

AI-POWERED SMART DISTRIBUTION BOARD

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Abstract – The AI-Powered Smart Distribution Board is designed to address critical inefficiencies in conventional electrical systems, such as load imbalance, low power factor, and the absence of real-time monitoring. By integrating artificial intelligence and automation, the system provides advanced energy management features. The primary functions include predicting electrical load demand using AI-based forecasting, which is crucial for optimized energy management. It automatically balances phase loads through intelligent switching mechanisms using relays or contactors. Power quality is improved, and energy costs are reduced by integrating capacitor banks for automated power factor correction. Furthermore, the system incorporates an IoT-enabled, real-time dashboard that facilitates remote monitoring, control, and fault alerts, significantly enhancing operational reliability and efficiency. This innovative solution is scalable, promotes sustainable energy practices, and is ideal for modern residential and commercial applications.

Key Words: AI, Smart Distribution Board, Load Forecasting, Power Factor Correction, IoT, ESP32, Load Balancing, Energy Management, Automation

1. INTRODUCTION

The rising global electricity demand has exposed the shortcomings of traditional power distribution systems, which lack intelligent monitoring and control. To address these inefficiencies, the AI-Powered Smart Distribution Board integrates Artificial Intelligence and IoT technologies. This innovation enables active energy management for improved efficiency and sustainability in both residential and commercial applications.

The increasing global demand for electricity has revealed significant limitations in traditional electrical distribution infrastructure. Conventional distribution boards are typically passive and lack the intelligence required for modern energy management, leading to inefficiencies, energy waste, and grid instability.

The major challenges include: (1) **Load Imbalance:** uneven load distribution across phases leading to overheating and energy losses; (2) **Poor Power Factor:** prevalence of inductive loads increasing total current; (3) **Lack of Real-Time Monitoring:** no insight into operational metrics or ability to forecast future load demand; and (4) **Manual Operation:** reliance on manual intervention causing inherent delays and inefficiency.

The primary objectives are: load forecasting using AI-based models; automatic load balancing across phases; power factor correction (PFC) with capacitor banks; real-time monitoring of Voltage, Current and Power Factor via IoT/cloud dashboard;

and a scalable solution adaptable from residential to commercial settings.

2. LITERATURE REVIEW

With the rapid advancement of IoT, AI, and smart grid technologies, energy management systems have evolved significantly. Researchers have focused on intelligent systems capable of real-time load monitoring, automated power factor correction, and AI-based load forecasting to improve efficiency and sustainability.

Y.-H. Lin et al. (2022) [1] proposed a smart home energy management system (SHEMS) using GPU-accelerated neurocomputing for non-intrusive load modeling and forecasting, enabling improved consumer home automation applications via smart meters.

M. U. Saleem et al. (2024) [2] demonstrated an IoT-based smart energy management system integrating Smart Grid with 5G and cyber-physical systems, achieving energy savings of 5% to 53% in various settings including air-conditioning systems.

M. U. Saleem et al. (2022) [3] designed and deployed an IoT-based SEMS utilizing smart meters for real-time load profiling. Evaluated at four locations, the SEMS effectively regulates consumption and supports various demand-side management strategies.

Athanasiadis et al. (2024) [4] proposed a HEMS optimizing residential demands using dynamic electricity tariffs and solar integration, achieving reductions in operational costs (up to 42%), environmental costs (27%), and grid stress (33%).

J. Lina (2022) [5] presented a smart home energy management system based on BLE technology, demonstrating BLE advantages of fast transmission rate and high interactivity over ZigBee for smart home energy management.

Aidell et al. (2024) [6] explored IoT-based demand response using AI algorithms with smart plugs and smart meters, showing significant potential for reducing energy costs and contributing to grid stability during peak demand.

Y. Ge et al. (2025) [7] presented adaptive feature selection for probabilistic multi-energy load forecasting using ProbLassoNet, combining multi-quantile regression with Lasso approach for pattern-specific feature selection.

Krishnaveni et al. (2024) [8] developed an Automatic Power Factor Monitoring and Correction (APFMC) system using ESP32 with PZEM-004T. The system dynamically adjusts capacitor connections via relay switches to optimize power factor correction.

S. Wang & H. Li (2025) [9] proposed short-term power load forecasting using a fractional-order dynamic pooling CNN, achieving approximately 7% MAPE demonstrating strong reliability for long-term load forecasting applications.

J. Liu et al. (2024) [10] introduced a soft-switched bidirectional single-phase AC-DC isolated converter achieving unity power factor, soft switching for all devices, and reduced semiconductor usage, improving efficiency and cost-effectiveness.

In this work, an integrated AI-powered smart distribution board is proposed combining real-time load monitoring, AI-based forecasting, automated power factor correction, cloud-based data management, and mobile/web dashboard support. The proposed system aims to overcome the limitations of existing solutions by providing a comprehensive, scalable, and efficient approach to modern electrical distribution.

3. SYSTEM DESIGN AND METHODOLOGY

The AI-Powered Smart Distribution Board is designed around a modular architecture enabling load monitoring, data analysis, load balancing, and power factor correction. The block diagram (Fig. 1) illustrates the interconnection and data flow among the major system modules.

The **Distribution Board** is the source of electrical data. The **Real-Time Load Monitoring** module acquires Voltage, Current, Power Factor etc. Data is transmitted to the **IoT Cloud** where the **ML module** processes it for load forecasting. Control signals drive **Power Factor Correction** (Capacitor Bank) and **Auto Load Balancing** (relay contactors). The **Mobile/Web Dashboard** provides remote monitoring and control interface.

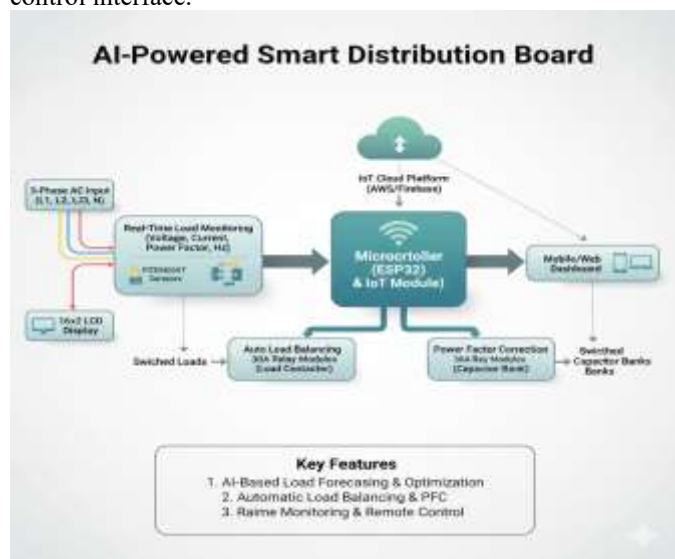


Fig. 1. Block Diagram of AI-Powered Smart Distribution Board

The system methodology: (1) **Sensor Acquisition:** PZEM004T sensors measure V, I, W, Hz, PF in real-time. (2) **Load Monitoring:** ESP32 processes sensor data, displays on 16x2 LCD, uploads to AWS/Firebase cloud. (3) **AI Load Forecasting:** Cloud ML module analyzes historical data to predict future demand. (4) **PFC:** System monitors power factor and dynamically switches capacitors via relays to bring PF close to unity. (5) **Auto Load Balancing:** 30A Relay Modules switch loads between phases to achieve optimal balance.

The schematic diagram (Fig. 2) illustrates hardware connections. **PZEM004T sensors** measure voltage and current per phase. **ESP32** is the central controller with built-in Wi-Fi for IoT communication. **Relay Modules** switch loads for balancing and control capacitor bank stages. **16x2 LCD** provides local status display.

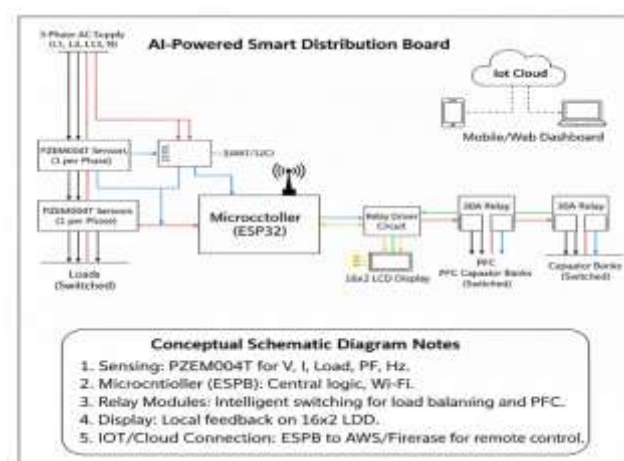


Fig. 2. Conceptual Schematic Diagram

4. HARDWARE COMPONENTS

Table 1 presents the hardware components for the AI-Powered Smart Distribution Board with their functions and estimated cost.

S.No	Component	Function	Price
1.	ESP32 / Arduino / Raspberry Pi	Central processing, data acquisition, cloud communication, control logic	2000/-
2.	PZEM004T Sensor Module	Measures real-time V, I, W, Hz, PF	1000/-
3.	16x2 LCD Display	Local display of monitored parameters	350/-
4.	Load Capacitor	Capacitor banks for power factor correction	800/-
5.	30A Relay Module	Intelligent switching for load balancing and PFC	350/-
6.	Safety Fuse (10A)	Overcurrent protection	100/-
7.	3D Printed Casing	Houses and protects electronics	1000/-

Table 1. Hardware Component Details

5. COMPARISON AND ADVANTAGES

The AI-Powered Smart Distribution Board offers significant advantages over existing conventional systems, as shown in Table 2.

Feature	AI-Powered Smart DB	Existing Distribution System
Load Management	AI-Based Load Forecasting predicts demand for optimized management	No Load Prediction capability
Load Balance	Automatic Load Balancing using relays/contactors	Loads manually set, become unbalanced
Power Quality	PFC with capacitor banks to maintain optimal PF	No Power Factor Control, poor efficiency
Monitoring	Real-Time V, I, Load monitoring via IoT/Cloud dashboard	Manual operation, no smart connectivity
Safety	Fault Detection & instant alert notifications	No Real-Time Alerts; delayed fault detection

Table 2. Comparison of Existing and Proposed System

6. FUTURE SCOPE

The project offers several avenues for future development: (1) **Advanced AI Models:** Integrate deep learning (CNN-LSTMs) for higher accuracy in load forecasting and anomaly detection. (2) **Renewable Energy Integration:** Manage power from rooftop solar and optimize battery storage. (3) **NILM:** Identify individual appliance consumption for granular consumer insights. (4) **Wireless Alternatives:** Explore BLE for local smart home communication. (5) **Economic Feasibility:** Conduct ROI analysis for large-scale industrial deployment. Integration of edge computing can reduce latency in remote areas. Use of renewable energy sources such as solar power can make the system energy-efficient and suitable for off-grid deployments, transforming it into a fully autonomous intelligent distribution management solution.

7. CONCLUSION

The AI-Powered Smart Distribution Board successfully proposes a comprehensive solution to overcome the limitations of conventional electrical distribution systems. By leveraging Artificial Intelligence and IoT, the system provides automatic load balancing, dynamic power factor correction, and real-time remote monitoring. These objectives ensure enhanced system efficiency, greater reliability, and substantial energy cost savings, positioning it as a viable and sustainable energy management solution for the future.

The implementation of automated control mechanisms including capacitor banks and relay-based load switching

enables timely corrective actions. The integration of cloud connectivity and mobile/web dashboard allows operators to monitor remotely and receive instant alerts, thereby improving operational efficiency and reducing manual effort.

Overall, the proposed system provides a cost-effective, scalable, and user-friendly approach to electrical distribution management. It enhances productivity, optimizes resource utilization, and supports sustainable energy practices. By leveraging IoT and smart AI technologies, this system offers a practical solution advancing intelligent energy infrastructure.

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