FINAL YEAR PROJECT REPORT

BSC Electrical Engineering and Technology

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Project Title

POWER FACTOR CORRECTION & FREQUENCY MEASURING USING ARDUINO

Department Of Electrical Engineering and Technology
Rise Group of Colleges, Lahore
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DECLARATION

We certify that this Final Year Project Titled "*Automatic Power Factor Correction and Frequency Measurement System using Arduino UNO*" is our project. The project has not been presented elsewhere for assessment. The material that has been used from other sources hasbeen properly acknowledged/referred to.

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ABSTRACT

In the current technological revolution, the electricity demand is increasing. So, it’s necessary to minimize power losses find out the main reasons for power losses, and improve the efficiency of the electrical system. On the industrial side and also on the domestic level the use of inductive load is increased therefore electric power system efficiency is decreasing due to low power factor. The Power Factor shows the efficiency of the electric system means it shows the ratio of useful work out of the supplied electric power. A poor power factor of the electric system causes decreased efficiency therefore when the power factor is decreased then electric losses increase and also increase the electricity bill in the form of a penalty if P.F. is less than from desired level.So, the power factor correction of electrical loads is a common problem for all industrial companies and also at the domestic level. Initially, the power factor correction was done by activating the capacitive bank manually. With time, different methods have developed for power factor correction One of them advanced suitable method is automatic power factor correction to improve the power factor in which capacitive bank activation is done automatically. Through Automatic power factor correction (APFC) the time of operation is decreased to correct the power factor and improve the electric power system efficiency. The main objective of This project is the design and implementation of automatic power factor correction using Arduino UNO microcontroller ATUNO 2560 which measures power factor and frequency using zero crossing detection method.

Keywords:

Real Power Apparent Power, Reactive Power, and Capacitor Banks. Power factor, PotentialTransformer, Current Transformer

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LIST OF ABBREVIATION

APC -	Automatic Power Correction
FMS -	Frequency Measurement System
UNO -	Arduino UNO (Microcontroller)
PFC -	Power Factor Correction
Hz -	Hertz (Unit of Frequency)
LCD -	Liquid Crystal Display (for displaying data)
ADC -	Analog-to-Digital Converter (for converting analog signals)
PWM -	Pulse Width Modulation (for controlling power output)
UART -	Universal Asynchronous Receiver-Transmitter (for communication)
AC -	Alternating Current (type of power supply)
DC -	Direct Current (type of power supply)
V -	Voltage (unit of electrical potential)
A -	Amperes (unit of electrical current)
PF -	Power Factor (measure of electrical efficiency)
RMS -	Root Mean Square (measurement method for AC voltage and current)
PCB -	Printed Circuit Board (used for circuit connections)
GUI -	Graphical User Interface (for user interaction)
I/O -	Input/Output (for connecting sensors and actuators)
API -	Application Programming Interface (for software integration)
LED -	Light Emitting Diode (for status indicators)

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The Power factor is defined as the ratio of actual power to the apparent power (the power received on consumer terminals). **OR** the cosine of the angle between voltage and current is called the power factor. When we connect inductive load then the power factor decreases and causes more energy loss due to low power factor and more reactive power is drawn from the supply and vice versa**.** Most of the loads in industries and domestics are inductive. For example, induction motors, induction furnaces, transformers, etc. for sustaining the magnetic field of inductive loads required reactive power. Which causes to decrease power factor. and wasting some part of the electrical energy due to the use of inductive loads also shown in below power triangle FIG 1.1 Hence, therefore is necessary to avoid (minimize) this wastage of electrical energy. If the power factor of the load is equal to one, it indicates that the voltage and current arein phase, which means apparent power is converted to real power. If the power factor of the load is less than one, it indicates that the voltage and current are not in phase, they are called out of phase. That means some reactive component (inductive or capacitive) of the load is present in thecircuit which causes apparent power not to be converted to real power. In our project for power factor correction and frequency measurement, we use a zero-crossing detection method for power factor and frequency measurement by converting sine wave to square wave (digital form) of current and voltage respectively. frequency is measured by measuring the period of the square waveform through Arduino UNO PWM pin and the power factor is measured from pulse (squarewave) generated after XOR operation of voltage and current waveform.

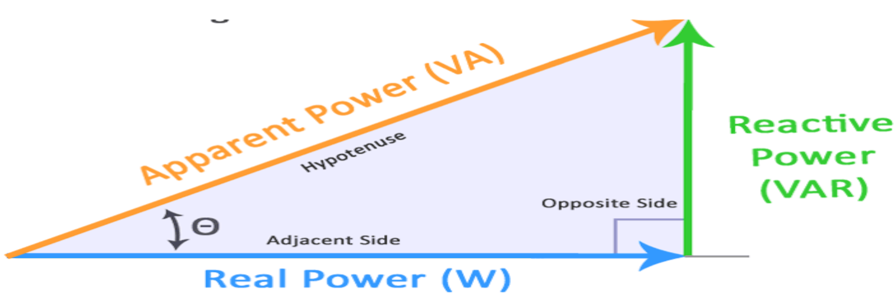

Figure 1-1: Power. Triangle

1.2 COMPONENTS OF ELECTRICAL POWER.

1.2.1 Apparent Power

It's the total amount of power supplied to an electric circuit that is known as apparent power. Apparent power is obtained as the product of RMS voltage and RMS current, measured in VA or kVA regardless angle between current and voltage. The apparent power is either be greater than the real power in the circuit if power the factor less than one and equal to real power if power thefactor is equal to one.

$$S = V \times I \ (volt\ Ampere) \ldots \ldots \ldots \ldots (1)$$

1.2.2 Real Power.

Real power is defined as the power that is consumed by the load in an AC circuit or the power which converted to useful work. Also known as active power, true power, measured in watts (w) In a DC circuit real power is simply the product of voltage and current supply to load. But in AC circuits due to the sinusoidal nature of supply real power is the product of current voltage and power factor. In the sample world, Real Power is the instantaneous product of the voltage and thecurrent and presents the ability to perform work. where COS Q is the power factor of the load which represents at which ratio apparent power is converted to actual power if all apparent poweris converted to real power in a circuit that means the power factor is unity from this we can also identify that power factor the value is not more than unity.

$$P = V \times I \times cos\theta \ (watt) \ldots \ldots \ldots \ldots (2)$$

1.2.3 Reactive Power.

The power that continuously bounces back and forth between source and load is known as reactive power means the power that does not convert to useful work or is not utilized by the load. Reactive power is caused by the inductive or capacitive nature of the load which stores the electrical energy in the form of a magnetic field (due to large inductance) while the capacitors store this

Electrical energy in the form of an electric field respectively. Reactive power decreases the efficiency of the power system and increases unwanted electric current flow in the circuit.

$$Q = V \times I \times sin\theta \ (VAR)\text{----------}(3)$$

From equation (2) it’s clear that for efficient utilization of electrical power, we need to improve the Power factor to a desirable level because due to the low power factor the electrical energy Source must be able to supply real power (watt full component) as well as reactive power (watt less component) according to load demand. Due to log P.F., it’s necessary to install heavy rating, more expensive power plant equipment, transformers, transmission lines, switchgears, etc. for only delivery of real power. Also, resistive losses in the distribution and transmission lines mean that some part of the electricity generated is lost because of the need for additional current to supply reactive power which heats the power lines. Therefore, for electric utilities, it’s essentiallyto control the power factor of the loads connected with its premises with an expected limit that they will supply electric power. Ideally, the power factor of the load is unity, which is possible only in pure resistive load, because it doesn’t require reactive power it only draws a small amount of current to supply real power according to the load. This ideal condition shows Real loads. Inductive loads (Electric motors etc.) are current lagging loads, so to counter their inductance requires capacitor banks which produce leading currents to cancel out the current lagging effect.

Sometimes, if the power factor is leading due to the capacitive nature of loads (i.e., over-excited synchronous motor), to cancel out their leading effect inductive loads are used to correct the power factor. In sample words inductive loads draw reactive power and capacitive loads supply reactive power, so the reactive power is just moving back and forth between the load and source during every AC cycle, to eliminate this problem through the capacitor bank. The capacitor banks are used to increase the power factor. There are three techniques for improving the power factor.

1 Static capacitor
2 Phase advancer
3 Synchronous condenser

However, the static capacitor or capacitor bank technique is the most popular and cost-efficient.

Because

a) This method has low losses
b) In this technique no rotating parts are involved therefore it’s a low maintenance cost
c) In this technique does not require any foundation for support because they have lightweight
d) The static capacitor bank work efficiently under ordinary atmospheric condition

So, we use the static capacitor bank method in our project, to improve the power factor of homes and factories which is very important to stop the losses of electricity.

The Automatic Power factor Correction system is designed to improve the utilization and efficient transmission of apparent power. If the consumer connects the inductive load, then the power factor lags, when the power factor goes below 0.96(lag) the Electric supply company charges a penalty to the consumer. So it is essential to maintain the Power factor below within a limit. The automatic Power factor correction system reads the power factor from line current and line voltage, if the power factor is less than unity which is caused by the inductive component is compensated by connecting the appropriate size of the capacitor bank through a relay in parallel.

1.3 TYPES OF LOADS.

There are commonly used three types of loads.

- The Resistive load.
- The inductive load.
- The capacitive Load.

The voltage and current in an alternating current (AC) system is in the form of the sine wave, the voltage and current may rise and fall together during each cycle in a circuit. The number of cycles completed in one second is measured in hertz called frequency which represents the number of alternations per second Due to the sinusoidal nature of the current the response of inductive and capacitive loads changes depending on supply frequency as compared to the DC system which is clear from below equations. For this, we also measure supply frequency to translate the dependency of the system in the case of a variable frequency supply system.

1.3.1 Resistive Load.

Resistive load components create a considerable quantity of heat that must be promptly dispersed. Any electrical device with a heating element that operates on the resistance operating principle is known as a resistive load. Resistive loads consume just Active Power and do not affect the value of the power factor due to the absence of reactance; therefore, the power factor value remains the same, which is one. A resistive load is a load that utilizes only active power. When we examine the voltage and current waveforms of such a load, we'll see that the voltage and current are exactly in phase. Resistive loads are those that contain any type of heating element. Examples of resistive loads are Incandescent lights, toasters, stoves, space heaters, and coffee machines in which resistive elements, tungsten, or nichrome elements are used (which have non-magnetic properties) for conversion of electrical power to heat or light.

Resistive load has zero reactance (apposition affair to AC is called reactance) but has some resistance (apposition affair to electric current flow in the circuit) which defends the resistivity of the material, length of material, and cross-sectional area of material The resistivity may differ of every material also called specific resistivity of material measure in a unit of Ohm meter while resistance measure in a unit of the ohm.

Resistive load resistance depends on the following parameters

- AREA of material (A): The resistance of material is inversely proportional to the cross- sectional area (A) of material. The resistance of a greater cross-sectional area of the same material is smaller and vice versa.
- Length of material (L): The resistance of the resistive element is directly proportional to the length of the material used. Greater the resistance of material if greater length of material and vice versa.

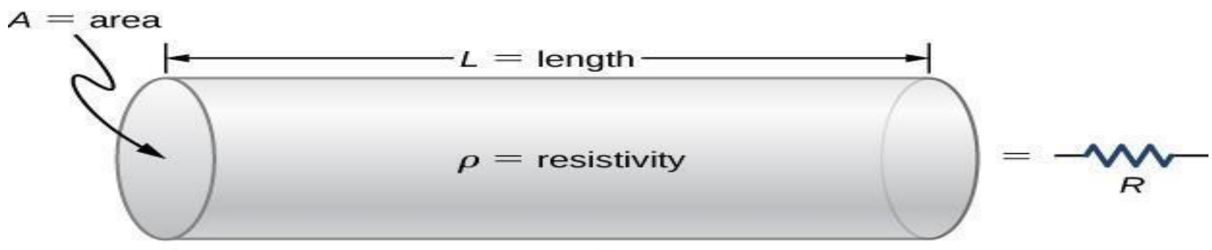

Figure 1-2: Resistive load

From the above discussion, we can represent the dependency of material resistance in the below equation.

$$R = \rho \frac{L}{A} \quad \dots \dots \dots (4)$$

From equation 4 it's clear that the resistance of material does not depend on supply frequency it depends on the material area, length, and resistivity so this means resistance is an opposition affair to both AC and DC regardless of supply frequency.

1.3.2 Inductive Load.

Inductive loads are those loads that store electrical energy in the form of a magnetic field using the principle of Faraday law of electromagnetic induction. Inductive load opposing change in current, which represents that the behavior of inductive load is the change in AC as compared to DC. Inductive load elements, also known as reactive load elements, produce inductive fields using wire coils. The energy required to produce and maintain these fields puts a strain on the power source being tested. Inductive load current peaks after voltage (current lag at 90 degrees from voltage shown in fig 1.3(c)), unlike resistive loads. Inductive coils create a lagging power factor as a result. Inductive load components are utilized to lower the power factor of a test load because they create lagging power factors. The current flowing in the inductive load depends on the inductive reactance of the inductive load. An inductive reactance of an inductor defining an opposition affair by an inductor to AC is called inductive reactance. Reactance of inductive depends on the inductance of inductive load and supply frequency which is shown in equation 5 it's clear that inductive reticence dependent resistance for AC.AC

$$\omega L = 2\pi f L \text{ ------------------(5)}$$

Where: f is the Frequency L is the Inductance of the Coil $2\pi f = \omega$ is the angular frequency andj shows the phase angle.

Current in inductor $I_L = V/X_L$

A pure inductive load has zero resistance but some reactance. There are several important differences between reactance and resistance, though. First, reactance changes the phase so that the current through the element is shifted by a quarter of a cycle relative to the voltage applied across the element. Second, power is not dissipated in a purely reactive element but is stored

d. Third, reactance can be positive or negative so that they can 'cancel' each other out. Finally, the main circuit elements that have reactance (capacitors and inductors) have a frequency-dependent reactance, unlike resistors which typically have the same resistance for all frequencies.

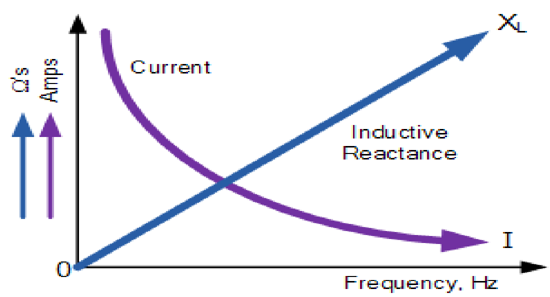

Figure 1-3: (b) Inductive Reactance against Frequency

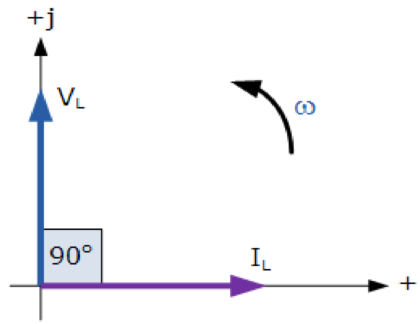

Figure 1-4: Phasor diagram for the inductor.

1.3.3 Capacitive Load.

Capacitive loads are those loads that store electrical energy (electric charge) in the form of an electric field. They resist voltage fluctuations (opposing change in voltage), causing current to peak before voltage at the end of each electrical cycle. As a result, capacitive load components have a higher leading power factor and may be utilized to improve circuit power factors. Current and voltage are out of phase in a capacitive load also shown in Fig 1.4(b), as they are in an inductive load. The distinction is that with a capacitive load, the current reaches its maximum value before the voltage reaches its maximum value. In a resistive load, the current waveform precedes the voltage waveform, whereas in an inductive load, the current waveform lags the voltage waveform. The current flowing in capacitive load depends on the capacitive reactance of the capacitive load. The opposition offered by a capacitive load to the flow of AC in the AC circuit is called capacitive reactance. Reactance of capacitive load also depends on the supply Frequency which is shown in equation 6, capacitive reactance is said to be inversely proportionalto the capacitance and the supply frequency which is clear in Fig 1.4(a). It is normally represented by (X_C) and measured in the SI unit of ohm (Ω). The capacitive reactance formula is

Given below.

$$X_c = 1/\ j\omega C = 1/\ j2\pi FC \text{---------------(6)}$$

Where: f is the Frequency C is the capacitance of the Capacitor $2\pi f = \omega$ is the angular frequency and j shows the phase angle.

A pure capacitive load leads current by 90 degrees due to infinite resistance but has some reactance.

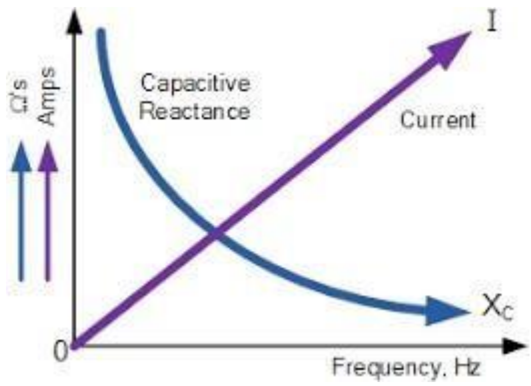

Figure 1-5: Capacitive Reactance against Frequency

It's clear from Fig 1.4(a) that if the supply frequency increases the capacitive reactance of the capacitor decreases and vice versa in sample words capacitor acts like an open circuit for DC anda short circuit for AC curreAC4

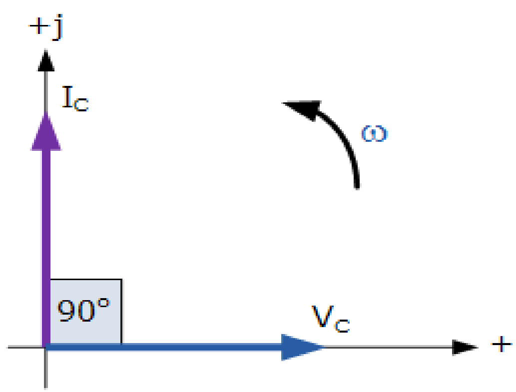

Figure 1-6: phasor diagram of pure capacitive load.

1.3.3.1 Frequency measurement:

The frequency of alternating current is defined as the number of cycles per second. In sample words, frequency is the rate of change at which current changes direction in one second and is measured in units of harts (Hz). As we know reactance (inductive or capacitive reactance) depends on supply frequency which is clear from equation (5,6). While power factors depend on the reactance of the loads so for accurate power factor measurement using the zero-crossing detection method it's very important to measure supply frequency. If we consider a series RLload after calculating equation (7) it's clear that the power depends on supply frequency. At the domestic level, the supply frequency always constant (50 +_2 % Hz) but on the industrial side variable drives the speed of motors are changing from time to time through changing supply frequency from which the power factor of the load also changes so the frequency measurement isimportant in our project for accurate measurement if load connected to variable frequency supplysystem. In the below equation, the relationship between power factor and frequency is given.

$$cos\theta = \frac{R}{\sqrt{R2 + (j2\pi f L)2}} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Where R = Resistance of the load.

F = supply frequency.

L = Inductance of the load.

Therefore, we measure supply frequency using the appropriate op amp (combination of transistors) which converts sine wave to square wave (shown in Fig below 1.5) for finding the pulse width of half wave to measure the frequency using the following equation.

$$f = 1/2t \text{ -----------------}(8)$$

Where f = frequency t = pulse width of half wave

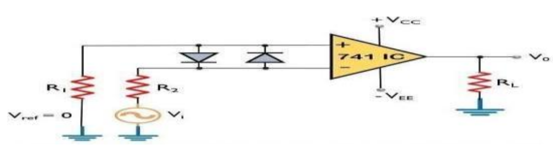

Figure 1-7: sine to square wave converter

1.3.3.2 Impedance triangle:

The Impedance triangle is the right-angle triangle, the base represents the resistance of the circuit, the perpendicular component shows the reactance of the entire circuit, and the resultant or hypotenuse represents the impedance of the total circuit. Also, when the frequency changes, the triangle will change form owing to differences in reactance (X). Resistance (R) will, of course, always be constant. We may expand on this concept by turning the impedance triangle into a power triangle, which represents the three power components in an AC circuit. According to Ohm Law, power (P) in watts is equal to current squared (I^2) time's resistance in a DC circuit (R). As a result, we may multiply the three sides of our impedance triangle by I^2 to get the power triangle.

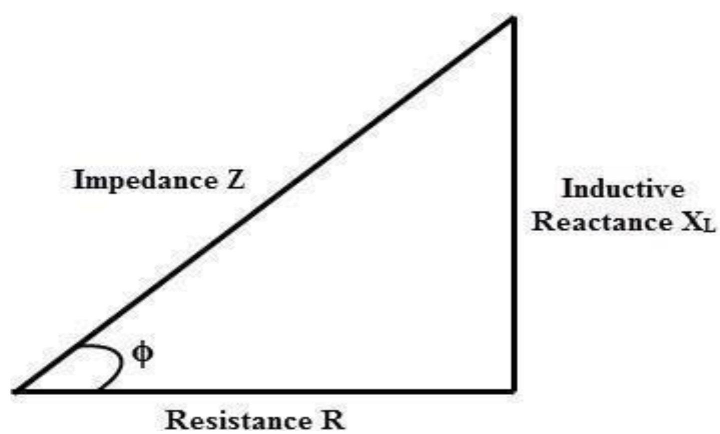

Figure 1-8: impedance triangle

1.3.3.3 Lagging Power Factor.

If the current waveform is ahead of the voltage waveform in phase, it is said to be leading. If the current waveform is behind the voltage waveform, it is said to be lagging. Because the load will "consume" reactive power, a small or low power factor indicates that the load is inductive.

1.3.3.4 Leading Power factor.

Because the load "supplies" reactive power, a leading power factor indicates that the load is capacitive, and therefore the reactive component Q is negative because reactive power is being provided to the circuit.

1.4 NEED FOR POWER FACTOR IMPROVEMENT.

The active or Real power is given by = $VI\ Cos\theta$. For transmitting a given amount of power at a given voltage, the electrical current is inversely proportional to $Cos\theta$. Has a result, if the PF increases, the current flowing decreases. Because for a given constant amount of power the current is changing w.r.t load power factor. A low current flow requires a smaller cross-sectional area of conductors, it saves both conductors and money. In sample words, a weak power factor increases the current flowing in a conductor and hence increases copper loss. When an electrical load runs on alternating current, it needs apparent power, which is made up of actual and reactivepower. The power utilized by the load is known as real power. When alternating current flows through a load with a reactive component, reactive power is continually required by the load and returned to the power source, and it is the cyclical effect that happens. Through different ways, power factor correction aims to bring the power factor of an AC load or an AC power transmission system to unity. Below some Drawbacks of low power factor are given.

1. Increasing reactive (wattles) power.
2. Increasing unwanted current flow between source andload.
3. Low puff increases voltage drop in line
4. A large cross-sectional area of the conductor is required for the transmission of electricalpower.
5. Low puff decreases the efficiency of the electrical transmission system.
6. A high KVA rating of equipment is required for the delivery of real and reactive power insteadof real power.
7. Low puff causing Poor voltage regula

1.5 LITERATURE REVIEW

The electrical load that works on alternating current requires apparent power, apparent powerconsists of real power and reactive power. Real power is the actual consumed power by the load. Reactive power is the power demanded by the load frequently and back to the source during each cycle. This cyclic effect occurs if alternating current passes from a load that contains a reactive component (inductive, capacitive). Due to industrialization majority of loads are highly inductive like DC/AC drives, induction motors, etc. which causes reactive power (wattles power) from power sources. so, if the reactive component is present in a load that causes the real power will be less thanthe apparent power a result of reactive power component causes a poor lagging power factor because the power factor is the ratio of real power and apparent power. A simple reactive power increases the unwanted flow of electric current between the source and load, which increases power losses in power lines. So the measurement of power factor and correction is necessary for increasing efficiency. There are a lot of studies found in the literature that address the issue of APFC.

[3],[4],[5] In the beginning the power factor was measured through an analog power factor meter, and power factor correction was performed by connecting the required size of the capacitor bank manually to correct the power factor. For power factor correction different techniques are used

1.5.1 Synchronous condenser.

In this technique, an over-excited synchronous motor is used whichdraws a leading current and acts as a capacitor to cancel out the lagging effect of load.

1.5.2 Static capacitors.

One of the simple techniques is a static capacitor in which capacitors areconnected to the load in parallel to cancel out the lagging effect of inductive load.

1.5.3 3-phase advancer.

In this method, induction motors are used to have field excited from ACexternal exciter to draw leading current instead of lagging current.

In [6] author discusses automatic power factor correction using Arduino in which instead of PT voltage divider circuits are used to step down voltage and instead of CT resistive networks are used to measure the peak value of current and voltage and find out power factor by sensing both peak values are in-phase or not. In [7] the automatic power factor correction was done by measuring puff

Using zero crossing detection method in which current and voltage are stepped down through CT and PT respectively and correct P.F using capacitor bank.

The main goal of our project is to bring improvement to the previous work. With the help of our project, we provide continuous power factor correction automatically without manual selectionof capacitor banks and frequency measurement with the advancement of leading and lagging P.F. identification. For this purpose, we will use an Arduino UNO microcontroller to measure power factor and frequency. For measurement of power factor, the Voltage across the load and currentis stepped down to a low voltage and current level which is desirable for Arduino processing, Forvoltage sensing instead of PT we use a series RC circuit with a waveform sensing transformer, and for current sensing CT transformers are used. Then both current and voltage signals are converted to square waves through a crossing detector (ZCD). The zero crossing of both signals current and voltage are detected by using a suitable Op-amp-based ZCD circuit. The output of both ZCDs is supplied to the digital XOR Gate to generate the resultant pulse of both signals. Thewidth of the resultant pulse is directly proportional to the phase difference (shown in equation 9) between the voltage and current of the load. The Arduino UNO are programmed in a such mannerthat measures the pulse width of the generated pulse of the XOR gate and the pulse of the voltage signal to find the power factor of the load and measure the frequency of the supply respectively, the frequency of the system is measured for accuracy purpose because the accuracy of the P.F measurement depend on the frequency which clears from equation (9)

Further, the power factor value is used to estimate the required size of the capacitor to correct thepower factor to the desired level. After this estimated value Arduino UNO switch ON relay to connect the estimated capacitor bank across the load. And the P.F. and frequency will be displayed on LCD. This project proposes an advanced technique by using the Arduino UNO for power factor correction which has many advantages compared to various conventional methods of power factor correction. The switching operation is done automatically by using the relay withan optocoupler to switch on the capacitor bank without harmonics so this technique is more accurate as compared to manual correction. It operates automatically, manpower is not, required for operation.

$$phase\ difference \Rightarrow \theta = td \times 2\pi \times f \text{ ....} \textbf{(9)}$$

Where t_d = the time difference between V and I or pulse width proportional to the phase difference. F supply frequency.

1.6 PROBLEM STATEMENT.

Low power factor is caused by reactive power. Capacitive loads generate reactive power whereasinductive loads absorb it. As a result, capacitor banks are utilized in power factor correction circuits to enhance power factor. The power factor is improved by connecting capacitor banks in parallel to the load.

1.7 AN EXISTING METHOD FOR POWER FACTOR MEASUREMENT.

The existing method for power factor measurement is a sample but it cannot differentiate between lagging and leading power factor [7] It measures power factor by sensing current and voltage waveform through CT and PT which further convert to a square wave (shown below fig) than after XOR operation of both square wave as a result output pulse generated which proportional to phase difference but from this pulse it can only help in calculating P.F using equation (9).also shown in fig 2.1(a),(b) in both cases inductive and capacitive load a resultant square wave generated after XOR operation are same in nature. From this it’s clear that this technique is unreliable because it cannot differentiate accurately between lagging and leading power factor.

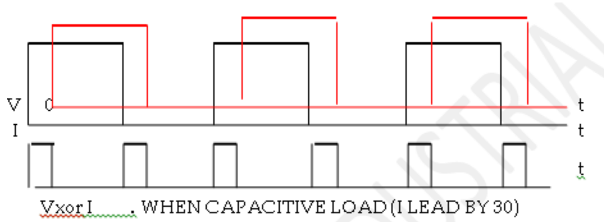

Figure 1-9: when capacitive load

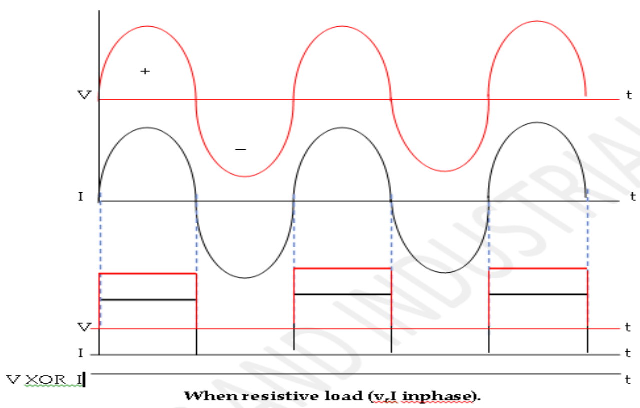

Figure 1-10: when resistive load.

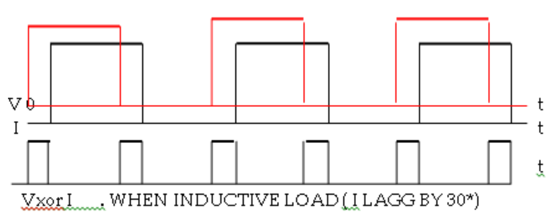

Figure 1-11: when inductive load.

1.8 A PROPOSED METHOD FOR POWER FACTOR MEASUREMENT (CHANGING REFERENCEPOINT).

In the proposed method we use the concept of analog power factor meter. In the proposedmethod we modify the existing method using the concept of a power factor meter to easily differentiate between lagging and leading power factor. For this approach, a reference signal is generated (using a similar concept used in analog P.F meter) from voltage, which shifted at angleQ (i.e., 70). After XOR operation a resultant pulse is generated from its properties we can obtain the following information which represents the leading lagging properties of P.F.

If the width of the pulse is equal to angle Q (i.e., 70) it shows (only consider) that P.F. is unity. Also shown in the below waveforms Fig 2.2(a).

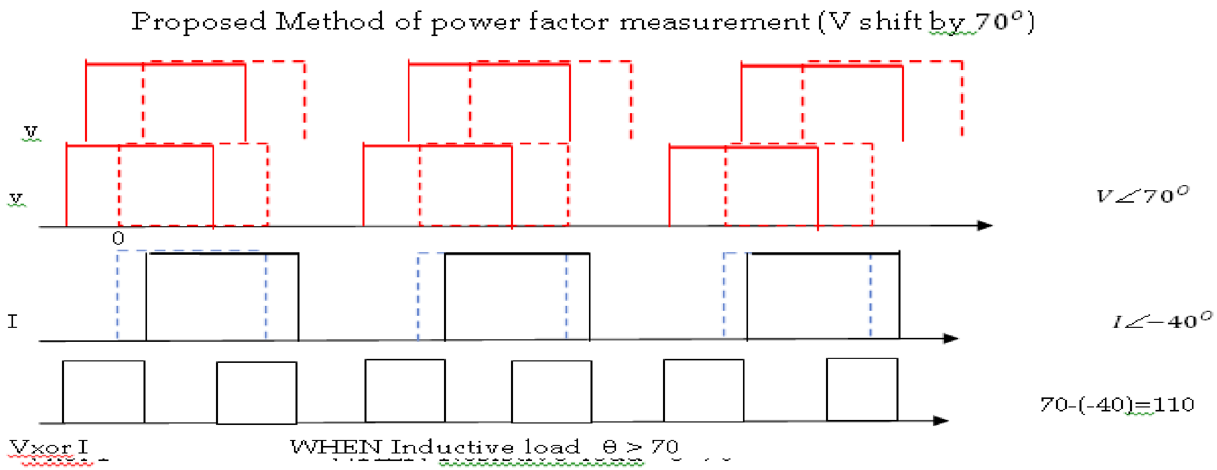

Figure 1-12: when resistive load (pulse width are constant).

If the width of the pulse is greater from angle Q (i.e., 70) it shows (only consider) that P.F. is lagging. Also shown in the below waveforms Fig 2.2(b).

Fig #1.8(b) when the inductive load (pulse width becomes wide).

If the width of the pulse is greater from angle Q (i.e., 70) it shows (only consider) that P.F. is lagging. Also shown in the below waveforms fig 2.2(c).

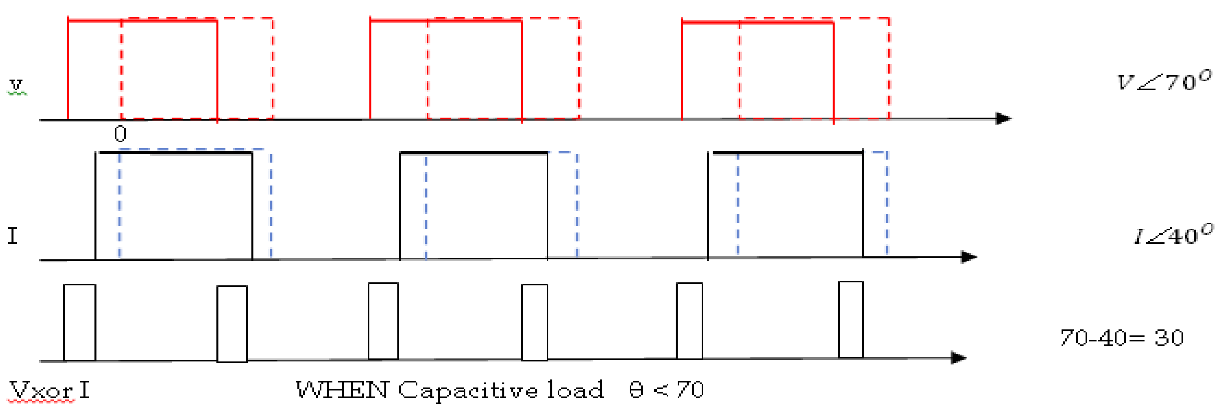

Figure 1-13: when the capacitive load (pulse width has become narrow).

1.8.1 Reasons for low power factor.

- Induction motors
- Power and distribution transformers,
- choke coils, neon signs,
- Mercury vapor lamp with choke etc.

1.8.2 Power factor correction for single phase load.

Correction of the Power Factor for Single-Phase Domestic Loads Making Use of a Microcontroller and TRIAC. Electrical power plays a crucial part in the industrial economy's output. Due to the existence of inductive components in the form of welding machines, inductionmotors, voltage regulators, power transformers, induction furnaces, and choke coils, the power factor may be low. It can result in significant losses due to a low power factor, which decreases the operational efficiency of any power plant, necessitating the use of bigger conductors and causing voltage drop as power loss grows. As a result, improving the power factor is a must for any electrical device to function at its best. Capacitance as reactive power can be used to increaseor regulate power factor. There are capacitor banks for reactive power to enhance power factor and their correction, resulting in plant management that is both economically and technically sound. So, in this article, there are different elements for enhancing the power factor. [8].

1.8.3 Shunt capacitor is used to increase the power factor

Electrical power is a significant part of the cost of manufacturing in industry. Induction motors, welding machines, power transformers, voltage regulators, arc and induction furnaces, choke coils, neon signs, and other electrical components can reduce power factor. A plant with a low power factor loses a lot of energy, which causes switchgear to overheat. The power factor adjustment achieved by employing capacitor banks to provide the reactive energy required for thetransmission of electrical usable power enables more efficient and logical plant management. With the aid of a case study, this article covers several elements of power factor enhancement ina typical industrial facility. The power factor of resistive loads in an electric circuit is unity, but the power factor of solely inductive loads is 0. In actuality, however, the actual loads in an electric circuit are a mix of resistive and inductive. The power factor of the plant is between zero and one due to the mix of inductive and resistive loads. If the power factor, the greater the losses shunt capacitors are used to increase the power factor. The necessary capacitance is determined by the kind of electrical load in the plant. Because of the high capital cost of capacitor installation, a high power factor on the order of 0.8 to 0.9 is considered when designing capacitors for power factor management.

1.9 STRATEGIES FOR POWER FACTOR CORRECTION

The term "reactive power" refers to a by-product of an electrical energy system. It travels through generators, transmission lines, and transformers, but it never reaches its destination. It must, however, be recognized and accounted for since it is critical to the system's stability, power cost, and voltage management. Reactive power is calculated using the same method as active power: a vector product of current and voltage. Other than the losses it causes through current circulation in the equipment and transmission lines, reactive power does not dissipate anyenergy. Except for a perfect heating load, every type of load creates reactive power. [10]Capacitors can be located as in:

1.9.1 Individual Compensation.

Capacitors are mounted parallel to the equipment and are controlled by a common switch in such systems. This is often used in induction motors, furnaces, and transformers with high output.

1.9.2 Group compensation:

The compensation of a set of loads fed from the same bus bar is used in this approach. This is particularly useful when small loads are connected to a commonbus bar.

1.9.3 Central Compensation:

This is true for both HT and LT capacitors. Depending on the starting power factor of the load and its fluctuation, the output of capacitors must be split into several stages with auto / manual control. [11]

To decrease penalties, losses, and power consumption, they employed a microcontroller-based automatic power factor modification technique in this article. By monitoring the load power factor regularly, the power quality may be improved. We all know that reducing the load's power factor below a particular point increases line current, resulting in voltage drop and line loss. The goal was to design a system that would inject the right amount of capacitance to keep the power factor from dropping below a certain threshold. In this project, they used a low-cost PIC Microcontroller to regulate static capacitors instead of more expensive and difficult-to- manufacture ones. For this study, several small-rated capacitors are connected in parallel. By automatically connecting the right quantity of static capacitors as specified, the microprocessor helps to keep the power factor close to unity. [12]

1.10 THE LOCATION OF THE P.F CORRECTING DEVICE

The strategic location of power factor correction is important to achieve all benefits of power factor correction. In a power system, there are three possible locations: at the distribution side of the main substation transformer, in parallel to each load, in central loads [13]

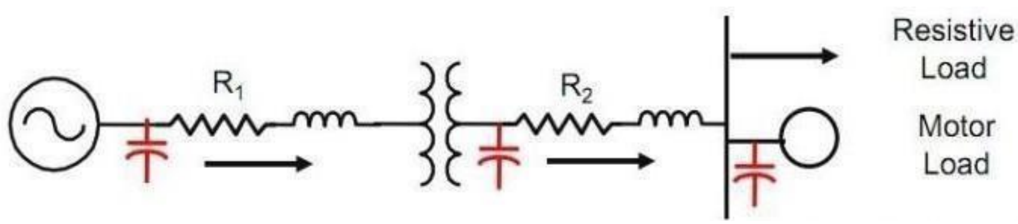

Figure 1-14: Different locations of capacitor bank [13]

The installation location may be near loads, near the transformer on the utility side. The location needs tobe decided based on the system voltage regulation.

1.11 OBJECTIVE OF THE PROJECT

- Automatic P.F. correction using capacitor banks is very efficient it reduces the cost bydecreasing power drawn from supply.
- It measures and displays the power factor of the single-phase load.
- It measures and displays the frequency of the supply system.
- Also measure and correct P.F of variable frequency system i.e., for speed controlling ofinduction motor variable frequency method are used.
- It improves power factor automatically and doesn’t require manpower.
- To reduce P.F. correction time as compared to manual correction.
- It increases the life of the capacitor bank.

CHAPTER 2 PROJECT METHODOLOGY AND PROJECT COMPONENTS

2.1 INTRODUCTION

The design methodology of this project presents a simple and accurate technique to design an automatic single-phase power factor correction and frequency measurement system by using Arduino UNO. The hardware implementation was developed by using Arduino UNO to correct P.F. up to 100-watt load.

The design methodology of this project is based on the zero-crossing detection (ZCD) method in the zed method the sine wave (analog form) is converted to a square wave (digital form) for digital operation because the microcontroller easily performs digital operation. For sine wave to square wave conversion a high gain operational amplifier is used. The power factor of the load was measured by using two circuits. Such as for load current waveform we use the current transformer that steps down the current to a low-level signal which is suitable for Arduino UNO processing. While for voltage waveform instead of PT we use an isolated RC series circuit with CT which leads current at 70 degrees from voltage and detects its waveform corresponding to voltage waveform through another CT. The advantage of voltage shifting is to differentiate b/w inductive and capacitive load. Both waveforms are converted to square waves using a crossing detector. Finally, for power factor measurement we feed both signals to the XOR gate. The outputof the XOR gate is further fed to an Arduino UNO PWM digital pin to measure the time difference between current and voltage which is proportional to phase difference. According to the power factor valve appropriate size of the capacitor bank is switched ON through a relay instructed by Arduino UNO. While for frequency measurement we feed a square wave of voltagesignal directly to Arduino UNO PWM pin for measurement of its period using an internal timer of microcontroller from which corresponding frequencies are calculated and display result on LCD, also shown in fig (3.1).

2.2 ALGORITHM.

Step-1; Take voltage and current waveform respectively.

Step 2; Convert both waveforms respectively to square waves using zero crossingdetector.

Step 3; Combine both square waves through XOR operation.

Step 4; Measure the time difference of the resultant square wave to find out thepower factor.

Step 5; Measure the period of the voltage wave to find the supply frequency.

Step 6; differentiate the b/w calculated and target power factor

Step 7; Switch the ON /OFF capacitor bank according to power factormeasure. Step-8; Display results on lcd.

2.3 PROJECT COMPONENTS.

2.3.1 Current Transformer.

A current transformer is a type of instrument transformer which are used to step down high line/ phase current to low current for measurement purpose means that The current transformerchanges a high value of current into a low value that can be measured easily by the instrument, whereas the potential transformer translates a high value of voltage into a low value that can be measured easily by the instrument. In the project, we used a current transformer to convert load current to low-level current which is suitable for Arduino processing and to isolate measurement circuits from the main line. In our project, the primary winding of current transformers is linked in series with the load which steps down load current at a specific ratio known as transformation ratio proportional to the primary current. While the secondary current transformer is connected to a zero crossing detector circuit to convert the sine wave to a square wave which corresponds to the load current waveform. Fig 3.2 shows the connection of CT with ZCD.

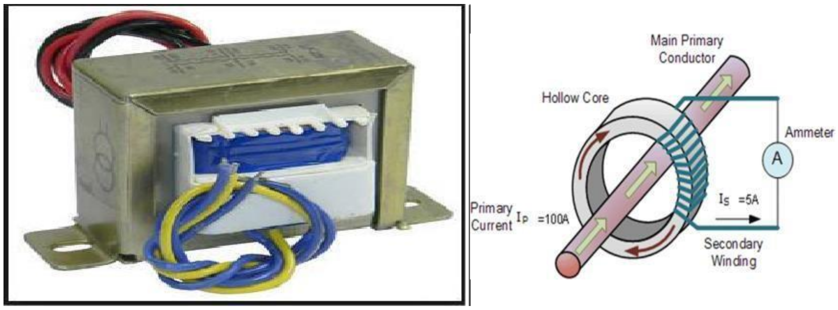

Figure 2-1: current transformer (ratio = 20/1)

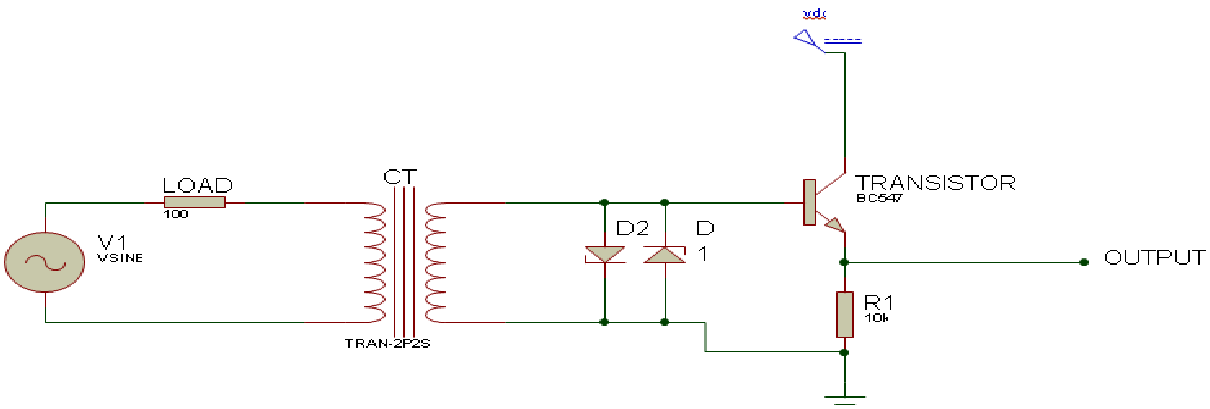

Figure 2-2: current transformer with zero crossing detector

2.3.2 ZERO CROSSING DETECTOR (ZCD).

The zero-crossing detector is a sine wave to square wave converter that converts a sinusoidal wave of current or voltage to a square wave. Zero crossing detector circuit is used in the project todetect zero crossing of sine wave (zero crossing is a point where sine wave changes direction from positive half cycle to negative half cycle and vice versa). To find the phase difference between current and voltage two zero-crossing detector circuits are used to convert two waveforms of sinusoidal current and voltage respectively. The voltage is first stepped down with instrument transformers, and then the current is stepped down with a current transformer whose rating is determined by the maximum load rating. Zero cross detectors are used to detect these two voltage and current pulses (ZCD). The waves that emerge over the ZCD's output are square waves. And their amplitude approaches that of the operational amplifier's biasing. Following zero cross-detection using a microcontroller algorithm, it is determined if the load is capacitive or inductive, and the microcontroller then triggers the necessary capacitive or inductive banks usingrelay-based switching circuitry to compensate.

A zero-crossing detection is an important application of an op-amp comparator circuit. It can alsobe referred to as a sine-to-square wave converter. Any of the inverting or non-inverting comparators can be used as a zero-crossing detector. If the op-amp used is a ZCD a reference voltage is set to zero in Fig 3.4(a ZCD is sown using op-amp in non-inverting mode)

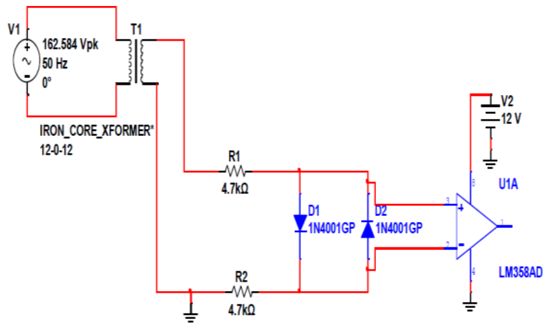

Figure 2-3: ZCD using l m 358 op- amp

MICROCONTROLLER (Arduino UNO).

The Microcontroller or the processing module is an interfacing and controlling module, that

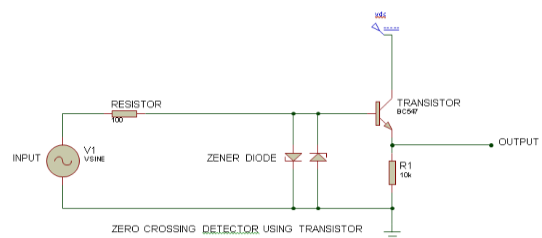

Figure 2-4: ZCD using BC 547 transistor

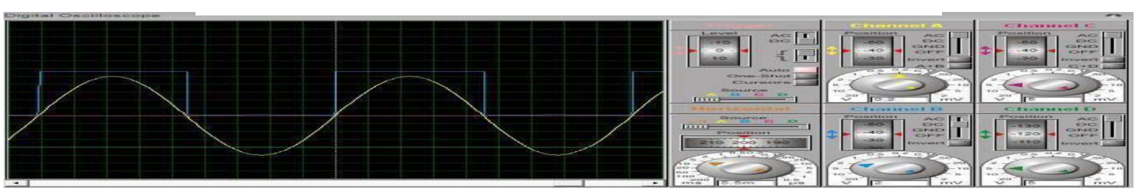

Figure 2-5: ZCD input and output waveform

interfaces the various peripherals and other modules used in the circuit. It integrates the function of various modules such as the Zero Crossing Detector (ZCD), X-OR gate, Relay circuit, LCD, etc. The heart of this project is the microcontroller which is responsible for all sequential and logical processing. It takes input, processes it according to the program written to it, and then gives the processed output. It also has some on-chip memory which is utilized to store some temporary variables during processing. The microcontroller used here is ATUNO2560 which is an 8-bit controller.

2.3.3 Overview of Arduino UNO

The Arduino UNO is a widely used microcontroller board developed as part of the Arduino platform. Here's a brief definition:

The Arduino UNO is a microcontroller board equipped with an ATmega328P microcontroller chip. It includes digital and analog input/output pins, a USB interface for programming and communication, and is designed for easy prototyping of electronic projects. The UNO board is known for its simplicity and versatility, making it a popular choice for both beginners and experienced electronics enthusiasts to create a wide range of projects.

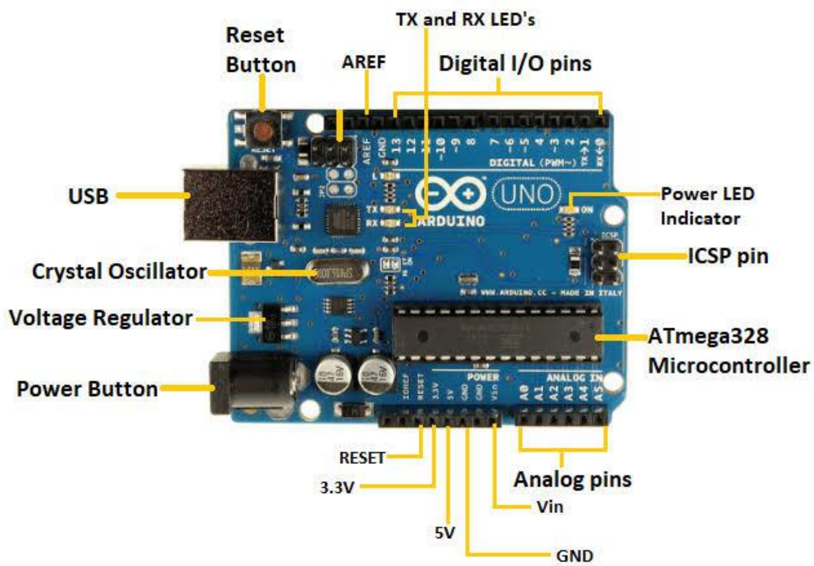

Figure 2-6: Arduino UNO [17]

1 Arduino UNO specification

The Arduino UNO has the following key specifications:

1 Microcontroller : ATmega328P

Architecture : 8-bit AVR

Clock Speed : 16 MHz

2 Digital Input/Output Pins : 14

PWM Output Pins : 6

3 Analog Input Pins : 6

4 Flash Memory : 32KB (of which 0.5KB is used by the bootloader)

5 SRAM : 2KB

6 EEPROM : 1KB

7 Operating Voltage : 5V

8 Input Voltage (recommended) : 7-12V

9 Input Voltage (limits) : 6-20V

10 DC Current per I/O Pin : 20 mA

11 DC Current for 3.3V Pin : 50 mA

12 USB Interface : Type-B

13 Power Jack : 2.1mm DC Barrel Jack

14 Dimensions : 68.6mm x 53.4mm

15 Weight : 25g

The Arduino UNO is known for its simplicity, versatility, and ease of use, making it a popular choice for a wide range of electronics and microcontroller projects. It provides a beginner-friendly platform for learning and prototyping, and it's supported by a vast community of makers and developers.

2 ARDUINO IDE.

IDE stands for “Integrated Development Environments”. It is an official software and is introduced by Arduino which is commonly used for writing programs, compiling them, and uploading the code to the Arduino Device.

Figure 2-7: ARDUINO IDE

2.3.4 GLASS RELAY

It works on the principle of electromagnetism. The electromagnetic field that creates the temporary magnetic field is energized when the relay's circuit detects the fault current. This magnetic field moves the relay armature to open or close connections.

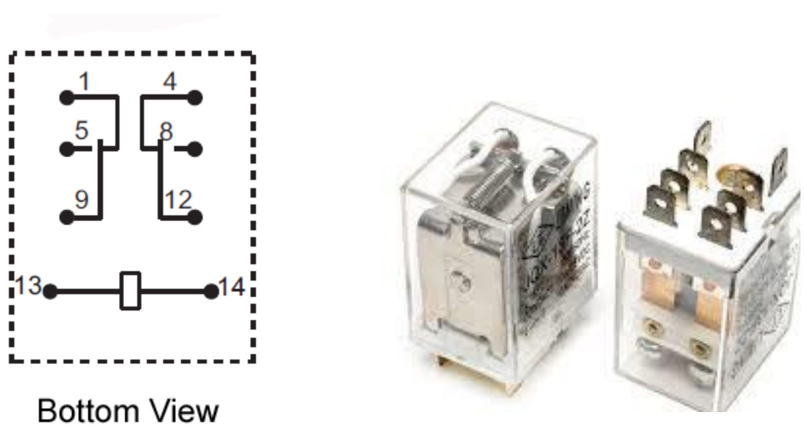

Figure 2-8: Glass Relay

2.3.5 POWER SUPPLY FOR CIRCUIT.

The DC power supply is essential for the operation of the microcontroller, relay energizing, coil, and other circuits like zero crossing detectors. Therefore, there is a need to convert the AC 220V supply to a DC 5V supply.so For DC power, we used two 5V DC adapters to convert 220v AC to5V DC for supplying DC power to the microcontroller and relay circuit respectively. An adaptor essentially consists of a transformer, rectifier, Zener diode, voltage regulator, filters, and some other circuitry. In 1st stage, the 220v AC is stepped down to low voltage AC in 2nd stage this low voltage AC is converted to pulsating DC through a full wave bridge rectifier in the final stage thepulsating DC is passed from the filter such as a capacitor, and inductor to convert pulsating DCto pure DC. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Output leads from an adapter can be inserted in the GND and VCC pin headers of the POWER connector.

2.3.6 16x2 LCD.

The 16x2 LCD is used in the project for displaying output results from the microcontroller. LCD stands for liquid crystal display. The 16x2 LCD means it consists of 16 columns and 2 rows for displaying text/number only. The 16x2 LCD consists of an LED backlight and can display 32 ASCII characters in two rows by displaying 16 characters in each row. Every single display element consists of 5x8 pixels which print any characters by switching some pixels ON and somepixels OFF as shown in Figure (3.7).16x2 lcd consists of two registers a command register (which stores printing command/instruction) and a data register (which stores data to be printed).The command or data register is selected through the RS pin of lcd.

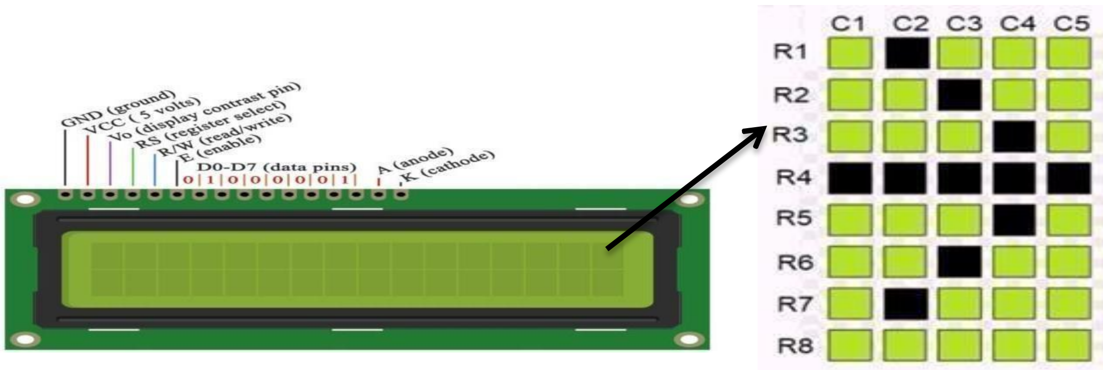

Figure 2-9: 16x2 LCD pinout

1 LCD connection

GND: GND of LCD are connected to Arduino ground pin.

VCC: It's a power supply pin of LCD connected to the 5-volt pin of Arduino.

VO (LCD contrast): VO is the brightness control pin of the LCD it controls the contrast and brightness of the LCD. This pin is connected to a potentiometer by dividing voltage to adjust the brightness of the LCD.

RS (Register select): This pin is used in LCD to select the command or data register. Through this pin, Arduino decides to send commands or data to the LCD register. RS pins are used TO differentiate between commands and data. Let's suppose if RS pin is set to LOW, it means we are sending the command to LCD if the RS is set to HIGH, it means we are sending data to lcd register. **R/W(Read/Write):** This pin is used in LCD for reading data from LC or writing data inLCD. Since we are using LCD as an output device, we are making this pin low which forces LCD into writing mode.

E (Enable): This pin is used to enable lcd.

DATA PINS (D0-D7): These 8 pins are used for sending 8-bit data to LCD. The data to be sent must be in the form of ASCII code.

A-K (Anode Cathode): They are used for LCD backlight connected to VCC with a series resistor and GND of Arduino respectively.

2.3.7 XOR GATE.

The XOR IC 7486 contains four independent EXCLUSIVE OR gates in a single IC chip. They provide the system designer with a means for implementation of the XOR function. The truth table with the Boolean equation is shown below. According to the basic introduction of the EXCLUSIVE OR gate, the output of the XOR gate will be HIGH only if both inputs are at different levels (HIGH and LOW) which is also clear from the truth table. So, we utilize this property of XOR operation to XOR both square wave signal of zero crossing detector of the line current and line voltage. The output waveform of the XOR gate generated represents the phase difference between current and voltage which is calculated by measuring the pulse width of the XOR gate output waveform. The square waveform of current, voltage, and output of the XOR gate are shown in the figure below.

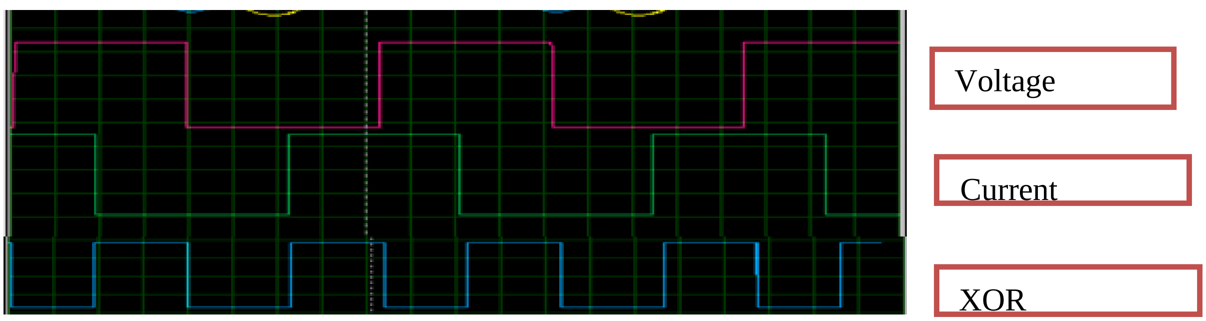

Figure 2-10: Input and output of XOR gate

2.4 MAPPING

Mapping an "Automatic Power Factor Correction and Frequency Measurement System using Arduino Uno" to the United Nations Sustainable Development Goals (SDGs) demonstrates how your project contributes to global sustainability efforts. Here's how it aligns with several relevant SDGs:

Table 2-1: Mapping to development goals

SDG	**Sustainable development Goal**	**Relevant aspect in monitoring system using Arduino**
SDG 1	Affordable and Clean Energy	Your system promotes energy efficiency, reducing electricity costs for businesses and encouraging the use of cleaner energy by optimizing power factor.
SDG 2	Industry, Innovation, and Infrastructure	Your system utilizes innovative technology (Arduino Uno) to improve power factor and infrastructure efficiency in industries and commercial buildings.
SDG 3	Sustainable Cities and Communities	By reducing energy waste and improving power quality, your system supports the development of sustainable and efficient urban areas.
SDG 4	Responsible Consumption and Production	It contributes to responsible consumption by helping businesses reduce energy consumption and minimize waste, aligning with sustainable production practices.
SDG 5	Climate Action	Improved power factor reduces greenhouse gas emissions by reducing the need for excessive electricity generation, contributing to climate mitigation efforts.
SDG 6	Partnerships for the Goals	Collaborations with stakeholders such as energy consultants, manufacturers, and businesses demonstrate the importance of partnerships to achieve sustainable development.

SDG 7	Life on Land (indirectly)	Energy efficiency measures, including power factor correction, can indirectly contribute to reducing land use for energy production and associated environmental impacts.
SDG 8	Peace, Justice, and Strong Institutions (indirectly)	Stable and efficient power systems support the functioning of institutions and contribute to economic stability, indirectly aligning with this goal. It's important to note that the extent of alignment with these goals can vary depending on factors such as the scale of implementation, the efficiency of the system, and the specific context in which it's used. To maximize the positive impact on these SDGs, you can also consider additional measures such as promoting awareness of sustainability, conducting energy audits, and supporting energy transition initiatives in regions where your system is deployed.

CHAPTER 3 DESIGN IMPLEMENTATION

3.1 INTRODUCTION.

The design implementation of this project presents a hardware implementation and design of an automatic-single-phases power factor correction and frequency measurement system using Arduino Mega. The hardware implementation was developed by using Arduino Mega.

The working principle of this project is based on the zero-crossing detection (ZCD) method the in ZCD method the sine wave (analog form) is converted to a square wave (digital form) for digital operation because the microcontroller easily performs digital operation. For sine wave to square wave conversion a high gain operational amplifier is used which converts sine wave to square wave. The power factor of the load was measured by using two circuits. Such as for load current waveform we use a current transformer that steps down current to low level signal which is suitable for Arduino mega processing. While for voltage waveform instead of PT we use an isolated RC series circuit with CT which leads to a small amount of current at 70 degrees from voltage and detects its waveform corresponding to voltage waveform through another CT. The advantage of voltage shifting is to differentiate b/w inductive and capacitive load. Both waveforms are converted to square waves using a zero-crossing detector.

The pulse width of both cycles (current and voltage) is the same but the position of the current cycle depends on the load. If the load is resistive both of the signals are in phase, if the load is inductive the current signal is lagging w.r.t voltage. There is a phase difference between the current and voltage signal. In simple words, we can say it's a time difference between voltage and current. For this purpose, to measure the power factor we feed both signals to the XOR gate which combines both wave forms in such a manner that their output pulse represents (proportional to phase difference) the phase difference between current and voltage. The output ofthe XOR gate is further fed to Arduino mega PWM digital pin 11 to measure the time difference between current and voltage which is converted to phase difference using equation (11) which is proportional to phase difference. According to the power factor valve appropriate size of the capacitor bank is switched ON through the relay

Instructed by Arduino *Mega*. While for frequency measurement we feed a square wave of voltagesignal directly to Arduino mega PWM pin 13 for measurement of its period using the internal timer of the microcontroller from which corresponding frequencies are calculated using equation

And display the result on LCD. The complete block diagram is shown in figure (4.1)

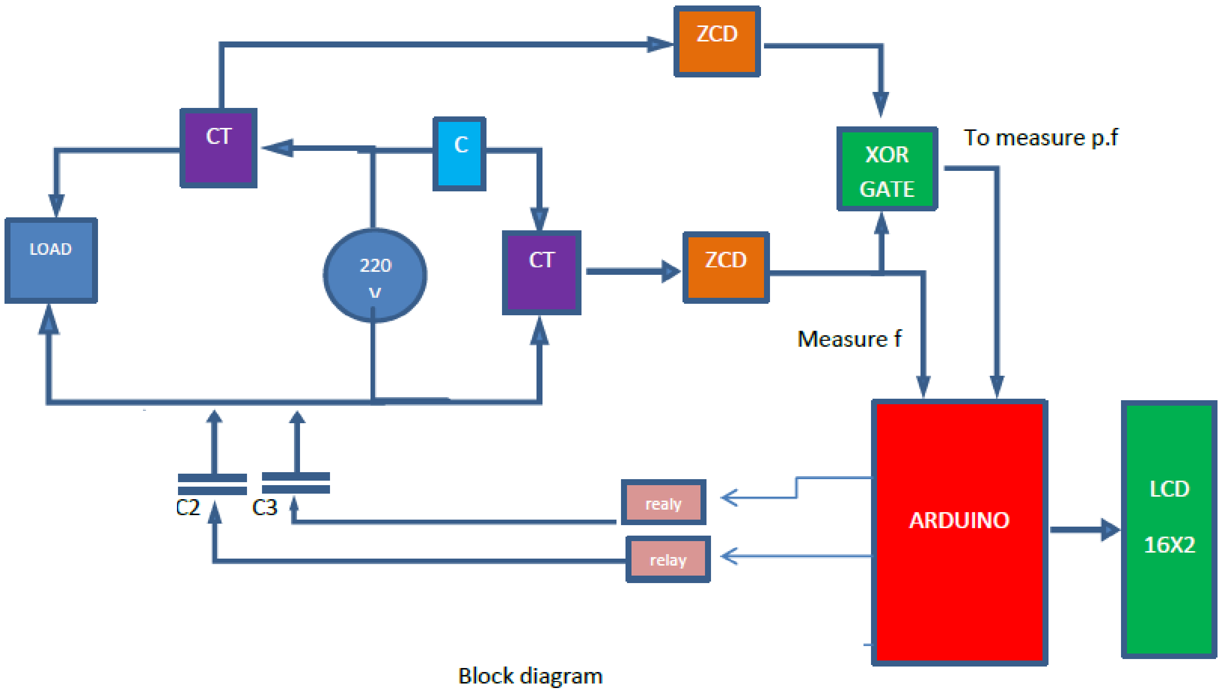

Figure 3-1: Block diagram of APFC system

$$f = \frac{1}{2t} \quad \ldots\ldots\ldots\ldots\ldots (12)$$

Where f = supply frequency

t = period/pulse width of half wave while 2 is used to convert the time of half wave to full wave.

3.2 WHAT AN AUTOMATIC POWER FACTOR CONTROLLER WORKS.

The power factor is a ratio of real power and apparent power. The ideal power factor is unity. Pure resistive loads have a unity power factor. But there is no such load that exists. So, we alwaystry to make the power factor close to unity. Reactive power is also the reason for the low power factor. Inductive loads absorb reactive power and capacitive loads provide reactive power. So, capacitor banks are used to improve power factor in power factor correction circuits. By connecting capacitor banks parallel to the load, the power factor is increased. Capacitor provides reactive power locally to load instead of getting from generators or power system which in returninduces a burden in the power system. This is the main objective of an automatic power factor controller.

3.3 WORKING PRINCIPLE

The working principle of the project is based on zero-crossing detection. A current transformer isused to get current waveform from load current and the current transformer also step-down AC. BC547 transistor is used as a comparator in this circuit. Similarly, for the voltage waveform, we used the RC series circuit with CT to get the current waveform of the RC circuit correspondingto the voltage waveform and feed this waveform to the comparator (ZCD) for conversion to square wave. After conversion from sine to square wave both current and voltage waveform are combined through XOR gate and fed to Arduino UNO PWM pins. Arduino UNO measurespower factor by measuring the time difference between current and voltage waveform. The time difference between current and voltage waveform is used to measure power factor using an atUNO2560 microcontroller. All input and output waveforms are shown in the figure below.

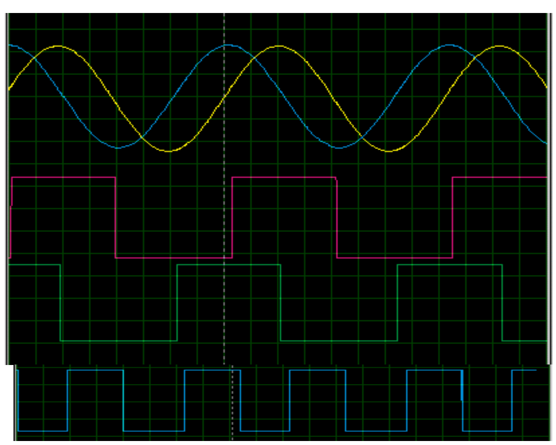

Figure 3-2: Input waveform of ZCD and XOR GATE

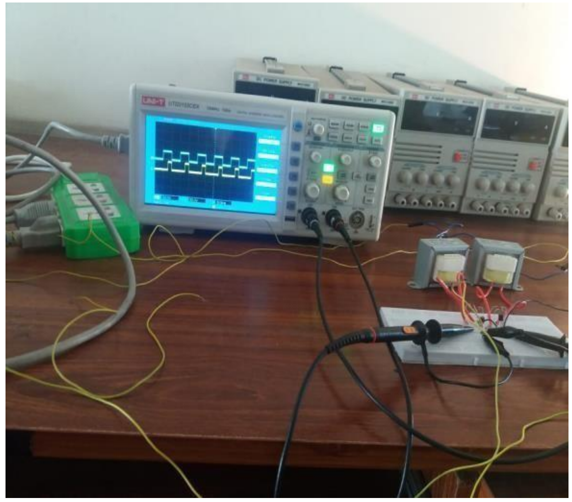

Figure 3-3: Output waveform of ZCD and XOR GATE

3.4 AUTOMATIC POWER FACTOR CONTROLLER CIRCUIT OPERATION

3.4.1 Step 1 of automatic power factor controller:

An alternating voltage of 220 volts is applied to the connected load. A step-down current transformer is connected in series to load to detect load current waveform, on the other side an isolated series RC circuit with CT is used to detect the current waveform of the RC circuit corresponding to the voltage waveform. A current transformer used to convert high current into low current for measurement purposes. The amount of current that is stepped down depends on the number of turns in the primary coil and number of turns in the secondary coil and the step- down ratio. If the current transformer has a ratio of 1000:10, then it means that such a step-down transformer can convert a current of 1000 amperes to 10 amperes. Step-down transformers can be used in circuits where circuits are required to operate on low currents and available currents are high in value. For example, if a relay is to be operated or a microcontroller is to be operated ina circuit. One has to use intelligent techniques to step down the current value for the use of circuits and for this purpose step-down transformers can be used. In the proposed work amicrocontroller is used which is why we have to step down the value of current for the microcontroller and a step-down current transformer can be used for this purpose.

3.4.2 Step 2 of automatic power factor controller:

Zero crossing detection is used to detect sine wave zero crossing from positive half cycle to negative half cycle or negative half cycle to positive half cycle. Zero crossing of two waves must be detected to measure the phase difference between the two waves. Zero crossing detector circuitconverts the sinusoid wave to a square wave. The outputs from step down current and voltage signal are fed into a zero-crossing detector circuit which converts the sinusoid waveform into to square waveform to be used by the microcontroller. BC547 transistor is used as a comparator for zero-crossing detector circuits. Two analog voltage levels are compared with one another using a BC547 transistor which looks like a comparator circuit and output depends upon the comparison of these voltage levels. The voltage which is higher in magnitude appears at the output. In a crossing detector circuit, one input wire is set at zero references (ground) and the second input wire is connected to the base of the transistor which feeds a sinusoidal wave to be converted into a square wave. Whenever the sinusoidal signal has a value greater than zero references, the output of the transistor has a positive value. As soon as the sinusoidal signal falls below zero reference, the

The output of the transistor falls to zero. In this way, a crossing detector circuit converts a sinusoidal signal to a square waveform.

3.4.3 Step 3 of automatic power factor controller:

The corresponding current and voltage square waveform are combined through XOR operationto obtain the resultant square waveform which presents phase difference.

3.4.4 Step 4 of automatic power factor controller:

The microcontroller then uses its abilities and program to calculate the phase angle/phase difference between two waveforms and frequency. The time difference between two waveformscan converted to phase difference easily using the following formula. Time difference = average values of the timer/1000000

In the above equation, 1000000 is used to convert time into seconds because of time measuredby the PWM pin of Arduino UNO is in microseconds.

θ = time difference * 2πPower factor = Cos (θ)

2 π is multiplied by the time difference value to convert it into radians as the phase angle is to be expressed in radians. Phase difference which is expressed as an angle is known as phase angle. Now using information power factor can be calculated easily. These calculations are done by writing software programs in microcontroller.

3.4.5 Step 5 of automatic power factor controller:

Arduino atUNO2560 is programmed in such a manner to calculate the phase difference between two sinusoid waves, frequency, and then power factor using this information and displays on LCD. A Liquid Crystal Display screen is a very basic module and is used very commonly in various circuits for display purposes. It finds a wide range of applications. LCD is preferred over LED display and seven-segment display. LCDs are easily programmable, economical, call, and can easily display characters, animations and so on 16×2 LCD has 2 lines and each line can display 16 characters. A command is an instruction that is fed to LCD, Commanders are used to execute some tasks that are predefined already such as initializing LCD, clearing its screen, controlling display and brightness, seeing and setting cursor position, etc. Command register stores such predefined instructions. The data register in LCD stores data that is to be displayed onscreen.

3.4.6 Step 6 of the automatic power factor controller:

If the power factor is less than a prescribed value then the microcontroller generates a command to turn on the relay. Turning on the relay will add a capacitor to the circuit which will help to improve the power factor. Capacitors add reactive load in the circuit which will help to increase the power factor. Number of capacitors that are to be added depends upon the power factor of thecircuit. As soon as the power factor drops from a specific value, the relay will act to add a capacitor to the circuit. If the power factor value drops a little to the prescribed value, then one capacitor is added. In case of power factor drops much more than the prescribed value then a second capacitor is also added and the system goes on this way.

The circuit will continue to add capacitors in parallel to the load until a good value of power factor is achieved. The entire circuit diagram of the project is shown below.

3.5 CIRCUIT DIAGRAM

Figure 4.4 shows the circuit diagram for this suggested system. The Arduino atUNO2560 servesas the system's main component and brain, and it has been designed to detect voltage and currentwaveforms as well as adjust the associated load's Power Factor. The supply sources current and voltage signal is stepped down to a low power signal acceptable for the system by utilizing a current transformer and series RC circuit with CT, The corresponding current and voltage signals are supplied to the microcontroller through a sensing circuit and a zero-cross detector, which measures the phase difference between current and voltage signals, frequency andthe circuit's power factor. The microcontroller will manage the entire circuit, as well as run the relay to turn on and off the capacitor. And display results on LCD.

3.6 PROJECT FLOWCHART & PROGRAMMING FLOWCHART

1 Take current and voltage signals respectively.
2 Measure the power factor of the load.
3 If the power factor is between 0.9 and 1 display P.F
4 If P.F. is not between 0.9 and 1 display P.F. and switch on the capacitor bank until P.F.becomes near to unity.

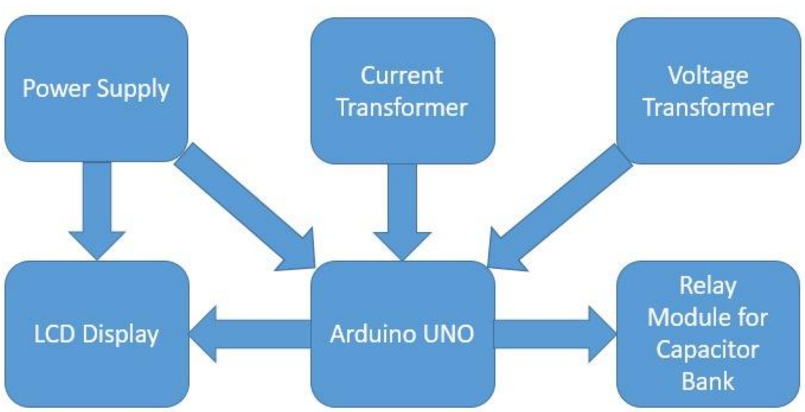

Figure 3-4: system flow chart

3.7 PROGRAMMING

The Arduino UNO is programmed in Arduino IDE software. The Arduino IDE is open-source software available in different libraries such as for LCD, math operation, etc. For Arduino programming Select "Arduino UNO from the Tools > Board menu (according to the microcontroller on board). The Arduino IDE was designed to give students an inexpensive and easy way to program interactive objects. It comes with a simple Integrated Development Environment (IDE) that runs on regular personal computers and allows writing programs for Arduino using a combination of simple Java and C or C++.

#include library: In Arduino UNO programming first, we include project-related libraries using the # include library function.

Void setup: a function that runs once at the start of the program that can be used for initializing input, and output variables.

Void Loop: the function that runs repeatedly until the power board is off. This function is used for writing the main program.

Pulse in (): This function reads a pulse (either HIGH or LOW) on a PWM pin. For example, if the value is HIGH, pulse in () waits for the pin to go HIGH, starts timing, then waits for the pin to go LOW, and stops timing. Returns the length of the pulse in microseconds. Gives up and returns 0 if no pulse starts within a specified time out. This function is used in the programming of this project for the measurement pulse width of pulse to measure power factor.

3.8 HARDWARE MODULE:

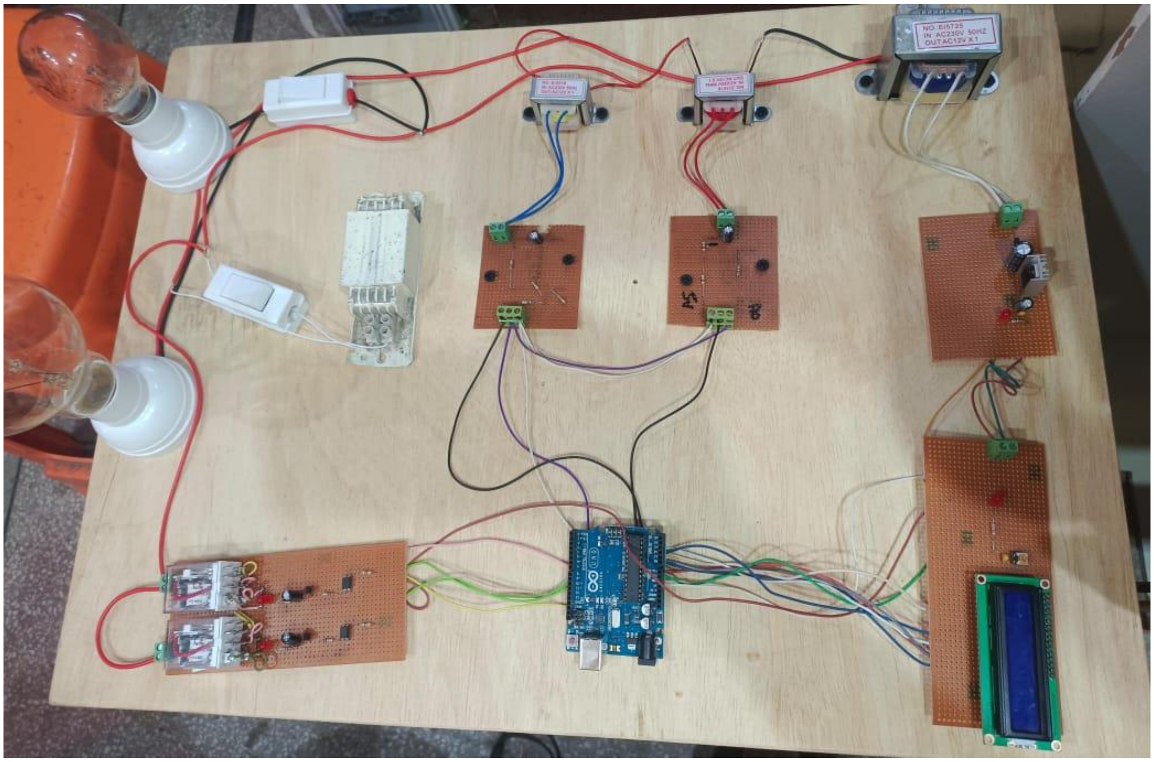

Figure 3-5: Hardware module

CHAPTER 4 COMMERCIALIZATION

4.1 END PRODUCT

Creating an end product like an "Automatic Power Factor Correction and Frequency Measurement System" using an Arduino Uno involves several components and steps. Here's an overview of what such a system might entail:

4.1.1 Components Needed:

1 Arduino Uno: This is your main microcontroller.

2 Sensors:

Voltage Sensor: To measure line voltage.

Current Sensor(s): To measure current.

Frequency Sensor: To measure the line frequency.

3 Relays: To control power factor correction capacitors.

4 Power Factor Correction Capacitors: These capacitors are switched on or off based on the power factor measurement.

5 LCD Display: To show the power factor and frequency.

6 Switches or Buttons: For user input or control.

7 Circuit Protection: Fuses or circuit breakers for safety.

8 Enclosure: To house and protect the components.

9 Power Supply: To provide power to the system.

4.1.2 Steps to Create the System:

1 Sensor Connections: Connect the voltage and current sensors to measure line voltage and current.

2 Frequency Sensor: Connect the frequency sensor to measure the line frequency.

3 Relay Connections: Wire the relays to the capacitors for power factor correction. The Arduino will control these relays based on measurements.

4 User Interface: If you want user control or monitoring, connect switches or buttons and an LCD display to the Arduino.

5 Coding: Write Arduino code to:

Read voltage, current, and frequency from sensors.

Calculate power factor based on measurements.

Control relays to adjust power factor correction capacitors.

Display results on the LCD (if used).

Handle user input (if applicable).

6 Testing and Calibration: Test the system with various loads and voltage conditions. Calibrate it to ensure accurate power factor correction.

7 Safety: Ensure proper safety measures are in place, such as fuses or circuit breakers to protect against electrical faults.

8 Enclosure: Place the components inside an enclosure to protect them from environmental factors and to ensure safety.

9 Documentation: Document the system's operation, connections, and calibration procedures.

10 Final Product: Assemble the components neatly, and your Automatic Power Factor Correction and Frequency Measurement System is ready as an end product

Remember that working with electrical systems involves potential hazards, so it's important to have a good understanding of electrical safety practices and consider consulting with an expert if you're not experienced in this field.

4.2 BUSINESS MODEL CANVAS*

Creating a Business Model Canvas (BMC) for an "Automatic Power Factor Correction and Frequency Measurement System" using Arduino Uno involves outlining the key elements of your business model. Here's a simplified BMC for such a project:

4.2.1 Customer Segments :

Industrial Facilities

Commercial Buildings

Renewable Energy Installations

4.2.2 Value Proposition :

Improved Power Efficiency

Reduced Electricity Costs

Maintenance of Optimal Power Factor

Accurate Frequency Measurement

4.2.3 Customer Relationships :

Online Support

Technical Assistance

Regular Updates and Maintenance

4.2.4 Channels :

Online Sales Platform

Distributors and Resellers

Direct Sales Team

4.2.5 Key Resources :

Arduino Uno Hardware

Sensor Components

Software Development Team

Manufacturing Facilities

4.2.6 Key Activities :

Hardware Development

Software Development

Manufacturing and Quality Control

Marketing and Sales

4.2.7 Key Partnerships :

Arduino Suppliers

Sensor Manufacturers

Distributors and Resellers

Technical Support Partners

4.2.8 Revenue Streams :

Product Sales (One-time)

Subscription for Software Updates and Support

Maintenance Contracts

4.2.9 Cost Structure :

Research and Development

Manufacturing Costs

Marketing and Advertising

Sales and Support Team

Operational Costs

4.2.10 Customer Segments :Regular Updates

Cost-Efficiency

Energy Savings

Reliability

This BMC provides a high-level overview of how your business might operate. It's important to conduct thorough market research, assess your competition, and refine your BMC as you gather more information and insights. Additionally, consider factors like pricing strategy, distribution channels, and scalability as you develop your business plan further.

4.3 MARKETABILITY

An Automatic Power Factor Correction and Frequency Measurement System using Arduino Uno has the potential to be highly marketable, depending on various factors and target markets. Here are some key points highlighting its marketability:

4.3.1 Energy Efficiency Demand:

There's a growing demand for energy-efficient solutions in both industrial and commercial sectors. Your system offers a way to improve power factor, which leads to reduced electricity costs and increased energy efficiency. This can be particularly attractive to businesses looking to cut energy expenses and reduce their carbon footprint.

4.3.2 Cost Savings:

By improving power factor, your system can lead to significant cost savings for businesses with high electricity bills. This cost-effectiveness can be a strong selling point.

4.3.3 Environmental Awareness:

As sustainability becomes a more prominent concern, businesses are actively seeking ways to reduce energy waste. Your system aligns with environmental goals, making it appealing to eco-conscious customers.

4.3.4 Easy Integration:

Arduino-based systems are known for their versatility and ease of integration. Your system can be designed to work with existing equipment, making it more attractive to businesses without the need for major infrastructure changes.

4.3.5 Data and Analytics:

Your system can provide valuable data on power factor and frequency, which can be used for analytics and predictive maintenance. This data-driven approach can be appealing to industries that rely on data insights for decision-making.

4.3.6 Remote Monitoring and Control:

If your system offers remote monitoring and control capabilities, it can be highly marketable to businesses looking for convenient and efficient ways to manage their power factor correction systems.

4.3.7 Diverse Market Segments:

Your system can be marketed to a wide range of industries, including manufacturing, healthcare, data centers, and more, which expands your potential customer base.

4.3.8 Regulatory Compliance:

In some regions, there are regulations and incentives related to power factor correction. Your system can help businesses comply with these regulations, making it a necessary investment.

4.3.9 Customization:

Offering customization options to meet specific customer needs can enhance marketability, as it allows businesses to tailor the system to their unique requirements.

4.3.10 Customer Support

Providing excellent customer support, including installation assistance and ongoing maintenance, can boost the marketability of your system by increasing customer confidence.

To maximize marketability, it's crucial to conduct market research, identify your target audience, understand their needs, and tailor your product and marketing strategies accordingly. Additionally, consider seeking partnerships with electrical contractors, energy consultants, and distributors to reach a broader audience.

4.4 APPLICATIONS

The suggested system can be extended to use in industries and electrical systems. Using the mostpowerful, extremely quick-acting, and fast-switching controllers, a fast power factor adjustment may be achieved. This can be done in the future, potentially saving a significant amount of energy for the power industry.

CONCLUSION

“The automatic P.F. correction and frequency measurement provide an efficient technique to improve power factor automatically. The system uses a capacitor bank only when P.F. is low otherwise they are cut off from supply which increases the life of the capacitor bank. It decreasesthe unwanted flow of current due to reactive loads. It Increases system efficiency and improves voltage regulation. The Power Factor is increased by adding appropriately sized power capacitorsto the circuit, bringing the value closer to 0.9 to 0.95, reducing line losses and increasing plant efficiency. The efficiency of the system is greatly improved by employing this microcontroller- based Power Factor Improvement solution. This is a very efficient system for a variety of loads since it uses various capacitor sizes and triggers relays that are controlled by the microcontroller. As a result, it is strongly advised to get the best results on the system that will be built as described above.”

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[15] Link: Https://www3.ntu.edu.sg/home/ehchua/programming/arduino/arduino.html

APPENDXIX

Arduino UNO Micro controller code

```
#include "EmonLib.h"  // Include Emon Library
EnergyMonitor emon1;
#include <LiquidCrystal.h>  s
LiquidCrystal lcd(9, 8, 7, 6, 5, 4);
#define p1_pt A0
#define p1_ct A1
#define p_c1 10
#define p_c2 11
float pf1=0;
int flag1=0,Set=0;
void setup(){
Serial.begin(9600);
pinMode(p_c1, OUTPUT);digitalWrite(p_c1, HIGH);
pinMode(p_c2, OUTPUT);digitalWrite(p_c2, HIGH);
emon1.voltage(p1_pt, 290.26, 1.7);   // Voltage: input pin, calibration, phase_shift
emon1.current(p1_ct, 50);        // Current: input pin, calibration.
lcd.begin(16, 2); // set up the LCD's number of columns and rows:
lcd.setCursor(0, 0);
lcd.print("  Welcome");
delay(2000);
```

```
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("  Power  Factor");
lcd.setCursor(0, 1);
lcd.print("   Improvement");
for(int i=0; i<15; i+=1){
emon1.calcVI(20, 2000);
delay(10);
}
  // Timer1 module configuration
  TCCR1A = 0;
  TCCR1B = 2;   // enable Timer1 module with 1/8 prescaler ( 2 ticks every 1 us)
  TCNT1  = 0;   // Set Timer1 preload value to 0 (reset)
  TIMSK1 = 1;   // enable Timer1 overflow interrupt

  EIFR |= 1;  // clear INT0 flag
  attachInterrupt(0, timer1_get, FALLING);
lcd.clear();
}
uint16_t tmr1 = 0;
float period, frequency;

void timer1_get() {
  tmr1 = TCNT1;
```

```
  TCNT1  = 0;   // reset Timer1
}
ISR(TIMER1_OVF_vect) {  // Timer1 interrupt service routine (ISR)
  tmr1 = 0;
}
void loop(){
 uint16_t value = tmr1;
 period = 8.0 * value/16000;
 if(value == 0)
  frequency = 0;   // aviod division by zero
  else
    frequency = 16000000.0/(8UL*value);
for(int i=0; i<8; i+=1){
emon1.calcVI(20, 2000);
delay(10);
}
  pf1=emon1.powerFactor;
  if(pf1>1.00){pf1=1.00;}
  lcd.setCursor(0, 0);
  lcd.print("PF:");
  lcd.print(pf1);
  lcd.print("  ");
```

```
  lcd.setCursor(10, 0);
  lcd.print("F:");
  lcd.print(frequency);
  lcd.print("  ");
  lcd.setCursor(0, 1);
  lcd.print("V:");
  lcd.print(emon1.Vrms,0);
  lcd.print("  ");
  lcd.setCursor(9, 1);
  lcd.print("I:");
  lcd.print(emon1.Irms);
  lcd.print("  ");
if(pf1<0.90){ flag1=0;
Set=Set+1;
if(Set>2)Set=0;
}
    if(Set==0){digitalWrite(p_c1, HIGH); digitalWrite(p_c2, HIGH); }
else if(Set==1){digitalWrite(p_c1, LOW);}
else if(Set==2){digitalWrite(p_c2, LOW);}
  delay(2000);
}
```