic high and logic low from four different outputs. The coded output is decoded with the help of a demultiplexer and the set of relays is controlled. The relay is connected in such a way that the triggering of one relay turns another relay off. The tentative design of the relay logic is presented in figure 8. The triggering of a specific relay helps to achieve the perfect number of turns and good voltage stabilization.

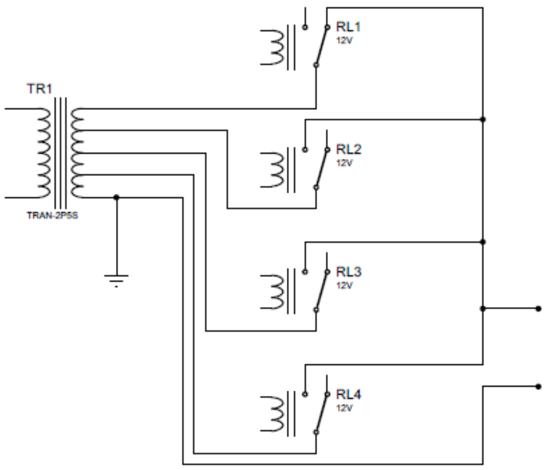


Figure 9: Relay Logic

Summary

The major theme in triggering the relay is turning on one relay automatically triggers all other relays off. The relay logic has been identified and the relay control has been simulated for 8 relays as shown in figure 9. The triggering of the relay is achieved from Arduino based on the input voltage. The encoded signal from the Arduino microcontroller is decoded and the relay is triggered using suitable circuits.

4.4. Display of Input and Output Voltage

Seven segment displays and LCD have been identified as the suitable display of the input and output voltage of the system. The display is controlled by the Arduino for the display input and output voltage. The simulation of the circuit has been shown in figure 9 and 10.

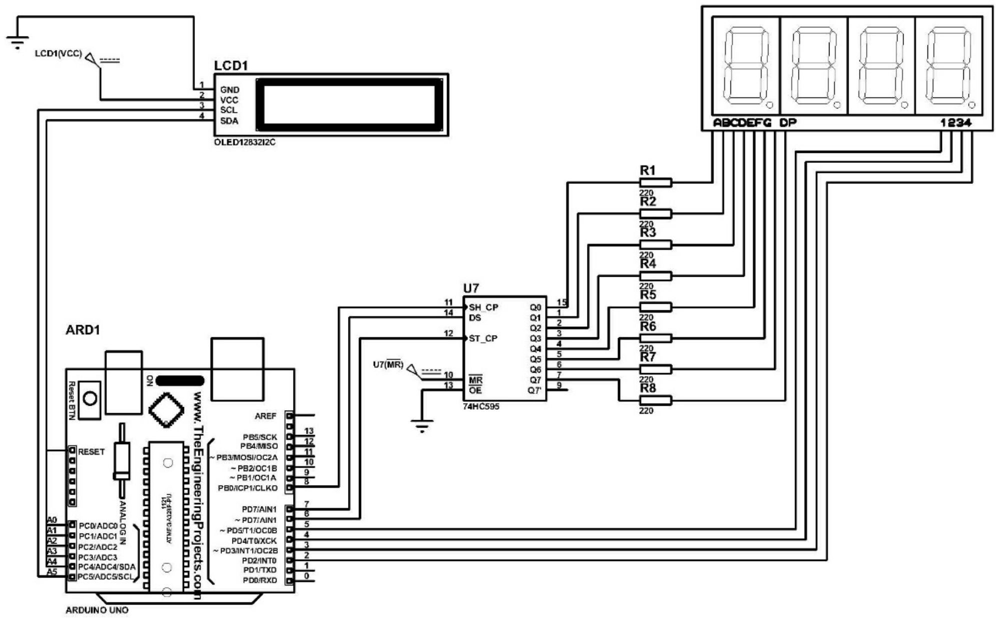


Figure 10: Display Simulation

Summary

The project focuses on the seven-segment display using a shift register and microcontroller. Seven segment display has been identified as a cheaper and more reliable method of voltage display. The shift register maintains a lesser number of pins.

Due to the limited number of pins in the Arduino microcontroller, an LCD has also been integrated in the system to display the voltage.

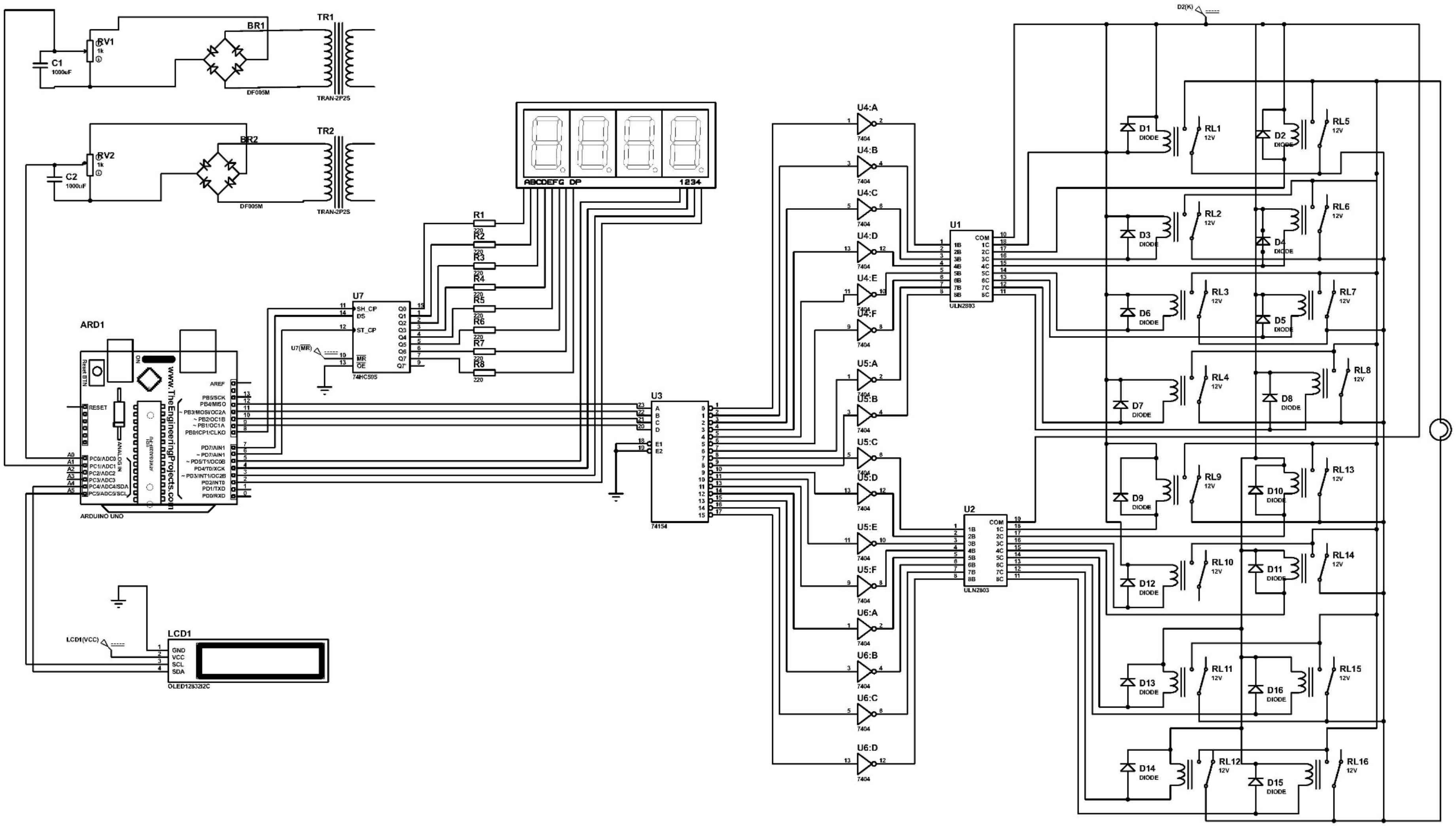
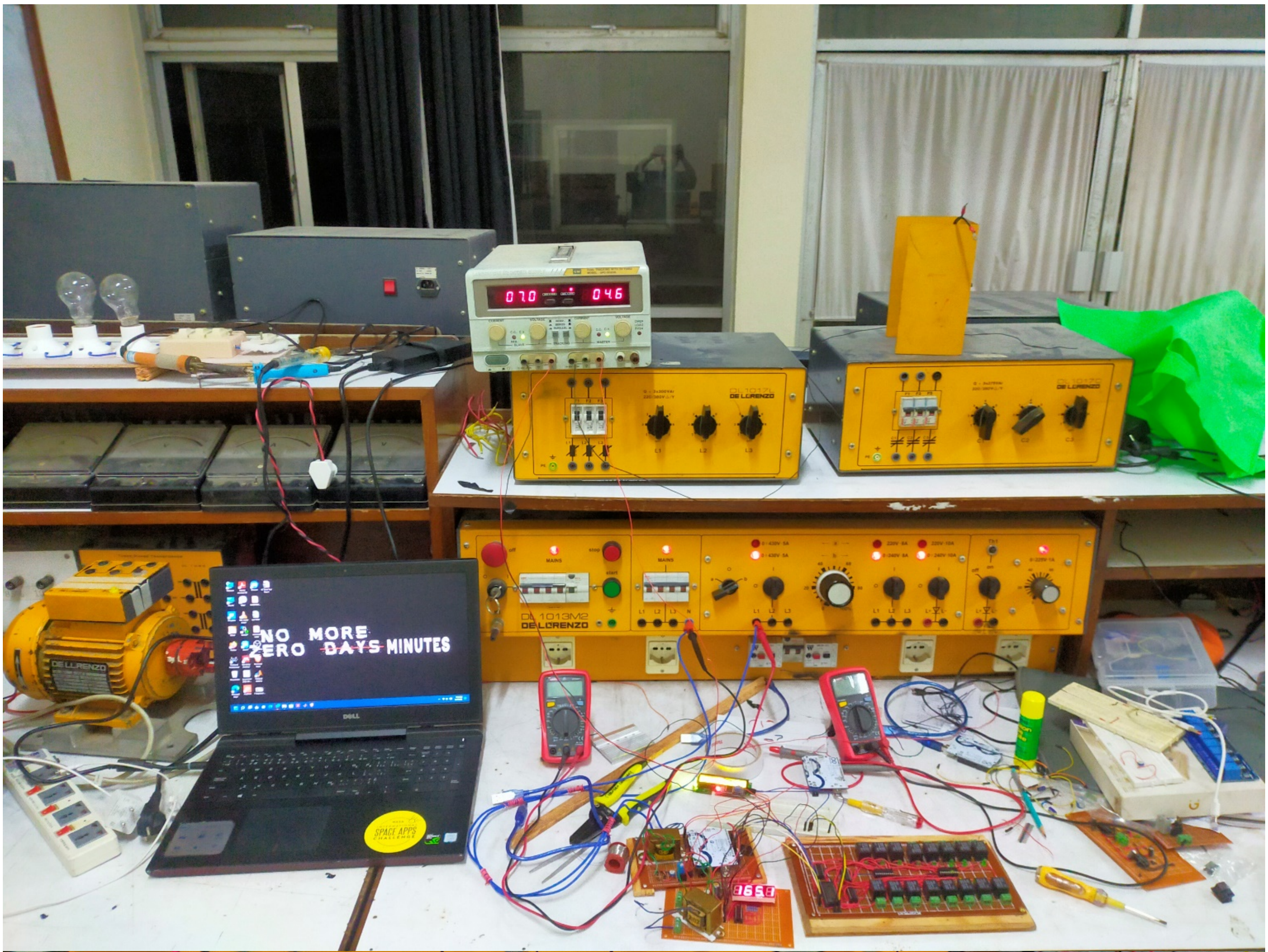


Figure 11: Overall Circuit Layout


NO MORE
ZERO DAYS MINUTES
DL 1013M2
DE LORENZO

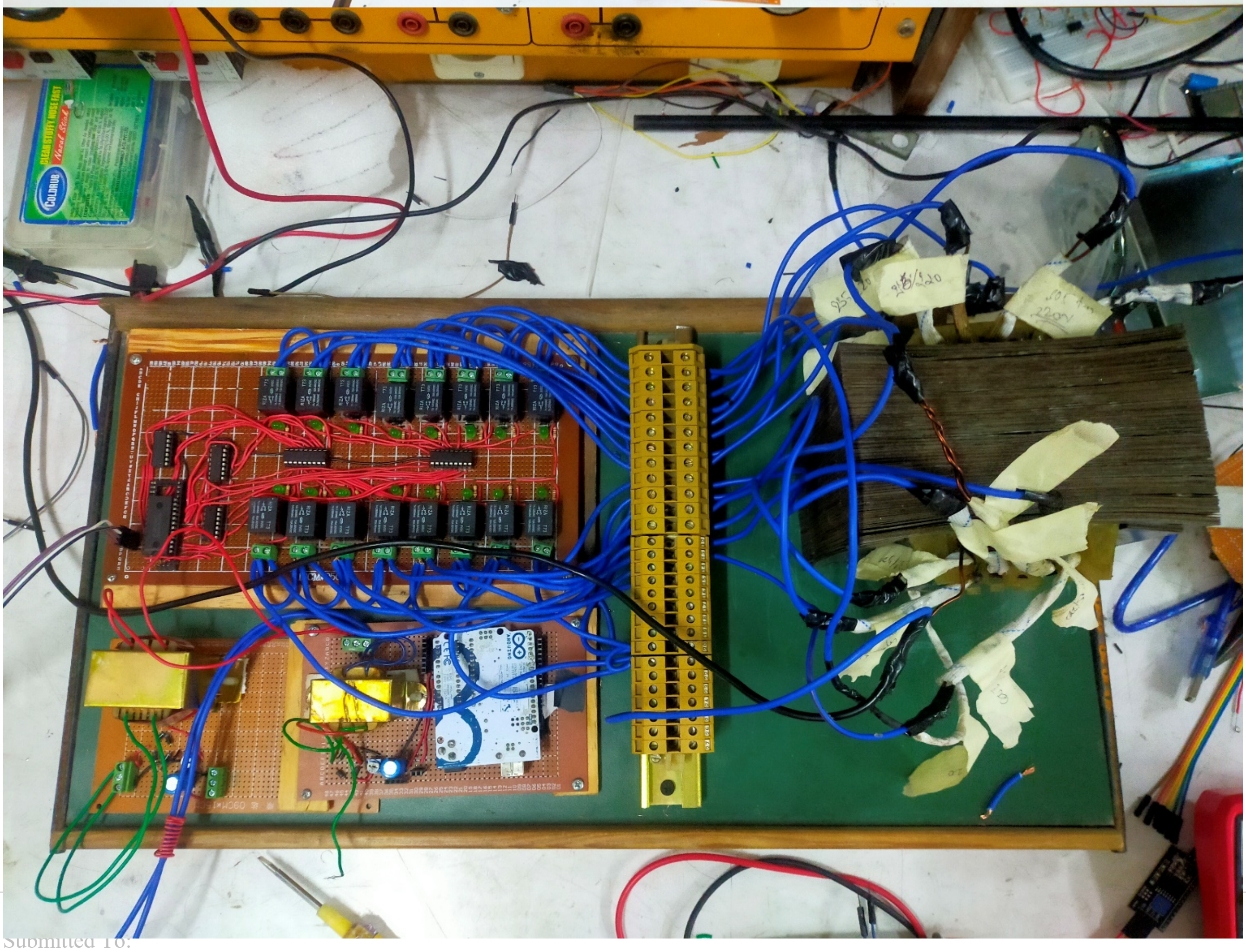


Figure 12: Glimpse of the project

CHAPTER V CONCLUSION

There has been an increasing trend of power problems due to power transients, yet loads need a quality supply of power. The power needs to be stabilized before being supplied to the loads. The system adopts the tap-changing methodology autotransformer to obtain stabilized voltage. The automatic voltage stabilizer aims to provide over-voltage protection, under-voltage protection, overload protection, and short-circuit protection after completion. The system under design provides a voltage consistency in the range of 190-260V. An autotransformer has been mathematically designed. Transformer-based AC voltage sensing has been integrated to sense the input and the output voltage. The signal is programmed in the Arduino microcontroller and relay logic is designed accordingly. The relay logic is employed within the project to change the tapping of the autotransformer. Seven segment display has been identified and controlled using a microcontroller to display the input voltage and the output voltage. The system provides a stable output voltage of 220V ± 5% to the connected loads.

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ANNEX

Source Code:

```
#include <LiquidCrystal_I2C.h>
// For Input Voltage Display
#include <TimerOne.h>  // Initializing for cascaded seven segment display

//Define 74HC595 Connections with arduino
const int Data=7;
const int Clock=8;
const int Latch=6;

const int SEG0=5;
const int SEG1=4;
const int SEG2=3;
const int SEG3=2;

int cc=0;
char Value[4];

//Refer Table 4.1 7-Segment Decoding
const char SegData[]={0x3F,0x06,0x5B,0x4F,0x66,0x6D,0x7D,0x07,0x7F,0x6F};

// set the LCD number of columns and rows
int lcdColumns = 16;
int lcdRows = 2;

//scl=A4 & SDA=A5
// set LCD address, number of columns and rows
// if you don't know your display address, run an I2C scanner sketch
LiquidCrystal_I2C lcd(0x27, lcdColumns, lcdRows);
```

```
//Input Voltage Sensing
float sensorA = A0;

//Output Voltage Sensing
float sensorB = A1;

//Relay Numbering
int RA = 9;
int RB = 10;
int RC = 11;
int RD = 12;

float invalues; // input voltage sensing values
float outvalues; //output voltage sensing value

//=============================================================
//              Setup
//=============================================================

void setup() {

  // put your setup code here, to run once:
    Serial.begin(9600);
    Serial.println("the program has started");   //Input Voltage and Output Voltage Signal Input
    pinMode(A1, INPUT);
    pinMode(A0, INPUT);

    //Relay Control
    pinMode(RA, OUTPUT);
    pinMode(RB, OUTPUT);
    pinMode(RC, OUTPUT);
```

```
    pinMode(RD, OUTPUT);

    // initialize LCD
    lcd.begin(lcdColumns,lcdRows);
    lcd.init();
    // turn on LCD backlight
    lcd.backlight();
  delay(1000);

   // Initialize the digital pin of seven segment as output
    pinMode(Data, OUTPUT);
    pinMode(Clock, OUTPUT);
    pinMode(Latch, OUTPUT);
    pinMode(SEG0, OUTPUT);
    pinMode(SEG1, OUTPUT);
    pinMode(SEG2, OUTPUT);
    pinMode(SEG3, OUTPUT);

    //Initialize Display Scanner
        cc=0;
    Timer1.initialize(1000); // set a timer of length 1000 microseconds
    //(or 0.1 sec - or 10Hz => the led will blink 5 times, 5 cycles of on-and-off, per second)
//    Timer1.attachInterrupt(timerIsr ); // attach the service routine here
     Timer1.attachInterrupt(timerIsr); // attach the service routine here

}

//===================================================================
//              Loop
//===================================================================
```

```
void loop() {

//  delay(1000);
  // put your main code here, to run repeatedly:

  //Input Voltage Sensing values

  invalues = analogRead(sensorA);
  float voltagea = invalues * 0.0048828125; //a a+1
float a=2.87;

  Serial.println("Voltage Input: ");
  Serial.println(voltagea);
  float voltin = voltagea*65.85;

  // Output voltage sensing values

  outvalues = analogRead(sensorB);
  float voltageb = outvalues * 0.0048828125;
  int voltout = voltageb*65.85;

   Serial.print(voltin);
   Serial.print(",");
  // Serial.print(voltout);
  // Serial.println();
   delay(200);

  //Serial.println("The input Voltage is: ");
  //Input AC Voltage Value
  //Serial.println(voltin);
  //Serial.println(",");  //use of comma for column break
```

```
 //Output AC Voltage Value



 Serial.println(voltout);
//  Serial.println(",");  //use of comma for column break
// INPUT VOLTAGE DISPLAY

 lcd.setCursor(0, 0);
 // print message

 lcd.print("Input Voltage: ");

 lcd.setCursor(0, 1);
 lcd.print(voltin);
 lcd.print("V");
 // delay(1000);

 //Cascaded Seven Segment Display Code

 char Volt[4];

 //Display Voltage on Segments
 sprintf(Volt,"%03d",voltout);
 //Serial.print(voltin);
 //Serial.println(",");
 Serial.println(voltout);//We get ASCII array in Volt
 //Serial.println(","); //use of comma for column break
Value[0]=Volt[0] & 0x0F;    //Anding with 0x0F to remove upper nibble
 Value[1]=Volt[1] & 0x0F;    //Ex. number 2 in ASCII is 0x32 we want only 2
 Value[2]=Volt[2] & 0x0F;
 Value[3]=Volt[3] & 0x0F;
```

```
 delay(200);

 if (voltagea>=a && voltagea<(a+0.1))
{
// Serial.println("Relay 1");
  digitalWrite(RA, LOW);
  digitalWrite(RB, LOW);
  digitalWrite(RC, LOW);
  digitalWrite(RD, LOW);
 }
else if (voltagea>=(a+0.1) && voltagea<(a+0.18))
{
    //Serial.println("Relay 2");
  digitalWrite(RA, LOW);
  digitalWrite(RB, LOW);
  digitalWrite(RC, LOW);
  digitalWrite(RD, HIGH);
  }
else if (voltagea>=(a+0.18) && voltagea<(a+0.25))
{
  //Serial.println("Relay 3");
  digitalWrite(RA, LOW);
  digitalWrite(RB, LOW);
  digitalWrite(RC, HIGH);
  digitalWrite(RD, LOW);
  }
else if (voltagea>=(a+0.25) && voltagea<(a+0.3))
{
   //Serial.println("Relay 4");
  digitalWrite(RA, LOW);
  digitalWrite(RB, LOW);
```

```
   digitalWrite(RC, HIGH);
   digitalWrite(RD, HIGH);
   }
 else if (voltagea>=(a+0.3) && voltagea<(a+0.38))
{
   //Serial.println("Relay 5");
   digitalWrite(RA, LOW);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, LOW);
   digitalWrite(RD, LOW);
}
 else if (voltagea>=(a+0.38) && voltagea<(a+0.48))
{
 //Serial.println("Relay 6");
   digitalWrite(RA, LOW);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, LOW);
   digitalWrite(RD, HIGH);
   }
 else if (voltagea>=(a+0.48) && voltagea<(a+0.54))
{
    //  Serial.println("Relay 7");
   digitalWrite(RA, LOW);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, HIGH);
   digitalWrite(RD, LOW);
}
else if (voltagea>=(a+0.54) && voltagea<(a+0.65))
{
      //Serial.println("Relay 8");
   digitalWrite(RA, LOW);
```

```
    digitalWrite(RB, HIGH);
    digitalWrite(RC, HIGH);
    digitalWrite(RD, HIGH);
}
else if (voltagea>=(a+0.65) && voltagea<(a+0.73))
{
      //Serial.println("Relay 9");
    digitalWrite(RA, HIGH);
    digitalWrite(RB, LOW);
    digitalWrite(RC, LOW);
    digitalWrite(RD, LOW);
    }
else if (voltagea>=(a+0.73) && voltagea<(a+0.8))
{
        //Serial.println("Relay 10");
    digitalWrite(RA, HIGH);
    digitalWrite(RB, LOW);
    digitalWrite(RC, LOW);
    digitalWrite(RD, HIGH);


}
  else if (voltagea>=(a+0.8) && voltagea<(a+0.88))
{
    //  Serial.println("Relay 11");
    digitalWrite(RA, HIGH);
    digitalWrite(RB, LOW);
    digitalWrite(RC, HIGH);
    digitalWrite(RD, LOW);


}
```

```
 else if (voltagea>=(a+0.88) && voltagea<(a+0.96))
{

   //  Serial.println("Relay 12");
   digitalWrite(RA, HIGH);
   digitalWrite(RB, LOW);
   digitalWrite(RC, HIGH);
   digitalWrite(RD, HIGH);

}
 else if (voltagea>=(a+0.96) && voltagea<(a+1.06))
{
     //Serial.println("Relay 13");
   digitalWrite(RA, HIGH);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, LOW);
   digitalWrite(RD, LOW);
}

 else
{
    // Serial.println("Relay 14");
   digitalWrite(RA, HIGH);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, LOW);
   digitalWrite(RD, HIGH);

}

//Timer1.attachInterrupt(timerIsr); // attach the service routine here
```

```
//Relay 2
 /*else if (voltagea>=4.05 && voltagea<4.16)
 {
    // Serial.println("Relay 15");
   digitalWrite(RA, HIGH);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, HIGH);
   digitalWrite(RD, LOW);
 }
 else
 {
    // Serial.println("Relay 16");
   digitalWrite(RA, HIGH);
   digitalWrite(RB, HIGH);
   digitalWrite(RC, HIGH);
   digitalWrite(RD, HIGH);
 }
 */
}
   //===================================================================
   //             Generates Bargraph
   //===================================================================
   void DisplayDigit(char d)
   {
     int i;

    for(i=0;i<8;i++)    //Shift bit by bit data in shift register
    {
     if((d & 0x80)==0x80)
     {
       digitalWrite(Data,HIGH);
```

```
}
else
{
  digitalWrite(Data,LOW);
}
d=d<<1;


      //Give Clock pulse
      digitalWrite(Clock,LOW);
      digitalWrite(Clock,HIGH);
}
//Latch the data
digitalWrite(Latch,LOW);
digitalWrite(Latch,HIGH);
}
//=====================================================================
//      TIMER 1 OVERFLOW INTTERRUPT FOR DISPALY
//=====================================================================
void timerIsr(){
  cc++;
  if(cc==5)  //We have only 4 digits
  {cc=1;}
  Scanner();
  TCNT0=0xCC;
}

//=====================================================================
//    SCAN DISPLAY FUNCTION
//=====================================================================
void Scanner()
{
```

```
switch (cc)    //Depending on which digit is selcted give output
{
  case 1:
    digitalWrite(SEG3,HIGH);
    DisplayDigit(SegData[Value[0]]);
    digitalWrite(SEG0,LOW);
  break;
  case 2:
    digitalWrite(SEG0,HIGH);
    DisplayDigit(SegData[Value[1]]); //0x80 to turn on decimal point
    digitalWrite(SEG1,LOW);
  break;
  case 3:
    digitalWrite(SEG1,HIGH);
    DisplayDigit(SegData[Value[2]] | 0x80);
    digitalWrite(SEG2,LOW);
  break;
  case 4:
    digitalWrite(SEG2,HIGH);
    DisplayDigit(SegData[Value[3]]);
    digitalWrite(SEG3,LOW);
  break;
}
}
```

APPENDIX

LM741 Operational Amplifier

1 Features

- Overload Protection on the Input and Output
- No Latch-Up When the Common-Mode Range is Exceeded

2 Applications

- Comparators
- Multivibrators
- DC Amplifiers
- Summing Amplifiers
- Integrator or Differentiators
- Active Filters

3 Description

The LM741 series are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common-mode range is exceeded, as well as freedom from oscillations.

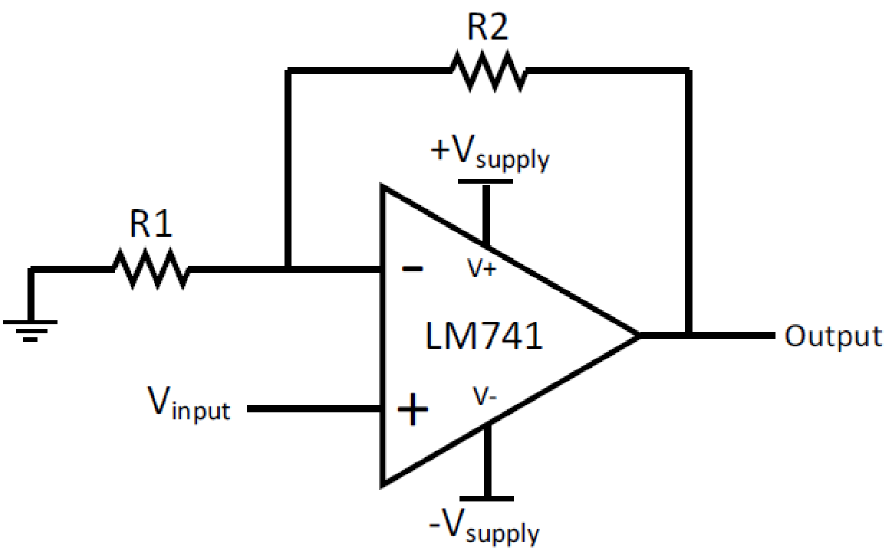
The LM741C is identical to the LM741 and LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Device Information[1]

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM741	TO-99 (8)	9.08 mm × 9.08 mm
	CDIP (8)	10.16 mm × 6.502 mm
	PDIP (8)	9.81 mm × 6.35 mm

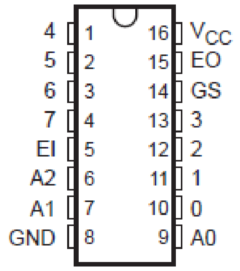
(1) For all available packages, see the orderable addendum at the end of the data sheet.

Typical Application

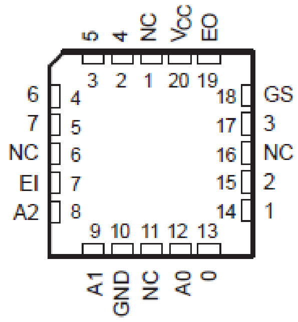


- Wide Operating Voltage Range of 2 V to 6 V
- Outputs Can Drive Up To 10 LSTTL Loads
- Low Power Consumption, 80-µA Max I_{CC}
- Typical t_{pd} = 16 ns
- ±4-mA Output Drive at 5 V
- Low Input Current of 1 µA Max
- Encode Eight Data Lines to 3-Line Binary (Octal)
- Applications Include:
  - n-Bit Encoding
  - Code Converters and Generators

SN54HC148 . . . J OR W PACKAGE
SN74HC148 . . . D, DW, N, OR NS PACKAGE
(TOP VIEW)



SN54HC148 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description/ordering information

The ’HC148 devices feature priority decoding of the inputs to ensure that only the highest-order data line is encoded. These devices encode eight data lines to 3-line (4-2-1) binary (octal). Cascading circuitry (enable input EI and enable output EO) has been provided to allow octal expansion without the need for external circuitry. Data inputs and outputs are active at the low logic level.

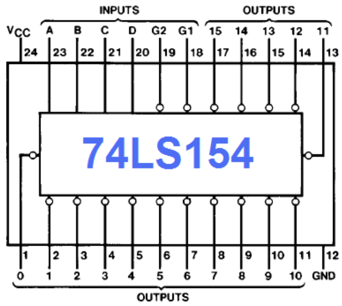
SN54HC148, SN74HC148
8-LINE TO 3-LINE PRIORITY ENCODERS

SCLS109G – MARCH 1984 – REVISED APRIL 2004

FUNCTION TABLE

INPUTS									OUTPUTS				
EI	0	1	2	3	4	5	6	7	A2	A1	A0	GS	EO
H	X	X	X	X	X	X	X	X	H	H	H	H	H
L	H	H	H	H	H	H	H	H	H	H	H	H	L
L	X	X	X	X	X	X	X	L	L	L	L	L	H
L	X	X	X	X	X	X	L	H	L	L	H	L	H
L	X	X	X	X	X	L	H	H	L	H	L	L	H
L	X	X	X	X	L	H	H	H	L	H	H	L	H
L	X	X	X	L	H	H	H	H	H	L	L	L	H
L	X	X	L	H	H	H	H	H	H	L	H	L	H
L	X	L	H	H	H	H	H	H	H	H	L	L	H
L	L	H	H	H	H	H	H	H	H	H	H	L	H

National Semiconductor



DM54LS154/DM74LS154 4-Line to 16-Line Decoders/Demultiplexers

General Description

Each of these 4-line-to-16-line decoders utilizes TTL circuitry to decode four binary-coded inputs into one of sixteen mutually exclusive outputs when both the strobe inputs, G1 and G2, are low. The demultiplexing function is performed by using the 4 input lines to address the output line, passing data from one of the strobe inputs with the other strobe input low. When either strobe input is high, all outputs are high. These demultiplexers are ideally suited for implementing high-performance memory decoders. All inputs are buffered and input clamping diodes are provided to minimize transmission-line effects and thereby simplify system design.

Features

- Decodes 4 binary-coded inputs into one of 16 mutually exclusive outputs
- Performs the demultiplexing function by distributing data from one input line to any one of 16 outputs
- Input clamping diodes simplify system design
- High fan-out, low-impedance, totem-pole outputs
- Typical propagation delay
  3 levels of logic 23 ns
  Strobe 19 ns
- Typical power dissipation 45 mW

Function Table

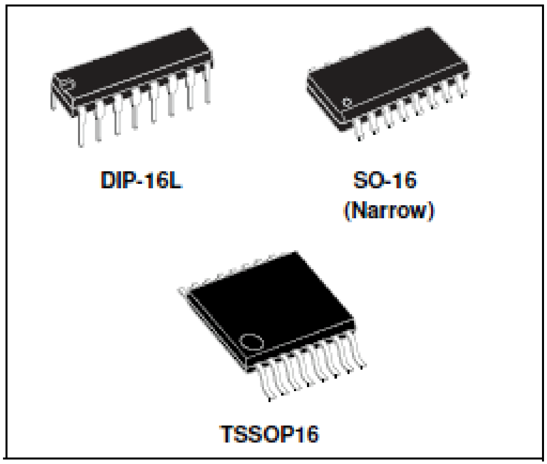
Inputs						Outputs															
G1	G2	D	C	B	A	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
L	L	L	L	L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	L	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	H	L	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	L	H	H	H	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H
L	L	L	H	L	L	H	H	H	H	L	H	H	H	H	H	H	H	H	H	H	H
L	L	L	H	L	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H	H	H
L	L	L	H	H	L	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H	H
L	L	L	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H	H	H	H
L	L	H	L	L	L	H	H	H	H	H	H	H	H	L	H	H	H	H	H	H	H
L	L	H	L	L	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H	H
L	L	H	L	H	L	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H	H
L	L	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H	H
L	L	H	H	L	L	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H	H
L	L	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H	H
L	L	H	H	H	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	H
L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L
L	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
H	L	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
H	H	X	X	X	X	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H

H = High Level, L = Low Level, X = Don't Care

ULN2001, ULN2002
ULN2003, ULN2004

Seven Darlington arrays

Datasheet - production data



Features

- Seven Darlingtons per package
- Output current 500 mA per driver (600 mA peak)
- Output voltage 50 V
- Integrated suppression diodes for inductive loads
- Outputs can be paralleled for higher current
- TTL/CMOS/PMOS/DTL compatible inputs
- Input pins placed opposite to output pins to simplify layout

Description

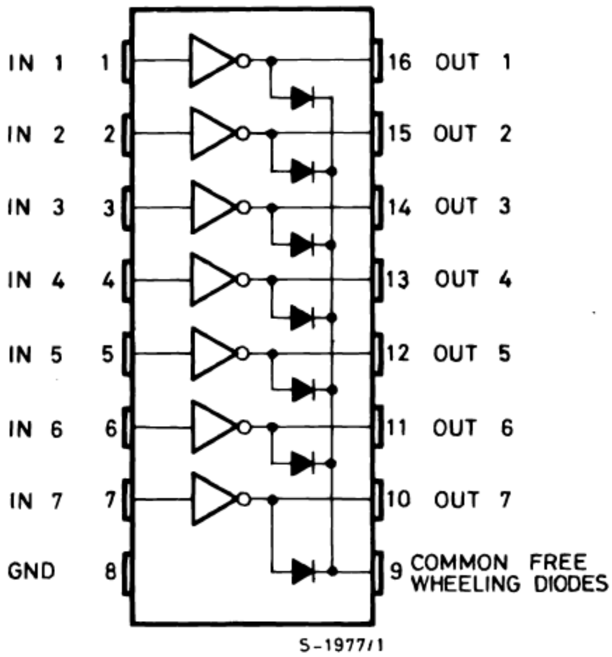
The ULN2001, ULN2002, ULN2003 and ULN 2004 are high-voltage, high-current Darlington arrays each containing seven open collector Darlington pairs with common emitters. Each channel is rated at 500 mA and can withstand peak currents of 600 mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout.

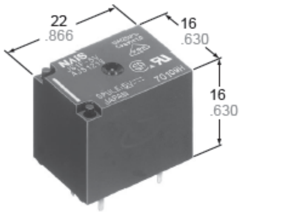
The versions interface to all common logic families: ULN2001 (general purpose, DTL, TTL, PMOS, CMOS); ULN2002 (14 - 25 V PMOS); ULN2003 (5 V TTL, CMOS); ULN2004 (6 - 15 V CMOS, PMOS).

These versatile devices are useful for driving a wide range of loads including solenoids, relay DC motors, LED display filament lamps, thermal printheads and high-power buffers.

The ULN2001A/2002A/2003A and 2004A are supplied in a 16-pin DIP package with a copper leadframe to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D1/2002D1/2003D1/ 2004D1.

ULN2003 is also available in TSSOP16 package, for reduced application space.





mm inch

FEATURES

- **Ultra-miniature size with universal terminal footprint**
- **High contact capacity: 10 A**
- **Class B coil insulation type available**
- **TV-5 type available**
  1 Form A type → TV-5
  1 Form C type → TV-5 (N.O. side only)
- **VDE, TÜV also approved**
- **Sealed construction for automatic cleaning**

SPECIFICATIONS

Contact

Arrangement		1 Form A, 1 Form C
Initial contact resistance, max. (By voltage drop 6 V DC 1 A)		100 mΩ
Contact material		Silver alloy
Rating (resistive load)	Nominal switching capacity	10 A 250 V AC 10 A 125 V AC 6 A 277 V AC
	Max. switching power	2,500 VA
	Max. switching voltage	250 V AC, 100 V DC
	Max. switching current	10 A (AC), 5 A (DC)
Expected life (min.ope.)	Mechanical (at 180 cpm)	10^7
	Electrical at 10 A 125 V AC, 6 A 277 V AC resistive (at 20 cpm)	10^5
	10 A 250 V AC resistive (at 20 cpm)	5×10^4 (No contact only)

Coil

Nominal operating power	360 mW

Remarks

- * Specifications will vary with foreign standards certification ratings.
- *1 Detection current: 10mA
- *2 Excluding contact bounce time
- *3 Half-wave pulse of sine wave: 11ms; detection time: 10µs
- *4 Half-wave pulse of sine wave: 6ms
- *5 Detection time: 10µs
- *6 Refer to 5. Conditions for operation, transport and storage mentioned in AMBIENT ENVIRONMENT (Page 24).
- *7 When using relays in a high ambient temperature, consider the pick-up voltage rise due to the high temperature (a rise of approx. 0.4% V for each 1°C 33.8°F with 20°C 68°F as a reference) and use a coil impressed voltage that is within the maximum allowable voltage range.

Characteristics

Max. operating speed		20 cpm
Initial insulation resistance		Min. 100 MΩ (at 500 V DC)
Initial breakdown voltage*1	Between open contacts	750 Vrms for 1 min.
	Between contacts and coil	1,500 Vrms for 1 min.
Operate time*2 (at nominal voltage)		Approx. 10 ms
Release time(without diode)*2 (at nominal voltage)		Approx. 10 ms
Temperature rise (at nominal voltage)		Max. 35°C
Shock resistance	Functional*3	Min. 98 m/s² {10 G}
	Destructive*4	Min. 980 m/s² {100 G}
Vibration resistance	Functional*5	Approx. 98 m/s² {10 G}, 10 to 55 Hz at double amplitude of 1.6 mm
	Destructive	Approx. 117.6 m/s² {12 G}, 10 to 55 Hz at double amplitude of 2 mm
Conditions for operation, transport and storage*6 (Not freezing and condensing at low temperature)	Ambient temp.*7	–40°C to +85°C –40°F to +185°F
	Humidity	5 to 85% R.H.
Unit weight		Approx.12 g .423 oz