

Priority-Based Dynamic Load Balancing Algorithm for Smart Grid- Integrated EV Charging

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Abstract— The increasing adoption of electric vehicles (EVs) is creating new challenges for charging infrastructure, particularly when multiple charging loads operate simultaneously under limited power availability. This paper presents the design and experimental development of a prototype smart EV charging management system for source-constrained charging applications. An ESP8266 microcontroller is used to monitor the charging-source voltage and the prototype battery voltage. Based on the available source power and the measured battery-voltage condition, the controller determines the charging state and operates a relay-based switching circuit to regulate the charging path.

To demonstrate renewable-energy-assisted charging, the prototype incorporates a solar photovoltaic panel and a 12 V, 200 Wh auxiliary battery-storage unit. The proposed controller estimates the available charging energy and approximate charging duration and adjusts the charging operation according to predefined voltage and power thresholds. Experimental tests are performed under different source-availability and battery-voltage conditions to evaluate the charging response, switching operation, and energy-utilization behavior.

The prototype demonstrates the fundamental principles of source-aware EV charging, basic dynamic load management, and solar-assisted energy utilization. However, the system is intended as a low-power experimental platform and does not replace a certified electric vehicle supply equipment (EVSE), automotive battery-management system, or grid-connected charging controller. The developed prototype provides a foundation for future work involving multi-EV coordination, current-based state-of-charge estimation, IoT monitoring, charging-priority algorithms, solar-energy optimization, and communication with standard-compliant EVSE systems.

Keywords— Electric vehicle charging, smart charging, dynamic load management, ESP8266, solar-assisted charging, battery storage, IoT, relay control, EVSE.

I. INTRODUCTION

The increasing adoption of electric vehicles (EVs) has

created a growing demand for reliable, efficient, and intelligent charging infrastructure. EVs utilize electrical energy stored in rechargeable batteries to drive electric motors and provide an alternative to conventional internal-combustion-engine vehicles. However, increasing EV penetration introduces challenges related to charging demand, energy utilization, and electrical distribution network loading. Simultaneous operation of multiple charging loads may increase peak demand and place additional stress on the available power infrastructure. Therefore, effective charging management is essential to improve energy utilization and support reliable EV charging [1]–[3].

Smart charging involves monitoring and controlling the charging process according to power availability, battery requirements, and predefined operating conditions. Depending on the system architecture, charging-management techniques can regulate charging operation, prioritize loads, or coordinate power allocation among multiple charging units. Implementing these techniques requires appropriate sensing circuits, control logic, and switching mechanisms. Microcontroller-based systems offer a practical platform for developing cost-effective charging-control prototypes and demonstrating basic energy-management principles [2], [4].

The integration of renewable energy sources is another important consideration in EV charging management. Solar photovoltaic (PV) energy can supplement the available charging supply and reduce dependence on conventional electricity when sufficient solar power is available. However, PV output varies with solar irradiance, shading, and weather conditions, making source monitoring and appropriate charging control important. Auxiliary battery storage can improve energy availability by storing surplus energy for later use, depending on the system configuration and operating conditions. Previous research has investigated the integration of photovoltaic generation with EV charging and the role of energy storage in electric-vehicle applications [5], [6].

This paper presents the design and development of a prototype EV charging-management system based on an ESP8266 microcontroller. The proposed system monitors the DC voltage of the charging source and the battery voltage of

the prototype through suitable sensing circuits. The controller compares the measured parameters with predefined voltage thresholds and operates a relay-based switching circuit to control the charging path. Solar PV energy and an auxiliary battery-storage unit are incorporated into the prototype to demonstrate solar-assisted charging and basic energy management.

The proposed system focuses on source-aware charging control and basic load management in a low-power experimental environment. Its operation can be assessed under different source-availability and battery-voltage conditions by observing charging response and relay-switching behavior. The system is intended as an experimental demonstration of fundamental smart-charging principles; it is not designed to replace certified commercial electric vehicle supply equipment (EVSE) or an automotive battery-management system.

The main contribution of this work is the development of a microcontroller-based prototype integrating voltage monitoring, threshold-based control, relay switching, and solar-assisted energy management. The prototype provides a foundation for further development of intelligent charging systems. Potential future enhancements include current measurement, improved battery state-of-charge estimation, Internet of Things (IoT)-based monitoring, intelligent charging-priority algorithms, and coordinated charging of multiple EVs.

II. RELATED WORK

The increasing penetration of Electric Vehicles (EVs) has attracted significant research attention toward intelligent charging strategies for smart grid integration. Existing studies have mainly focused on coordinated charging, demand-side management, optimization techniques, Vehicle-to-Grid (V2G) operation, and renewable energy integration to reduce peak demand and improve grid stability [1], [2], [7], [8].

Several researchers have investigated uncontrolled and controlled EV charging strategies and their impact on distribution networks. Uncontrolled charging, in which EVs begin charging immediately after connection, can increase peak demand, voltage deviation, transformer loading, and power losses. To overcome these issues, coordinated charging methods have been proposed to regulate charging time and charging power according to grid conditions [3], [14].

Demand-side management (DSM) techniques have also been widely explored for managing EV charging demand. These techniques shift EV charging from high-demand periods to low-demand periods, thereby improving the load profile of the distribution network. Time-of-use pricing has also been studied as a method to encourage charging during off-peak hours. However, such strategies may depend on user behavior and charging preferences [2], [8], [10].

Optimization-based charging methods have been developed to achieve efficient allocation of charging power among multiple EVs. These methods consider factors such as grid load, State of Charge (SOC), charging duration, electricity cost, and renewable energy availability. Although optimization-based approaches can

provide improved charging schedules, their implementation may require accurate system information, communication infrastructure, and higher computational complexity [8], [12], [15].

Another important research direction is Vehicle-to-Grid (V2G) technology, which enables bidirectional power flow between EV batteries and the electrical grid. During periods of high electricity demand, EV batteries can supply energy back to the grid, while during low-demand periods, vehicles can be charged. V2G can support peak-load reduction and frequency regulation; however, practical implementation requires suitable communication, control, and bidirectional charging infrastructure. Frequent charging and discharging may also affect battery performance and life [5], [6].

The integration of renewable energy sources such as solar photovoltaic (PV) and wind energy with EV charging infrastructure has also been studied. Renewable energy-based charging can reduce dependence on conventional power generation and improve environmental sustainability. However, the intermittent nature of renewable energy creates challenges in maintaining a continuous balance between energy generation and EV charging demand [7], [12].

Although several existing studies have addressed EV charging management, there is still a need for simple, low-cost, and adaptable charging strategies that can dynamically respond to changing grid load conditions. Therefore, this research proposes an Arduino Uno-based Smart Grid EV Charging System with Load Balancing to monitor grid demand and control EV charging according to available capacity. The proposed system aims to reduce peak demand, distribute charging loads more uniformly, and improve the overall utilization and reliability of the power system.

III. PROBLEM STATEMENT

The rapid adoption of electric vehicles (EVs) is increasing electricity demand and creating additional challenges for existing power distribution networks. In conventional charging systems, EV charging may begin immediately after connection without considering the real-time availability of power from the charging source. When multiple EVs are charged simultaneously, the combined demand may exceed the available supply capacity, potentially causing excessive loading, voltage deviations, inefficient energy utilization, and increased stress on charging infrastructure.

A major challenge is the absence of a simple and efficient mechanism for managing EV charging according to source availability and battery-voltage conditions. Without appropriate charging control, increasing EV adoption may place additional stress on distribution networks. Meanwhile, EV users require reliable charging while maintaining suitable battery operating conditions.

Therefore, a smart EV charging management system is required to monitor the available charging-source voltage and auxiliary-battery voltage and control the charging path according to predefined operating conditions. The system should be capable of enabling, limiting, or disabling charging when the available energy supply is insufficient

and permitting charging when suitable conditions are detected. The key challenge is to implement source-aware charging control while reducing unnecessary loading and making effective use of available energy.

To address this challenge, the proposed research develops an ESP8266-based smart EV charging management prototype with solar-assisted energy management. The system monitors the charging-source voltage and auxiliary-battery voltage and controls the charging path using a relay-based switching mechanism. A solar photovoltaic panel and a 12 V, 200 Wh auxiliary battery-storage unit are incorporated to demonstrate renewable-energy-assisted charging under limited-power conditions. The prototype is intended to demonstrate basic source-aware charging control and improved utilization of available energy. Its performance is evaluated through voltage monitoring, relay-switching behavior, and charging-operation tests under different source and battery conditions.

IV. PROPOSED METHODOLOGY

A. Overall Methodology

The proposed system implements an ESP8266-based smart EV charging management prototype integrated with a solar photovoltaic (PV) panel and an auxiliary battery-storage unit. The system is designed to monitor the charging-source voltage and auxiliary-battery voltage and control the charging path through a relay-based switching mechanism. The methodology consists of system initialization, voltage acquisition, operating-condition evaluation, charging control, and continuous monitoring. The controller compares the measured voltage conditions with predefined thresholds to determine whether the charging path should remain enabled or be disconnected.

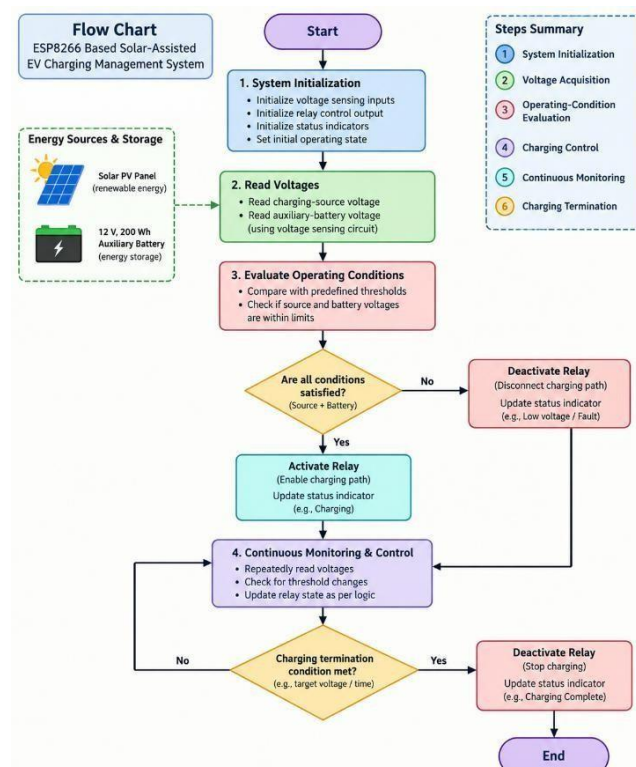


Fig. 1. Flowchart of the Proposed ESP8266-Based Solar-Assisted EV Charging Management System.

B. System Initialization

Initially, the ESP8266 microcontroller initializes the voltage-sensing inputs, relay-control output, and status indicators. The controller establishes the initial operating state and prepares the sensing and control modules for operation. Charging is permitted only after the monitored parameters have been evaluated against the predefined operating conditions.

C. Charging-Source Voltage Monitoring

The voltage of the charging source is measured using a suitable voltage-sensing circuit. The sensed signal is scaled to a range compatible with the input specifications of the ESP8266. The controller processes the measurement and compares it with the defined operating limits. This procedure enables the system to determine whether the source voltage is suitable for the intended charging operation.

D. Auxiliary-Battery Voltage Monitoring

The auxiliary-battery voltage is monitored to evaluate its electrical condition during system operation. The measured voltage is compared with predefined threshold values to determine whether the battery condition is suitable for the intended operating mode. Since battery voltage alone does not provide an exact measurement of the state of charge, the voltage-based assessment is treated as an approximate indicator of battery condition.

E. Solar-Assisted Energy Management

A solar photovoltaic panel and a 12 V, 200 Wh auxiliary battery-storage unit are incorporated into the prototype to demonstrate renewable-energy-assisted operation. The solar panel provides electrical energy under suitable irradiation conditions, while the auxiliary battery serves as an energy-storage component according to the implemented circuit configuration. The measured electrical conditions are used by the controller to manage the charging path. The actual contribution of solar energy depends on solar availability, conversion losses, storage conditions, and the connected load.

F. Relay-Based Charging Control

The ESP8266 evaluates the measured source and auxiliary-battery voltages using predefined control conditions. When the required operating conditions are satisfied, the controller activates the relay output to permit charging. If the measured parameters fall outside the permitted limits, the controller deactivates the relay output to disconnect the charging path. This switching mechanism provides basic source-aware charging control for the prototype.

G. Continuous Monitoring and Control

The system repeatedly acquires voltage measurements and evaluates the operating conditions during operation. Whenever a monitored parameter crosses its predefined threshold, the controller updates the relay state according to the programmed logic. Continuous monitoring enables the prototype to respond to variations in source availability and auxiliary-battery voltage.

H. Charging Termination

The charging operation is terminated when the

programmed stopping condition is satisfied, such as reaching a predefined voltage threshold or detecting an operating condition that requires disconnection. The ESP8266 then deactivates the relay output and updates the system status through the status indicator. Battery-specific charging limits and suitable protection circuitry are necessary for safe battery charging.

I. Working Principle

The working principle of the proposed system is based on voltage monitoring and relay-based control. The ESP8266 receives voltage measurements from the sensing circuits and compares them with predefined operating limits. Based on this evaluation, the controller enables or disables the charging path. The solar photovoltaic panel and auxiliary battery support renewable-energy-assisted operation according to the implemented hardware arrangement. The repeated measurement-and-control cycle provides a basic mechanism for managing the charging operation under changing electrical conditions.

The prototype is intended to demonstrate source-aware charging control and renewable-energy-assisted operation. Quantitative improvements in energy utilization, load balancing, or distribution-network performance require additional measurements and experimental validation.

This project uses the ESP8266 NodeMCU as the main controller for a smart EV charging station. Its job is to keep track of the electrical readings, estimate how much power the connected charging loads are using, and control the loads when the total demand gets too high.

The setup described in this report includes a voltage sensor, an ACS712 current sensor, an LCD, a relay driver, multiple charging loads and Firebase for online monitoring. The NodeMCU reads the sensor values and follows a priority-based method to decide which loads should remain connected when power is limited.

A suitable AC-to-DC power supply provides power to the controller and its electronic components. The voltage and current sensors measure the connected circuit, and the controller uses these readings to estimate the power being consumed. If the total demand is within the set limit, the loads can continue operating. If the demand goes above that limit, the controller can switch off an active load with a lower priority through the relay circuit.

The controller can also send readings and load-status information to Firebase over Wi-Fi. The LCD gives a local view of the system, while a compatible web or mobile dashboard can be used to view the stored data remotely. The main aim is to share the available power more carefully and reduce the chance of overloading.

1. Hardware Components and Their Functions

Each component has a particular role in measuring the electrical parameters, controlling the loads or displaying the system status.

1.1 ESP8266 NodeMCU Controller

The ESP8266 NodeMCU is the central controller. It receives readings from the sensors, works out the estimated power consumption and applies the load-balancing rules. It also sends signals to the relay driver when a load needs to be switched on or off. Since the board has built-in Wi-Fi, it can send the collected data to Firebase as well.

1.2 Voltage Sensor

The voltage sensor measures the voltage of the supply or the circuit being monitored. Its output is connected to the controller through a suitable sensing interface. The voltage reading is used together with the current reading to estimate power consumption.

1.3 ACS712 Current Sensor

The ACS712 measures the current flowing through the monitored circuit. The NodeMCU reads its output to estimate how much current a connected load is drawing. This helps the controller keep track of the demand from the charging loads.

1.4 Load Control Module and Relay Driver

The relay driver lets the NodeMCU control the connected loads. When the load-balancing rules call for a change, the controller sends a signal to switch the selected load on or off. The relay and driver must be rated for the load they are controlling.

1.5 LCD Display

The LCD shows information selected in the program, such as voltage, current, estimated power and load status. It gives the user a quick way to check the system locally without opening the online dashboard.

1.6 Firebase Real-Time Database

Firebase is used to store the readings and status information sent by the NodeMCU over Wi-Fi. A compatible web or mobile dashboard can retrieve this information so that the

V. Block Diagram

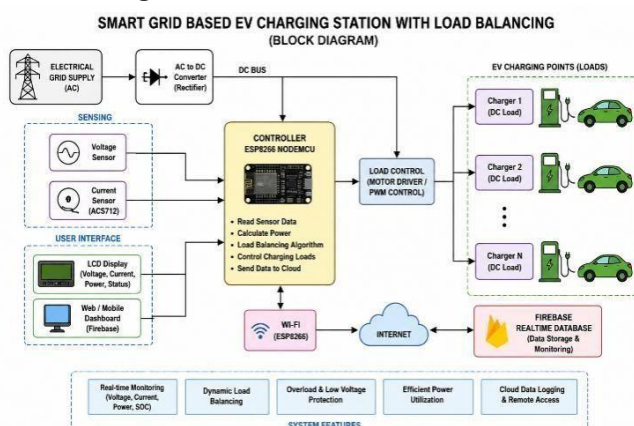


Fig. II. Block Diagram of the Proposed Smart Grid-Based EV Charging Station with Load Balancing.

Fig. 2 illustrates the conceptual architecture of the proposed Smart Grid Based EV Charging System with Load Balancing. The laboratory prototype implements the measurement, load monitoring, decision-making, and charging control functions using an Arduino Uno, voltage and current sensors, relay modules, and simulated EV loads.”

VI. IMPLEMENTATION USING ESP8266 NODEMCU

system can be checked remotely. The actual data shown will depend on the database and dashboard code used in the project.

1.7 EV Charging Loads

The charging loads represent the charging points managed by the system. Each one is given a priority in the control program. When the total demand is too high, the controller can disconnect a lower-priority active load and restore it later when enough capacity is available, following the programmed rules.

2. Mathematical Formulation

The controller estimates the power used by each connected load from the voltage and current readings. The following equations describe the calculations used to compare the total demand with the power limit.

For a load with a unity power factor, power can be estimated using:

$$P_i = V_i \times I_i \quad (1)$$

Here, P_i is the power used by load i in watts (W), V_i is its voltage in volts (V), and I_i is the current in amperes (A).

For an AC load with a power factor other than unity, the power factor also needs to be included:

$$P_i = V_i \times I_i \times \cos \phi_i \quad (2)$$

In this equation, $\cos \phi_i$ is the power factor of the load.

For n connected loads, the total power demand is the sum of the power used by each load:

$$P_{\text{total}} = \sum P_i, \text{ for } i = 1 \text{ to } n \quad (3)$$

Here, n is the number of connected loads.

The system can continue normal operation when the total demand is no greater than the power available to the charging station:

$$P_{\text{total}} \leq P_{\text{available}} \quad (4)$$

If the total demand exceeds the available limit, an overload condition exists:

$$P_{\text{total}} > P_{\text{available}} \quad (5)$$

The controller then applies the load-balancing rules to reduce demand, for example by disconnecting a lower-priority load. After switching, it checks the demand again. The target condition is:

$$P_{\text{balanced}} \leq P_{\text{available}} \quad (6)$$

P_{balanced} is the total demand after the control action. These equations provide the basis for the controller's decisions. The first equation assumes a unity power factor; for real AC loads, reliable active-power measurement may require power-factor measurement and suitable voltage and current sampling.

3. Priority-Based Load-Balancing Algorithm

When the system starts, the NodeMCU initializes the sensors, LCD, relay outputs and Wi-Fi connection. The power limit is set in the program, and each charging load is assigned a priority.

The controller reads the voltage and current values and estimates the power used by each active load. It adds these values to find the total demand, then compares that total with the configured limit. If the demand is within the limit, the current load states are left unchanged.

If demand is too high, the controller selects an active load with a lower priority and sends a signal to the relay driver to disconnect it. It then calculates the total demand again to check whether the system is back within its limit. The LCD is updated with the latest readings and load status, and the available data is sent to Firebase over Wi-Fi.

A disconnected load may be restored when sufficient capacity becomes available, according to the priority rules in the program. If the demand is still above the limit

and no more eligible loads can be disconnected, the system should indicate that the available capacity is insufficient. It should not report that the demand has been balanced unless the calculated demand is within the configured limit.

4. Working Principle of the Proposed System

The system follows a simple sequence: measure the electrical parameters, estimate the power demand, compare it with the set limit and control the loads when needed.

First, the NodeMCU starts the connected sensors, LCD, relay-control interface and Wi-Fi connection. The voltage sensor and ACS712 current sensor provide readings from the monitored circuit. The controller uses these readings to estimate the power consumption of each active load and calculate the total demand.

The total demand is then compared with the power capacity set for the system. If the demand is within the limit, the loads continue operating according to their assigned conditions. If it is too high, the controller chooses a lower-priority active load and switches it off through the relay circuit.

After this action, the controller checks the total demand again. The process continues until the demand is within the limit or no eligible loads remain to be disconnected. Voltage, current, estimated power and load status can be shown on the LCD. The NodeMCU can also send these readings to Firebase so that they can be viewed on a compatible dashboard.

In this way, the project brings together sensor-based monitoring, automatic load switching and online data viewing. The actual performance will depend on the hardware, sensor calibration and the control logic implemented.

5. Monitoring and Data Management Using Firebase

Firebase can store the readings and status information collected by the NodeMCU. Depending on the program, this may include voltage, current, estimated power consumption, total demand and the status of each charging load. A compatible dashboard can retrieve the stored data and display the current condition of the station.

The table below shows an example of how the test results may be presented. The values and observations are illustrative sample data, not measurements collected from the actual hardware. Replace them with real readings before final submission.

6. Safety Considerations and Limitations

The NodeMCU can monitor the system and control relays, but it does not replace the electrical protection needed in a real EV charging installation. The voltage sensor, ACS712, relay driver and switching devices must be selected for the circuit's actual voltage and current ratings.

Proper isolation, overcurrent protection, earthing and suitable charging equipment are important for safe operation. The controller should also account for faulty sensor readings, communication loss and unexpected switching conditions. If

Parameter	Minimum	Maximum	Average	Reference Range	Observation
Station Voltage (V)	228 V	232 V	230 V	220–240 V	Stable
EV Battery Voltage	46 V	50 V	48 V	48 V nominal	46–50 V

(V)					
Sensor Error (%)	1.2%	1.5%	1.33%	Below 2%	1.33%

Wi-Fi stops working, essential local load-control functions should still operate safely.

The system's performance depends on the quality of the sensor readings, how quickly the controller responds and whether the switching circuit works as intended. Its ability to balance demand is also limited by the configured power limit and the priority rules in the program.

Parameter	Minimum	Maximum	Average	Observation
Station Voltage (V)	228 V	232 V	230 V	4 V variation

VIII. ADVANTAGES AND LIMITATIONS

A. Advantages

The proposed Smart Grid-Based Electric Vehicle (EV) Charging System with Load Balancing helps manage the charging of multiple electric vehicles in an efficient way. When many EVs are charged at the same time, the electricity demand can increase and put extra pressure on the electrical grid. This system helps reduce that pressure by controlling the charging process during peak demand periods.

The system distributes the available power among different EV charging points according to their priority and power requirements. This helps prevent excessive power consumption and makes better use of the available electricity. It uses sensors to measure voltage and current, while the controller processes this information and controls the relay modules to manage the charging loads. Another major advantage of the system is its simple and low-cost design. Components such as Arduino Uno, voltage sensors, current sensors, relay modules, and LCD displays are easily available and can be used to develop the prototype at a reasonable cost. This makes the system suitable for students, laboratory experiments, and small-scale projects.

The system also allows users to monitor important electrical parameters and charging status through the LCD display and serial communication. This makes it easier to observe the system's operation and understand how the load-balancing process works. By controlling the connected loads, the system can help reduce the chances of overloading and support more stable operation.

The design can also be improved in the future to manage a larger number of EV charging points. Advanced communication systems and centralized monitoring can be added to make the charging process more flexible and efficient. The system can also be connected to renewable energy sources, such as solar panels, to use clean energy for EV charging. Overall, it provides a simple and affordable approach to managing EV charging demand

and improving the use of available electrical power.

B. Limitations

Although the proposed Smart Grid-Based EV Charging System with Load Balancing offers several benefits, it also has some limitations. The current system is developed as a small-scale prototype, so it has not been fully tested under real-world conditions with a large number of electric vehicles. Its performance may differ when used in a larger charging station with higher power requirements.

The system uses relay modules to control the charging loads. These relays can switch the loads ON or OFF, but they cannot continuously adjust the charging power. Because of this, the system cannot provide the same level of charging control as advanced commercial EV charging stations.

Another limitation is that the charging process depends on predefined power limits and priority settings. If these values are not selected correctly, the system may not distribute the available power as expected. During periods

EV Battery Voltage (V)	46 V	50 V	48 V	48 nominal V
Sensor Error (%)	1.2%	1.5%	1.33%	<2%

of high electricity demand, EVs with lower priority may have to wait longer before charging begins. This can increase the waiting time for some users.

The current prototype also does not include advanced communication between the utility grid, charging stations, and electric vehicles. Such communication could help improve monitoring and allow the system to respond more effectively to changing power demand. In addition, the system does not use advanced technologies such as Artificial Intelligence, Machine Learning, or other optimization methods to make charging decisions.

The system also has limited battery monitoring capabilities. To measure the battery's State of Charge (SOC) accurately, a suitable Battery Management System would be required. This feature is not included in the present prototype.

Furthermore, the accuracy of the system depends on the sensors used to measure voltage and current. If the sensors are not properly calibrated, the readings may contain errors and affect the load-balancing process. The current prototype also does not include all the advanced safety features required in commercial charging systems, such as complete electrical isolation, battery protection, and advanced fault detection.

Therefore, the proposed system can be improved by adding better charging control, advanced monitoring, improved communication, and additional safety features. Further testing under practical conditions would also be necessary before using it in a real-world EV charging station.

IX. CONCLUSION

The use of Electric Vehicles (EVs) is increasing because they provide a cleaner alternative to traditional fuel-based vehicles. However, charging a large number of EVs at the same time can increase the demand for electricity. If all vehicles start charging together, the electrical grid may

experience a high load, which can affect its performance. Therefore, it is important to manage EV charging properly so that the available electricity can be used efficiently without putting too much pressure on the power system.

To address this problem, this project focuses on a Smart Grid-Based EV Charging System with Load Balancing. The main aim of the system is to control the charging of multiple electric vehicles according to the available power. An Arduino-based controller is used to monitor the electrical conditions with the help of voltage and current sensors. Based on the readings and the priority assigned to each charging load, relay modules are used to control which loads can remain active.

The basic idea behind this system is to avoid charging all connected EVs at full demand at the same time when the available power is limited. During peak hours, the system can temporarily delay the charging of lower-priority EVs so that the total load stays within the available power limit.

When electricity demand decreases, the system can allow more EVs to charge. This helps distribute the charging demand over time and makes better use of the available electrical power.

The developed concept also shows that EV charging can be managed using simple and affordable electronic components. By monitoring voltage, current, and connected loads, the controller can make charging decisions according to the programmed conditions. This provides a basic understanding of how load balancing can help manage electricity demand in an EV charging setup. Comparing controlled and uncontrolled charging conditions can further help demonstrate the benefits of coordinating the charging process.

One of the main benefits of the proposed system is that it offers a simple approach to reducing unnecessary load on the electrical grid. It can also serve as a starting point for developing more advanced EV charging systems. However, the current prototype has certain limitations, and further testing would be needed to evaluate its performance in larger and more practical charging environments.

In the future, the system could be improved by adding IoT technology for remote monitoring, cloud-based data storage, and communication between charging stations and the power grid. Renewable energy sources, such as solar panels, could also be integrated to support cleaner charging. Other factors, including battery State of Charge (SOC), user charging preferences, electricity prices, and battery health, could be considered to make charging decisions more effective.

In conclusion, the Smart Grid-Based EV Charging System with Load Balancing provides a practical starting point for managing the growing electricity demand caused by electric vehicles. By controlling charging according to available power and predefined priorities, the system can help improve load distribution and make

better use of electricity. With further improvements and testing, this approach could contribute to more efficient, reliable, and sustainable EV charging in future Smart Grid systems.

X. FUTURE SCOPE

The proposed Smart Grid-Based EV Charging System with Load Balancing can be improved further to make it more useful in real-life situations. At present, the system focuses on managing the charging load according to the available power and the priority of each EV. In the future, some additional features can be added to make the charging process easier, smarter, and more efficient.

1. Charging Multiple Electric Vehicles

The current system can be extended to handle more electric vehicles at the same time. Separate charging points can be provided for each vehicle, with sensors to measure its voltage and current. This would help the controller keep track of the power used by each EV and distribute the available electricity more effectively. It would also make the system more suitable for places such as parking areas, offices, and public charging stations. **Better Battery Monitoring**

In the future, the system can include better battery monitoring to understand how much charge is left in an EV's battery. Instead of depending only on voltage readings, the system could use current, temperature, and other battery information to estimate the State of Charge (SOC) more accurately. It could also monitor the State of Health (SOH) to get an idea of the battery's condition over time. This information would help the system decide which vehicle needs charging first and avoid unsuitable charging conditions.

2. Using AI to Manage Charging

Artificial Intelligence (AI) and Machine Learning (ML) could be used to make charging decisions more intelligently. For example, the system could study previous charging records and identify the hours when electricity demand is usually high. Based on this information, it could plan charging schedules in advance instead of reacting only when the load increases. Methods such as Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) could also be tested to find better charging schedules while considering power availability, charging priorities, electricity prices, and user needs.

3. Using Solar Energy for EV Charging

Another useful improvement would be to connect the system with solar panels. The controller could monitor how much solar power is available and adjust the charging load accordingly. When sunlight is strong and more solar energy is being generated, more electricity could be used for charging EVs. When solar generation is low, the system could adjust charging according to the available power. This would help make better use of renewable energy and reduce dependence on conventional electricity sources.

4. Mobile Application and Online Monitoring

The system could also be connected to the internet using IoT technology. This would allow users to check the

charging status without being physically present at the charging station. A mobile application or website could show which charging points are available, how much power is being used, and how long charging may take. Charging information could also be stored online so that users and operators can check previous records whenever needed.

5. Managing Charging Costs and Peak Demand

In the future, the system could consider electricity prices while deciding when an EV should be charged. Electricity rates may vary depending on the time of day, so charging could be scheduled during cheaper periods whenever possible. The system could also reduce or delay some charging loads when the overall electricity demand is high. This would help users save money while reducing unnecessary pressure on the electrical grid.

6. Vehicle-to-Grid Technology

A further development could be the use of Vehicle-to-Grid (V2G) technology. With this technology, a compatible EV can send some of its stored energy back to the electrical grid when extra power is needed. This could help support the grid during periods of high demand. However, this

feature would require compatible vehicles, special bidirectional chargers, and proper control and safety systems. It cannot be implemented simply by adding it to the existing relay-based setup.

7. Online Booking and Payment

If the system is developed for use at public charging stations, online booking and payment facilities could also be introduced. Users could check available charging points, reserve a time slot, and view their charging history through a mobile application or website. These features would make the charging process more convenient and help operators manage the station in a better way.

8. Managing Multiple Charging Stations

The system could eventually be expanded to manage several EV charging stations from a central platform. An Energy Management System (EMS) could collect information from different stations and help distribute power according to their requirements. Cloud computing could be used to store charging records and study power consumption over time. This would make it easier to understand demand patterns and plan charging more effectively across multiple locations.

9. Connection with Smart City Systems

In the future, EV charging could become a part of a larger Smart City system. Charging stations could work together with solar-powered buildings, energy storage systems, and other local sources of electricity. For example, available solar power from a building could be used to support nearby EV charging when suitable infrastructure is available. Connecting these systems could help reduce energy waste and improve the overall use of available electricity.

Overall, there are many ways in which the proposed EV charging system can be developed further. Features such

as improved battery monitoring, solar power integration, online monitoring, and better charging schedules could make it more useful and efficient. The system could also be expanded to support more vehicles and charging stations. With further development and testing, it may provide a practical way to manage the growing demand for EV charging while making better use of the available electrical power.

XI. REFERENCES

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