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AI-POWERED VOICE-CONTROLLED ENERGY TRACKING & BILL PREDICTION USING JAVA FULL STACK & ML

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Abstract

In recent years, the demand for intelligent and efficient energy management systems has increased significantly. Traditional electricity meters only provide total energy consumption data and fail to offer appliance-wise monitoring, resulting in a lack of transparency and control over energy usage. This paper presents PowerVision, an AI-powered Smart Energy Tracker and Bill Predictor designed to monitor real-time, appliance-wise power consumption and predict future electricity bills using Artificial Intelligence (AI) and Machine Learning (ML) techniques. The proposed system bridges the gap between Electrical Engineering and Information Technology by integrating hardware sensors with a Java Full Stack web application. Real-time data from household appliances such as PC, fan, and bulb are collected using sensors interfaced with a microcontroller (ESP32) and stored in a MySQL database. The web-based dashboard, built using HTML, CSS, and Bootstrap, provides a responsive and user-friendly interface with graphical visualization of power usage and AI-generated bill prediction. Additionally, the system supports voice control features for enhanced interactivity. The implementation demonstrates accurate power tracking, intelligent bill forecasting, and an intuitive visualization platform that can be extended for residential and industrial applications. The project thus contributes to efficient energy management for the future.

INTRODUCTION

Energy consumption has become a critical aspect of modern living, with the increasing use of electrical and electronic appliances in homes, offices, and industries. Traditional electricity meters provide only the total power

consumption at the end of a billing cycle, offering no insight into individual appliance usage. This limitation makes it difficult for users to monitor, analyze, and optimize their energy consumption patterns. With the growing need for energy efficiency and cost management, smart

monitoring systems are emerging as an essential part of sustainable energy solutions.

The proposed system, PowerVision, aims to overcome these limitations by providing real-time, appliance-wise energy tracking and AI-based bill prediction. The project integrates Electrical Engineering principles with Information Technology using a Java Full Stack web application, MySQL database, and AI/ML algorithms. Hardware components such as the ESP32 microcontroller, current and voltage sensors, and power supply unit are employed to capture real-time data from appliances like a PC, fan, and bulb. This data is transmitted to the backend server for processing and visualization. analytics through interactive charts and provides users with accurate bill forecasting. Additionally, a voice-controlled interface enhances user interaction, making the platform more intelligent and accessible. The overall objective of PowerVision is to enable users to manage their electricity usage efficiently, reduce unnecessary energy wastage, and forecast electricity expenses using AI-driven insights.

This project not only demonstrates the integration of Electrical and Computer Engineering concepts but also contributes to the development of smart, sustainable, and user-centric energy management systems, paving the way for future IoT-based smart grids and AI-enabled automation in the energy sector.

LITERATURE SURVEY

In recent years, several research studies and technological developments have focused on smart energy monitoring systems, artificial intelligence-based billing prediction, and Internet of Things (IoT) integration for energy management. The following section reviews the related work that forms the foundation of the proposed system PowerVision.

In [1], the authors proposed a Smart Energy Meter using IoT for monitoring household appliances through Wi-Fi-based microcontrollers. The system enabled remote data access and visualization, improving consumer awareness about energy usage. However, it lacked an intelligent prediction mechanism and did not offer appliance-level energy segregation.

In [2], a Machine Learning-based Power Consumption Prediction Model was introduced to estimate future electricity bills using historical energy data. The study demonstrated that regression models and neural networks could effectively predict monthly consumption, but the proposed system relied solely on past data and did not provide real-time monitoring or user interaction.

In [3], a Smart Energy Management System using ESP32 and Cloud Services was developed for real-time monitoring of voltage and current parameters. The project achieved efficient data collection and cloud storage but lacked an integrated AI-based analysis or billing prediction feature.

In [4], researchers designed an IoT-enabled Smart Plug System capable of measuring the energy consumed by connected appliances. The data was processed using cloud analytics to suggest power-saving actions. Although this approach achieved appliance-level monitoring, it required costly infrastructure and was not optimized for scalability.

In [5], an AI-powered Smart Grid Prototype was proposed to predict and manage energy distribution in smart cities. The system utilized deep learning models to forecast load demand and optimize supply. While suitable for industrial or city-level applications, it was complex for small-scale domestic use.

From the above literature, it is evident that previous systems either focused on monitoring or prediction, but rarely combined both features into a unified framework. The proposed system PowerVision uniquely integrates real-time appliance-wise monitoring, AI-based bill prediction, and a responsive web interface using Java Full Stack and MySQL. It provides users with actionable insights, voice control functionality, and a low-cost, scalable architecture suitable for residential as well as small industrial applications. Thus, the literature survey establishes a clear research gap that PowerVision aims to fill — combining the strengths of IoT-based hardware design, AI-driven analytics, and full-stack web technology to create a next-generation smart energy management system.

CONCEPT AND METHODOLOGY

The proposed system PowerVision is designed to provide real-time, appliance-wise energy monitoring and AI-based bill prediction using an integration of hardware components, software modules, and machine learning algorithms. The overall methodology involves four major phases: data acquisition, data transmission, data processing, and data visualization & prediction.

A. System Architecture

The system architecture of PowerVision consists of both hardware and software components integrated to achieve efficient data collection and intelligent analysis. The hardware unit includes an ESP32 microcontroller, current and voltage sensors, and a regulated power supply. These components measure electrical parameters such

as current, voltage, and power for each connected appliance (PC, fan, and bulb).

The software part is developed using the Java Full Stack framework, consisting of Spring Boot for backend logic, Hibernate for ORM mapping, and MySQL as the central database for data storage. The frontend interface is designed using HTML, CSS, and Bootstrap, offering a responsive dashboard for users to view real-time power usage, graphical charts, and AI-based bill predictions.

B. Data Acquisition

The ESP32 microcontroller serves as the central control unit. It interfaces with sensors to collect real-time electrical parameters.

- Current Sensor measures current flow through each appliance.
- Voltage Sensor detects voltage level across appliances.
- The instantaneous readings are used to compute power and energy consumption.

The collected data is processed and formatted within the microcontroller and transmitted wirelessly to the web server through the built-in Wi-Fi module of the ESP32.

C. Data Transmission

Once the data is collected, it is transmitted using Wi-Fi communication to the backend server, where it is stored in the MySQL database. The system uses RESTful APIs built with Spring Boot for smooth data transfer between the hardware and the server. Each appliance is assigned a unique identifier to ensure proper segregation of readings and easy retrieval for analysis.

D. Data Processing and Storage

The backend server receives and processes incoming data. Using Hibernate, data is mapped to respective database tables and stored efficiently. The server also performs basic computations such as total energy consumption, peak load detection, and daily usage summary.

The data is further used by an AI/ML module that applies regression-based models to predict the expected electricity bill for upcoming cycles. The algorithm is trained on historical usage patterns, enabling accurate and dynamic predictions.

E. Visualization and User Interface

The frontend dashboard of PowerVision displays real-time consumption data using graphical charts and dynamic indicators. Users can view:

- Appliance-wise energy consumption
- Total monthly usage
- Predicted electricity bill
- Power trends and comparison charts

The interface is designed with a futuristic theme and includes voice control functionality that allows users to navigate and retrieve data using voice commands, enhancing accessibility and interactivity.

F. Flow of Operation

1. Initialization: System starts and sensors are activated.
2. Measurement: Sensors collect current and voltage readings.
3. Processing: ESP32 calculates power and energy in real-time.
4. Transmission: Data sent to backend through Wi-Fi.
5. Storage: Data stored in MySQL database.
6. Prediction: AI model analyzes historical data to forecast bills.
7. Visualization: Dashboard displays usage trends and predictions.

G. Implementation Overview

The complete prototype has been implemented and tested in the Electrical Engineering laboratory using three appliances – PC, fan, and bulb. The system demonstrated accurate data collection, real-time visualization, and reliable AI-based bill prediction. The integration of hardware with web technology makes.

PowerVision a unique solution combining electrical measurement and intelligent analytics in a single platform.

BLOCK DIAGRAM:

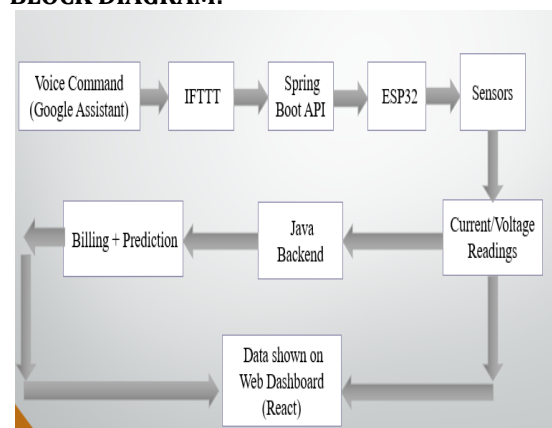


Fig: Block Diagram of System Architecture

FEATURES

The PowerVision system incorporates several innovative features that distinguish it from traditional energy monitoring solutions. It combines Electrical Engineering, Artificial Intelligence, and Web Technology to deliver a modern, user-friendly, and intelligent energy management experience. The key features are as follows:

A. Real-Time Appliance-Wise Monitoring

The system continuously tracks the power consumption of individual appliances such as PC, fan, and bulb. Using current and voltage sensors interfaced with the ESP32 microcontroller, the energy usage of each appliance is measured and transmitted in real time to the web dashboard for visualization.

B. AI-Based Bill Prediction

The system employs Artificial Intelligence (AI) and Machine Learning (ML) algorithms to analyze historical consumption patterns and predict future electricity bills. This feature helps users estimate their upcoming expenses and plan power usage efficiently, promoting cost-effective energy management.

C. Web-Based Dashboard

A Java Full Stack web application has been developed using Spring Boot, Hibernate, and MySQL for backend, and HTML, CSS, Bootstrap for frontend design. The dashboard provides graphical visualization of real-time data, showing total energy consumption, appliance-wise trends, and predictive insights through interactive charts.

D. Voice Control Functionality

To enhance accessibility and user convenience, the system integrates a voice control feature. Users can interact with the dashboard through voice commands to view power data, predicted bills, or appliance status, providing a futuristic and smart interface experience.

E. Data Storage and Analytics

The system stores all energy data in a MySQL database for analysis and future reference. The use of Hibernate ORM ensures efficient data management, while the backend server processes readings and generates detailed energy consumption summaries and reports.

F. Responsive and Futuristic User Interface

The frontend interface is designed to be responsive, ensuring smooth operation across all devices including desktops, tablets, and mobile phones. The design includes gradient backgrounds, dashboard animations, and a futuristic theme, making it visually engaging and easy to navigate.

G. Cost-Effective and Scalable Design

The system uses low-cost hardware components such as the ESP32 and open-source software technologies, making it affordable and easily scalable for residential, commercial, or industrial applications.

H. Integration of Electrical and IT Domains

PowerVision serves as an interdisciplinary bridge between Electrical Engineering and Information Technology. It combines real-time hardware data acquisition with intelligent AI-based software analytics, demonstrating a unified approach to modern energy monitoring.

The PowerVision system offers significant advantages over conventional energy monitoring solutions by combining real-time appliance-wise tracking, AI-based prediction, and a user-friendly interface. The primary benefits of the system include:

- **Appliance-Level Monitoring:** Provides detailed insights into individual device energy consumption.
- **AI/ML-Based Bill Prediction:** Accurately forecasts electricity bills based on historical and real-time data.
- **Enhanced Energy Efficiency:** Enables users to reduce wastage and optimize electricity usage.
- **User-Friendly Web Dashboard:** Displays energy data and predictions through interactive charts and graphs.
- **Voice-Controlled Operation:** Allows hands-free interaction for convenience and accessibility.
- **Real-Time Data Visualization:** Offers live readings of voltage, current, and power for each appliance.
- **Scalable and Flexible Design:** Can be extended to industrial and commercial applications.

Integration of Electrical and IT Domains: Bridges hardware monitoring with software analytics

- **Cost-Effective and Reliable:** Uses affordable hardware components and secure data management via MySQL.
- **Supports Energy Conservation Initiatives:** Helps users make informed decisions to reduce energy consumption.

SCOPE OF THE STUDY

The proposed system PowerVision aims to transform traditional energy monitoring into an intelligent, data-driven, and user-friendly experience. The scope of this study extends across multiple dimensions including domestic energy management, industrial applications, and future integration with IoT and AI technologies.

A. Residential Energy Monitoring

The system is designed to monitor and analyze household appliance-wise energy consumption in real time. It enables users to understand power usage behavior, predict monthly bills, and control

electricity expenses effectively. This makes PowerVision highly suitable for smart homes and domestic automation systems.

B. Industrial and Commercial Applications

The scalable design of the system allows it to be extended for industrial and commercial environments. By integrating more sensors and expanding the database infrastructure, PowerVision can monitor multiple machines, departments, or units simultaneously, providing detailed power analytics for energy optimization and cost reduction.

C. AI and Data Analytics Integration

The use of Artificial Intelligence and Machine Learning enhances the analytical capability of the system. The study covers the development of models that can forecast future energy consumption and billing patterns based on historical data. Future versions can include deep learning algorithms for even more accurate prediction and anomaly detection.

D. Web and IoT Connectivity

The system's Java Full Stack web platform allows remote access, while the ESP32 microcontroller provides built-in Wi-Fi connectivity. This combination ensures seamless integration with IoT-based smart grid systems, enabling centralized data management and remote control of appliances.

E. Research and Academic Potential

The project demonstrates an interdisciplinary approach combining Electrical Engineering, Computer Science, and Artificial Intelligence, making it a valuable reference for research, academic projects, and prototype development in the field of smart energy systems.

F. Future Enhancement Scope

The study can be further expanded to include features such as:

- Integration with mobile applications for remote access and notifications.
- Automatic appliance control based on load conditions or user preferences.
- Cloud data storage for large-scale deployment and analytics.
- Integration with renewable energy sources such as solar panels for intelligent load management.

The overall scope of PowerVision thus extends from individual user-level monitoring to large-scale smart grid applications, promoting energy efficiency, sustainability, and technological advancement in the power sector.

ADVANTAGES

The proposed system PowerVision provides several advantages over conventional energy monitoring systems by combining real-time data acquisition, AI-based prediction, and web-enabled visualization. The key advantages are outlined below:

A. Real-Time Monitoring

The system offers instantaneous tracking of energy usage for each connected appliance. This enables users to monitor power consumption continuously and take immediate action to reduce unnecessary load.

B. Appliance-Wise Consumption Analysis

Unlike traditional meters that show only total energy usage, PowerVision provides individual appliance-level monitoring, helping users identify which devices contribute most to power consumption.

C. AI-Powered Bill Prediction

The integration of Artificial Intelligence (AI) and Machine Learning (ML) algorithms allows accurate electricity bill forecasting based on historical consumption data, helping users plan budgets efficiently.

D. User-Friendly Web Interface

A responsive web dashboard designed with HTML, CSS, and Bootstrap provides easy access to all power data. Users can view real-time graphs, appliance status, and predicted bills through an intuitive and visually appealing interface.

E. Voice Control Feature

The system includes a voice-controlled interaction module, allowing users to navigate and retrieve data individual user-level monitoring to large-scale smart grid applications, promoting energy efficiency, sustainability, and technological advancement in the power sector.

F. Low Cost and High Efficiency

Using affordable components such as the ESP32 microcontroller, voltage and current sensors, and open-source software technologies, the system achieves cost-effective implementation with high operational accuracy.

G. Scalable and Customizable Design

The architecture of PowerVision is modular and easily expandable, allowing new appliances or features to be added with minimal hardware or software changes. This ensures adaptability for both residential and industrial applications.

H. Energy Conservation and Awareness

By providing users with clear insights into their energy consumption behavior, the system promotes energy-efficient habits, contributing to sustainability and environmental protection.

I. Integration of Electrical and IT Domains

The project effectively bridges Electrical Engineering and Information Technology by integrating hardware-based energy measurement with software-based AI analytics, serving as a model for multidisciplinary innovation.

DISADVANTAGES

A. Initial Setup Complexity

The system requires proper installation of sensors, microcontroller, and wiring for each appliance. Users without technical knowledge may find the initial setup challenging.

B. Dependence on Internet Connectivity

As the system relies on Wi-Fi communication for transmitting data to the web server, any network disruptions may affect real-time monitoring and predictive functionality.

C. Limited Appliance Support in Prototype

The current prototype supports a few appliances (PC, fan, and bulb) in a laboratory setup. Scaling to cover all household or industrial appliances requires additional hardware and configuration.

D. Data Accuracy Concerns

The system's sensor-based measurements may be affected by electrical noise, fluctuations, or sensor calibration errors, potentially leading to minor inaccuracies in energy readings and predictions.

E. Resource Requirements for AI Computation

The AI-based bill prediction module requires processing power and memory for model computation. On low-end servers or limited devices, performance may be slower during high data loads.

F. Maintenance and Troubleshooting

Regular maintenance of sensors, ESP32 microcontroller, and backend server is necessary to ensure accuracy and continuous operation. Troubleshooting hardware or software issues may require technical expertise.

G. Security and Privacy Concerns

Since the system stores appliance-wise consumption data and user information on a server, there exists a potential risk of data breach if proper security measures are not implemented.

CONCLUSION

The proposed project PowerVision successfully demonstrates a real-time, appliance-wise energy monitoring system integrated with AI-based electricity bill prediction. By combining Electrical Engineering, IoT technology, and Java Full Stack development, the system provides users with an intelligent, user-friendly, and cost-effective solution for energy management.

The key achievements of the project include:

- Accurate appliance-level energy tracking using ESP32 and sensor modules.
- Integration of AI/ML algorithms for precise bill forecasting.
- A responsive web dashboard with graphical visualization and voice control functionality.
- A scalable and modular design that allows expansion for additional appliances and industrial applications.

The system enhances energy awareness, encourages efficient electricity usage, and enables users to plan and optimize power consumption, contributing to both economic savings and environmental sustainability. Furthermore, PowerVision serves as a practical demonstration of interdisciplinary innovation, bridging hardware measurement techniques with software-based predictive analytics.

Future enhancements may include mobile application integration, cloud-based analytics, and renewable energy management, making the system suitable for smart homes, industrial setups, and smart grid applications. Overall, PowerVision establishes a foundation for next-generation energy monitoring solutions that combine convenience, intelligence, and sustainability.

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