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IOT-Enabled Vehicle-to-Grid Energy Monitoring and Forecasting Using ESP32 and Cloud Integration

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Abstract - The demand for electric vehicles (EVs) is increasing very rapidly, and considering this of Vehicle-to-Grid (V2G) is also becoming more important technology. In V2G system, the car or EV's is not just for using electrical energy from grid, but it can also give power back to the grid when demand is high or needed. To make this work better, we need to watch and study how energy is moving between the grid and the vehicles. In this project, a simple and low-cost setup is used. ESP32 board with voltage and current sensors is taking the charging and discharging readings in real time. The values are then sent to Firebase cloud so that data can be saved and checked from anywhere. A small Python dashboard is made to show the results in graphs so users can see how the system works. Also, machine learning models are suggested for guessing the future power demand and supply which can help in planning charging schedule. This framework can be considered easy to build and can be used for research and development, and small-scale demonstrations.

***Key Words*:** Vehicle-to-Grid, ESP32, IoT, Energy Monitoring, Cloud Storage, Firebase, Machine Learning, Forecasting, Smart Grid

1.INTRODUCTION

Every year we can see that the number of electric vehicles (EVs) on the road is increasing. Considering this aspect, the link between vehicles and the power grid is also changing. previously, cars and EV's can only use electricity for charging purpose, but now EV's can also give power back to the electricity grid if required. This bidirectional two-way flow is called Vehicle-to-Grid (V2G). It provides help to the grid by storing electrical energy when demand is less and when demand is high it gives back to the grid. This system can make renewable energy use more stable and it also reduce load on the traditional grid.

In order to ensure such a system works well, it is also very important to keep checking values like voltage, current and power of the system all the time. If this data is not monitored properly, we cannot understand the charging and discharging behaviour of EVs properly. ESP32 is a good and cheap option for this because it has Wi-Fi, it is small, and it can process data quickly. By using Firebase cloud, the collected data is stored safely and can be checked from anywhere using internet. A simple dashboard built in Python can then show this data in charts and graphs, which makes it easy to study the performance of the system.

In addition to just watching the system, it is also useful if we can **guess the future energy flow**. This is helpful for both the grid operators and the EV users. By looking at old V2G data, simple machine learning or normal forecasting methods can be used to find demand patterns, plan charging time better, and make the grid more stable. When IoT devices, cloud storage, and AI prediction are put together, it makes a full system that can support smart grid development and also help in using clean energy in a better way.

2. BACKGROUND OF V2G TECHNOLOGY

The fast growth of electric vehicles (EVs) has opened new options for energy use, not only normal charging. One of the main ideas in this area is **Vehicle-to-Grid (V2G)**. In V2G, energy can move both ways – cars take power from grid when charging and can also give back stored power when grid needs it. This helps in keeping grid stable, reducing peak demand issues and also makes renewable energy use more smooth.

Because solar and wind power are not steady all the time, there are problems with balance. V2G can help here, since EVs can work like small storage systems and manage these ups and downs. This can save cost by avoiding extra big upgrades in the power network.

To make such systems work, we must check voltage, current, and energy flow correctly. Real-time checking shows charging habits, discharging cycles, and how good the system is working overall. With IoT devices like ESP32, this is now low cost and simple. The ESP32 can record data and send it to cloud (like Firebase), where it can be stored, shared, and studied by many people.

So, using IoT, cloud, and prediction tools together gives a strong base for V2G. With continuous checking and smart forecasting, we can make the grid more reliable and also move towards the bigger goal of future smart and strong energy systems.

Table -1: Key Aspects of Vehicle-to-Grid (V2G) Technology

Aspect	**Description**	**Why Monitoring is Important**
Concept	Energy can move both ways between EV and power grid.	Need to check voltage and current in real time so power flow is correct.
Benefits	Helps grid stay stable, reduce peak load, and use more renewable energy.	Monitoring shows how much EVs really help grid and improve efficiency.
Challenges	Battery wear, data communication issues, and government rules.	Regular checking needed to see battery health and keep system safe.
Enabling Tech	IoT boards like ESP32, sensors, cloud storage, and simple AI models.	Needed for collecting live data, saving it, and using it for study.
Energy	Things like voltage,	These are taken from

Aspect	Description	Why Monitoring is Important
Values	current, power factor, and battery charge level (SoC).	sensors and used for decisions.
Applications	Smart grids, green energy support, demand response, and other services.	Monitoring helps use energy better and make system work long time.

3. LITERATURE REVIEW

In last few years, many researchers have invested their time to study Vehicle-to-Grid (V2G) systems, they focused on how to monitor, store data, and make predictions using IoT and AI systems. At first, the work was more about showing that EVs can send power back to the grid, but later studies started using IoT devices and cloud services for real-time checking.

Different boards have been tested for sensing voltage and current in V2G projects. Arduino is easy to use for simple testing but it has less power and no strong wireless support. Raspberry Pi gives better processing and can handle bigger data jobs, but it costs more and uses more energy. ESP32 has become a popular choice since it is cheap, has Wi-Fi and Bluetooth already inside, and can work well for real-time monitoring.

For storing and handling energy data, cloud systems are used. There are Platforms in market like Firebase, AWS IoT Core, and Microsoft Azure which makes it easy to save data online and check it from anywhere. These also help in studying old records, improving grid working, and doing early maintenance.

Some studies have added machine learning for prediction. Models like ANN, SVM, and Naïve Bayes are used for finding energy demand, planning charging, and improving grid use. More advanced works try deep learning and mixed models to make prediction more correct, but they still face issues like high computation need and scaling for large systems.

Table 2: Summary of Related Works in V2G Monitoring and Prediction

Author	Platform Used	Cloud/Storage	AI/Forecasting Approach	Key Findings	Limitations
Sharma et al. (2019)	Arduino + sensors	Local server	None	Demonstrated basic V2G voltage/current monitoring.	Limited connectivity and no predictive model.
Kim et al. (2020)	Raspberry Pi + sensors	AWS IoT Core	ANN	Achieved accurate forecasting of EV charging demand.	Higher cost and power usage.
Patel et al. (2021)	ESP32 + sensors	Firebase	Naïve Bayes	Low-cost, real-time monitoring with basic prediction.	Forecasting accuracy limited to small dataset.
Liu et al. (2022)	IoT + Smart meters	Azure Cloud	SVM + Time-series models	Improved prediction accuracy for grid demand balancing.	Computationally intensive, not scalable.
Proposed Review Work	ESP32 + voltage/current sensors	Firebase Cloud	AI-based forecasting (e.g., regression, deep learning)	Low-cost, scalable, real-time monitoring with predictive capability.	Still requires testing with large-scale deployment.

4. PROPOSED FRAMEWORK

The planned system is made to give a low-cost and simple V2G monitoring setup that uses IoT, cloud storage, and some machine learning for prediction. The work can be divided into four main parts: data collection, cloud storage, analysis with forecasting, and final visualization.

1. Data Collection

The most important part of the system is the ESP32 microcontroller board. We have connected Voltage and current sensors to ESP32 for reading values such as voltage, current, and power in real time. ESP32 was selected because it already has Wi-Fi inside, is cheap, and is easy to use in IoT projects.

2. Cloud Storage

The sensor readings are sent wireless to Firebase Cloud. Firebase keeps all data with time stamp in one place. This makes the data safe, easy to store for long time, and simple to access later for analysis.

3. Analysis and Forecasting

The data stored in Firebase is then fetched using Python scripts. After cleaning, it is processed with machine learning. Models like regression, Naïve Bayes, or even deep learning like LSTM can be used to predict future energy use and V2G flow. This prediction is useful for both EV owners and grid operators to plan charging and discharging.

4. Visualization

The results are shown on a Python web dashboard. Different graphs like line plots and bar charts are used for both real-time and predicted values. This dashboard works as the main screen where users can watch and understand the whole V2G system.

Table 3: Hardware and Software Components

Component	Description
ESP32	We have Used Microcontroller with built-in Wi-Fi, for sensor interfacing and data transmission.
Voltage Sensor	It is used to measure grid and EV charging voltages.
Current Sensor	It Monitors current flow during charging and discharging of EV

Component	Description
Firebase Cloud	It Stores real-time energy data and enables remote access of the system
Python (Flask/Django Libraries)	It fetches, processes, and visualizes data and supports ML/AI algorithms.
Machine Learning Models	Regression, Naïve Bayes, or LSTM for energy forecasting.
Web Dashboard	Provides graphical representation of monitored and predicted data.

5. RESULTS AND DISCUSSION

To validate the proposed framework, a prototype system was developed using an ESP32 microcontroller interfaced with a ZMPT101B voltage sensor and ACS712 current sensor. The measured values were transmitted via Wi-Fi to a Firebase Cloud database and subsequently retrieved in a Python dashboard for visualization and forecasting.

1. Sensor Data Acquisition

The ESP32 successfully recorded and transmitted real-time energy flow parameters. Table 1 summarizes the sample dataset collected during a 60-minute monitoring session of a simulated Vehicle-to-Grid setup.

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

Our sensors showed stable operation with an average voltage measurement error observed was **±1.5%**, which is normal for non-commercial and prototype systems

2. Cloud Integration and Dashboard

Data was uploaded to Firebase at 5-second intervals without packet loss. Our Python dashboard is used to display real-time voltage, current, and power graphs.

3. AI-Based Forecasting

In order to evaluate the performance of the system, we used a dataset of 500 entries was used to train ML models:

4. Discussion

The results show that using ESP32 with Firebase can work as a cheap but useful way for V2G monitoring. It is simple to set up and can give live data. When we add AI models for prediction, it becomes more helpful because it can guess future charging and discharging patterns. This type of forecasting can help the power grid stay balanced and also plan for demand.

Still, there are some problems. Sensors need proper calibration or else the readings may not be correct. The system also depends on internet connection, so if network is weak the data flow may stop. Also, since the data size used is small, the AI predictions may not always be very strong. For big use, we may need better sensors and more solid data transfer methods like MQTT with some local backup at edge device.

In general, the project looks promising. It gives a low-cost and scalable way to monitor EV energy. This can be useful not only for charging stations but also in mixing renewable energy with grid.

6. Challenges and Limitations

The suggested framework gives a good way for V2G monitoring, but there are still some problems and limits that must be kept in mind:

1. Sensor Accuracy and Calibration
   Cheap sensors like ZMPT101B and ACS712 are fine for simple checking, but they can give noisy or drifting values. They don't have very high precision, so they need regular calibration. Without that, results may not be trusted much, specially in grid level work.
2. Internet Dependency
   This system depends on Firebase Cloud, so it always needs internet. If internet is weak or gone, data can be lost, updates will be late, or system may not work properly.
3. Data Security and Privacy
   When data is sent to cloud, there is risk of hacking or misuse. To make it safe, encryption and secure login is needed, and rules of data protection should be followed.
4. Scalability Issues
   ESP32 with Firebase is good for lab or small demo, but if many EVs and chargers are used, then stronger servers and more data handling will be required.
5. AI Forecasting Limits
   Machine learning works only if there is enough real data. If dataset is small, then predictions will not be much accurate. Also, heavy models like LSTM need more power, which small boards like ESP32 cannot handle easily.
6. Battery Degradation
   Repeated charging and discharging of EV batteries slowly reduce their life. Current forecasting system does not check this properly. Adding battery health monitoring is still a challenge.

CONCLUSION & FUTURE SCOPE

This paper looked at the idea of Vehicle-to-Grid (V2G) and gave a simple framework to monitor energy using ESP32, cloud with Firebase, and some AI for forecasting. The study showed that watching voltage and current in real-time is very important to make bidirectional energy flow more smooth and reliable. By using low-cost boards and easy cloud platforms, the system can be useful for both students and people working on smart grid projects.

Adding machine learning makes the setup even better, because it can try to guess future energy use and grid behaviour. Simple models like regression and Naïve Bayes can be a start, but stronger models like LSTM may give more accurate results when enough data is available.

For future work, the system needs to be tested with many EVs and chargers to check scalability. More efforts are also needed for better sensor accuracy, data safety, and also checking battery health. If the system is linked with renewable energy, it can give even more benefit for clean and stable power use.

In short, this approach shows how cheap IoT boards, cloud, and AI can work together to grow V2G technology and help build smart and strong energy systems for future.

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