7th Semester Project Report

on

IoT-Based Transformer Monitoring and Protection System

Submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering under Assam Science and Technology University (ASTU)

Session : 2024

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ABSTRACT

This project presents an innovative IoT-based system tailored for the monitoring and protection of electrical transformers. It utilizes a microcontroller as the central processing unit to gather essential operational data, including voltage levels, current flow, temperature variations, and oil levels. This data is then transmitted wirelessly to a centralized server for real-time monitoring and analysis. The system is meticulously designed through a series of phases encompassing sensor integration, circuitry development, and software programming. By seamlessly integrating diverse sensor functionalities, the system aims to enhance the reliability and efficiency of power distribution networks. Through continuous monitoring and proactive protection measures, potential faults and operational inefficiencies can be swiftly identified and mitigated, leading to improved operational performance and reduced maintenance costs. Furthermore, the project sets the stage for future advancements in IoT technology, promising opportunities for further innovation and refinement in the realm of electrical system monitoring and management.

CANDIDATES’ DECLARATION

We hereby declare that the work which is being presented in this report entitled “IoT-Based Transformer Monitoring and Protection System”, in partial fulfillment for the degree of Bachelor of Technology in Electrical Engineering from Assam Engineering College, under Assam Science and Technology University is an authentic record of our own work carried out under the supervision of Dr. Purobi Patowary, Department of Electrical Engineering, Assam Engineering College, Guwahati, Assam. The matter presented in this report has not been partially or fully copied.

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7th Semester

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ACKNOWLEDGEMENT

With immense pleasure we take this opportunity to express sincere gratitude and appreciation to our project guide Dr. Purobi Patowary, Professor, Department of Electrical Engineering, Assam Engineering College, for precious guidance, encouragement, constructive criticism, and valuable suggestions during the course of the project work and in preparation of the manuscript.

We also extend our heartfelt gratitude to Dr. Runumi Sarma, Head of Department, Electrical Engineering, Assam Engineering College.

We thank all the faculty members of the Department of Electrical Engineering, Assam Engineering College.

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CHAPTER 1: INTRODUCTION

In electric power distribution, the transformer plays a major role in efficient power distribution. Almost all the load is driven by the output of the transformer. Depending on the requirement of power (in KW) we have transformers of different sizes and capacities. When the transformer is providing the load, through transmission lines, it is affected by certain parameters like temperature, and moisture, along with the obvious parameters like voltage, current, frequency as well and oil level. In the case of large transformers to maintain the temperature, oil is used. The oil level has to be maintained properly to protect the transformer from overheat. To monitor the efficiency of the transformer, it is necessary to check these parameters from time to time.

An automatic system that can measure and monitor all vital parameters automatically, take decisions if needed and store data in a certain location will be much more helpful for the maintenance of the transformer as well as protection from overvoltage and overload.

The IOT has become a buzzing word in the field of technology related to communication, automation, and computing. At the same time, IoT became a standard for industrial use to monitor a transformer remotely as well as log the data effectively.

1.1 BACKGROUND

In the context of electric power distribution, transformers are vital for efficient power delivery. Their size and capacity vary based on kilowatt requirements, and they are subject to critical parameters like voltage, current, temperature, moisture, and oil level. Maintaining optimal conditions is crucial for preventing overheating and ensuring longevity. Regular monitoring is essential for efficiency assessment and prompt deviation detection. In large-scale power distribution, an automated IoT-based system becomes invaluable for continuous measurement, monitoring, and decision-making, providing maintenance and protection against overvoltage and overload. This project explores leveraging IoT technology to enhance transformer reliability and performance.

1.2 MOTIVATION

This project aims to transform transformer monitoring using IoT, addressing environmental factors like temperature, moisture, voltage, and oil levels. The proposed system automates monitoring, enabling timely interventions for optimal efficiency and protection against overvoltage and overload. Leveraging IoT in power distribution aligns with contemporary needs, emphasizing the project's goal to enhance maintenance, performance, and resilience in the evolving technological landscape.

1.3 OBJECTIVES

- Temperature monitoring
- Oil level monitoring
- Voltage monitoring
- Current measurement
- Power consumption calculation
- Circuit breaking
- IoT-based implementation
- Centralized storage of data
- Over Voltage Protection
- Over Current Protection
- User and password-based authentication system

1.4 LITERATURE REVIEW

Paper1:

In the paper titled "HEALTH CONDITION MONITORING SYSTEM FOR DISTRIBUTION TRANSFORMER USING INTERNET OF THINGS(IoT)" by Rohit R. Pawar, Dr. S.B.Deosarkar introduces a two-part system centered around a Remote Terminal Unit (RTU) designed with a PIC18F4550 microcontroller. The RTU collects data from various sensors near the transformer, including temperature, vibrations, humidity, oil level, and current. This data is sent to a monitoring node via the GSM-GPRS module. The monitoring node utilizes software to receive and display this data for operating engineers. The hardware design of the RTU includes sensors, a microcontroller, an LCD, a buzzer, and a GSM/GPRS module. This system aims to enhance transformer monitoring, detect faults, and provide real-time status viewing on a computer.

On the other hand, our project work focuses on a distributed system where various parameters of a transformer, such as temperature, oil level, voltage, and current, are measured using different sensors. The microcontroller collects and processes this data, displaying it on an LCD. The information is then transmitted to a web server through a WiFi modem, allowing users to access it remotely via network-enabled devices. The system employs sensors like DS18B20 for temperature, a resistive method with a floating ball system for oil level, and a step-down transformer for voltage.

In summary, while both papers involve monitoring transformer parameters, the first paper emphasizes centralized RTU systems using GSM-GPRS for communication, and our paper focuses on distributed data processing with Wi-Fi connectivity. The sensor configurations and communication methods differ between the two approaches.

Paper 2:

In the paper titled "IoT BASED TRANSFORMER MONITORING AND CONTROL"
By author 1Ms. Sneha Jalindar Kamble, 2Prof. S. S. Patil, 3Prof. A. S. Mali, the author has described the voltage sensor using Arduino where the exact information is not provided. When we use Arduino or any microcontroller with internal as well as external ADC it can handle at most the specified input voltage level by the manufacturer. For example – in the case of Arduino it can handle a maximum of 5 V as analog input. On the other hand, ESP32 or ESP8266 can handle a maximum of 3.3 V and in both cases it is DC but when we have to measure the AC voltage like 220 to 240 V the working principle is different. They are also

using ACS712 for current sensing which is also our choice. Though it has some limitations still it the best choice for current measurement. For the oil level sensor, they have mentioned the ultrasonic sensor but after studying various articles we have found that the ultrasonic sensor is not the right choice for liquid level measuring especially in the case of transformer oil as the reading of the ultrasonic sensor is affected by air temperature and moisture level.

Paper 3:

In the paper titled "TRANSFORMER HEALTH MONITORING SYSTEM USING IOT" by Author S. Swetha, they are using an ultrasonic sensor as an oil level sensor. In this paper, the author has not used any LCD or local display unit but we have realized that having a local or on-circulating unit is much more important for debugging and monitoring of the system. In both the paper the protection part is not implemented which is one of the major aspects of our project work.

Paper 4:

In the paper titled "IOT BASED TRANSFORMER MONITORING SYSTEM " by Shrutika Shitole, Najma Shaikh, Pratiksha Patil, and Radhika Mithari uses the implementation of IoT concept is implementing third-party applications and services like ThingSpeak. When we used ThingSpeak we did not have much control over it and we could not configure it for industrial implementation.

In our project work, we have decided to develop the web application/IoT application from scratch so that all the basic features can be implemented and configured according to our requirements.

CHAPTER 2 : HARDWARE AND SOFTWARE REQUIREMENTS

2.1 HARDWARE REQUIREMENTS

The selection and integration of hardware components are crucial to the success and functionality of the IoT-based transformer monitoring and protection system. This chapter outlines the essential hardware required for the project, focusing on components that ensure accurate data collection, efficient real-time processing, and robust Wi-Fi communication.

We will explore the role of various sensors, microcontrollers, and communication modules, as well as power management components like voltage regulators and rectifiers. Each hardware element is chosen for its specific function and contribution to the overall system reliability. Understanding these requirements is fundamental for replicating the project and considering future enhancements.

2.1.1ATMEGA328P

Introduction

The Atmel® picoPower® ATmega328/P is a low-power CMOS 8-bit microcontroller based on the AVR® enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega328/P achieves throughputs close to 1MIPS per MHz. This empowers the system designer to optimize the device for power consumption versus processing speed.

The Atmel AVR® core combines a rich instruction set with 32 general-purpose working registers. All 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in a single instruction executed in one clock cycle. The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers. The ATmega328/P provides the following features: 32Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 1Kbytes EEPROM, 2Kbytes SRAM, 23 general purpose I/O lines, 32 general purpose working registers, Real Time Counter (RTC), three flexible Timer/Counters with compare modes and PWM, 1 serial programmable USARTs , 1 byte-oriented 2-wire Serial Interface (I2C), a 6-channel 10-bit ADC (8 channels in TQFP and QFN/MLF packages) , a programmable

Watchdog Timer with internal Oscillator, an SPI serial port, and six software selectable power saving modes. The Idle mode stops the CPU while allowing the SRAM, Timer/Counters, SPI port, and interrupt system to continue functioning. The Power-down mode saves the register contents but freezes the Oscillator, disabling all other chip functions until the next interrupt or hardware reset. In Power-save mode, the asynchronous timer continues to run, allowing the user to maintain a timer base while the rest of the device is sleeping. The ADC Noise Reduction mode stops the CPU and all I/O modules except the asynchronous timer and ADC to minimize switching noise during ADC conversions. In Standby mode, the crystal/resonator oscillator is running while the rest of the device is sleeping. This allows very fast start-up combined with low power consumption. In Extended Standby mode, both the main oscillator and the asynchronous timer continue to run. Atmel offers the QTouch® library for embedding capacitive touch buttons, sliders, and wheels functionality into AVR microcontrollers. The patented charge-transfer signal acquisition offers robust sensing and includes fully debounced reporting of touch keys and includes Adjacent Key Suppression® (AKS™) technology for unambiguous detection of key events. The easy-to-use QTouch Suite toolchain allows you to explore, develop and debug your touch applications. The device is manufactured using Atmel's high-density non-volatile memory technology. The On-chip ISP Flash allows the program memory to be reprogrammed In-System through an SPI serial interface, by a conventional nonvolatile memory programmer, or by an On-chip Boot program running on the AVR core. The Boot program can use any interface to download the application program in the Application Flash memory. Software in the Boot Flash section will continue to run while the Application Flash section is updated, providing true Read-While-Write operation. By combining an 8-bit RISC CPU with In-System Self-Programmable Flash on a monolithic chip, the Atmel ATmega328/P is a powerful microcontroller that provides a highly flexible and costeffective solution to many embedded control applications. The ATmega328/P is supported with a full suite of program and system development tools including: C Compilers, Macro Assemblers, Program Debugger/Simulators, In-Circuit Emulators, and Evaluation kits.

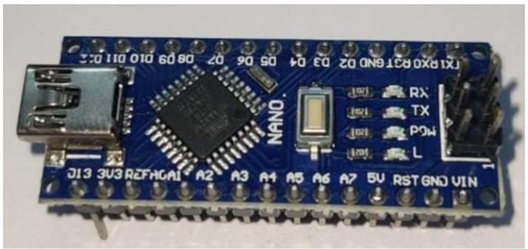

Fig2.1: Arduino Nano Board (ATmega328P Microcontroller)

Pin Diagram

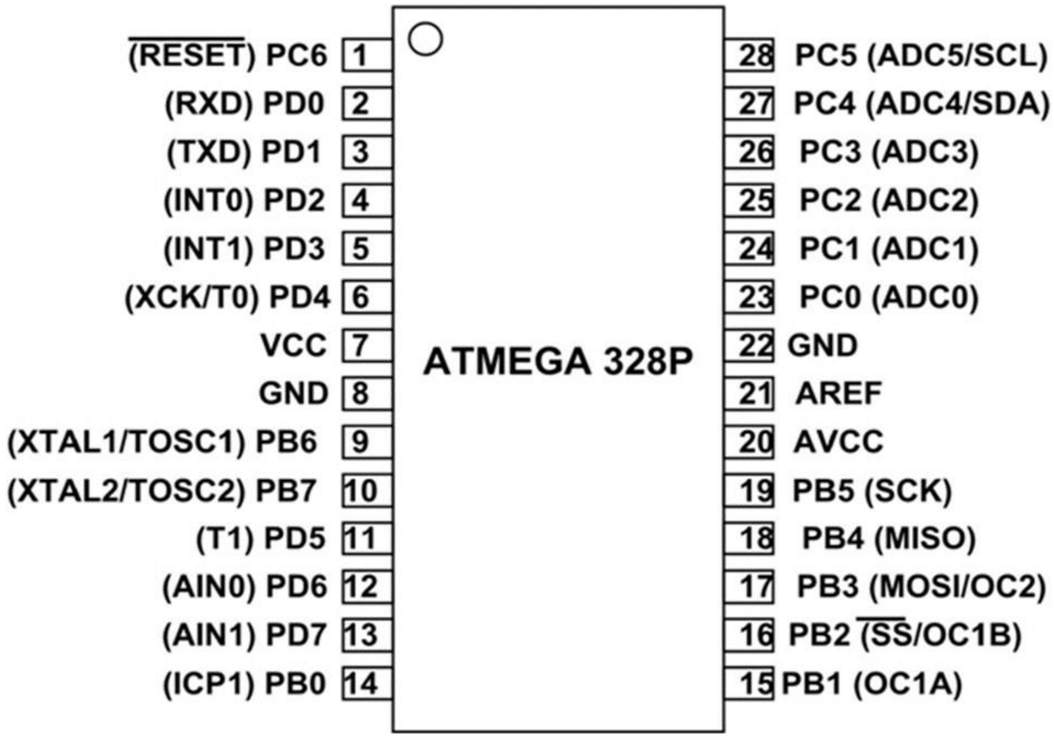

Fig.2: Pin diagram of ATmega328P

Block Diagram

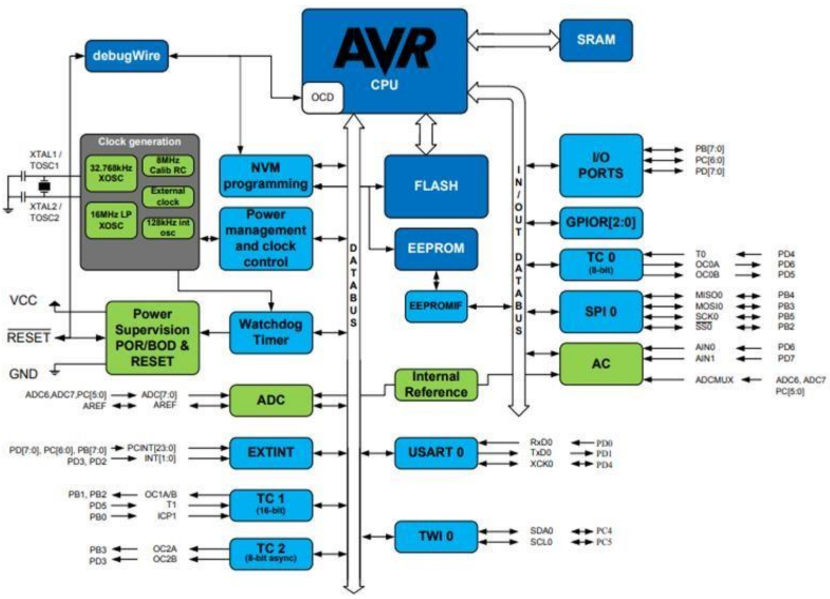

Fig2.3: Block diagram of ATmega328P

Features

High Performance, Low Power Atmel®AVR® 8-Bit Microcontroller Family

• Advanced RISC Architecture

– 131 Powerful Instructions

– Most Single Clock Cycle Execution

– 32 x 8 General Purpose Working Registers

– Fully Static Operation

– Up to 20 MIPS Throughput at 20MHz

– On-chip 2-cycle Multiplier

• High Endurance Non-volatile Memory Segments

– 32KBytes of In-System Self-Programmable Flash program

Memory

– 1KBytes EEPROM

– 2KBytes Internal SRAM

– Write/Erase Cycles: 10,000 Flash/100,000 EEPROM

– Data Retention: 20 years at 85°C/100 years at 25°C(1)

– Optional Boot Code Section with Independent Lock Bits

• In-System Programming by On-chip Boot Program

• True Read-While-Write Operation

– Programming Lock for Software Security

• Atmel® QTouch® Library Support

– Capacitive Touch Buttons, Sliders and Wheels

– QTouch and QMatrix® Acquisition

– Up to 64 sense channels Atmel-42735B-328/P_Datasheet_Summary-11/2016

• Peripheral Features

– Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode

– One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode

– Real Time Counter with Separate Oscillator

– Six PWM Channels

– 8-channel 10-bit ADC in TQFP and QFN/MLF package

• Temperature Measurement

– 6-channel 10-bit ADC in PDIP Package

• Temperature Measurement

– Two Master/Slave SPI Serial Interface

– One Programmable Serial USART

– One Byte-oriented 2-wire Serial Interface (Philips I2C compatible)

– Programmable Watchdog Timer with Separate On-chip Oscillator

– One On-chip Analog Comparator

– Interrupt and Wake-up on Pin Change

• Special Microcontroller Features

– Power-on Reset and Programmable Brown-out Detection

– Internal Calibrated Oscillator

– External and Internal Interrupt Sources

– Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby

• I/O and Packages

– 23 Programmable I/O Lines

– 28-pin PDIP, 32-lead TQFP, 28-pad QFN/MLF and 32-pad QFN/MLF

• Operating Voltage:

– 1.8 - 5.5V

• Temperature Range:

– -40°C to 105°C

• Speed Grade:

– 0 - 4MHz @ 1.8 - 5.5V

– 0 - 10MHz @ 2.7 - 5.5V

– 0 - 20MHz @ 4.5 - 5.5V

• Power Consumption at 1MHz, 1.8V, 25°C

– Active Mode: 0.2mA

– Power-down Mode: 0.1µA

– Power-save Mode: 0.75µA (Including 32kHz RTC)

2.1.2 LCD Introduction

A liquid crystal display (LCD) is a flat panel display, electronic visual display, or video display that uses the light-modulating properties of liquid crystals (LCs).

LCs do not emit light directly.

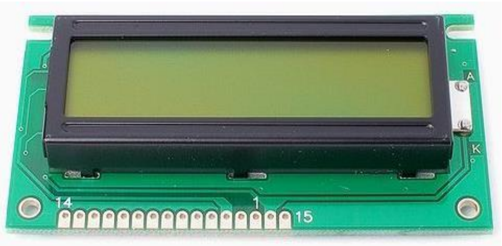

Fig 2.4: LCD Display

LCDs are used in a wide range of applications, including computer monitors, television, instrument panels, aircraft cockpit displays, signage, etc. They are common in consumer devices such as video players, gaming devices,clocks, watches, calculators, and telephones. LCDs have replaced cathode ray tube (CRT) displays in most applications. They are available in a wider range of screen sizes than CRT and plasma displays, and since they do not use phosphors, they cannot suffer image burn-in. LCDs are, however, susceptible to image persistence.

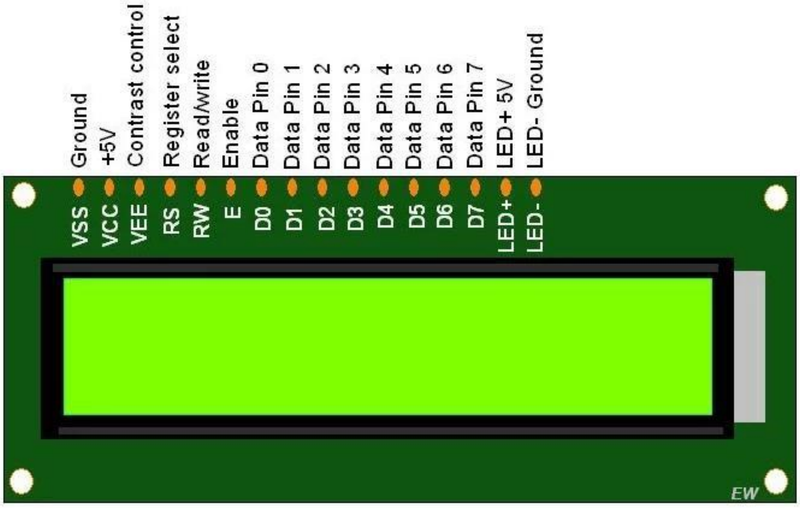

Fig2.5: Pin diagram of LCD Display

PIN NUMBER	SYMBOL	FUNCTION
1	Vss	GND
2	Vdd	+ 3V or + 5V
3	Vo	Contrast Adjustment
4	RS	H/L Register Select Signal
5	R/$\overline{W}$	H/L Read/Write Signal
6	E	H →L Enable Signal
7	DB0	H/L Data Bus Line
8	DB1	H/L Data Bus Line
9	DB2	H/L Data Bus Line
10	DB3	H/L Data Bus Line
11	DB4	H/L Data Bus Line
12	DB5	H/L Data Bus Line
13	DB6	H/L Data Bus Line
14	DB7	H/L Data Bus Line
15	A/Vee	+ 4.2V for LED/Negative Voltage Output
16	K	Power Supply for B/L (OV)

Table 2.1: LCD pin configurations

Sr.No.	Hex Code	Command to LCD instruction Register
1	01	Clear display screen
2	02	Return home
3	04	Decrement cursor (shift cursor to left)
4	06	Increment cursor (shift cursor to right)
5	05	Shift display right
6	07	Shift display left
7	08	Display off, cursor off
8	0A	Display off, cursor on
9	0C	Display on, cursor off
10	0E	Display on, cursor blinking
11	0F	Display on, cursor blinking
12	10	Shift cursor position to left
13	14	Shift the cursor position to the right
14	18	Shift the entire display to the left
15	1C	Shift the entire display to the right
16	80	Force cursor to the beginning (1st line)
17	C0	Force cursor to the beginning (2nd line)
18	38	2 lines and 5×7 matrix

Table2.2: LCD Commands

2.1.3 POWER SUPPLY Introduction to Power Supply

The power supplies are designed to convert high-voltage AC mains electricity to a suitable low-voltage supply for electronic circuits and other devices. A power supply can be broken down into a series of blocks, each of which performs a particular function. A d.c power supply that maintains the output voltage constant irrespective of a.c mains fluctuations or load variations is known as a “Regulated D.C Power Supply”

For example, a 5V regulated power supply system as shown below:

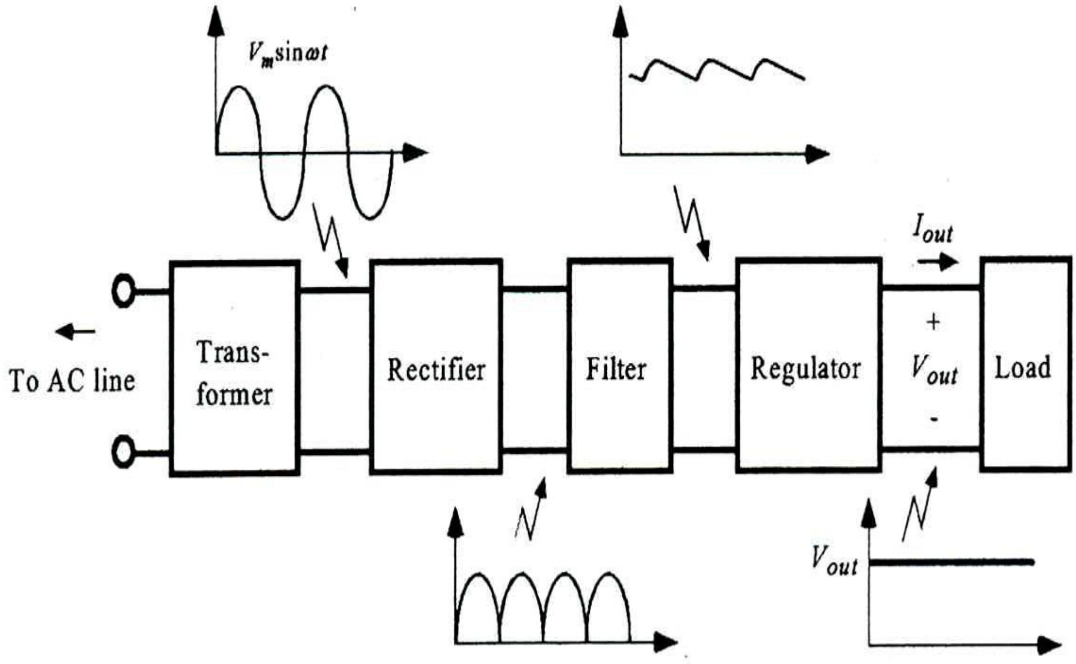

Fig 2.6: Components of a typical power supply

Transformer and its types

A transformer is an electrical device which is used to convert electrical power from one Electrical circuit to another without change in frequency. Transformers convert AC electricity from one voltage to another with little loss of power. Transformers work only with AC and this is one of the reasons why mains electricity is AC.

Step-up transformers increase in output voltage, step-down transformers decrease in output voltage. Most power supplies use a step-down transformer to reduce the dangerously high mains voltage to a safer low voltage. The input coil is called the primary and the output coil is called the secondary. There is no electrical connection between the two coils; instead, they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core. Transformers waste very little power so the power out is (almost) equal to the power in. Note that as voltage is stepped down current is stepped up.

The ratio of the number of turns on each coil, called the turn's ratio, determines the ratio of the voltages.

A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

Fig2.7:An Electrical Transformer

Turns ratio = $V_p / V_S = N_p / N_S$

Power Out= Power In

$V_S \times I_S = V_P \times I_P$

V_p= primary (input) voltage

N_p = number of turns on the primary coil

I_p = primary (input) current

RECTIFIER:

A circuit that is used to convert a.c to DC is known as RECTIFIER. The process of conversion a.c to d.c is called “rectification”

TYPES OF RECTIFIERS:

- Half wave Rectifier
- Full wave rectifier
    1. Centre tap full wave rectifier.
    2. Bridge type full bridge rectifier.

Parameter	Type of Rectifier		
	Half wave	Full wave	Bridge
Number of diodes	1	2	4
PIV of diodes	Vm	2Vm	Vm
D.C output voltage	Vm/ π	2Vm/ π	2Vm/ π
Vdc,at no-load	0.318Vm	0.636Vm	0.636Vm
Ripple factor	1.21	0.482	0.482
Ripple frequency	f	2f	2f
Rectification efficiency	0.406	0.812	0.812
Transformer Utilization Factor(TUF)	0.287	0.693	0.812
RMS voltage Vrms	Vm/2	Vm/√2	Vm/√2

Table 2.3: Comparison of rectifier circuits:

Half-wave Rectifier:

A half-wave rectifier converts an AC signal to DC by passing either the negative or positive halfcycle of the waveform and blocking the other. Half-wave rectifiers can be easily constructed using only one diode, but are less efficient than full-wave rectifiers.

Since diodes only carry current in one direction, they can serve as a simple half-wave rectifier. Only passing half of an AC causes irregularities, so a capacitor is usually used to smooth out the rectified signal before it can be usable.

Full-wave Rectifier(FWR):

From the above comparison, we came to know that the full wave bridge rectifier has more advantages than the other two rectifiers. So, in our project, we are using a full wave bridge rectifier circuit.

Bridge Rectifier: A bridge rectifier makes use of four diodes in a bridge arrangement to achieve full-wave rectification. This is a widely used configuration, both with individual diodes wired as shown and with single component bridges where the diode bridge is wired internally.

A bridge rectifier makes use of four diodes in a bridge arrangement as shown in Fig 2.8 to achieve full-wave rectification. This is a widely used configuration, both with individual diodes wired as shown and with single component bridges where the diode bridge is wired internally.

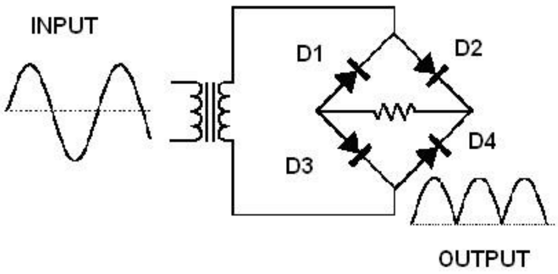

Fig2.8: Full Wave Rectifier

Operation:

During the positive half cycle of secondary, the diodes D2 and D3 are forward biased while D1 and D4 are reverse biased as shown in fig2.9. The current flow direction is shown in fig (b) with dotted arrows.

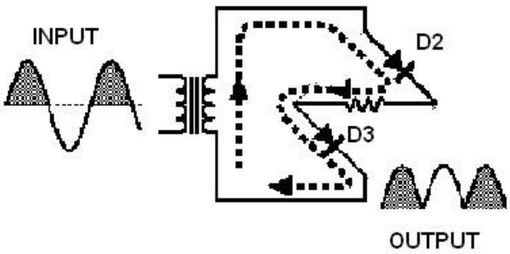

Fig2.9:Operation of FWR during positive half cycle

During the negative half cycle of secondary voltage, the diodes D1 and D4 are in forward biased while D2 and D3 are reverse biased as shown in fig 2.10. The current flow direction is shown in the fig (c) with dotted arrows.

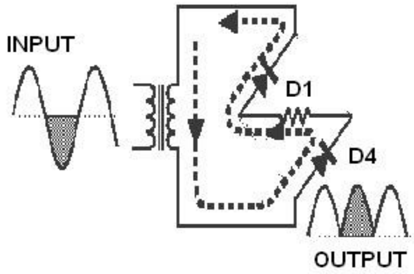

Fig2.9:Operation of FWR during negative half cycle **Filter Circuit for Noise Reduction:**

A Filter is a device that removes the a.c component of rectifier output but allows the d.c component to reach the load.

Capacitor Filter:

We have seen that the ripple content in the rectified output of a wave rectifier is **121%** or that of a full-wave or bridge rectifier or bridge rectifier is **48%** such high percentages of ripples is not acceptable for most of the applications. Ripples can be removed by one of the following methods of filtering.

(a) A capacitor, in parallel to the load, provides an easier bypass for the ripple voltage though it due to low impedance. At ripple frequency and leave the d.c.to appears the load.

(b) An inductor, in series with the load, prevents the passage of the ripple current (due to high impedance at ripple frequency) while allowing the d.c (due to low resistance to d.c)

(c) Various combinations of capacitor and inductor, such as L-section filter section filter, multiple section filter, etc. which make use of both the properties mentioned in (a) and (b) above. Two cases of capacitor filter, one applied on half wave rectifier and another with full wave rectifier. Filtering is performed by a large value electrolytic capacitor connected across the DC supply to act as a reservoir, supplying current to the output when the varying DC voltage from the rectifier is falling. The capacitor charges quickly near the peak of the varying DC, and then discharges as it supplies current to the output. Filtering significantly increases the average DC voltage to almost the peak value (1.4 × RMS value).

To calculate the value of the capacitor(C),

$$C = \frac{1}{4}*\sqrt{3}*f*r*Rl$$

Where,

f = supply frequency,

r = ripple factor, Rl =

load resistance Note: In our circuit, we are using 1000μF. Hence large value of the capacitor is placed to reduce ripples and to improve the DC component.

2.1.4 BUCK CONVERTER LM2596

LM2596 is a voltage regulator mainly used to step down the voltage or to drive load under 3A.

- It is also known as a DC-to-DC power converter or buck converter which is used to step down the voltage from its input supply to the output load. The current goes up during this voltage step-down process.
- LM2596 comes with a remarkable load and line regulation. It is available in both versions: fixed output voltage version with 3.3V, 5V, 12V, and customized output version where you can choose the output as per your requirement.
- This regulator is incorporated with a fixed-frequency oscillator and an internal frequency compensation method.
- Frequency compensation is applied by adjusting both phase and gain characteristics of the open-loop output to avoid oscillation and vibration in the circuit. This is achieved with the help of resistance-capacitance networks.
- A minimum number of external components are required for this regulator that works at a fixed frequency of 150 kHz.

Fig 2.11: LM2576 Buck Converter

- The LM2596 comes with total of five pins as follows: **Vin** = I = This is the input supply pin interlaced with the input bypass capacitor to provide the switching current and to reduce voltage transients. **Output** = O = This is the internal switch with voltage switches between (Vin – Vsat) and -0.5V. It comes with a duty cycle of Vout/Vin. The PCB copper area attached to this pin is used to minimize the coupling. **Ground** = This pin is connected to the ground. **Feedback** = I = This pin identifies the regulated output voltage for the feedback loop. **ON/OFF** = I = This pin is used to shut down the voltage regulator circuit with the input supply current reducing to 80uA. When the voltage on this pin goes below the threshold voltage of 1.3V, it turns on the buck converter. And when the voltage goes above the 1.3V, it turns off the converter. You can get rid of this shutdown feature by attaching the pin to the ground or leaving it open. In both cases, the regulator remains ON.

LM2596 Features

- Fixed versions i.e. 3.3-V, 5-V, 12-V, and customizable output versions
- Customizable output version with voltage range: 1.2-V to 37-V ±4% maximum overload and line conditions
- Available in two packages including TO-263 and TO-220 packages.
- Can drive load under 3A.
- 40 V is the input voltage range
- 4 external components are needed
- Remarkable load and line regulations
- Internal oscillator with a fixed frequency of 150 kHz
- TTL shutdown capability
- Comes with low-power standby mode, commonly 80 µA

2.1.5 STEP DOWN TRANSFORMER

A transformer is an electrical device that is used to convert electrical power from one Electrical circuit to another without a change in frequency. Transformers convert AC electricity from one voltage to another with little loss of power. Transformers work only with AC and this is one of the reasons why mains electricity is AC. Step-up transformers increase in output voltage, stepdown transformers decrease in output voltage. Most power supplies use a step-down transformer to reduce the dangerously high mains voltage to a safer low voltage. The input coil is called the primary and the output coil is called the secondary. There is no electrical connection between the two coils; instead, they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core. Transformers waste very little power so the power out is (almost) equal to the power in. Note that as voltage is stepped down current is stepped up. The ratio of the number of turns on each coil, called the turn's ratio, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

Fig 2.12: Step Down Transformer

2.1.6 1N4007 – RECTIFIER DIODE

The **1N400x** (or 1N4001 or 1N4000[1]) series is a family of popular one-ampere generalpurpose silicon rectifier diodes commonly used in AC adapters for common household appliances. Its blocking voltages vary from 50 volts (1N4001) to 1000 volts (1N4007).

1N4007 Features

Fig 2.13: 1N4007 – Rectifier diode

- Package Type: DO-41
- Max Repetitive Reverse Voltage: 1000 V
- Forward Voltage: 1.1 V
- Average Forward Current: 1 A
- Non-repetitive Max Forward Current: 30 A

- Reverse current: 5 uA
- Max Power Dissipation is: 3 W
- Max Storage & Operating temperature: -55 to +175 Centigrade

2.1.7 2200uF/25V – CAPACITOR

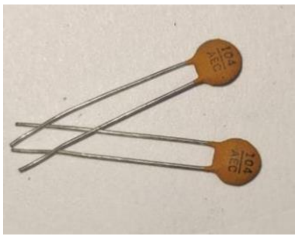

Fig 2.14: 2200uF/25V Capacitors

2.1.8 10K POTENTIOMETER AS OIL LEVEL SENSOR

Fig 2.15: 10K Potentiometer

2.1.9 ACS712 – CURRENT SENSOR

The Allegro™ ACS712 provides economical and precise solutions for AC or DC sensing in industrial, commercial, and communications systems. The device package allows for easy implementation by the customer. Typical applications include motor control, load detection and management, switch-mode power supplies, and overcurrent fault protection. The device is not intended for automotive applications. The device consists of a precise, low-offset, linear Hall circuit with a copper conduction path located near the surface of the die. Applied current flowing through this copper conduction path generates a magnetic field which the Hall IC converts into a proportional voltage. Device accuracy is optimized through the proximity of the magnetic signal to the Hall transducer. A precise, proportional voltage is provided by the low-offset, chopper-stabilized BiCMOS Hall IC, which is programmed for accuracy after packaging. The output of the device has a positive slope (>VIOUT(Q)) when an increasing current flows through the primary copper conduction path (from pins 1 and 2, to pins 3 and 4), which is the path used for current sampling. The internal resistance of this conductive path is typically 1.2 mΩ, providing low power loss.

Fig 2.16: ACS712 Current Sensor

Features and Benefits

- Low-noise analog signal path
- Device bandwidth is set via the new FILTER pin
- 5 µs output rise time in response to step input current
- 80 kHz bandwidth
- Total output error 1.5% at TA = 25°C
- Small footprint, low-profile SOIC8 package
- 1.2 mΩ internal conductor resistance
- 2.1 kV RMS minimum isolation voltage from pins 1-4 to pins 5-8
- 5.0 V, single supply operation
- 66 to 185 mV/A output sensitivity
- Output voltage proportional to AC or DC currents
- Extremely stable output offset voltage
- Nearly zero magnetic hysteresis

2.1.10 DS18B20 – DIGITAL TEMPERATURE SENSOR

The DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with non-volatile user-programmable upper and lower trigger points. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor. It has an operating temperature range of -55°C to +125°C and is accurate to ±0.5°C over the range of -10°C to +85°C. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply. Each DS18B20 has a unique 64-bit serial code, which allows multiple DS18B20s to function on the same 1-Wire bus. Thus, it is simple to use one microprocessor to control many DS18B20s distributed over a large area. Applications that can benefit from this feature include HVAC environmental controls, temperature monitoring systems inside buildings, equipment, or machinery, and process monitoring and control systems.

Fig 2.17: DS18B20 Temperature Sensor

Features:

- Unique 1-Wire® Interface Requires Only One Port Pin for Communication Each Device has a Unique 64-bit Serial Code Stored in an On-Board ROM
- Multidrop Capability Simplifies Distributed Temperature-Sensing Applications
- Requires No External Components
- Can Be Powered from Data Line; Power Supply Range is 3.0V to 5.5V
- Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
- ±0.5°C Accuracy from -10°C to +85°C
- Thermometer Resolution is User Selectable from 9 to 12 Bits
- Converts Temperature to 12-bit Digital Word in 750ms (Max)

2.1.11 I2C DRIVER PCF8574:

This 8-bit input/output (I/O) expander for the two-line bidirectional bus (I2C) is designed for 2.5-V to 6-V VCC operation. The PCF8574 device provides general-purpose remote I/O expansion for most microcontroller families by way of the I2C interface , and serial data.

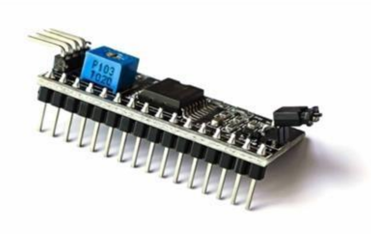

Fig 2.18: PCF8574 I2C Driver

2.1.12 2N222

The 2N2222 is a widely used NPN bipolar junction transistor (BJT) ideal for low-power amplifying and switching applications. It can handle a maximum collector-emitter voltage of 40V, a collector current of 800mA, and power dissipation of 500mW. With a current gain (hFE) between 100 and 300 and a transition frequency of 250 MHz, it is suitable for high-speed operations. Its pin configuration includes an emitter (E) connected to the ground, a base (B) for control, and a collector (C) connected to the load.

Fig 2.19: 2N222

2.1.13 ESP8266

ESP8266 is a complete and self-contained Wi-Fi network solution that can carry software applications, or through Another application processor uninstall all Wi-Fi networking capabilities. ESP8266 when the device is mounted and as the only application of the application processor, the flash memory can be started directly from an external Move. Built-in cache memory will help improve system performance and reduce memory requirements.

Fig 2.20: ESP8266

AT COMMANDS

ESP8266 AT Command Set

Function	***AT Command***	***Response***
Working	AT	OK
Restart	AT+RST	OK [System Ready, Vendor:www.ai-thinker.com]
Firmware version	AT+GMR	AT+GMR 0018000902 OK
List Access Points	AT+CWLAP	AT+CWLAP +CWLAP:(4,"RochefortSurLac",-38,"70:62:b8:6f:6d:58",1) +CWLAP:(4,"LiliPad2.4",-83,"f8:7b:8c:1e:7c:6d",1) OK
Join Access Point	AT+CWJAP? AT+CWJAP="SSID","Password"	Query AT+CWJAP? +CWJAP:"RochefortSurLac" OK
Quit Access Point	AT+CWQAP=? AT+CWQAP	Query OK
Get IP Address	AT+CIFSR	AT+CIFSR 192.168.0.105 OK
Set Parameters of Access Point	AT+ CWSAP? AT+ CWSAP= <ssid>,<pwd>,<chl>, <ecn>	Query ssid, pwd chl = channel, ecn = encryption
WiFi Mode	AT+CWMODE? AT+CWMODE=1 AT+CWMODE=2 AT+CWMODE=3	Query STA AP BOTH
Set up TCP or UDP connection	AT+CIPSTART=? (CIPMUX=0) AT+CIPSTART = <type>,<addr>,<port> (CIPMUX=1) AT+CIPSTART= <id><type>,<addr>, <port>	Query id = 0-4, type = TCP/UDP, addr = IP address, port= port
TCP/UDP Connections	AT+ CIPMUX? AT+ CIPMUX=0 AT+ CIPMUX=1	Query Single Multiple
Check join devices' IP	AT+CWLIF	
TCP/IP Connection Status	AT+CIPSTATUS	AT+CIPSTATUS? no this fun
Send TCP/IP data	(CIPMUX=0) AT+CIPSEND=<length>; (CIPMUX=1) AT+CIPSEND= <id>,<length>	
Close TCP / UDP connection	AT+CIPCLOSE=<id> or AT+CIPCLOSE	
Set as server	AT+ CIPSERVER= <mode>[,<port>]	mode 0 to close server mode; mode 1 to open; port = port
Set the server timeout	AT+CIPSTO? AT+CIPSTO=<time>	Query <time>0~28800 in seconds
Baud Rate*	AT+CIOBAUD? Supported: 9600, 19200, 38400, 74880, 115200, 230400, 460800, 921600	Query AT+CIOBAUD? +CIOBAUD:9600 OK
Check IP address	AT+CIFSR	AT+CIFSR 192.168.0.106 OK
Firmware Upgrade (from Cloud)	AT+CIUPDATE	1. +CIPUPDATE:1 found server 2. +CIPUPDATE:2 connect server 3. +CIPUPDATE:3 got edition 4. +CIPUPDATE:4 start update
Received data	+IPD	(CIPMUX=0): + IPD, <len>: (CIPMUX=1): + IPD, <id>, <len>: <data>
Watchdog Enable*	AT+CSYSWDTENABLE	Watchdog, auto restart when program errors occur: enable
Watchdog Disable*	AT+CSYSWDTDISABLE	Watchdog, auto restart when program errors occur: disable

Table 2.4: AT Commands of ESP8266

2.1.14 7805 VOLTAGE REGULATOR

The 7805 voltage regulator is a three-terminal positive voltage regulator available in the TO220/D-PAK package with fixed output voltages. They offer features like internal current limiting, thermal shutdown, and safe operating area protection. With adequate heat sinking, they can deliver over 1A output current. While primarily fixed voltage regulators, they can be used with external components for adjustable voltages and currents. Key features include output current up to 1A, output voltages ranging from 5V to 24V, thermal overload protection, short circuit protection, and output transistor-safe operating area protection.

Fig 2.21: 7805 Voltage Regulator

2.1.15 S1117-33pi

The S1117 is an adjustable low dropout voltage regulator series available in space-saving SMD types like SOT-223 and D-Pak (TO-252). With a 1.1V dropout voltage and 1.0A output current, it offers current limiting, thermal protection, and over-current protection. The output voltage is trimmed to within 2% tolerance for precision, and it boasts a fast transient response. To optimize transient response and stability, a minimum of 10uF tantalum capacitor is needed at the output.

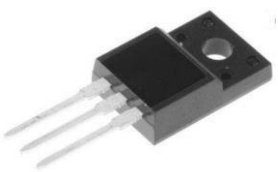

Fig 2.22: S1117-33pi Voltage Regulator

2.1.16 BUZZER

A buzzer or beeper is an audio signaling device, which may be mechanical, electromechanical, or piezoelectric (piezo for short). Typical uses of buzzers and beepers include alarm devices, timers, training and confirmation of user input such as a mouse click or keystroke.

Fig 2.23: Buzzer

2.1.17 ELECTROMAGNETIC RELAY

Electromagnetic relays are operated by electromagnetic action. Although modern electrical protection relays often use microprocessor-based relays, electromagnetic relays remain prevalent. Their complete replacement by microprocessor-based static relays will take considerable time. Therefore, understanding the various types of electromagnetic relays is essential.

3.2 BLOCK DIAGRAM

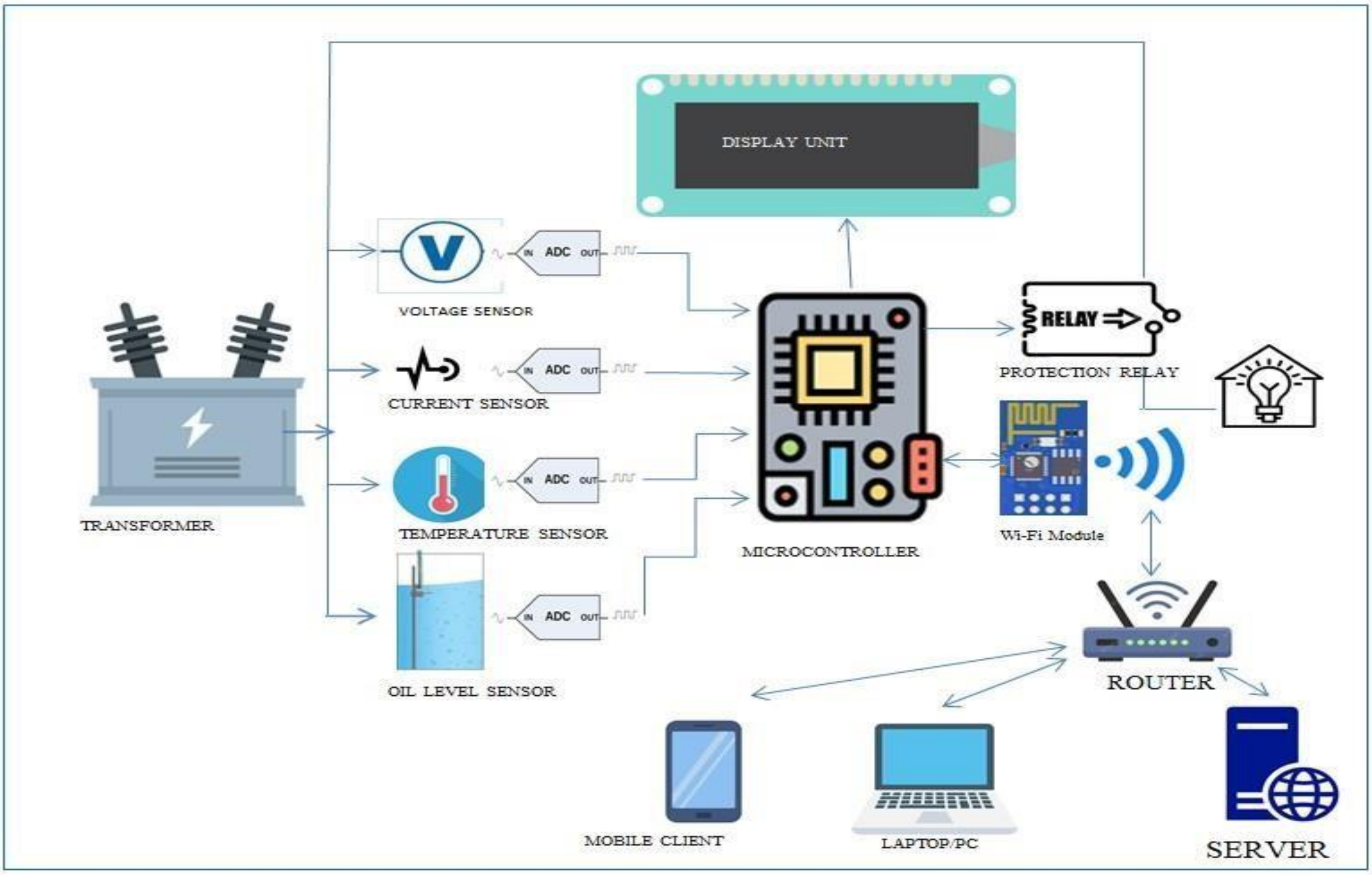

Fig 3.3: Block Diagram

3.3 CIRCUIT DESCRIPTION

The circuit diagram of the IoT-based transformer monitoring and protection system is designed around easily available components, a microcontroller, and a Wi-Fi module. The power supply of the component requires regulated +5V except for the ESP8266 which needed a 3.3V regulated power supply. To provide the power supply we are using a 220 V /12 V step-down transformer with, a current rating of 750 mA. The step-down AC is converted into DC with the help of a rectifier bridge designed around four 1N4007 rectifier diodes. When we convert AC to DC it has ripple or high harmonic noise due to pulsating DC. To minimize the noise a 1200µF (electrolytic capacitor) is connected between the positive and the ground terminal. All the components, i.e., ATMEGA382 (Arduino Nano), I2C driver PCF8574, LCD, ACS712 as well as DSI8B20 require regulated +5V. To provide regulated +5V we are using a 7805 linear voltage regulator. 7805 has three terminals. Pin 1 is input where we can give a 7-18 Volt regulated or unregulated power supply. Pin 2 is ground and Pin 3 is regulated +5V (± 0.1V) output irrespective of input voltage of Pin 1. To reduce any noise to ceramic capacitor of value 100nF is connected across Pin 1 and 2 and Pin 2 and 3 of the voltage regulator 7805 as a decoupling capacitor. To indicate the availability of power supply an LED is connected across the ground and +5V through 1k resistance.

The heart and brain of the circuit is the ATMEGA328P Arduino Nano board which has an inbuilt USB-TTL converter that allows to connection of the microcontroller directly to the laptop or PC using a USB cable. ATMEGA328 has 32k flash memory with 8 ADC channels of 10-bit precision. ATMEGA328 is an 8-bit microcontroller.

To display the sensor’s output and various information live server IP-connected accessories we are using a 20×4 LCD. It is a parallel-type LCD which have to connect with the microcontroller’s I/O pin. It needs a minimum of six digital pins to work with the LCD. To minimize the circuit complexity and save I/O pins we are using serial to parallel I2C driver PCF8574. The I2C communication has two dedicated pins SCL and SDA, i.e., serial code and serial data. Atmega328 has a dedicated I2C protocol. Analog pins A4 and A5 are SDA and SCL pins. The PCF8574 will covert the serial data coming through the SDA pin, and convert it into parallel outputs through P0 to P7 pins. The output of PCF8574 is connected to the control pin and data pin of the LCD. The I2C module has an inbuilt potentiometer to adjust the contrast of the LCD. One terminal of the potentiometer is connected to VCC. The other terminal is connected to the ground and the center term is connected to the VEE pin of the LCD. By rotating the potentiometer clockwise and anticlockwise we can adjust the contrast of the LCD by changing voltage at the VEE pin.

To measure the AC voltage we have to step down the 220V into 12 V using a stepdown transformer TR1 as ADC can handle a maximum 5V i.e. to DC hence we have to step down the voltage greater than 220V AC into DC to a suitable range. Thus step-down AC is converted into DC by using a rectifier bridge constructed around four 1N4007 rectifier diodes. To reduce noise we have used a 100 µF capacitor as a filter capacitor across plus 200V and ground.

To calculate the AC voltage we have implemented the concept of voltage divider rule, where a voltage divider circuit is used to reduce the output voltage. In this method, two resistances R1 and R2 are used.

$$V_{out} = \frac{R2}{R1+R2} \times V_{in}$$

A 10k resistance is used as R1 and 2.7k resistance is used as R2 in the voltage divider circuit. To minimize the noise a 100 nF capacitor is connected between ground and V_{out} of the voltage divider circuit. The output of the voltage divider circuit using a voltage sensor connected to the A6 (Analog pin of the Arduino board). The program executing in the microcontroller is responsible for mapping. The lower DC volt into higher AC voltage.

One of the objectives of our project work is to measure the flow of current to the load to protect from overload and prevent the transformer from prospective damage. To measure the flow of current we are using the popular current sensor ACS712 which is based on the Hall Effect sensor. ACS712 has three variants, i.e., for 5 Amps, 20A, and 30A current rating. For experimental purposes, we are using a 5A variant. If we need to measure more than 30 A instead of using ACS712 we can use a conventional method by implementing a current transformer.

According to the datasheet the ACS712 retains voltage ranging from 0 to 5V. It can measure both negative as well as positive current. From 0 to 2.5 V is considered as negative current and from 2.5 V to 5V is considered as positive current. Hence in programming, we have deducted 250 mV from the output voltage of the ACS712 and then divided it by 185 to get the flow of current.

$$I = V_0 / 185$$

Where V_0 is the output voltage of the current sensor 250 mV

The output of the current sensor is connected to A0 of Arduino Nano.

To measure the temperature of the current we are using the DS18B20 temperature sensor from Dollar Semiconductor. It can measure from -80^{0}C to +125^{0}C with the accuracy of ± 0.5 ^{0}C . DS18B20 is a digital temperature sensor. It comes under a smart sensor as unlike an analog sensor it provides data to the microprocessor host., if and only if the request is sent to the sensor with a specific command. DS18B20 converts the analog temperature value into digital data and transmits it to the microprocessor using a wire communication protocol. In this method, the same wire is used to send a command to the sensor as well as to get the temperature value. We have connected the DQ pin of DS18B20 to pin 17 of the Arduino Board. The Arduino digital pin cannot be used as an analog pin but all the analog pins can be used as digital pins.

To measure the oil level we have implemented the resistive method with the help of a 10K potentiometer. The one terminal of the potentiometer is connected to +5V, the other terminal is connected to GND and the center terminal is connected to the A7 of the Arduino board. Depending on the oil level the potentiometer will rotate clockwise or anticlockwise with the help of an arm where a floating ball (filled with air) is connected to one end of the arm and the other arm is attached to the potentiometer shaft. The program is written in such a way that if any of the parameters goes beyond the limit (oil level goes below the limit) the microprocessor will shut the load with the help of an electromagnetic relay. The electromagnetic relay is nothing but a mechanical circuit breaker operated by a magnetic field. To energise the magnetic coil of the relay we have used an NPN transistor 2N2222 from Phillips. One terminal of the relay coil is connected to +12v and the other terminal is connected to the collector of the switching transistor 2N2222. When the base of the transistor receives adequate triggering voltage, the current will flow from the base to the emitter, and eventually current will flow collector and emitter to complete the circuit. The base of the transistor is connected to Pin 3 of the Arduino board through 1k resistance. As we know when we use inductive load it may be affected by reverse current, hence a rectifier diode 1N4007 is connected across the relay coil terminal parallelly in the reverse direction as a freewheel diode.

In our project, we have also added a buzzer to indicate an audible alarm for overvoltage and low oil levels. One terminal of the buzzer is connected to the ground and the positive terminal is directly connected to the D9 microcontroller. Before connecting we checked whether the buzzer could be driven from the IO pin without any transistor or not. As it was working, we avoided the switching part.

The project is based on the concept of IoT where the device must have a communication protocol to share data and establish communication with the server and other devices. The IoT protocol (communication protocol) can be Bluetooth, Wi-Fi, Zigbee, etc. But we have decided to use Wi-Fi communication as it is very popular among the others. To establish the Wi-Fi communication, we are using ESP8266E1. The ESP8266 has an inbuilt microcontroller as well as a Wi-Fi modem. It can be used as a standalone device as well as it can be used as a Wi-Fi modem. In our circuit, we are using ESP8266 only for communication purposes and the primary operations are performed by Arduino. Esp8266 requires regulated 3.3 V . We could have used the inbuilt 3.3 V regulator of the Arduino to power up the ESP8266 but during the Wi-Fi connectivity the ESP8266 may drain up to 150mA and the inbuilt voltage 3.3 V regulator of Arduino Nano may get due to more current drawn by the module. Hence we are using the most reliable 3.3 V regulator S1117-33PI. It has three pins. Pin 1 is ground, Pin2 is regulated 3.3V output and Pin3 is regulated or unregulated input. The input to the S1117-33PI is drawn from the output of the 7805 voltage regulator and to reduce noise a 10 µF capacitor is connected across ground and V_{out} as well as ground and V_{in}. ESP8266E1 has eight pins. TX, GND, CHPD, GPIO2, RST, GPIO0, VCC and RX. The GND is connected to the ground. The VCC is connected to the V_{out} of S111733PI. The CHPD is pulled up by connecting to 3.3V with a 4.7 k resistance. The RST pin, GPIO0, and GPIO2 are unused in our circuit. The RX and TX pin of ESP8266 is connected to pin11 and pin10 of the Arduino Nano. We have configured the pin10 and pin11 of the Arduino Nano as virtual serial ports RX and TX. The microcontroller is responsible for sending the appropriate AT commands to ESP8266 through serial communication to establish the communication between the source and ESP8266 through WiFi as well and AT commands are responsible for initializing the communication channel and transmitting the data to the server.

3.4 CIRCUIT DIAGRAM

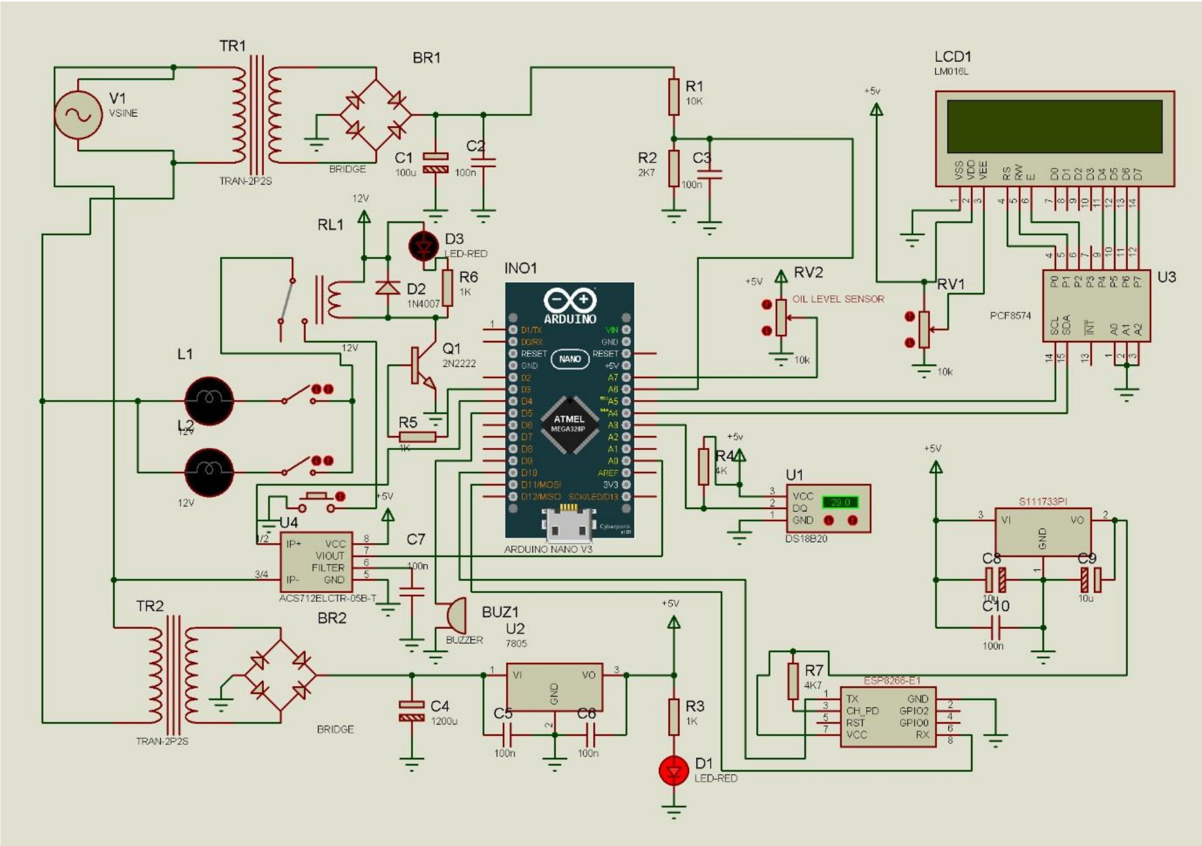

Fig 3.4: Circuit Diagram

3.5 WORKING PRINCIPLE

The IoT-based transformer monitoring and protection system operates by integrating various sensors and communication protocols to ensure continuous monitoring and protection of a transformer. The power supply starts with a 12V/220V step-down transformer, converting high-voltage AC to 12V AC, which is then rectified to DC using a bridge made of four 1N4007 diodes. A 1200µF capacitor minimizes noise and ripple in the DC output. A 7805 linear voltage regulator provides a stable +5V for most components, while an S1117-33PI regulator provides 3.3V for the ESP8266 Wi-Fi module. The ATMEGA328P Arduino Nano serves as the core processor, reading data from various sensors and processing it accordingly.

For voltage measurement, the system steps down 220V AC to 12V AC using a transformer, converting it to DC and further reducing it via a voltage divider circuit to levels suitable for the microcontroller's ADC. Current measurement is handled by the ACS712 sensor, which uses the Hall Effect to measure the load current and outputs a proportional voltage read by the microcontroller. Temperature is measured by the DS18B20 digital sensor, which converts temperature readings to digital data transmitted to the microcontroller via a one-wire protocol. Oil level measurement is achieved using a 10K potentiometer connected to a floating arm, which alters resistance based on oil levels, affecting the voltage read by the microcontroller.

A 20×4 LCD, connected via a serial-to-parallel I2C driver (PCF8574), displays realtime sensor data, using SCL and SDA pins for efficient data transmission. For protection, if any parameter exceeds predefined limits, the microcontroller triggers an electromagnetic relay to shut off the load, preventing damage, and an audible alarm (buzzer) indicates issues like overvoltage or low oil levels. The ESP8266 Wi-Fi module establishes wireless communication with a server, with the microcontroller sending AT commands to transmit data, enabling remote monitoring and control. This comprehensive integration ensures continuous and reliable monitoring, data processing, local display, and remote communication, enhancing the safety and efficiency of transformer operations.

Conclusion

The IoT-based transformer monitoring and protection system developed in this project marks a significant advancement in the realm of power distribution management. By leveraging Internet of Things (IoT) technology, the system offers a seamless, automated solution for monitoring critical parameters such as voltage, current, temperature, and oil levels in real time. Using an ATMEGA328P microcontroller as the processing core, the system integrates a variety of sensors to ensure accurate and continuous data collection. The collected data is displayed locally on an LCD screen and transmitted wirelessly via the ESP8266 module, enabling remote monitoring and control.

One of the most noteworthy aspects of this project is its ability to implement automated protective measures. The system uses an electromagnetic relay to disconnect the load and prevent transformer damage if any parameter exceeds predefined thresholds. Additionally, an audible alarm via a buzzer provides immediate alerts for anomalies like overvoltage or low oil levels. These features enhance operational reliability and reduce the risks associated with manual intervention.

This project stands apart by addressing limitations identified in existing systems. For instance, it avoids dependency on third-party IoT platforms by incorporating a custom-built web application, providing greater control and configurability. The system also incorporates advanced fault detection capabilities and local display units, which are often missing in other designs. By doing so, it ensures robust monitoring, quick fault mitigation, and a user-friendly interface, making it ideal for industrial and large-scale applications.

The environmental and economic benefits of the system are equally important. Continuous monitoring helps in early fault detection, reducing downtime and maintenance costs while extending transformer life. Additionally, by ensuring efficient operation, the system contributes to energy conservation and sustainability, which are essential in today’s rapidly evolving energy landscape.

The IoT-based transformer monitoring system also lays a strong foundation for future enhancements. Integrating predictive maintenance through machine learning algorithms could further enhance fault prediction and system reliability. Similarly, expanding the system to monitor multiple transformers simultaneously could make it an integral part of smart grid systems. The modular design and use of widely available components ensure that the system can be easily scaled and adapted to various use cases.

In conclusion, this project demonstrates the transformative potential of IoT in revolutionizing transformer monitoring and protection systems. By offering real-time data acquisition, remote control capabilities, and automated protection mechanisms, it sets a new standard for efficiency, reliability, and user convenience in power distribution management. With its ability to address contemporary challenges and its potential for further innovation, the system is poised to become a cornerstone in the advancement of intelligent energy infrastructure.

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