Development and Deployment of a High-Precision Power Factor Measurement Meter

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Abstract:- This research article presents the development and deployment of a high-accuracy power factor measurement meter. Power factor measurement is crucial for assessing the efficiency of electrical systems and ensuring optimal power usage. The proposed meter employs advanced signal processing techniques to accurately measure both leading and lagging power factors with high precision. The design incorporates robust hardware components such as ATMega8 micro-controlling chip and sophisticated algorithms to minimize errors and provide reliable measurements even in challenging operating conditions. Experimental results demonstrate the effectiveness of the proposed meter in accurately measuring power factor across a wide range of electrical loads. The developed meter offers significant improvements in accuracy and reliability compared to existing solutions, making it suitable for various industrial and commercial applications where precise power factor measurement is essential for efficient energy management.

Keywords:- *Power Factor, High-Accuracy Meter, Active Power, Apparent Power, Reactive Power, Energy Efficiency.*

I. INTRODUCTION

The demand for electrical energy in industrial applications continues to rise, driving the need for improved system efficiency through power factor correction [1], [2]. System efficiency, quantified by the ratio of real power to apparent power, is critical in electrical systems where loads, predominantly motors or inductive loads, draw both reactive power and active from the lines. While active power is converted into various forms of energy like heat and mechanical energy, reactive power remains unutilized [3]. Failure to compensate for reactive power can lead to oversized transformers and transmission lines, as reactive power is necessary for transmitting active power, arising from the rotary field in alternating current machines and magnetic field in transformers. Reactive power compensation has traditionally involved the use of capacitor groups controlled by relays and contactors, underscoring the importance of accurately measuring power factor for effective compensation. The proliferation of electronic equipment and power devices has heightened concerns about harmonic distortion in power systems [4], necessitating research into power factor correction to mitigate harmonic contamination and enhance transmission line efficiency [5].

Numerous studies have explored the development of smart meters [6-8], with installations expanding across various settings worldwide, including homes, schools, universities, and industrial premises [9, 10]. Beyond recording electricity consumption, smart meter infrastructure offers additional benefits such as streamlined billing processes, fraud detection, blackout alerts, and real-time pricing schemes [11].

This paper presents the design and measurement of pf using the ATMega8 microcontroller chip, noted for its cost-effectiveness, simplicity, and high accuracy, offering a practical solution to power factor monitoring.

➢ *Objective of Studies*

The main objectives of the project are to construct a power factor measurement system using AVR Atmel microcontroller because perceiving the power factor is crucial for implementing reactive power compensation measures.

- *Objectives of this Project are given Below:*

✓ To development a low cost power factor meter
✓ To design a simple but high accuracy power factor meter

➢ *Power Factor*

There are three main types of loads:

- *Resistive*
- *Capacitive*
- *Inductive*

When AC voltage is applied to resistive loads, it doesn't alter the current waveform. However, inductive loads cause the current waveform to lag behind the voltage waveform, while capacitive loads cause the current waveform to lead the voltage waveform.

A waveforms of inductive load is shown below. A phase shift of thirty degrees is evident in the current waveform.

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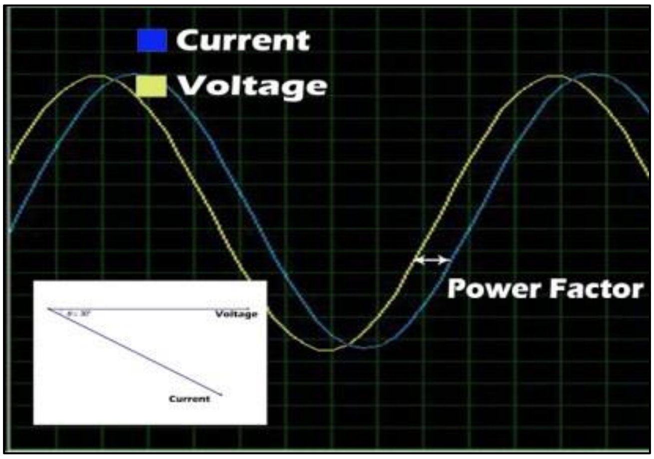

Fig 1 Waveform of Inductive Load

The power factor represents the ratio of KW to KVA consumed by an electrical load, where KW denotes the actual load power and KVA signifies the apparent load power. It serves as a metric for assessing the efficiency of current conversion into useful work output, offering insights into the impact of load current on supply system efficiency [12].

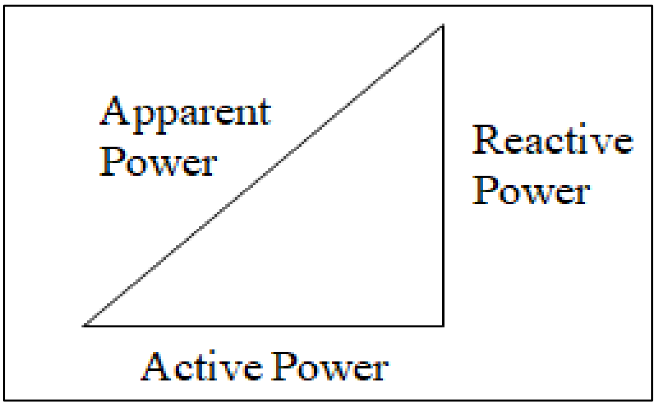

Fig 2 Power Triangle

All currents contribute to losses within the supply and distribution system. A power factor of 1.0 indicates the most efficient utilization of the power supply, whereas a power factor of 0.5 results in significantly higher losses within the system. A poor power factor may arise from either a notable phase disparity between voltage and current at the load or from a high harmonic contents or distorted/discontinuous current wave.

On the other hand, distorted current waveforms can stem from rectifiers, variable speed drives, switched-mode power supplies, discharge lighting, or further electronic loads. However, rectifying a poor power factor attributed to a distorted current waveform often necessitates equipment redesign or the use of expensive harmonic filters to achieve significant improvement. Despite claims of inverters having a pf over 0.95, the actual pf may fall between 0.5 and 0.75. The 0.95 figure is typically derived from the cosine of angle between voltage and current, neglecting the discontinuous nature of the current waveform, which ultimately leads to increased losses within the supply [13].

II. PROJECT DESIGN METHODOLOGY

A. This Project Work is done in Two Steps

- *Designing Microcontroller based Power Factor Measurement Circuit*

- *Microcontroller Programming*

The pf essentially represents the cosine of phase angle between voltage and current. Put simply, if there's a lagging current in relation to voltage, taking the cosine of that angle yields the pf.

Zero cross detection is a crucial method for measuring the time interval between voltage and current. It essentially detects when the voltage or current waveform crosses zero. There are various approaches to implementing this technique, but accuracy is paramount. In this study, zero crossing is implemented using an 8-pin IC containing dual amplifiers named LM358. The objective is to detect a "high" value precisely at the moment of zero crossing in the waveforms. To obtain this value, an amplifier is employed as a comparator, tasked with comparing the non-inverting reference value and subsequently responding as necessary.

So, I assess the time variance between the two waveforms to ascertain the necessary angle using the formula provided below:

$\theta = \Delta t \cdot f \cdot 360°$

Where f is the frequency of the system which can be 50 or 60 Hz.

The output of the comparators is depicted in the figure below, where the yellow waveform represents the output of voltage, and the blue waveform represents the output of current, exhibiting some lag.

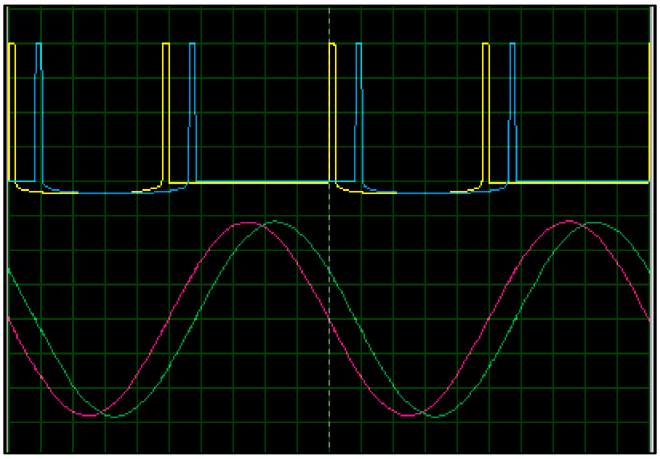
Fig 3 Comparator Outputs

- *Calculations*

After measuring the time of both waveforms, we can write

$\Delta t = d / 1000000$ [To convert it into second]

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Where, Delay, d is the value from the timer.

So, we can ascertain the necessary angle using the formula,

$\theta = \Delta t \cdot f \cdot 360°$

Where f is the frequency of the system which can be 50 or 60 Hz.

To convert it into radians,

$\theta = \Delta t \cdot f \cdot 360\ (3.14/180)$

$pf = \cos(\theta)$

to express as percentage,

$pf = \cos(\theta) * 100$

III. DEVELOPMENT OF THE PROJECT

In this project a microcontroller based pf measurement system is designed to measure the phase disparity between the voltage and current which is passing through the load, hence calculate pf.

- *Block Diagram of Microcontroller based Pf Assessment System is Shown in Below:*

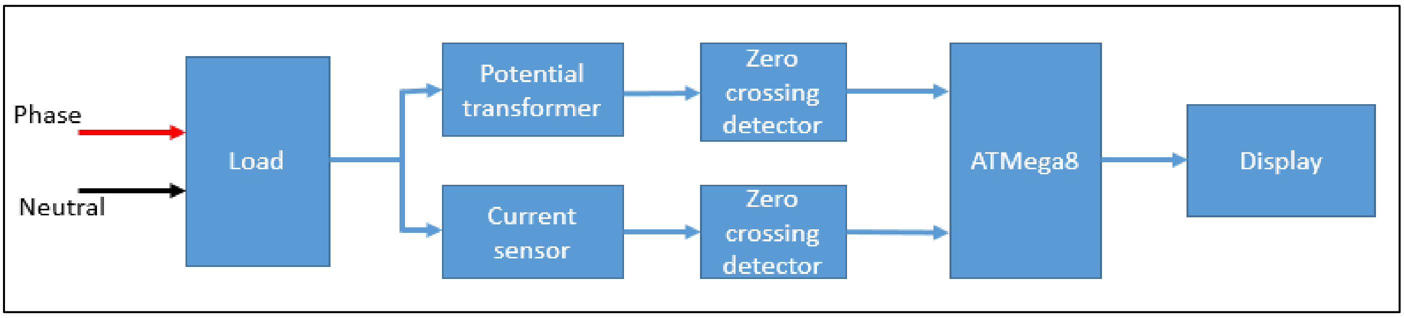

Fig 4 Block Diagram of Microcontroller based Power Factor Measurement System

In this setup, the power supply represents the line voltage directed to the load. The secondary coil of the potential transformer is linked to a zero-crossing detector, while the current passing through the load is detected by the current sensor. The output from the sensor is then directed to another zero-crossing detector. The outputs from both zero-crossing detectors are connected to pins PC4 and PC5 of the ATmega8 microcontroller. Finally, the results are displayed.

- *PROTEUS Simulating Software is used to Design and Test the Circuit. Circuit Diagram of the Power Factor Measurement System is Shown in Below:*

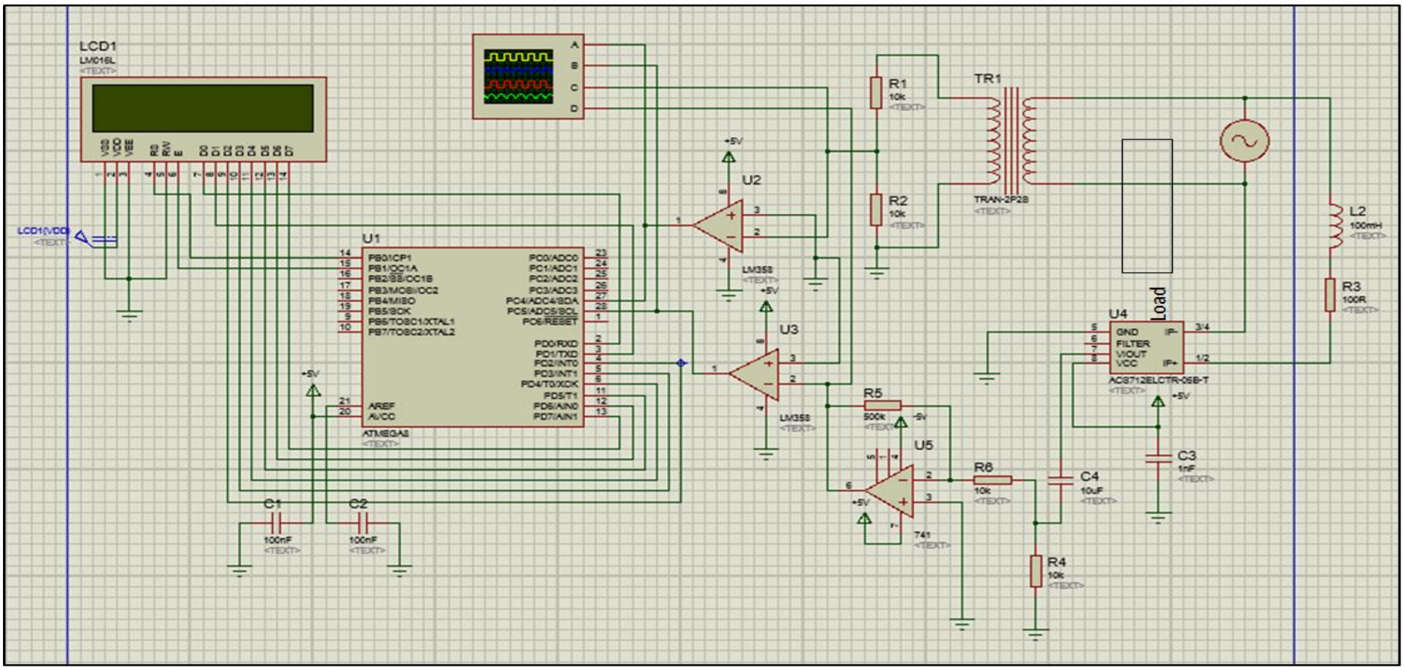

Fig 5 Overall Circuit Diagram of Microcontroller based Power Factor Meter

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Here an alternator has been used for the line 220 peak voltage. The secondary coil of the potential transformer is connected to a zero crossing detector LM358. The current which is passing through the load is sensed by the ACS712 (20Ams) current sensor. The output of the sensor is given in voltage. Then this output voltage of the sensor is fed to 741 IC for increasing the voltage, then fed to another zero crossing detector LM358. The output of both zero crossing detector is fed to pin PC4 & PC5 respectively of ATMega8 microcontroller. In this design reference voltage is considered as 5V dc, that's why AV_{cc} port of microcontroller is connected the 5V dc line. For displaying the result of this design a 16X2 LCD display has been used.

In the simulation, I've designated the upper sine generator to represent the output of the Potential Transformer (PT), while the lower sine generator represents the output of the ACS712 (20 Amp) Current Sensor (CS). The rationale for employing both CS and PT is that the LM358 IC cannot withstand high voltage; exposing it to such voltage would cause severe damage. Therefore, the voltage and current are first stepped down to ensure that the highest peak of current and voltage does not exceed 5V.

To address the high voltage output of the PT, which reaches 9 volts, I've integrated a voltage divider. The PT's 9-volt output yields a peak of 1.4 * 9 = 12.6 volts, which poses a risk to the IC. Therefore, I've implemented a voltage divider to reduce the peak to 4.2 volts. An active filter is used to block dc component before 741 op-amp. 741 IC is used for increasing the output voltage of the current sensor.

Atmel Studio 6.2 serves as the platform for programming and compiling the Atmega8 microcontroller once the design process is complete. This software streamlines the process by eliminating the need for additional software or applications to generate the *.hex file, which is then programmed into the microcontroller.

IV. RESULT AND DISCUSSION

The designed High-Accuracy Power Factor Measurement Meter, implemented using an ATmega8 microcontroller, underwent comprehensive testing to evaluate its performance. The meter was subjected to measurements across various loads to ascertain its accuracy and reliability in determining power factor.

During testing, the power factor of different loads was measured using the designed meter. These loads included a variety of electrical appliances and equipment commonly found in households and industries. The obtained measurements were then compared with the readings obtained from a conventional meter available in the market.

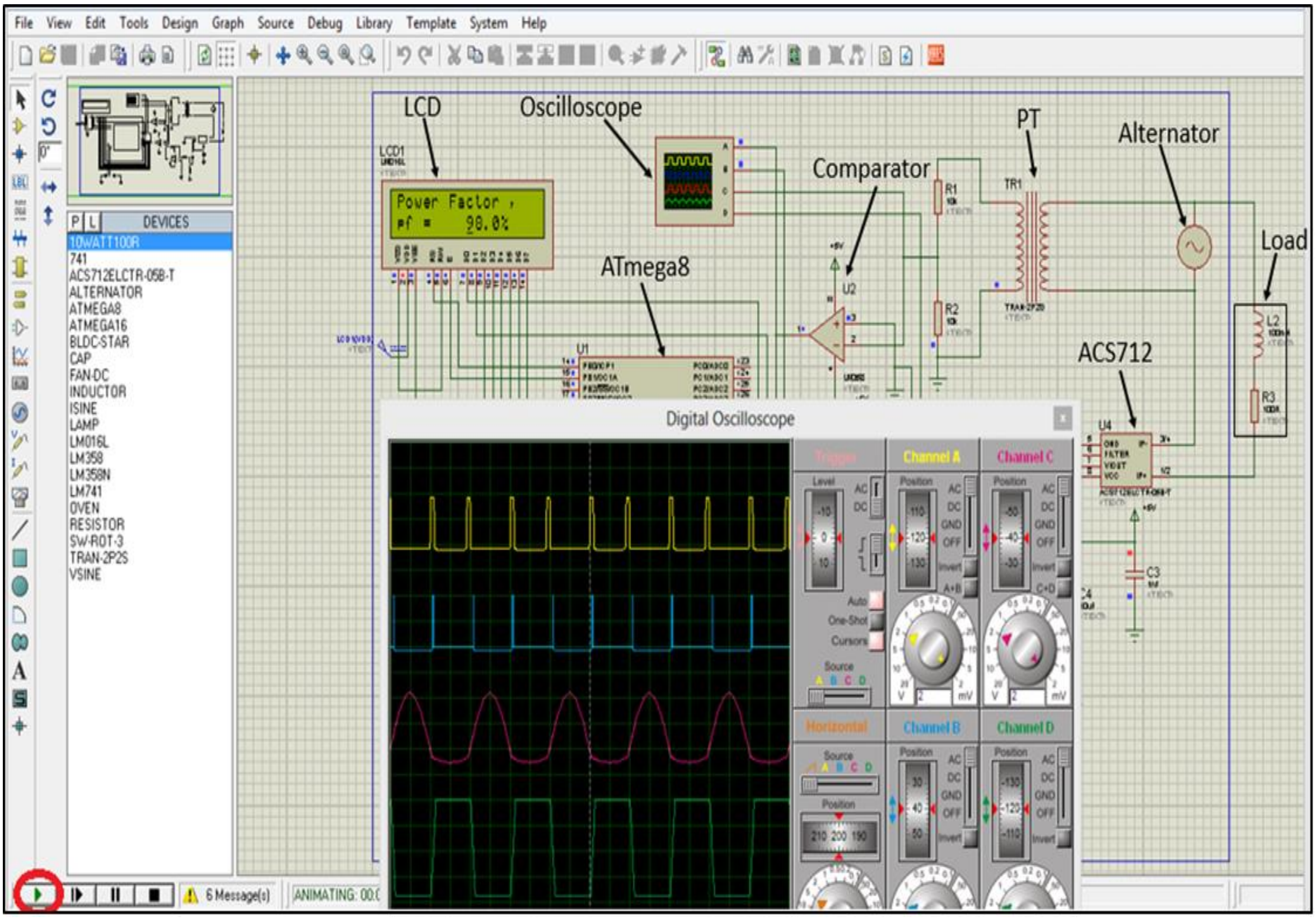

Fig 6 Simulation Result of an Inductive Load

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Comparison of power factor of certain loads measured by conventional meter available in the market and power factor measured by my designed meter is shown in the Table 1. Standard power factor reading as given by manufacturer are also shown in the table.

Table 1 Showing the Power Factor of Certain Loads Measured by Conventional Meter Available in Market and Power Factor Measured by my Designed Meter

S/N	Tested Load	Standard PF	Measured PF By Conventional Meter	Measured PF By Designed Meter
1	Television	0.93-0.96	0.93	0.96
2	Rechargeable lamp	0.98-1.0	0.97	0.99
3	Drilling machine	0.80-0.90	0.85	0.89
4	Blender	0.79-0.81	0.82	0.84
5	DVD	0.93 -0.96	0.95	0.96
6	Printer	0.80-0.82	0.83	0.85
7	Soldering iron	0.90-0.97	0.93	0.94
8	Standing fan	0.94-0.97	0.95	0.96
9	Ceiling fan	0.80-0.86	0.82	0.84
10	Iron	0.91-0.96	0.92	0.94

The results of the comparison revealed that the designed power factor meter exhibited high accuracy and reliability in measuring power factor across different loads. The readings obtained from the meter closely matched those obtained from the conventional meter, indicating the effectiveness of the designed system.

Furthermore, the meter demonstrated consistent performance across a range of loads, showcasing its versatility and robustness in real-world applications. The accuracy and precision offered by the designed meter make it a valuable tool for power factor measurement in various settings, including residential, commercial, and industrial environments.

Overall, the results and discussions highlight the successful design and implementation of a high-accuracy power factor measurement meter based on the ATmega8 microcontroller. The meter's performance, as demonstrated through testing and comparison with conventional meters, underscores its potential for widespread adoption in diverse applications.

V. CONCLUSION

In conclusion, the development and deployment of the High-Accuracy Power Factor Measurement Meter utilizing the ATmega8 microcontroller have proven to be successful and effective. Through comprehensive testing and comparison with conventional meters, several key findings have emerged:

- *Accuracy and Reliability:*

The designed meter exhibited high accuracy and reliability in measuring power factor across various loads. The readings obtained from the meter closely matched those obtained from a conventional meter, indicating its precision and trustworthiness.

- *Consistent Performance:*

The meter demonstrated consistent performance across a range of loads, showcasing its versatility and robustness in real-world applications. This consistent performance is essential for ensuring reliable power factor measurements in different settings.

- *Versatility and Robustness:*

The meter's versatility and robustness make it suitable for use in diverse environments, including residential, commercial, and industrial settings. Its ability to accurately measure power factor across different loads enhances its utility and practicality.

Overall, the development and deployment of the High-Accuracy Power Factor Measurement Meter represent a significant advancement in power measurement technology. With its high performance and reliability, the meter addresses the need for accurate power factor measurement and offers a practical solution for enhancing energy efficiency and management in diverse settings.

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