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APFC (Automatic Power Factor Compensation) for Industrial Loads to Minimize Penalty

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Abstract: *In industrial sectors, poor power factor not only leads to increased electricity bills but also results in inefficient power usage and potential penalties from utility providers. To address this challenge, this project presents a low-cost, efficient system for Automatic Power Factor Compensation using components such as optocouplers, capacitors, relays, a power board, distribution board (DB), two-line relay, Arduino UNO, 2-pin plug, and choke. The system continuously monitors the load conditions through an Arduino UNO, which processes the power factor data obtained via voltage and current sensing circuits involving optocouplers and chokes. Based on the real-time analysis, the Arduino activates or deactivates capacitor banks using relays to correct the power factor towards unity. The two-line relay and power board ensure safe and reliable switching of capacitive loads, while the distribution board organizes the wiring neatly for industrial standards. By maintaining an optimal power factor automatically, this setup helps industries minimize energy losses, avoid penalty charges, and improve overall energy efficiency, leading to significant cost savings. The design emphasizes affordability, modularity, and ease of maintenance, making it a practical solution for small to medium-sized industrial applications. The proposed system integrates modern components such as digital meters, microcontrollers, and communication interfaces to provide a reliable and automated solution for power factor correction*.

Keywords: active power, reactive power, capacitor banks, Arduino UNO

I. INTRODUCTION

Power factor is defined as the ratio between the KW (actual load power) and the KVA (apparent load power) drawn by an electrical load. It is simply a measure of how efficiently the load current is being converted into useful work output. The lower the power factor of a system, the less economically it operates. A low power factor can be the result of a significant phase difference between voltage and current at load terminals, a high harmonic content, or even a distorted current waveform. Generally it is the use of inductive loads such as induction motors, power transformers or induction furnaces that causes a current to lag behind voltage. A poor power factor resulting from inductive loads can be improved by power factor correction method, but a poor power factor resulting from distorted current waveform requires a change in equipment design or addition of harmonic filters . Since power factor in inductive loads is generally lower, they have to be supplied with reactive power in order to reduce increased power consumption of the machine.

II. LITERATURE SURVEY

[1] "Using capacitors", International Journal of Engineering Trends & Technology (IJETT), Volume 4, Issued 7-July 2013. The project's main goal was to develop corrective machinery that could measure the 2701 JOURNAL OF Issue 12 | electrical system's power factor and raise it to a target level. [2] Tagwira, M. P., Design of an Automatic Power Factor Correction System, (2014) The majority of industrial loads, including induction motors, function at comparatively low power factors. The power system's total power factor is low since motors make up about 60% of the utility load. These motors are innately low power factor devices, depending on the intensity of the load. These motors

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have a power factor that ranges from 0.30 to 0.95 depending on the size of the motor and other operational factors. As a result, utilities, users, and industrial power systems are always concerned with the power factor level. Automatic Power Factor Compensation (APFC) is a critical system used in industries to correct the power factor of electrical loads. Power factor (PF) is the ratio of the real power (active power) to the apparent power in an electrical system, and it indicates effectively the electrical power is being used. A low power factor means that more current is drawn to perform the same amount of work, which can lead to higher electricity costs and penalties imposed by utility companies. This literature survey provides a comprehensive overview of the technologies and methods utilized for automatic power factor compensation in industrial loads to minimize penalties.

1. Power Factor and Its Significance

Power factor is a crucial metric for industries that deal with electrical loads, especially inductive loads such as motors, transformers, and other equipment that typically lead to poor power factor. According to *Sarkar et al. (2012)*, a low power factor can result in various detrimental effects, including: Increased power loss in the distribution network. Higher charges on electricity bills due to penalties. Reduced capacity of electrical systems. Increased equipment wear and tear .Industries usually aim for a power factor close to 1 (unity) to maximize efficiency and reduce financial penalties. A typical target for power factor correction in most industrial setups is above 0.9 or 0.95, as lower values can attract penalties from utilities.

2. Power Factor Correction Techniques

Several methods and techniques have beenproposed in the literature for improving power factor in industrial loads. These include both passive and active methods:

Passive Compensation: This method involves using fixed or switched capacitors to provide reactive power compensation. It is one of the most widely used techniques due to its simplicity and low cost.

Active Compensation: Active filters or power electronic devices, such as dynamic compensators, are used to provide real-time adjustment of reactive power.

III. PIEZM V3 AND ACS712 VOLTAGE & CURRENT SENSORS

A power quality and energy monitoring module (assumed to monitor voltage, current, power factor, etc.).Good for capturing real-time power factor, apparent power, reactive power

Core monitoring unit that measures:

Voltage , Current , Real power (kW) , Apparent power (kVA), Reactive power (kVAR) , Power factor (PF) .

Provides real-time power factor and power consumption data .Acts as the brain's eyes to decide when compensation is needed.Used by the microcontroller to calculate required kVAR for capacitor switching.

A current sensor module (based on Hall effect). Provides analog voltage output proportional to current. Available in 5A, 20A, 30A versions

Sample Flow Diagram

Sensing → PF Calculation → Determine Required Compensation → Control Relays → Repeat .

apacitor banks must be rated for industrial load and switching frequencies.

Piezm V3 must be configured for correct CT/PT ratio.

ACS712 is not very precise at low currents; use for supplementary per-phase feedback.

FEATURES OF ACS712 CURRENT SENSOR

Based on the Hall effect; provides isolation from high voltages.Outputs an analog voltage (typically 0–5V) proportional to current flow. Comes in 3 versions: 5A, 20A, and 30A (choose according to expected current).

Helps in phase-wise current monitoring, especially useful if:Your system is 3-phase, and you want to analyze individual phase loads.The current before and after compensation, to see the improvement. If any overcurrent or imbalance happens after capacitor switching. ACS712 is low-cost and effective, but not very precise for low currents or noisy industrial environments—it's good for supplementary readings.

FEATURES OF PIEZM V3 VOLTAGE SENSOR

Monitors AC voltage, current, power factor, and energy consumption.
Can communicate over MODBUS RTU/RS485,
UART, or I²C (depending on model).
Some models include onboard current transformers
(CTs) or external CT support.

Modular Architecture

Design the APFC panel in a modular way (each module = microcontroller + sensor + relay + capacitor).
Makes it **scalable** and **easy to troubleshoot**.
Always use **optocouplers** or **solid-state relays (SSR)** between the microcontroller and high-voltage switching devices.
ACS712 provides built-in isolation, but Piezm V3 should also be isolated (especially RS485 communication).

Safety and Protection Mechanisms

Over/Under Voltage Protection
Monitor voltage with Piezm V3 to prevent switching capacitors during voltage spikes or drops. Add **temperature sensors** near capacitor banks.
Use **surge protection devices (SPDs)** and **fuses** for safety .

IV. EXISTING SYSTEM

The system aims to monitor and improve the power factor of an inductive load using an Arduino-based control setup. The main supply powers the inductive load, which tends to lower the power factor due to reactive power. To counter this, the system employs multiple capacitors (Capacitor1, Capacitor2, Capacitor3), switched via relays (Relay1, Relay2, Relay3) under the control of an Arduino UNO.

The Arduino UNO receives real-time data from:

ACS712 Current Sensor – measures the current consumed by the load. Piezo Voltage Sensor – monitors the voltage level.

Based on this input, the Arduino calculates the power factor and activates the appropriate relay to connect one or more capacitors, thus improving the power factor.An optocoupler is used for electrical isolation and safe triggering of Relay1. The system displays real-time voltage, current, and power factor data on an LCD.In the existing systems used for power factor correction in industrial setups, manual or semi-automatic methods are typically employed. These systems rely on fixed or manually switched capacitor banks that are operated by maintenance personnel based on periodic power factor readings.

The drawbacks of such existing systems include: Delayed correction due to manual intervention. Inaccuracy in compensation because of fixed capacitors. Lack of real-time monitoring, leading to inefficient power usage.

Inability to respond dynamically to varying industrial loads. Higher electricity bills and penalties due to low power factor during peak loads.

Moreover, traditional systems lack microcontrollerbased intelligence, making them unsuitable for dynamic industrial environments where load conditions change frequently.

In traditional industrial power factor correction systems, manual capacitor banks or electromechanical relay-based systems are used to improve the power factor. These systems involve switching fixed capacitors ON or OFF based on the apparent load observed by operators or through basic timer-based circuits. However, these systems have multiple limitations: Manual Operation: In many industries, capacitors are turned ON/OFF by technicians based on observed power factor values. This approach is time-consuming and prone to human error, especially during fluctuating load conditions.

Fixed Compensation: Fixed-value capacitors are installed, which may not match the reactive power demand at all times. As a result, overcompensation or under-compensation can occur, further affecting system efficiency.

No Microcontroller or Smart Logic: Conventional systems do not use microcontrollers or sensors to intelligently analyze and respond to load changes. They miss out on automation and adaptability.

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Penalties and Inefficiency: Power utilities impose penalties on industrial users for poor power factor (typically below 0.9). Existing systems often fail to maintain the required threshold, resulting in financial losses and inefficient energy use.

Higher Maintenance and Low Flexibility: Relaybased or manually operated systems require frequent maintenance and are not scalable or flexible to accommodate expanding industrial loads.

Existing Power Factor Correction Methods:

1.Capacitor Banks: Describe how capacitor banks are used to provide reactive power (kVAR) and improve the power factor.

Explain the manual switching of capacitors, which is often time-consuming and inefficient for varying loads. Highlight the limitations of static capacitor banks, such as their inability to adapt to rapidly changing loads.

2.Manual Switching of Capacitors: Discuss the need for manual intervention to adjust capacitor banks for different loads and power factor requirements.

Other Traditional Methods: Briefly mention other methods like synchronous condensers or phase advancers, but focus on capacitor banks as the most common.

3. Challenges with Existing Systems: Explain the inefficiencies and inaccuracies of manual switching for dynamic loads. Discuss the difficulty in maintaining the optimal power factor for varying loads.

V. PROPOSED METHOD

The system aims to monitor and improve the power factor of an inductive load using an Arduino-based control setup. The main supply powers the inductive load, which tends to lower the power factor due to reactive power. To counter this, the system employs multiple capacitors (Capacitor1, Capacitor2, Capacitor3), switched via relays (Relay1, Relay2, Relay3) under the control of an Arduino UNO.The Arduino UNO receives realtime data from:

.Piezo Voltage Sensor – monitors the voltage level. Based on this input, the Arduino calculates the power factor and activates the appropriate relay to connect one or more capacitors, thus improving the power factor.

An optocoupler is used for electrical isolation and safe triggering of Relay1. The system displays real-time voltage, current, and power factor data on an LCD.

APFC (Automatic Power Factor Correction) is a method used in electrical systems to automatically improve power factor, which is a measure of how effectively electrical power is being used. A low power factor results in higher energy losses and inefficiencies. The proposed method of APFC typically involves using microcontrollers or digital controllers to monitor and correct the power factor dynamically by switching capacitor banks.

.Enhances energy efficiency and reduces electrical losses.

Proposed Method for Automatic Power Factor Compensation (APFC) in Industrial Power Systems

In industrial environments, inductive loads such as motors, welding equipment, and transformers dominate. These loads cause a lagging power factor, increasing the reactive power demand. Utilities charge penalties for poor power factor (typically below 0.9 or 0.95), which increases operational costs.

To counter this, Automatic Power Factor Correction (APFC) systems are employed to dynamically correct the power factor by injecting leading reactive power using capacitor banks, thus reducing penalties and improving energy efficiency.

1.Components Used

Arduino UNO – Microcontroller for processing and control

PZEM-004T v3 – Voltage, current, power factor, and energy monitoring module

Optocoupler (e.g., PC817) – Provides isolation between control and relay switching circuits

Relays (5V or 12V) – To switch capacitor banks based on PF

Capacitor Banks – To compensate reactive power

LCD Display (16x2 or I2C) – To show voltage, current, PF, and correction status

Load (Inductive) – Like a fan or motor

Power Supply – 5V or 12V regulated supply for Arduino and relays

Objective To automatically monitor and correct the power factor in real-time.

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To minimize or eliminate power factor penalties imposed by utility companies.
To improve system efficiency and reduce reactive power losses.

Proposed Method Overview The proposed APFC method involves a closed-loop control system that dynamically measures, calculates, and corrects power factor using switching capacitor banks in response to varying load conditions. depending on required compensation.

4.Feedback and Display: Once correction is done, the updated PF is calculated and displayed on the LCD/serial monitor.

The system continues monitoring and adjusting in real-time.
Benefits of the Proposed Method
Penalty Reduction Maintains PF above threshold, avoiding utility charges.
Energy Efficiency Reduces line losses and improves voltage regulation.
Equipment Longevity Reduces stress on transformers, cables, and switchgear.
Cost Savings Lower electricity bills and maintenance costs.
Improved System Capacity More real power can be delivered without increasing apparent power demand.

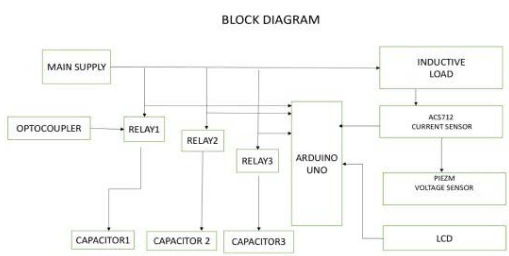

Fig1 : block diagram

Features of the Proposed Method
Automatic Operation: No manual intervention is needed once installed.
Real-Time Monitoring and Correction: Instant response to changes in load.
Scalable Design: Can be expanded with more capacitor banks for industrial applications.
Cost-Effective: Uses affordable components while achieving good correction.

VII. RESULTS & DISCUSSION

The Automatic Power Factor Correction (APFC) unit was successfully designed, implemented, and tested in both loaded and unloaded conditions. The system continuously monitored the power factor (PF) of an inductive load and dynamically corrected it by switching capacitor banks using a microcontrollerbased control unit.

Experimental Setup Included:
Microcontroller (e.g., Arduino UNO/8051)
Current and voltage sensors (e.g., CT, ZMPT101B)
Relays for capacitor bank switching
Capacitor banks (1 µF – 10 µF, depending on load)
Load (inductive, e.g., motor or fan)

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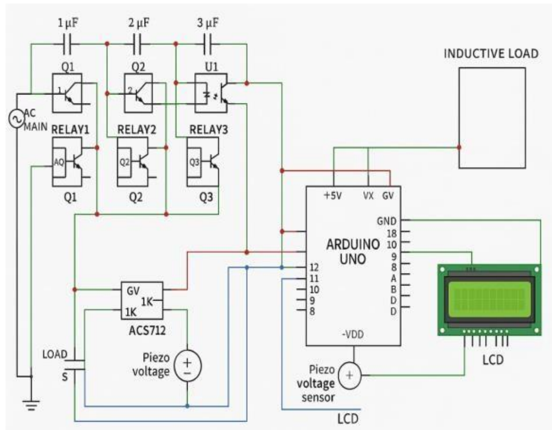

Fig2 :Schematic Diagram

oad Type	Initial PF	Corrected PF	Capacitors Switched	Remarks
Ceiling Fan	0.68 (lag)	0.94	2 × 2.2 μF	Good response
Tube Light	0.72 (lag)	0.96	1 × 1 μF	Stable PF
Induction Motor	0.60 (lag)	0.98	3 × 4.7 μF	Higher improvement

Fig 3: pf correction table

Challenges Faced

Precise power factor measurement in low-load conditions was slightly unstable due to low reactive power.

Inrush current during capacitor switching created brief voltage drops; snubber circuits can help mitigate this.

Balancing capacitor values for staged correction took iterative tuning for different loads.

VIII. CONCLUSION

Power factor correction equipment designed based on microcontroller and capacitor banks was used for measurement and monitoring of modeled electrical load and the following deductions were obtained: • The power factor correction device designed was able to improve the power factor from 0.88 to 0.97 under the test load conditions. • The average savings in energy consumption was about 1.7% for the designed load and different load patterns. • With the proper amount of reactive power compensation, the system capacity is released as there is a reduction in current drawn. • The economic analysis suggested the payback period to be around 9 months with a significant amount of savings in energy cost.current is lagging the voltage (inductive load) . From our project, we observed that this APFC Panel will help us in finding 1) Raising the power factor has been proven to help utilities and end users use electricity more efficiently. 2) It reduces the consumer\'s electricity bills. 3) It also helps to reduce the cable size and circuit breaker size. 4) It can concluded that the power factor correction technique can be applied to industries, power systems, and households to ensure their stability, resulting in the system becoming stable and the efficiency of the systems and apparatus increasing. If the compensator rating is less than the load observed by the detected power, it will improve the power given by the AC supply and reduce the power consumption. Good power quality is achieved by reducing the apparent power drawn from the AC supply and minimizing the power transmission losses. Hence, the efficiency of both the systems and apparatus increases.

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IX. FUTURE SCOPE

Reduces harmonic content in the network which further reduces disturbances in the telecommunication network, misbehavior in control equipment and relay protections, measuring errors in the metering system • Reduces network losses

Reduces equipment overloading & stress on insulation

Reduces cost, unplanned outages and increases power availability

Integration with Smart Grids

Smart grids require efficient power management systems.

APFC systems can be integrated into smart grid infrastructures to automatically maintain optimal power factor and reduce energy losses.

IoT and Remote Monitoring

With the rise of IoT, APFC panels can be enhanced with sensors and cloud connectivity for remote monitoring, diagnostics, and predictive maintenance.

Renewable Energy Systems

APFC can play a crucial role in solar and wind power systems where power factor tends to vary.

Helps in stabilizing voltage levels and improving the overall efficiency of hybrid power setups.

Industrial Automation

Industries are increasingly adopting APFC to meet energy efficiency standards and avoid penalties.

There's growing demand for intelligent, autotuned APFC panels in manufacturing, textile, and heavy machinery sectors.

AI-Based Optimization

Future systems may use machine learning to predict load behavior and dynamically adjust correction parameters.

Enhances performance and lowers operational costs.

Compact and Modular Designs

Development of more compact, modular APFC systems suited for smaller installations, like commercial buildings or residential complexes.

REFERENCES

[1]. S. Powniker and S. Shelar, "Development of Active Power Factor Correction controller using boost converter," 2016 IEEE
[2]. International WIE Conference on Electrical and Computer Engineering (WIECON-
[3]. ECE), Pune, India, 2016, pp. 212- 216, doi: 10.1109/WIECON ECE.2016.8009120.
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[6]. Buso S, Matta Villi P, Rosette L and Spiazzi G (2006) \"Simple digital control improving the dynamic performance of power factor pre regulators,\" IEEE Trans. Power
[7]. Electronics, issue 5, Vol. 13, pp. 814-823.
[8]. Gusseme K and. Melkebeek J. (2002)
[9]. "Design issues for digital control of boost power factor converters,\" IEEE International Symposium on Industrial Electronics
[10]. Fu M and Chen O): \"A DSP-based controller for power factor correction(PFC) in a rectifier circuit,\" IEEE Applied Power Electronics Conference, (2012)[7]Feng Y.T, Tsai G.L, and Tzou AC/DC converter with fast YY Digital control of a single-stage single-switch flyback PFC Vol. 2, pp. 1251- 1256 (2009): response,\" IEEE

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ISSN: 2581-9429 Volume 5, Issue 1, May 2025 Impact Factor: 7.67

[11]. Power Electronics Specialists Conference, TECHNOL of ElecNE CAMPUS SWPANV

[12]. Rao U M, Vijaya M A, Venakata S S, Williams T J, Butter N G, -An Adaptive Power Factor Controller For 3 Phase Induction Generations], IEEETransaction on Power Apparatus and Systems 2012

[13]. Mr. Musthafa P, Mr. M. Sivasubramanian, Mr. K. Sakthidhasan, -Analysis of Dynamic Power Factor Correction Using Flexible Ac Transmission Systems

[14]. Jain Sandesh, Thakur Shivendra Singh and Phulambrikar S.P., "Improve Power Factor And Reduce the Harmonic Distortion of the System"**,** International Journal of Advanced

[15]. Research in Computer Science and Software Engineeriong. Volume 1(5), issued November 2012.

[16]. Jones, L. D.; Blackwell, D. -Energy Saver Power Factor Controller for Induction Motors IEEE (1983)

[17]. Rakendu Mandal Sanjoy Kumar Basu; Asim Kar; Shyama Pada Chowdhury-A

[18]. Microcomputer – Based Power Factor Controller, IEEE Transactions on Industrial Electronics (1994).

[19]. Systems, Kluwer Academic Publishers, Boston. 53

[20]. Power Factor Correction Using APFC Panel on Different Loads - Vinay Sehwag, Vaibhav Dua, Ajendra Singh, Jitendra Nath Rai, Vineet Shekhar.

[21]. Real time implementation of unity power factor correction converter based on fuzzy logic – Abderrahmen Benyamina and Samir Moulahoum

[22]. Automatic Power Factor Compensation for Industrial Use to Minimize Penalty Dharmesh J. Pandya, Yogendra Kumar, Dureshwar Pratap Sigh,Dinesh Kumar

[23]. Vairavel, A. Deepak, A Kakoli Rao, Ajay Rana.

[24]. Automatic Power Factor Measurement and Correction Using MyDAQ -Patthi Sridhar, Ranjith Kumar Gatla, Alladi Sathish Kumar