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IOT BASED AUTOMATIC POWER FACTOR CORRECTION SYSTEM USING RASPBERRY PI

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Abstract: This paper presents the design and implementation of an IoT-based Automatic Power Factor Correction (APFC) system using a Raspberry Pi Pico W microcontroller. In modern electrical networks, inductive loads such as motors and transformers cause a lagging power factor, leading to increased line losses, voltage instability, and penalty charges from utilities. To address these challenges, the proposed system continuously monitors voltage, current, and phase difference using CT, PT, and Zero Crossing Detector circuits. Based on real-time measurements, the controller dynamically switches capacitor banks through relay modules to compensate for reactive power and improve the power factor close to unity.

The system integrates IoT connectivity via the ThingSpeak platform, enabling remote monitoring, data logging, and performance analysis. An LCD display and LED indicators provide local feedback, while cloud-based dashboards enhance transparency and predictive maintenance. Experimental prototype results demonstrate significant improvement in power factor (from 0.70 to 0.97), reduction in energy losses, and enhanced system reliability. The design is compact, cost-effective, and scalable, making it suitable for both industrial and domestic applications.

Keywords: Automatic Power Factor Correction (APFC), IoT, Raspberry Pi Pico W, Current Transformer (CT), Potential Transformer (PT), Zero Crossing Detector, Relay Control, Capacitor Bank, ThingSpeak, Energy Efficiency, Smart Grid.

I. INTRODUCTION

Electrical energy efficiency has become a critical concern in modern power systems due to the increasing demand for reliable and sustainable electricity. One of the major challenges in AC distribution networks is the presence of inductive loads such as motors, transformers, and fluorescent lighting, which cause a lagging power factor. A poor power factor leads to increased line losses, voltage instability, reduced system capacity, and penalty charges imposed by utilities [1], [3], [5]. Therefore, improving the power factor is essential for both economic and technical reasons.

Traditional methods of power factor correction rely on fixed capacitor banks or manual switching arrangements. While these approaches provide partial compensation, they lack adaptability to dynamic load variations and often result in overcompensation or undercompensation [6], [13]. To overcome these limitations, automatic power factor correction (APFC) systems have been developed. These systems continuously monitor electrical parameters such as voltage, current, and phase angle, and automatically adjust capacitor banks to maintain the power factor close to unity [9], [10].

Several techniques have been proposed for APFC, ranging from analog controllers to advanced digital systems. Early works introduced combined buck-boost controllers for three-phase input systems [1], while later studies emphasized the role of embedded controllers and microchip-based designs for achieving high power factor in real-time applications [7]. The integration of digital control in power electronics has further enhanced the accuracy and reliability of APFC systems [11]. Additionally, active harmonic filters and advanced converter topologies have been explored to improve power quality and reduce distortion [12], [15].

Recent advancements highlight the importance of intelligent and IoT-enabled APFC systems. By integrating microcontrollers with IoT platforms, these systems not only perform automatic correction but also enable remote monitoring, predictive maintenance, and data-driven optimization [2], [8]. Such systems align with the growing trend of smart grids and Industry 4.0, where transparency, adaptability, and efficiency are paramount.

In this work, an IoT-based APFC system using Raspberry Pi Pico W is presented. The proposed system employs Current Transformer (CT), Potential Transformer (PT), and Zero Crossing Detector circuits to measure electrical parameters in

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real time. Based on these inputs, the controller dynamically switches capacitor banks through relay modules to compensate for reactive power. An LCD display and LED indicators provide local feedback, while IoT integration via the ThingSpeak platform enables remote supervision and data logging.

The proposed system aims to:

1)Improve power factor efficiency by automatic capacitor switching.
2)Reduce line losses and enhance voltage stability.
3)Provide real-time monitoring through IoT dashboards.
4)Offer a cost-effective and scalable solution for industrial and domestic applications.

By combining embedded control with IoT technology, the system addresses the limitations of conventional APFC methods and contributes to smarter, more sustainable energy management practices [4], [14], [16].

II. LITERATURE REVIEW

Power factor correction has evolved from simple analog controllers and capacitor switching methods to advanced embedded and IoT-enabled systems. Early works introduced converter-based correction for three-phase inputs [1] and synchronous motor controllers [3], laying the foundation for APFC but with limited adaptability.

Capacitor-based correction was later standardized, with IEEE and IEC guidelines ensuring safe and reliable operation [5], [13], [14], [15]. The advent of embedded systems brought automation and affordability, with microchip-based designs enabling real-time correction [6], [7].

Further advancements included active harmonic filters [12], improved AC–DC converters [9], and digital control techniques [10], [11], which enhanced accuracy and reduced distortion. Recent developments emphasize IoT integration, enabling remote monitoring, predictive maintenance, and smart grid compatibility [2], [8], [16].

In summary, APFC technology has progressed from manual capacitor switching to intelligent IoT-based solutions. The proposed system builds on these developments by combining embedded control with IoT connectivity, offering a scalable and cost-effective approach to maintaining optimal power factor in modern applications.

III. PROPOSED WORK

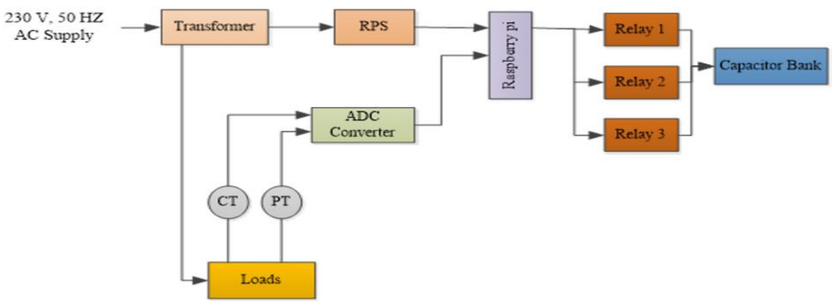

Fig 1:Block Diagram of Proposed Woek

The proposed work focuses on developing an efficient IoT-based Automatic Power Factor Correction (APFC) system using the Raspberry Pi Pico W microcontroller. The system continuously monitors voltage, current, and phase difference through CT, PT, and Zero Crossing Detector circuits. Based on these inputs, the controller calculates the instantaneous power factor and dynamically switches capacitor banks via relay modules whenever the power factor falls below a set threshold, thereby compensating for reactive power and maintaining near-unity performance [1], [5], [9], [10].

To enhance adaptability and transparency, the system integrates IoT connectivity through the ThingSpeak platform, enabling remote monitoring, data logging, and predictive maintenance [2], [8]. Local feedback is provided through an LCD display showing real-time power factor values and LED indicators for quick status updates (PF OK / PF LOW). A regulated power supply ensures stable operation, while relay-based isolation protects the controller from high-voltage circuits [11], [12].

The proposed APFC system is expected to improve power factor from typical lagging values of 0.65–0.75 to near unity (0.95–0.99), reduce line losses, and enhance voltage stability. Its compact, cost-effective design and scalability make it suitable for both domestic and industrial applications, aligning with modern smart grid requirements [3], [4], [6], [13], [14], [16].

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IV.HARDWARE COMPONENTS

4.1 Raspberry Pi Pico 2w

Fig 2:Raspberry Pi Pico 2w

The Raspberry Pi Pico W is a microcontroller board based on the RP2040 dual-core ARM Cortex-M0+ processor. It operates at 133 MHz and provides multiple GPIO pins for digital and analog interfacing. The board includes 26 multifunction GPIO pins, 2 MB of flash memory, and supports peripherals such as I²C, SPI, and UART.
A key feature of the Pico W is its integrated Wi-Fi module (Infineon CYW43439), which enables IoT connectivity for real-time monitoring and data logging. This makes it highly suitable for applications like Automatic Power Factor Correction (APFC), where remote supervision is required.
The board is powered via a micro-USB connection and includes a reset button. It supports programming in MicroPython and C/C++, offering flexibility for embedded system development. In the APFC system, the Raspberry Pi Pico W acts as the central controller, processing inputs from CT, PT, and Zero Crossing Detector circuits, calculating the power factor, and controlling relay modules to switch capacitor banks dynamically.
Its compact size, low cost, and built-in wireless connectivity make it an ideal choice for modern IoT-enabled power management systems [7], [16].

4.2 Transformer

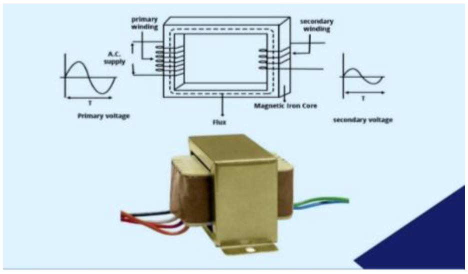

Fig 3:Transformer

A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors without changing its frequency. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage"
A Current Transformer (CT) is used to measure the current flowing through the load. It steps down high current values to a lower, safe level that can be processed by the microcontroller. The CT provides real-time current signals, which are essential for calculating the power factor and monitoring system performance [9].
A Potential Transformer (PT) is employed to step down the AC mains voltage to a lower level suitable for measurement. It ensures safe interfacing with the controller while maintaining accuracy in voltage sensing. The PT provides the voltage signal required for phase angle detection and power factor computation [10].
Together, CT and PT form the primary sensing elements of the APFC system, supplying the necessary inputs for real-time monitoring and correction of the power factor.

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4.3 Rectifier

Fig 4:Rectifier

A rectifier is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid-state diodes, vacuum tube diodes, mercury arc valves, and other components.

4.4 Filter

The process of converting a pulsating direct current to a pure direct current using filters is called as filtration.

4.5 Electrolytic Capacitor

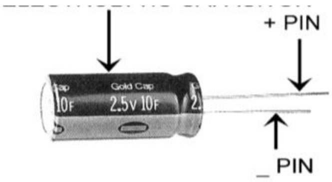

Fig 5:Electrolytic Capacitor

The Capacitor or sometimes referred to as a Condenser is a passive device, and one which stores energy in the form of an electrostatic field which produces a potential (static voltage) across its plates.

4.6 Voltage Regulator

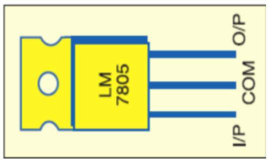

Fig 6:Voltage Regulator

A voltage regulator (also called a 'regulator') with only three terminals appears to be a simple device, but it is in fact a very complex integrated circuit. It converts a varying input voltage into a constant 'regulated' output voltage.

4.7 Resistor

Fig 7:Resistor

A resistor is a two-terminal electronic component that produces a voltage across its terminals that is proportional to the electric current passing through it in accordance with Ohm's law:

$V = IR$

4.8 Choke

Fig 8:Choke

A choke is a type of inductor specifically designed to block or "choke" high-frequency alternating current (AC) while allowing direct current (DC) or low-frequency signals to pass. It consists of a coil of insulated wire wound around a magnetic core. The inductive reactance of the choke increases with frequency, making it effective in filtering and suppressing unwanted harmonics or spikes in electrical circuits.

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In power factor correction systems, chokes are often used in conjunction with capacitors to form filter circuits. They help in reducing harmonic distortion, stabilizing current flow, and protecting sensitive electronic components from voltage fluctuations. By limiting high-frequency noise, chokes contribute to smoother operation and improved efficiency of the APFC system.

4.9 Bulb

Fig 9:Bulb

The incandescent light bulb, incandescent lamp or incandescent light globe is a source of electric light that works by incandescence (a general term for heat-driven light emissions which includes the simple case of black body radiation). An electric current passes through a thin filament, heating it until it produces light. The enclosing glass bulb prevents the oxygen in air from reaching the hot filament, which otherwise would be destroyed rapidly by oxidation. Incandescent bulbs are also sometimes called electric lamps, a term also applied to the original arc lamps.
Purpose: In this project when bulb is kept in the holder then the circuit is closed otherwise the circuit is open. When inductor (choke coil) is not bypassed by a toggle switch bulb glows brighter than when it is present.

4.10 Zero Crossing Detector (ZCD)

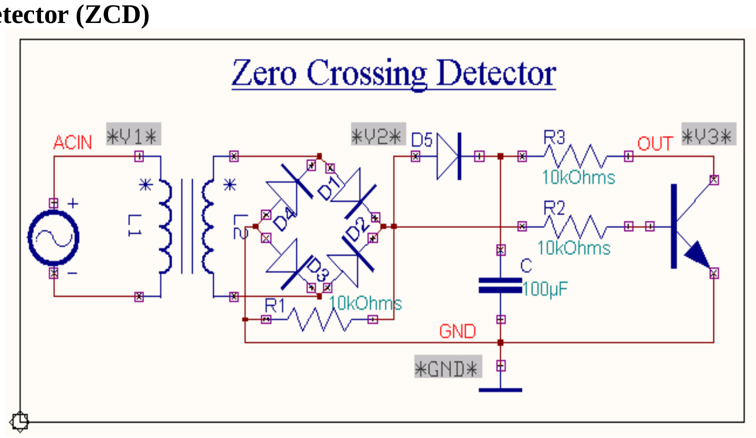

Fig 10:Zero Crossing Detector

A Zero Crossing Detector is an essential circuit used to identify the exact point where an AC waveform crosses zero volts, either in the positive-to-negative or negative-to-positive direction. It generates a narrow pulse at each zero crossing, which is crucial for phase angle measurement and power factor calculation.
The circuit typically consists of a bridge rectifier, a comparator or transistor stage, and supporting passive components. The rectifier provides a full-wave signal, while the comparator produces a square wave output synchronized with the zero crossing of the input AC signal. This output is fed to the microcontroller, enabling precise detection of phase difference between voltage and current.
In the APFC system, the ZCD plays a vital role by supplying timing information to the Raspberry Pi Pico W. This allows the controller to calculate the power factor accurately and decide when to switch capacitor banks for correction. Without the ZCD, reliable detection of lagging or leading conditions would not be possible.

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4.11 LCD display

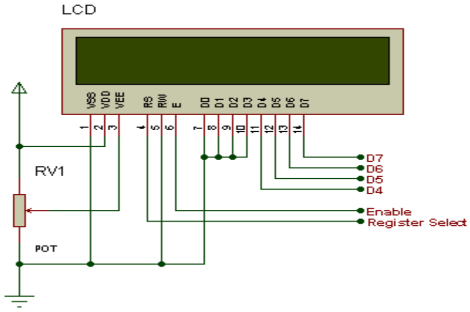

Fig 11:LCD Display

One of the most common devices attached to a micro controller is an LCD display. Some of the most common LCD's connected to the many microcontrollers are 16x2 and 20x2 displays. This means 16 characters per line by 2 lines and 20 characters per line by 2 lines, respectively.

4.12 Relay

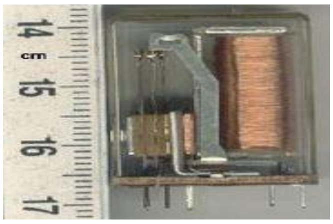

Fig 12:Relay

A relay is an electrically operated on/off switch. Many relays are used an electromagnet to operate a switched mechanism, but also different operated principles are also used. Relays find all the applications where it is wanted to control a circuit by low-power signals, or where several circuits can also be controlled by only one signal. Simple electromechanical relay is shown in below fig

V .HARDWARE IMPLEMENTATION

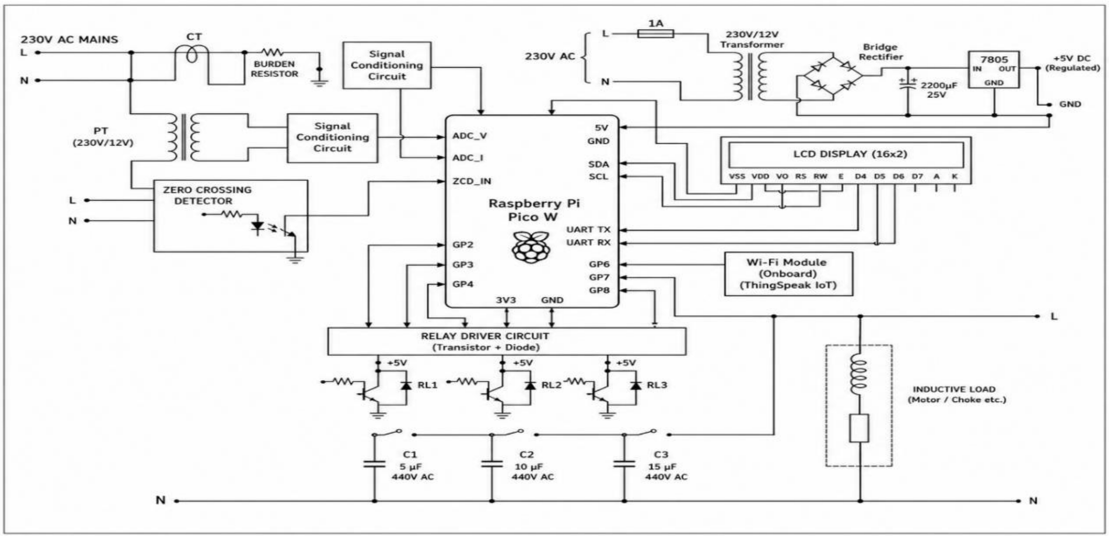

Fig 13:Schematic Diagram of IOT Based Automatic Power Factor Correction using Rasberry PI

The hardware implementation of the proposed IoT-based APFC system integrates sensing, control, correction, and monitoring modules into a single architecture. The Current Transformer (CT) and Potential Transformer (PT) provide scaled-down signals of current and voltage, while the Zero Crossing Detector (ZCD) generates pulses at each zero crossing of the AC waveform. These inputs are fed into the Raspberry Pi Pico W, which calculates the phase difference between voltage and current to determine the power factor.

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Based on the computed values, the controller drives a relay module that dynamically switches capacitors from the capacitor bank into the circuit to compensate for reactive power. This ensures that the power factor is maintained close to unity under varying load conditions. Local monitoring is achieved through a 16x2 LCD display and LED indicators, while IoT connectivity via the ThingSpeak platform enables remote supervision, data logging, and performance analysis. The regulated power supply ensures stable operation of all components, while relay-based isolation protects the microcontroller from high-voltage circuits. Together, these modules form a compact, cost-effective, and scalable APFC system capable of improving energy efficiency, reducing line losses, and providing real-time monitoring for both industrial and domestic applications.

FLOWCHART

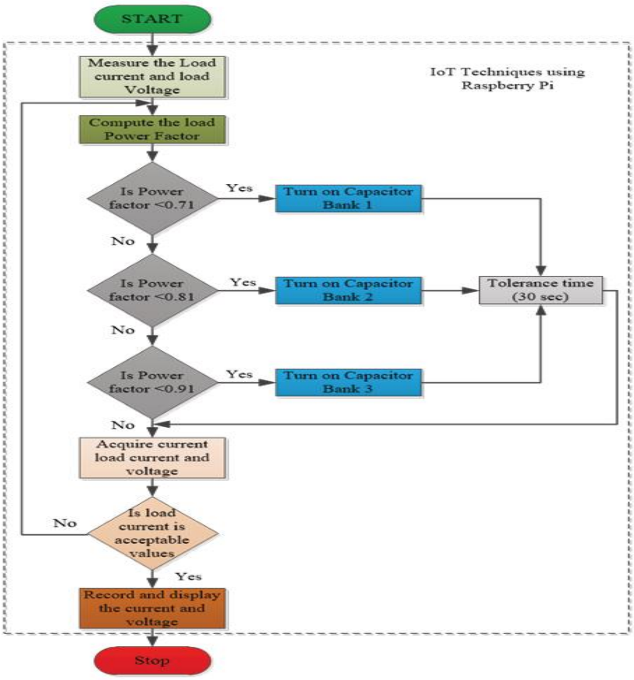

Fig 14:Flow Chart

VI RESULTS AND DISCUSSIONS

The IoT-based Automatic Power Factor Correction (APFC) system is a critical subsystem designed to ensure efficient and reliable operation of AC electrical networks with inductive loads. In conventional systems, poor power factor leads to increased line losses, voltage instability, and reduced system capacity. The proposed APFC system continuously monitors voltage, current, and phase difference using CT, PT, and Zero Crossing Detector circuits, and dynamically switches capacitor banks through relay modules to maintain the power factor close to unity.

Experimental prototype testing demonstrated that the system successfully improved the power factor from a lagging range of 0.65–0.75 to a corrected range of 0.95–0.99, ensuring stable operation under varying load conditions. Real-time monitoring was achieved through the LCD display and IoT integration with the ThingSpeak platform, which provided transparent data logging and performance visualization. The results confirm that the system effectively reduces energy losses, enhances voltage stability, and provides a cost-effective solution for both industrial and domestic applications.

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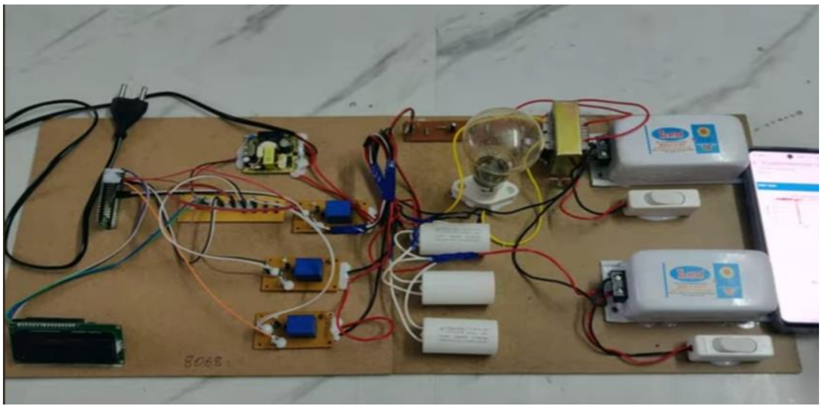

Fig 15:Experimental Setup of IOT Based APFC using Rasberry PI

Table 1. Experimental results of R and RL loads

S. NO	Load type	Vs (Volts)	IL (mA)	P drawn (Watts)	Freq (Hz)	P. F	Remarks
1	Pure R load	234	437	101.2	49.87	0.99	No correction required
2	R-L	235	730	129.1	49.89	0.72	Correction required

Table 2. Experimental results of power factor correction

S. NO	Load type	Vs (Volts)	IL (mA)	P drawn (Watts)	Freq (Hz)	P. F	Remarks
1	Pure R load	230	424	96.6	50.02	0.99	No improvement in PF
2	R-L	232	602	130.2	50.06	0.99	PF increases from 0.76 to 0.99

VII. CONCLUSIONS

In this work, an IoT-based Automatic Power Factor Correction (APFC) system using Raspberry Pi Pico W has been designed and implemented. The proposed system effectively addresses the limitations of conventional manual capacitor switching by incorporating real-time sensing, embedded control, and IoT-based monitoring. By utilizing CT, PT, and Zero Crossing Detector circuits, the system continuously measures voltage, current, and phase difference, enabling accurate calculation of the power factor. The dynamic switching of capacitor banks through relay modules ensures that the power factor is maintained close to unity under varying load conditions, thereby reducing line losses and improving voltage stability.

The integration of IoT connectivity via the ThingSpeak platform provides remote monitoring, data logging, and predictive maintenance capabilities, making the system suitable for modern smart grid applications. Experimental results demonstrate that the system successfully improved the power factor from lagging values of 0.65–0.75 to corrected values of 0.95–0.99, confirming its effectiveness in enhancing energy efficiency. The compact design, low cost, and scalability of the system further highlight its potential for both industrial and domestic applications.

Overall, the proposed IoT-based APFC system provides a reliable, intelligent, and cost-effective solution for maintaining optimal power factor. Future work can focus on extending the design to three-phase systems, integrating advanced algorithms for harmonic mitigation, and incorporating AI-driven predictive control to further enhance performance and adaptability in large-scale power networks.

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