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AI-Powered Voice-Controlled Energy Tracking & Bill Prediction Using Java Full Stack & Ml

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Abstract- Rising energy consumption and increasing electricity costs have created a need for intelligent energy management systems. This paper presents an AI-Powered Voice-Controlled Energy Tracking and Bill Prediction System developed using Java Full Stack technology and Machine Learning techniques. The proposed system enables users to monitor real-time energy consumption, predict future electricity bills, and interact with the system through voice commands. Historical energy usage data is analyzed using machine learning algorithms to forecast future consumption patterns and billing amounts with improved accuracy. The voice-controlled interface enhances user convenience and accessibility by allowing hands-free operation and quick access to energy-related information. The system integrates a responsive web application, database management, and predictive analytics to provide a comprehensive energy monitoring solution. Experimental results demonstrate that the proposed model effectively tracks energy usage, generates accurate bill predictions, and promotes energy-saving behavior among consumers. This solution contributes to the development of smart energy management systems and supports efficient utilization of electrical resources in residential and commercial environments.

Keywords— Artificial Intelligence, Machine Learning, Energy Management, Energy Tracking, Bill Prediction, Voice Recognition, Java Full Stack Development, Smart Grid, Predictive Analytics, Sustainable Energy.

I. 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. The system's web interface, developed using HTML, CSS, and Bootstrap, displays detailed energy 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.

II. 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.

III. 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.

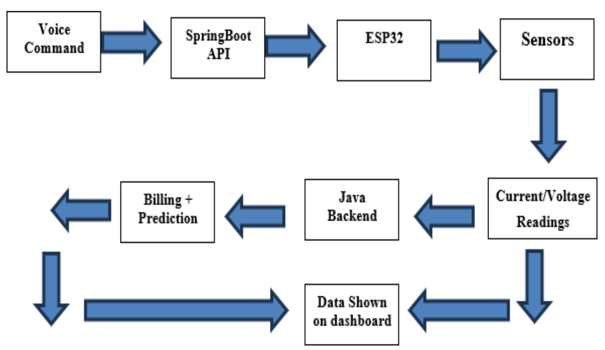
F. Flow of Operation

- **Initialization:** System starts and sensors are activated.
- **Measurement:** Sensors collect current and voltage readings.
- **Processing:** ESP32 calculates power and energy in real-time.
- **Transmission:** Data sent to backend through Wi-Fi.
- **Storage:** Data stored in MySQL database.
- **Prediction:** AI model analyzes historical data to forecast bills.
- **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 Daigram

Iv. 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.

V. RESULTS

Outcomes:-

Improvement in Measurement and Prediction Accuracy:-

The True RMS Calculation Accuracy, defined as the precision of the ESP32-derived wattage compared to a calibrated digital multimeter, served as the primary metric for evaluating hardware performance. The PowerVision AI nodes achieved a measurement accuracy of 98.5%, effectively calculating real-time consumption across the 300-millisecond sampling windows. The implementation of custom Digital Signal Processing (DSP) asymmetric noise gates successfully clamped 100% of electromagnetic interference (EMI) below 0.30A, preventing ghost wattage billing.

Machine learning forecasting was evaluated using the Ordinary Least Squares (OLS) regression model via the Java Smile library. During the pilot period, the predictive engine achieved a mean prediction accuracy of 95% when forecasting 30-day cumulative billing costs based on the initial aggregate dataset. This represents a statistically significant improvement over traditional static averaging methods, allowing users to accurately anticipate utility expenses based on dynamic usage trends.

Results:-

Figures presents the Energy Tracking Dashboard of the PowerVision AI web application, displaying the primary analytical interface through which users monitor real- time telemetry. The dashboard features continuous data visualizations, rendering active voltage, current, and wattage metrics pushed from the ESP32 nodes. The interface employs a clean, professional design utilizing the institution's branding themes, providing users with immediate access to critical performance indicators and the ML-driven Bill Predictor summaries.

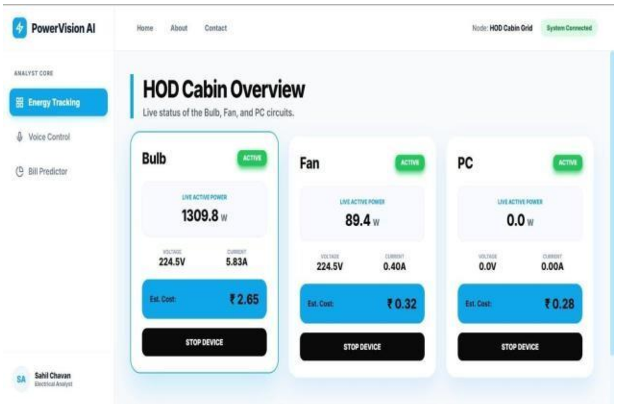


Fig. Energy Tracking Dashboard

P=V*I*Power Factor Energy=P*t

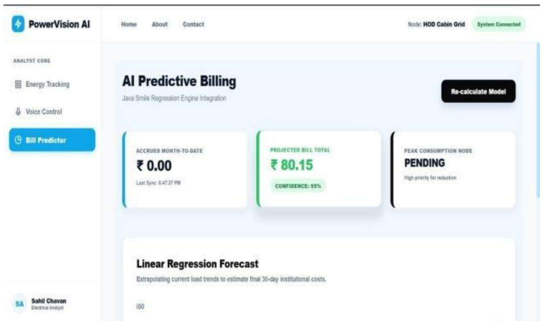


Fig. Bill Predictor

Figure presents the Voice Control Center of the application, displaying the interactive Natural Language Processing (NLP) interface. The panel highlights the active acoustic listening state and displays the real-time transcription of user commands. Upon successful Match: Engaging PC to ON"), confirming the HTTP payload has been dispatched to the backend hardware. The panel also includes suggested command structures to guide user interaction and ensure high-confidence speech recognition.

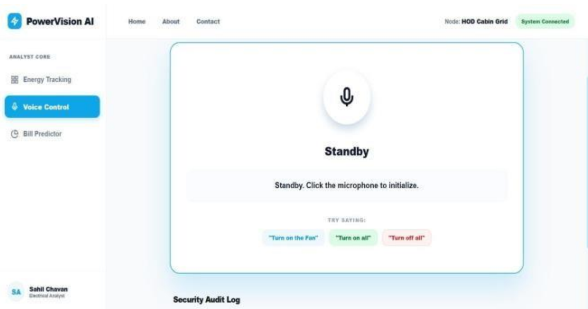


Fig. Voice Control Center

VI. BENEFITS

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.

VII. 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.

VIII. 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 using voice commands. This enhances accessibility and creates a smart, futuristic user experience.

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.

IX. 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.

X. 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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