



G2V & V2G Bidirectional Power Transfer Integrated with Solar Energy Source

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ABSTRACT: This project, G2V & V2G Bidirectional Power Transfer Integrated with Solar Energy Source, focuses on the design and implementation of an intelligent energy management system that enables two-way power flow between the grid, solar panel, and electric vehicle (EV) battery. The system utilizes an AC-to-DC converter to charge the EV battery from either the grid or solar energy, while an inverter circuit allows excess stored energy to be fed back into the grid. Voltage sensors are used to continuously monitor solar panel output and battery levels, and these parameters are processed by an Arduino microcontroller. Based on real-time conditions, the controller determines the direction of power flow, ensuring efficient utilization of available energy sources and maintaining battery health. The system operates in multiple modes to enhance efficiency and reliability. When sufficient solar energy is available and the battery is not fully charged, the EV battery is charged using solar power. If the battery reaches full capacity and additional solar energy is still available, the system switches to Vehicle-to-Grid (V2G) mode, where excess energy is supplied back to the grid through an inverter. In situations where solar energy is insufficient and the battery level is low, the Grid-to-Vehicle (G2V) mode is activated, allowing the grid to charge the battery using a buck converter. Relay modules are employed for automatic switching between these modes, and an LCD display is used to show real-time system parameters for user monitoring. Furthermore, the system enhances energy reliability and promotes sustainable energy usage by effectively integrating renewable sources with conventional grid supply. Safety features such as over-voltage protection, under-voltage protection, and overcharging prevention are incorporated to ensure secure operation of the battery and associated components.

The Arduino controller continuously analyzes sensor inputs and manages switching operations to maintain stable and efficient energy flow. This approach not only improves battery life but also reduces peak load demand on the grid. The system can be further upgraded with IoT-based monitoring for remote access, data logging, and smart

grid integration, making it a cost-effective and future-ready solution for electric vehicle energy management.

KEYWORDS: Bidirectional Power Transfer, Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), Solar Energy Integration, Arduino Microcontroller, Energy Management System, Renewable Energy, Electric Vehicle (EV) Charging.

1. INTRODUCTION

This paper introduces the global shift toward sustainable transportation and renewable energy has highlighted the need for sophisticated energy management systems capable of handling bidirectional power flow. Traditional power systems are largely unidirectional, designed for energy to flow from the grid to the load. However, the rising adoption of Electric

Vehicles (EVs) and the integration of intermittent renewable sources like solar power necessitate more dynamic interactions.

This project focuses on the design and implementation of an intelligent, bidirectional power transfer system that integrates Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) technologies with a primary solar energy source. By utilizing an embedded Arduino-based control approach, the system manages energy distribution between solar panels, EV batteries, and the utility grid in real-time.

The system prioritizes renewable energy by using solar power to charge the EV battery whenever sufficient sunlight is available. In scenarios where the battery is fully charged and surplus solar energy exists, the system operates in V2G mode, feeding power back into the grid to support stability and peak demand management. Conversely, when solar output is insufficient and the battery level is low, the G2V mode is activated to ensure continuous power availability. Through automatic relay-based switching and continuous voltage monitoring, this system offers a cost-effective, scalable solution for improving grid efficiency and promoting eco-friendly energy usage.

Table 1.1: Literature survey of some of the existing work :

S.No	Author Name	Description of Work	Methodology / Focus	Key Finding(s)
1.	M. Eltohamy, A. Y. Abdelaziz, and M. A. Tolb	Detailed study on V2G systems and energy storage	Explaining bidirectional power flow and control strategies for grid stability.	Proper energy management is critical for maintaining grid stability using EV storage.
2.	R. Kumar, S. Singh, and P. Sharma	Analysis of large-scale V2G integration.	Focus on system-level applications and grid interaction.	EVs significantly assist in load balancing and peak shaving for improved grid performance.
3.	E. Yayla, O. Erdinc, and M. Uzunoglu	Development of a smart energy management system.	Integration of solar energy to optimize power flow between panels, battery, and grid.	Optimization reduces energy costs and improves overall system efficiency.
4.	K. Srihari, B. Ramesh, and P. Venkatesh	Proposed an optimization-based approach for renewables.	Intelligent control of renewable energy sources.	Prevents system overloading and improves overall reliability
5.	N. Rotering and M. Ilic	Study on the economic aspects of V2G systems.	Research into the financial impact of bidirectional power.	Bidirectional transfer can reduce electricity costs and improve energy utilization efficiency
6.	M. Rana, A. Q. Al-Shetwi, and M. A. Hannan	Review of bidirectional converter topologies.	Analysis of AC-DC and DC-DC converter designs.	Analysis of AC-DC and DC-DC converter designs.
7.	S. Habib, M. Kamran, and U. Rashid	Impact of V2G on grid stability and power quality.	Study of voltage fluctuations and harmonics.	Improper control leads to voltage fluctuations and power quality issues.
8.	Y. Liu, C. Wang, and J. Wang	Control strategies for bidirectional converters.	Focus on voltage and current regulation	Proper regulation is key to enhancing system performance and reliability.
9.	A. Dubey and S. Santoso	Smart grid communication systems.	Analysis of data exchange requirements between EV and grid.	Effective V2G operation depends heavily on robust data exchange for proper control.

II. PROBLEM STATEMENT

The increasing adoption of electric vehicles (EVs) and the growing demand for renewable energy integration have introduced new challenges in energy management and power distribution. Conventional charging systems primarily support unidirectional power flow (Grid to-Vehicle), which limits the efficient utilization of stored energy in EV batteries. At the same time, renewable energy sources such as solar power are intermittent in nature, leading to situations where excess energy is either wasted or insufficient to meet demand. Additionally, there is a lack of intelligent systems that can automatically manage energy flow between solar panels, EV batteries, and the grid based on real-time condition

Existing systems do not effectively support bidirectional power transfer (Vehicle-to Grid), dynamic switching between energy sources, or optimal energy utilization. This results in inefficient energy usage, increased dependency on the grid, and underutilization of renewable energy. Furthermore, manual monitoring and control of such systems are impractical and prone to errors. Therefore, there is a need for an automated, cost effective, and intelligent system capable of managing bidirectional energy flow, ensuring efficient EV charging, utilizing excess solar energy, and maintaining reliable power availability under varying conditions.

III. METHODOLOGY

The methodology of this project follows a structured sequence focused on integrating renewable energy with bidirectional power electronics through an intelligent embedded control system. The process begins with **real-time sensing**, where voltage sensors continuously monitor the DC output of the solar panels and the state of

charge of the lithium-ion battery. This data is fed into an **Arduino Uno microcontroller**, which serves as the central processing unit to execute the system's decision-making logic. Based on the voltage inputs, the Arduino manages **automatic mode switching** via relay modules to prioritize solar-based charging whenever sunlight is sufficient and the battery is not full.

If the battery reaches full capacity while excess solar energy is available, the controller activates an **inverter circuit** to convert DC power to AC for the **Vehicle-to-Grid (V2G)** mode. Conversely, in the absence of sunlight and at low battery levels, the system triggers the **Grid-to-Vehicle (G2V)** mode, utilizing an AC-to-DC converter and a **buck converter** to step down grid power for regulated battery charging. This closed-loop methodology ensures optimal energy utilization, maintains battery health through over-voltage and under-voltage protection, and provides constant status updates via a 16x2 LCD display.

The implementation of this bidirectional power transfer system is centered on a sophisticated hardware-software co-design that ensures seamless energy transitions between the grid, the vehicle, and renewable solar assets. At the heart of the hardware architecture is a high-performance Arduino Uno microcontroller, which functions as the "brain" by executing a real-time control algorithm based on continuous data streams from analog voltage sensors. These sensors are calibrated to monitor the photovoltaic (PV) array's output and the lithium-ion battery's state-of-charge, providing the necessary feedback to maintain system equilibrium. To handle the physical power conversion, the methodology employs a diverse set of power electronic modules. For Grid-to-Vehicle (G2V) operations, the system utilizes a bridge rectifier circuit to convert incoming AC utility power into DC, followed by a buck converter stage that steps down the voltage to a regulated level appropriate for the battery chemistry, thereby preventing thermal stress or overcharging.

The intelligence of the system is most evident in its autonomous decision-making logic, which prioritizes sustainability and grid resilience. The software is programmed to operate in a "Solar-First" mode, where the EV battery acts as a primary sink for clean energy whenever the sensors detect sufficient irradiance. However, the methodology expands beyond simple charging; it incorporates a dedicated Vehicle-to-Grid (V2G) pathway. When the microcontroller identifies that the battery has reached its upper voltage limit and solar production remains high, it triggers a single-channel relay to engage the DC-to-AC inverter. This allows the vehicle to transform from a passive load into a distributed energy resource, feeding surplus electricity back into the local network to assist with peak shaving.

Furthermore, the methodology integrates critical safety protocols and user-centric feedback mechanisms to ensure long-term reliability. The Arduino code includes software-based debouncing and threshold hysteresis to prevent "chatter" or rapid, damaging switching of the mechanical relays during fluctuating weather conditions. For real-time monitoring, a 16x2 Liquid Crystal Display (LCD) is interfaced with the controller to provide a constant readout of solar voltage, battery status, and the current operational mode (G->V, V->G, or Solar Charging). This comprehensive approach not only demonstrates the technical feasibility of bidirectional EV integration but also provides a scalable framework for future smart-grid applications.

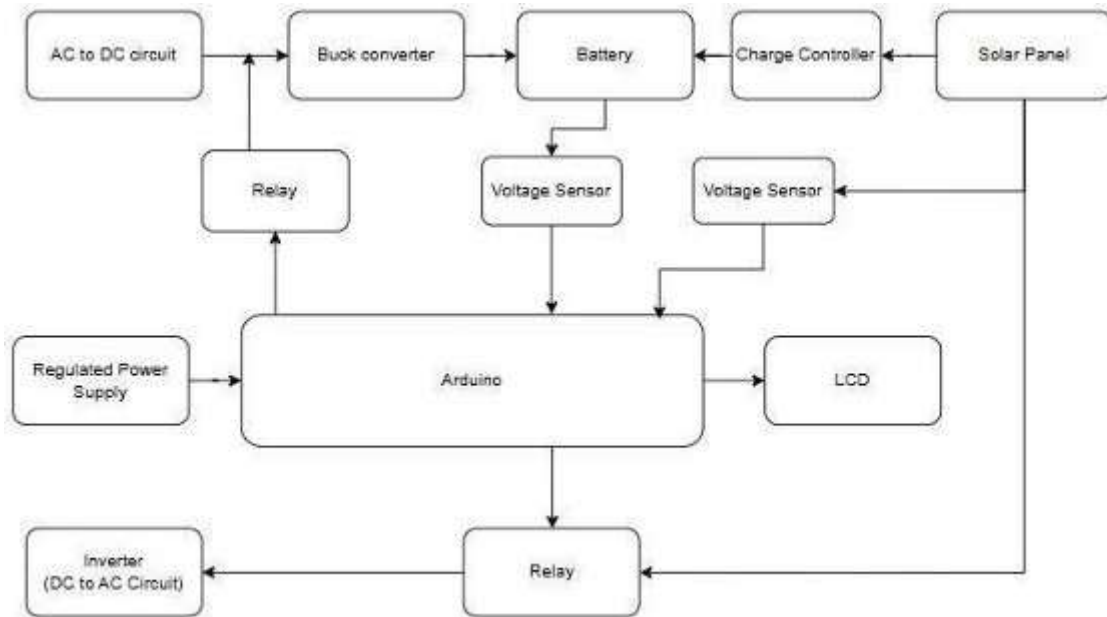


Fig 3.1: Block Diagram of Solar V2G – G2V System

Fig 3.1 represents a bidirectional power transfer system integrating grid power, solar energy, and an electric vehicle (EV) battery with intelligent control. The AC supply from the grid is first converted into DC using an AC-to-DC circuit, and then regulated through a buck converter to charge the battery in G2V mode. At the same time, the solar panel generates DC power, which is controlled by a charge controller before supplying energy to the battery. Voltage sensors continuously monitor both the solar panel output and battery voltage, and this data is sent to the Arduino microcontroller. Based on these real-time inputs, the Arduino controls relay modules to automatically switch between different modes of operation. When excess energy is available in the battery, the system activates the inverter to convert DC back to AC and feed it to the grid (V2G mode). A regulated power supply provides stable power to the Arduino, and an LCD is used to display system

parameters such as voltage levels and operating status. Overall, the system ensures efficient energy management and seamless power flow between the grid, solar source, and EV battery.

IV. SYSTEM DESIGN AND IMPLEMENTATION

The circuit diagram represents a bidirectional power transfer system that connects the grid, solar panel, and EV battery with intelligent control using an Arduino.

A. HARDWARE INTERFACING:

The grid AC supply is first converted into DC using an AC-to-DC converter. This DC power is then regulated through a buck converter to safely charge the battery in G2V mode. At the same time, the solar panel generates DC power, which is passed through a charge controller to provide a stable output for charging the battery. The battery acts as the main energy storage unit in the system.

Voltage sensors are used to continuously monitor the solar panel voltage and battery voltage. These sensor values are given to the Arduino microcontroller, which acts as the brain of the system. Based on these inputs, the Arduino controls relay modules to decide the direction of power flow. When solar energy is sufficient, the battery is charged using solar power. If the battery is fully charged and excess energy is available, the system activates the inverter to convert DC power from the battery into AC and sends it back to the grid (V2G mode). When solar power is low and the battery level is also low, the system switches to grid charging mode (G2V).

A regulated power supply provides a constant 5V to the Arduino and other control circuits. The LCD display shows important parameters such as solar voltage, battery voltage, and the current mode of operation.

Overall, this circuit ensures efficient energy management by automatically switching between solar, battery, and grid, enabling smooth bidirectional power flow.

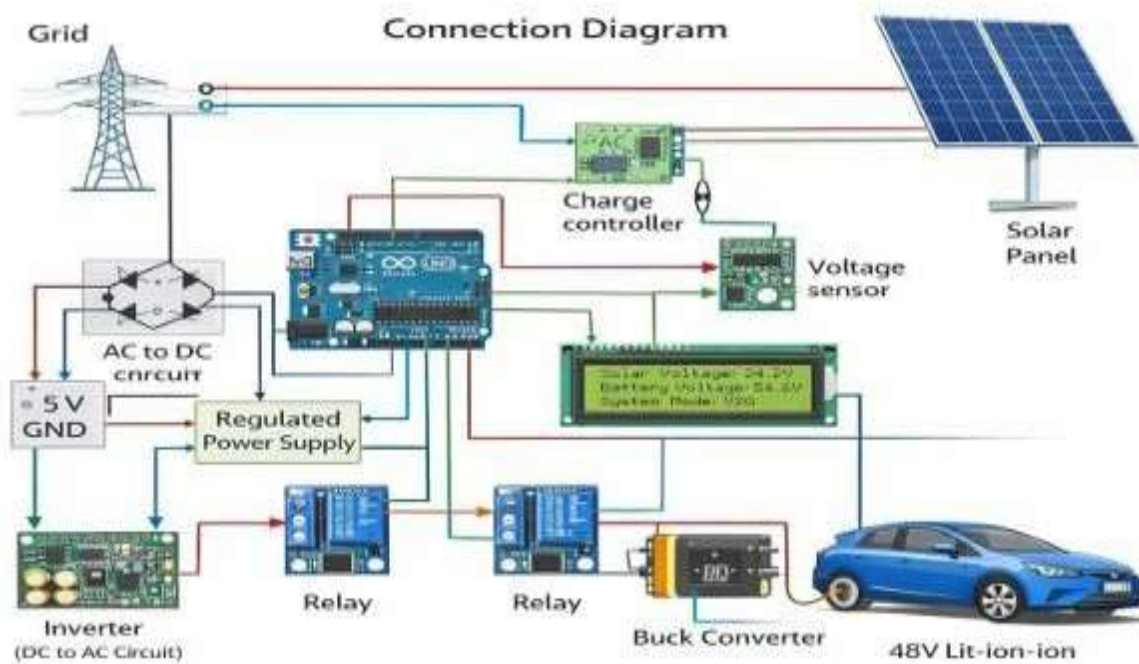


Fig 4.1: Circuit Diagram of Solar V2G – G2V System

B. SYSTEM FLOWCHART :

The process starts by initializing all components such as the Arduino, sensors, relays, and LCD. Then, the system continuously reads the solar panel voltage and battery voltage using sensors. Based on these values, the system first checks whether the available solar power is sufficient.

If solar power is sufficient, the system checks the battery condition. If the battery is not fully charged, it uses solar energy to charge the battery. If the battery is already charged, the system can manage excess energy (typically sending it back to the grid in V2G mode).

If solar power is not sufficient, the system checks whether the battery level is low. If the battery is low, it switches to G2V mode and charges the battery from the grid using an AC-to-DC converter and buck converter. If the battery level is not low, the system remains in standby mode without unnecessary power transfer.

After each operation, the system updates all parameters on the LCD display for user monitoring. This process runs continuously in a loop, ensuring automatic decision-making, efficient energy usage, and smooth switching between solar, battery, and grid power sources.

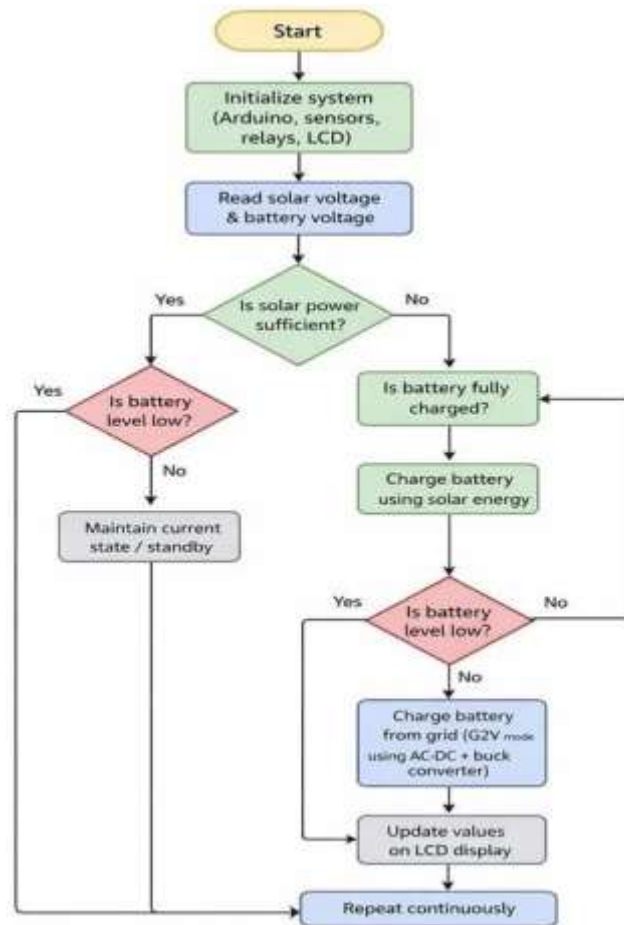


Fig 4.2: Flowchart of Solar V2G – G2V System

V. RESULTS AND DISCUSSION:

5.1 System Implementation Results:

The proposed bidirectional power transfer system was successfully implemented and tested under different operating conditions. The integration of solar panel, EV battery, grid supply, and control circuits was achieved using an Arduino-based control system. The hardware setup functioned reliably, enabling smooth switching between different modes such as solar charging, Vehicle-to Grid (V2G), and Grid-to-Vehicle (G2V). The system effectively monitored solar and battery voltages in real time and performed automatic decision-making based on predefined conditions.

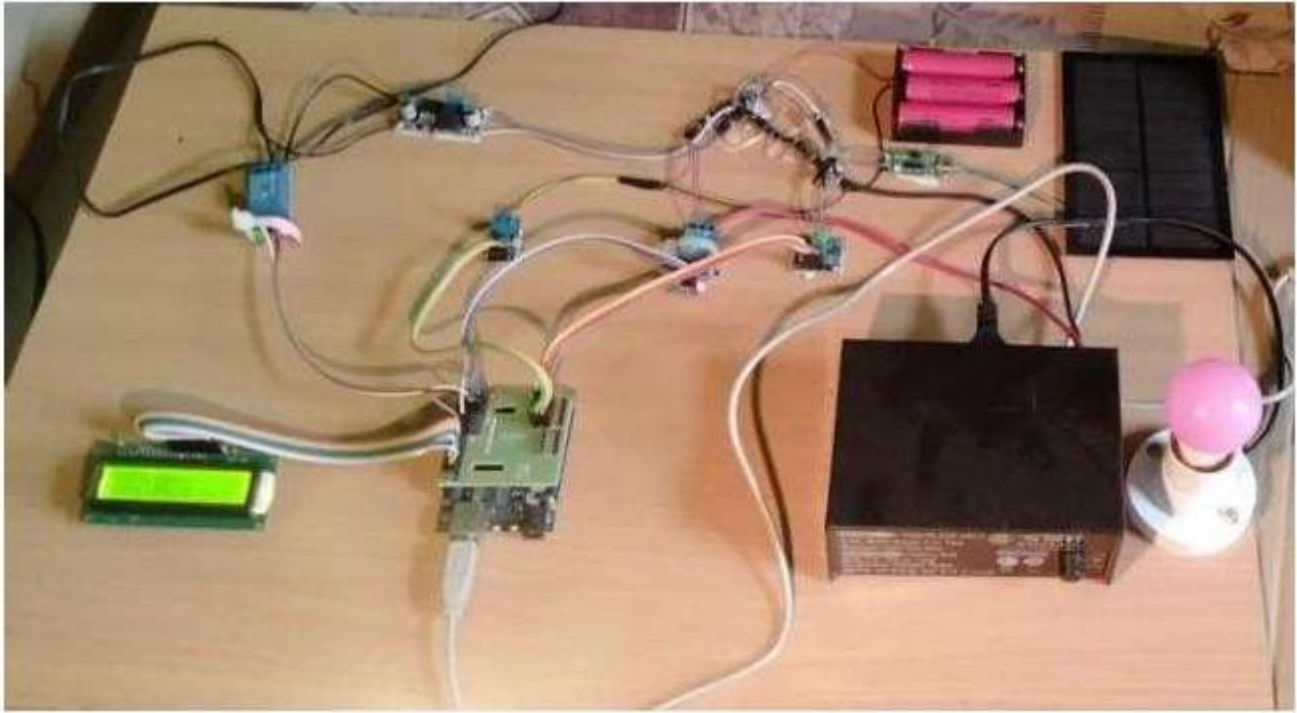


Fig 5.1: Hardware Prototype of G2V and V2G Bidirectional Power Transfer System

Figure 5.1 shows that the implemented bidirectional power transfer system integrates solar panel, EV battery, grid supply, and Arduino-based control unit. The setup enables efficient switching between solar charging, V2G, and G2V modes. It successfully monitors voltage levels and performs automatic control, ensuring reliable and stable system operation under different conditions.

5.1.1 Solar Based Charging Performance:

When sufficient solar voltage was available and the battery was not fully charged, the system successfully utilized solar energy for charging the EV battery. The charging process was stable, and the battery voltage increased gradually as expected. This demonstrates efficient utilization of renewable energy and reduced dependency on Grid power.



Fig 5.2: Solar Charging Mode Showing Battery Charging from Solar Panel

Figure 5.2 shows that the system operates in Vehicle-to-Grid (V2G) mode when solar energy is available and the battery is fully charged. The inverter circuit is activated to feed excess energy back to the grid. The transition occurs automatically, ensuring efficient utilization of surplus power without any energy wastage..

5.1.2 Vehicle To Grid (V2g) Operation:

The system was tested under conditions where solar energy was available and the battery was fully charged. In this scenario, the inverter circuit was activated, and excess energy was successfully fed back into the grid. The transition to V2G mode was automatic and seamless, ensuring that surplus energy was not wasted.

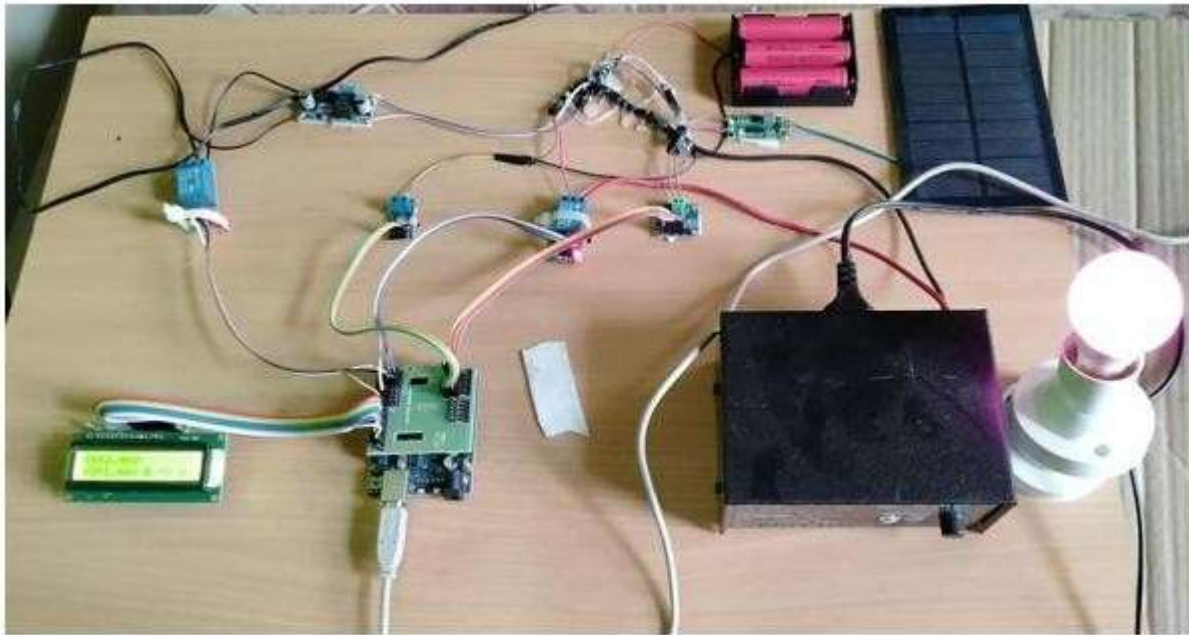
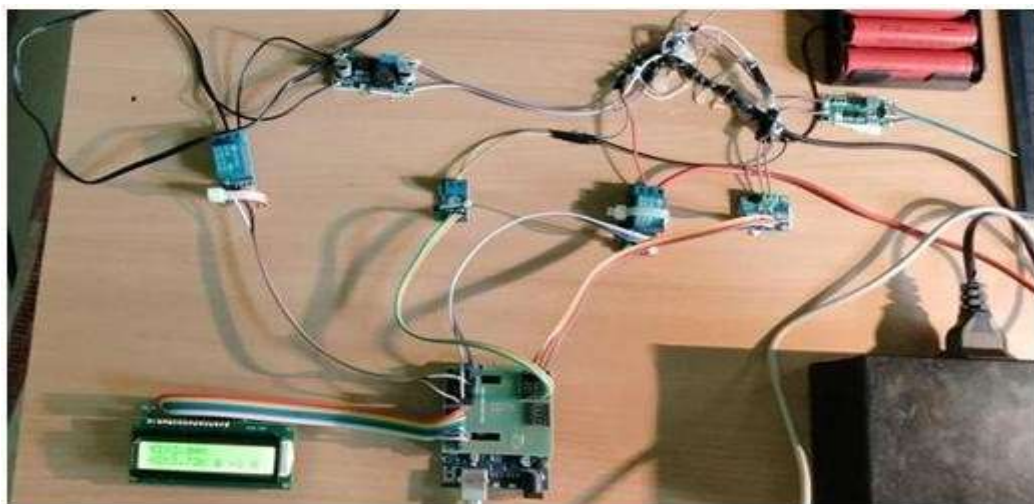


Fig 5.3: V2G Mode Operation Showing Power Transfer from Battery to Grid:

Figure shows that the system is operating in Vehicle-to-Grid (V2G) mode when sufficient solar energy is available and the battery is fully charged. The inverter circuit is activated to transfer excess energy back to the grid, indicated by the glowing bulb. The process occurs automatically, ensuring efficient use of surplus power without wastage.

5.1.3 Grid To Vehicle (G2V) Operation:



When solar energy was insufficient and the battery voltage dropped below the threshold, the system switched to G2V mode. The grid power was converted using an AC-to-DC converter and regulated through a buck converter to safely charge the battery. The charging process was stable, ensuring continuous battery availability even during low solar conditions.

Fig 5.4: G2V Mode Operation Showing Battery Charging from Grid Supply

Figure shows that the system operates in Grid-to-Vehicle (G2V) mode when solar energy is insufficient and the battery voltage falls below the set threshold. The grid power is converted and regulated to safely charge the battery. This ensures stable charging and continuous power availability during low solar conditions.

5.1.4 Automatic Switching Performance:

The relay-based switching mechanism was tested for different conditions, and the system successfully transitioned between operating modes without manual intervention.

- Fast response to changing voltage conditions
- Reliable switching between solar, battery, and grid
- No interruption in system operation

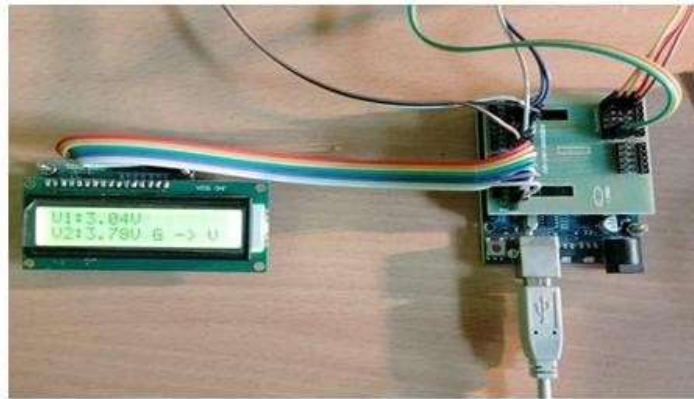


Fig 5.5: Relay Switching Mechanism for Mode Selection

Figure shows that the relay-based switching mechanism operates efficiently under different conditions. The system responds quickly to voltage changes and automatically switches between solar, battery, and grid modes. The transition is smooth and reliable, ensuring continuous operation without any interruption.

5.1.5 Voltage Monitoring And Display:

The voltage sensors accurately measured solar and battery voltages, and the values were displayed on the LCD in real time. The display provided clear information about system status and operating mode.

Fig 5.6 LCD Display Showing Solar Voltage, Battery Voltage, and Mode



Figure shows that the voltage sensors accurately measure solar and battery voltages, which are displayed on the LCD in real time. The display clearly indicates voltage values and system operating mode, providing easy monitoring and better understanding of system status.

5.1.6 System Efficiency And Performance:

The system demonstrated efficient energy management by:

- Prioritizing solar energy usage
- Preventing overcharging of battery
- Utilizing excess energy through V2G
- Ensuring backup through grid supply

The performance indicates that the system is suitable for real-time applications and small scale implementations.

5.2 Discussion

The results confirm that the proposed system effectively implements bidirectional power transfer using simple hardware and control logic. The automatic switching mechanism ensures optimal utilization of available energy sources while maintaining battery safety. The system successfully addresses key challenges such as renewable energy intermittency and efficient energy distribution. However, the system can be further improved by incorporating advanced control algorithms and higher-efficiency converters. Overall, the proposed system provides a practical, cost-effective, and scalable solution for integrating EVs with renewable energy and smart grid systems. The voltage sensor's 5:1 reduction ratio means that small fluctuations in the reference voltage can lead to significant discrepancies in the calculated State of Charge (SOC), potentially impacting the long-term health of the battery cells. Furthermore, the transition between power sources involves inherent switching latencies; in a real-world smart grid application, these micro-delays could result in transient voltage spikes or "inrush currents" that stress the power electronics. To mitigate this, the discussion should highlight the necessity of implementing software-based debouncing and hardware-level snubber circuits to protect the MOSFETs or relays during high frequency switching. Moving forward, the integration of IoT-based monitoring would transform this from a localized controller into a node within a decentralized energy network, allowing for "Peak Shaving" strategies where the EV battery acts as a buffer for renewable intermittency. By evolving from simple threshold-based logic to predictive algorithms, the system could anticipate energy demand based on historical usage patterns, thereby maximizing the economic viability of the bidirectional hardware while minimizing the thermal stress on the conversion stages.

VI. CONCLUSION:

The proposed project successfully demonstrates the design and implementation of a bidirectional power transfer system for Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) applications integrated with solar energy. The system effectively manages energy flow between the solar panel, EV battery, and grid using an Arduino-based control mechanism. By continuously monitoring solar and battery voltages, the system intelligently selects the appropriate mode of operation, ensuring efficient and reliable performance under varying conditions. The system prioritizes the use of solar energy for charging the EV battery, thereby promoting the utilization of renewable resources and reducing dependence on conventional grid power. When excess solar energy is available and the battery is fully charged, the system successfully operates in V2G mode by feeding surplus energy back to the grid through the inverter. In situations where solar energy is insufficient, the system ensures uninterrupted operation by switching to G2V mode and charging the battery using grid power through a regulated buck converter. The implementation of automatic switching using relay modules ensures smooth transitions between different operating modes without manual intervention. The use of voltage sensors and LCD display enhances system monitoring by providing real-time feedback to the user. The overall system demonstrates reliability, cost-effectiveness, and ease of implementation, making it suitable

for small-scale applications and educational purposes. In conclusion, the proposed bidirectional power transfer system provides an efficient solution for integrating electric vehicles with renewable energy and grid systems. It contributes to improved energy utilization, reduced energy wastage, and enhanced grid support. Future enhancements can focus on improving conversion efficiency, incorporating advanced battery management systems, and integrating IoT or smart grid technologies for large-scale deployment and intelligent energy management.

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