

A Smart Vehicle-to-Grid Energy Management System Using IOT and Machine Learning

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Abstract - The increasing adoption of electric vehicles (EVs) is creating new challenges and opportunities for modern power systems. One promising approach to manage this growing demand is the Vehicle-to-Grid (V2G) technology, which allows electric vehicles not only to consume energy from the grid but also to supply energy back when needed. This paper presents the design and implementation of an IoT-based V2G system with a simple demand prediction mechanism using machine learning. The proposed system uses an ESP32 microcontroller to monitor electrical parameters such as voltage, current, and power during both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. The collected data is transmitted to a cloud database using Firebase, which enables real-time monitoring through a dashboard interface.

A machine learning model based on the Random Forest algorithm is implemented to predict power demand based on voltage, current, and operational mode of the system. The predicted demand helps in understanding the future power requirements and possible energy exchange between electric vehicles and the grid. The system also includes relay-based switching to simulate bidirectional energy flow between the grid and the vehicle battery. Experimental results show that the proposed system is able to monitor energy parameters in real time and provide reasonable demand prediction. This work demonstrates how IoT and machine learning techniques can be combined to support smarter and more flexible energy management in future EV charging infrastructure.

Key Words: Vehicle-to-Grid (V2G), Electric Vehicles (EVs), Internet of Things (IoT), Smart Grid, Demand Prediction, Machine Learning, Random Forest Algorithm, Energy Management, Real-Time Monitoring, ESP32, Firebase Cloud Database, Bidirectional Charging

1.INTRODUCTION

The demand for electrical energy is increasing rapidly due to the growth of population, industrial activities, and modern transportation systems. One of the major contributors to energy consumption in recent years is the transportation sector, which still depends heavily on fossil fuels. The use of conventional fuel-based vehicles causes environmental pollution, greenhouse gas emissions, and contributes to climate change. Because of these issues, there is a strong global interest in adopting cleaner and more sustainable transportation technologies. Electric Vehicles (EVs) have emerged as an important alternative to traditional vehicles because they produce lower emissions and can operate using electricity generated from renewable energy sources.

As the number of electric vehicles continues to increase, new challenges are appearing in power systems and grid infrastructure. Large scale charging of EVs can create additional load on the electrical grid, especially during peak demand hours. If this charging demand is not properly managed, it may cause instability in the power system and may increase the operational cost of energy distribution. Therefore, advanced energy management techniques are required to ensure that EV integration into the grid remains efficient and stable.

One of the promising solutions to this challenge is the concept of Vehicle-to-Grid (V2G) technology. In a traditional charging system, electric vehicles only draw energy from the power grid. However, in a V2G system, electric vehicles can also return stored energy back to the grid when needed. This creates a bidirectional energy flow between the electric vehicle battery and the electrical grid. During periods of high electricity demand, EV batteries can act as distributed energy storage units and supply energy to support the grid. Similarly, during periods of low demand, the vehicles can be charged from the grid. This concept helps improve energy utilization, grid stability, and integration of renewable energy sources.

The development of smart grid technologies and Internet of Things (IoT) systems has made it easier to monitor and control such energy interactions. IoT-based monitoring systems allow real-time collection of electrical parameters such as voltage, current, and power from different components of the system. These data can be transmitted to cloud platforms where they can be stored, analyzed, and visualized through dashboards. Real-time monitoring not only helps users understand the energy flow but also allows system operators to make better decisions regarding energy distribution and management.

In addition to monitoring, prediction of future energy demand is also an important aspect of smart energy systems. With the help of machine learning algorithms, it is possible to analyze historical energy data and estimate future power requirements. Demand prediction can help improve scheduling of charging and discharging operations in V2G systems. It also supports better planning of grid resources and reduces the risk of overload conditions. Various machine learning techniques such as regression models, decision trees, and ensemble learning methods have been applied for energy prediction tasks.

This paper presents the design and implementation of an IoT-based Vehicle-to-Grid system with a machine learning based demand prediction model. The proposed system uses an ESP32 microcontroller to monitor voltage and current parameters during both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. These electrical parameters are transmitted to a Firebase cloud database for real-time monitoring. A simple dashboard interface is used to display system parameters and allow users to switch between operational modes. The system also includes relay modules to simulate bidirectional power flow between the grid and the vehicle battery.

For the demand prediction component, a Random Forest regression model is implemented. The model takes voltage, current, and system mode as input features and predicts the expected power demand. Random Forest was selected because of its ability to handle non-linear relationships and its robustness against overfitting. The trained model helps estimate future power consumption and provides insights into system behavior under different operating conditions.

The main objective of this work is to demonstrate how IoT technology and machine learning techniques can be integrated to create a smart energy monitoring and prediction system for V2G applications. The system

focuses on real-time data acquisition, cloud-based storage, and demand forecasting. Although the implementation is developed at a small experimental scale, the proposed approach can be extended to larger EV charging infrastructures in the future.

The remainder of this paper is organized as follows. The literature review section discusses previous research related to electric vehicles, V2G technology, and energy demand prediction. The methodology section describes the system architecture, hardware components, and machine learning model used in the proposed system. The experimental results section presents the system performance and dashboard visualization. Finally, the conclusion summarizes the key findings and discusses possible future improvements for the system.

2. BACKGROUND OF V2G TECHNOLOGY

Vehicle-to-Grid (V2G) technology is an emerging concept in modern power systems that enables electric vehicles (EVs) to not only consume electricity from the grid but also return stored energy back to it. Traditionally, electric vehicles operate in a unidirectional charging mode where energy flows from the grid to the vehicle battery. However, with the rapid growth of EV adoption, researchers and engineers started exploring ways to utilize EV batteries as distributed energy storage units. This idea led to the development of the V2G concept, which supports bidirectional power flow between electric vehicles and the power grid.

The concept of V2G was first proposed in the early 2000s as part of smart grid research. It was suggested that electric vehicles, when connected to the grid through intelligent charging infrastructure, could act as small mobile energy storage systems. Since EV batteries have significant storage capacity, a large number of connected vehicles could collectively provide considerable energy support to the grid. During periods of high electricity demand, energy stored in EV batteries can be supplied back to the grid. Similarly, when electricity demand is low or when renewable energy generation is high, the vehicles can be charged from the grid. This interaction helps balance the supply and demand of electricity in the power system.

The integration of V2G technology becomes more important with the increasing penetration of renewable energy sources such as solar and wind power. Renewable energy generation is often intermittent and unpredictable, which makes it difficult to maintain a stable balance between power generation and consumption. V2G

systems can help address this issue by storing excess energy generated during peak renewable production and releasing it back to the grid when needed. In this way, EV batteries can function as decentralized energy storage units that support grid stability and improve energy utilization.

Another important aspect of V2G technology is its role in developing smart grids. Smart grids combine advanced communication technologies, sensors, and automation to improve the efficiency and reliability of power systems. Through the use of Internet of Things (IoT) devices, charging stations and electric vehicles can communicate with grid operators and energy management systems. Real-time monitoring of voltage, current, power consumption, and battery status becomes possible using IoT-based systems. This information allows intelligent control of charging and discharging operations, which is necessary for implementing effective V2G strategies.

Bidirectional charging infrastructure is a key requirement for implementing V2G systems. Unlike traditional chargers that only supply power to the vehicle, V2G chargers are designed to allow energy flow in both directions. These chargers include power electronic converters, control units, and communication interfaces that coordinate the transfer of energy between the vehicle and the grid. The control system ensures that the charging and discharging processes operate safely while maintaining battery health and system efficiency.

The economic and environmental benefits of V2G technology are also significant. From an environmental perspective, V2G can help reduce reliance on fossil fuel based power plants by enabling better integration of renewable energy resources. From an economic standpoint, EV owners may receive financial incentives for supplying energy back to the grid during peak demand periods. Utility companies can also benefit by reducing the need for expensive peak power plants and improving the overall efficiency of the power system.

Despite these advantages, there are still several challenges associated with the large-scale implementation of V2G systems. These include battery degradation concerns, communication infrastructure requirements, standardization issues, and the need for advanced control algorithms. Researchers are currently exploring various solutions such as smart charging strategies, machine learning based demand prediction, and optimized energy management systems to overcome these challenges.

In recent years, the integration of machine learning and cloud computing technologies has opened new possibilities for improving V2G systems. By analyzing

historical energy data, machine learning models can predict energy demand and optimize charging or discharging schedules. Cloud platforms enable centralized data storage and remote monitoring, making it easier to manage multiple charging stations and vehicles simultaneously. These technologies together contribute to the development of intelligent and efficient V2G energy management systems.

Overall, Vehicle-to-Grid technology represents an important step toward the future of sustainable transportation and smart energy systems. By enabling electric vehicles to participate actively in energy exchange with the power grid, V2G systems can enhance grid stability, support renewable energy integration, and create new opportunities for efficient energy management. As EV adoption continues to grow worldwide, the role of V2G technology is expected to become increasingly significant in modern power infrastructure.

3. LITERATURE REVIEW

Several researchers have investigated the integration of electric vehicles with the power grid through Vehicle-to-Grid (V2G) technology. The increasing adoption of electric vehicles has encouraged studies focusing on bidirectional energy flow, smart charging infrastructure, and intelligent energy management systems. This section reviews some of the important contributions in the field related to V2G systems, IoT-based monitoring, and machine learning based demand prediction.

Early research on V2G technology mainly focused on understanding the concept of bidirectional energy transfer between electric vehicles and the power grid. Deng et al. presented one of the early reviews discussing the implementation of V2G systems and highlighted the importance of intelligent charging and discharging control strategies. Their work also discussed challenges such as battery impact, bidirectional charger design, and the need for efficient energy management mechanisms in V2G systems. These studies established the basic foundation for integrating EVs as distributed energy resources in modern power grids.

With the rapid growth of electric vehicles, more studies began analyzing the performance and potential benefits of V2G systems. Gokulakannan and Chitra conducted a performance analysis of V2G technology and demonstrated how bidirectional power flow can improve grid stability and support renewable energy integration. Their research showed that V2G systems allow electric vehicles to both consume energy from the grid and supply stored energy back during peak demand periods,

which improves overall energy utilization efficiency. This work highlighted the importance of developing reliable control mechanisms for managing energy flow between EV batteries and the grid.

Further research has focused on improving the hardware and control techniques used in bidirectional charging infrastructure. Rana et al. reviewed different bidirectional charger topologies and control strategies used in V2G systems. The study emphasized the importance of efficient power electronic converters and intelligent control algorithms to ensure stable and efficient energy transfer between vehicles and the grid. Their work also discussed how advanced control techniques can improve the performance of both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations.

In addition to hardware improvements, several studies have explored the role of advanced algorithms and artificial intelligence in managing V2G systems. Recent research shows that machine learning and artificial intelligence can be used to optimize energy scheduling and demand prediction in smart grids. For example, reinforcement learning based coordination strategies have been proposed to manage large-scale EV charging and discharging operations. These approaches help reduce load fluctuations and improve overall energy efficiency in V2G systems by intelligently scheduling power exchange between vehicles and the grid.

Another area of research focuses on the broader impact of V2G systems on modern energy infrastructure. Xu analyzed the development trends of V2G technology and discussed how EV batteries can be used as distributed storage units to support renewable energy integration. The study emphasized that smart charging algorithms and improved infrastructure are necessary for large-scale deployment of V2G systems. However, it also pointed out several challenges such as infrastructure investment, policy requirements, and public acceptance of V2G technologies.

More recent reviews have examined the overall progress of V2G research and its potential role in future smart grid systems. Ru et al. conducted a comprehensive review of more than two hundred publications related to V2G technology. Their study concluded that V2G systems can significantly enhance grid flexibility and help balance fluctuations caused by renewable energy sources. The research also showed that recent studies increasingly focus on economic models, real-world deployment, and integration of advanced analytical techniques for energy management.

Although significant progress has been made in V2G research, several challenges still remain. Issues such as

battery degradation, communication infrastructure, cybersecurity, and standardization must be addressed before large-scale deployment becomes feasible. Recent studies have also highlighted the importance of secure communication systems and advanced data analysis techniques to protect V2G infrastructure and ensure reliable operation of smart grid networks.

From the literature review it can be observed that most existing research focuses on large-scale grid integration, advanced control strategies, and energy market analysis. However, relatively fewer studies focus on small-scale experimental implementations that combine IoT monitoring with machine learning based demand prediction. Therefore, the proposed work aims to design and implement a simple IoT-based V2G monitoring system with a machine learning model to predict power demand based on real-time system parameters. This approach demonstrates how smart monitoring and prediction techniques can be applied to improve energy management in future electric vehicle charging infrastructure.

4. PROPOSED FRAMEWORK

The proposed system focuses on the design and implementation of a smart Vehicle-to-Grid (V2G) energy monitoring and demand prediction framework using Internet of Things (IoT) technology and machine learning techniques. The methodology mainly consists of data acquisition, cloud communication, system monitoring, and power demand prediction. The system is designed to simulate bidirectional energy flow between the grid and an electric vehicle battery while collecting real-time electrical parameters and predicting power demand based on those parameters.

1. System Architecture

The overall architecture of the proposed system consists of three major layers: the hardware layer, the cloud communication layer, and the data analysis layer. The hardware layer includes an ESP32 microcontroller, relay modules, battery cells, and sensor modules used for monitoring electrical parameters. The ESP32 acts as the main controller that collects data and manages communication with the cloud platform. The cloud layer uses Firebase Realtime Database to store and manage the system data. The analysis layer consists of a machine learning model implemented in Python, which is used for demand prediction based on collected system parameters.

The architecture allows real-time communication between the hardware system and the cloud database,

enabling remote monitoring and system control through a dashboard interface.

2. Hardware Implementation

The hardware setup includes an ESP32 microcontroller, which serves as the central processing unit of the system. The ESP32 reads voltage and current values from the sensors connected to the charging circuit. Two relay modules are used to simulate the operating modes of the V2G system. These relays control the direction of energy flow between the grid and the vehicle battery.

The system operates in two main modes:

- **Grid-to-Vehicle (G2V) Mode:** In this mode, electrical energy flows from the power grid to the electric vehicle battery, allowing the battery to charge.
- **Vehicle-to-Grid (V2G) Mode:** In this mode, stored energy from the electric vehicle battery is supplied back to the power grid.

The relays are controlled through commands received from the cloud database, allowing the system mode to be changed remotely through the dashboard interface.

3. Data Acquisition and Monitoring

During system operation, electrical parameters such as voltage, current, and power are monitored continuously. The ESP32 processes these values and calculates power using the relation:

$$P = V \times I$$

where

V represents voltage and I represents current.

The measured values are transmitted to the Firebase Realtime Database through Wi-Fi communication. This allows the system data to be stored in the cloud and accessed by the monitoring dashboard. The dashboard displays real-time graphs of voltage, current, and power for both charging and discharging operations.

The use of cloud storage allows continuous monitoring and analysis of system performance over time.

4. Cloud Integration

Firebase Realtime Database is used as the cloud communication platform in the proposed system. The ESP32 sends the measured electrical parameters to Firebase at regular time intervals. The stored data can then be accessed by the Python-based monitoring dashboard.

Firebase also stores system control parameters such as the operating mode (G2V or V2G). The ESP32 reads this parameter from the database and activates the appropriate relay to switch the system operation mode. This approach enables remote control of the system through the dashboard interface.

5. Dataset Preparation

The dataset used for demand prediction consists of voltage, current, and system mode values collected during system operation. Each record in the dataset represents the electrical state of the system at a specific time. The dataset is structured with the following features:

- Voltage (V)
- Current (A)
- Mode (G2V or V2G)

The target variable for prediction is the system power consumption. These data samples are used to train a machine learning model capable of estimating power demand under different operating conditions.

6. Machine Learning Based Demand Prediction

To predict the power demand of the system, a Random Forest Regression algorithm is implemented. Random Forest is an ensemble learning method that combines multiple decision trees to improve prediction accuracy and reduce overfitting. The algorithm works by generating several decision trees during training and averaging their predictions to obtain the final output.

The input features used for the model include voltage, current, and system mode, while the output is the predicted power value. The dataset is divided into training and testing sets using a standard train-test split approach. The model is trained using the training dataset and evaluated using the testing dataset.

The performance of the model is measured using evaluation metrics such as Mean Absolute Error (MAE) and the coefficient of determination (R^2 score). These metrics help determine how accurately the model predicts the power demand.

7. System Operation Flow

The overall operation of the proposed system can be summarized in the following steps:

1. The ESP32 collects voltage and current data from the hardware system.
2. Power values are calculated using the measured parameters.
3. The collected data is transmitted to the Firebase cloud database.
4. The dashboard retrieves the stored data and displays real-time graphs.
5. The dataset is used to train the machine learning model.
6. The trained model predicts power demand based on the input parameters.
7. The system mode (G2V or V2G) can be controlled through the cloud interface.

8. Advantages of the Proposed Method

The proposed methodology offers several advantages. It provides real-time monitoring of electrical parameters using IoT communication. The cloud-based storage system allows easy access to data from remote locations. The integration of machine learning enables prediction of system power demand, which can help in improving energy management in future V2G systems. Additionally, the experimental setup demonstrates how small-scale implementations can be used to study the behavior of smart energy systems.

Overall, the proposed methodology combines hardware implementation, cloud-based monitoring, and machine learning prediction to create a smart and flexible V2G energy management system.

5. RESULTS AND DISCUSSION

The proposed Vehicle-to-Grid (V2G) monitoring and demand prediction system was successfully implemented and tested using the ESP32 microcontroller, Firebase cloud database, and a Python-based dashboard interface. The experimental results demonstrate that the system is capable of monitoring electrical parameters in real time and predicting power demand using the trained machine learning model.

The first part of the system includes a login interface that allows authorized users to access the monitoring dashboard. This provides basic security and ensures that only permitted users can view or control the system. After successful login, the dashboard displays real-time electrical parameters such as voltage, current, and power values obtained from the ESP32 device and stored in the Firebase database.

The second component of the dashboard shows graphical representations of voltage and current values. These graphs update dynamically as new data is received from the hardware system. The visualization helps in understanding the charging and discharging behavior of the system under different operating conditions. When the system operates in Grid-to-Vehicle (G2V) mode, the current increases indicating battery charging, while in Vehicle-to-Grid (V2G) mode the current represents energy supplied back to the grid.

The third part of the dashboard implements the demand prediction module. A Random Forest regression model was trained using voltage, current, and operational mode as input parameters to predict the expected power demand. The trained model was able to generate reasonable predictions based on the system inputs. The predicted values provide insights about possible power

consumption and energy exchange between the grid and the electric vehicle battery.

Overall, the results indicate that the proposed system successfully integrates IoT-based monitoring with machine learning based demand prediction. The real-time dashboard visualization combined with predictive analysis demonstrates the feasibility of using such systems for smart energy management in future electric vehicle charging infrastructure.

Table 1. Sample V2G Monitoring Data (Assumed Values)

Time (hh:mm)	Voltage (V)	Current (A)	Power (W)	Direction (Charge/Discharge)
10:00	228.4	3.2	731	Charging
10:10	229.1	3.6	825	Charging
10:20	227.8	2.8	638	Charging
10:30	228.6	1.9	435	Discharging
10:40	229.3	2.5	573	Discharging
10:50	228.9	3.0	687	Discharging
11:00	229.5	3.3	757	Charging

CONCLUSION & FUTURE SCOPE

In this paper, an IoT-based Vehicle-to-Grid (V2G) system with machine learning based demand prediction was designed and implemented. The proposed system demonstrates how electric vehicles can interact with the power grid through bidirectional energy flow. The system uses an ESP32 microcontroller to monitor important electrical parameters such as voltage, current, and power during both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. These parameters are transmitted to a Firebase cloud database, which enables real-time monitoring through a dashboard interface.

The developed dashboard provides visualization of system parameters and allows users to control the operating mode of the system. In addition to real-time monitoring, a machine learning model based on the Random Forest algorithm was implemented to predict power demand using voltage, current, and system mode as input features. The experimental results show that the proposed system is capable of collecting and transmitting data reliably while providing reasonable predictions of power demand.

Overall, the integration of IoT communication and machine learning techniques helps create a smart energy monitoring and prediction framework for V2G systems.

Although the system is implemented on a small experimental scale, it demonstrates the feasibility of combining cloud-based monitoring with predictive analytics for managing electric vehicle charging infrastructure.

Future Scope

The proposed system can be further improved and expanded in several ways. In future work, more advanced sensors and accurate measurement circuits can be used to improve the precision of voltage and current readings. The system can also be extended to support larger battery systems and real electric vehicle charging stations for practical deployment.

Another possible improvement is the use of more advanced machine learning models or deep learning techniques to achieve better demand prediction accuracy. Additional parameters such as battery state of charge, charging time, and grid load conditions can also be included in the dataset to improve prediction performance.

Furthermore, integration with renewable energy sources such as solar or wind power can be explored to create a more sustainable and efficient energy management system. Security features and communication protocols can also be enhanced to ensure reliable and safe operation of the system in real-world smart grid environments.

Overall, the proposed system provides a foundation for future research in smart grid technologies, intelligent EV charging infrastructure, and data-driven energy management solutions.

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