

Design And Development Of A Smart Bidirectional Vehicle-To-Grid Charger For Electric Vehicles

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Abstract: The rapid progression of electric vehicles (EVs) in the transportation sector poses a potential challenge of increased peak energy demand on existing grid structures. Consequently, the significance of V2G power conversion technology becomes paramount in managing sudden surges in energy requirements. To address this issue, the authors propose a "Bidirectional Converter Based on V2G and G2V Operation" which focuses on facilitating energy transfer between vehicles and the grid through bidirectional converters, catering to both V2G and G2V operations. In this work, the authors analyzed a bidirectional buck-boost converter interface with an H bridge AC/DC converter together with the related control method in a reduced topology. The efficiency of the developed system is evaluated with the help of a developed simulation model in MATLAB/SIMULINK

I. INTRODUCTION

Today, the electrification of transportation has been one of the major aspects of modernization and innovation, with the primary need for environmental sustainability and the gradual phasing out of fossil fuels being its major driving forces (1)(2). Along with this, the usage of Electric Vehicles (EVs) is claimed to be a possible solution for the reduction of greenhouse gases and lowering the carbon footprint(3)(4), thus the adoption of EVs is going at an accelerated pace. In the case where the EVs charging is unmanaged and they are getting charged randomly or at the same time, this situation is called "uncontrolled charging," it becomes hard on the grid which might lead to instability, local losses, congestion, and deviations of either voltage or frequency(5)(6)(7).

To resolve these issues, research and development of sophisticated charging technologies have been carried out for managing the vehicle-grid interaction. The first efforts were around Grid-to-Vehicle (G2V) technology, which works with only one-way power flow to control charging at peak hours so that the grid is not completely loaded.(6)

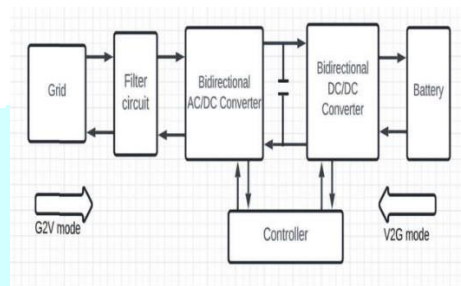
The next breakthrough over this method is the Vehicle-to-Grid (V2G) technology that comes with a bidirectional converter that lets power to flow both ways between the EV and the grid(8)(9). Here, the EV is not treated as just a load but instead as the energy storage device or local supplier that is capable to give power back to the grid. By this power, the EVs can assist in the following:- frequency regulation, spinning reserve, peak shaving, and load balancing, which are all ancillary services to the power grid(10)(11).

Apart from grid assistance, two-way chargers make moves for Vehicle-to-Home (V2H) operations. During V2H operation, the power that is stored in the battery of the EV can be the optimizer if the power cuts

during the day or at night and in grid unconnected areas, it can be used as a backup primary source of power (12)(13). The bidirectional charger is classified as an indispensable part in the development of highly efficient and connected power distribution systems as well as very smart homes due to its multiple functionalities (14).

The configuration of a bidirectional charger usually encompasses two power conversion sub processes which are interconnected via a common DC link: a full-bridge AC/DC converter connected to the grid and a bidirectional DC/DC converter connected to the vehicle battery (15)(16). In the case of charging (G2V), the circuit is regarded as a rectifier with power factor correction (PFC) resulting in a sinusoidal current draw, while the DC/DC section behaves as a buck converter (17)(18). On the other hand, during discharging (V2G or V2H), the DC/DC part is in boost mode to increase the voltage of the battery, and the AC/DC part acts as an inverter deliver the power back to the grid or home load(19)(20). This research illustrates the provision and evaluation of such a bidirectional converter, furthermore, it gives the insights on the control strategies and performance of the converter in different operational modes.

II. SYSTEM DESCRIPTION:-



The entire block diagram of the proposed bidirectional charging system is represented in Fig. 1. The diagram delineates the total combination of the bi-directional converter which is used for both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) modes. It demonstrates plainly the interconnections of the blocks and the power flow between the grid and the electric vehicle battery.

The proposed system is made up of a filter circuit and two bi-directional power converter stages. The filter circuit's, i.e., its main function is to lessen the harmonics, particularly the total harmonic distortion (THD) level which is accomplished through decreasing the grid side current. A controller is used to control the DC-DC converter stage along with the charging of the DC voltage and hence providing a 400 V stable DC bus voltage.

A single-phase 230 V AC grid has been chosen as the power source.

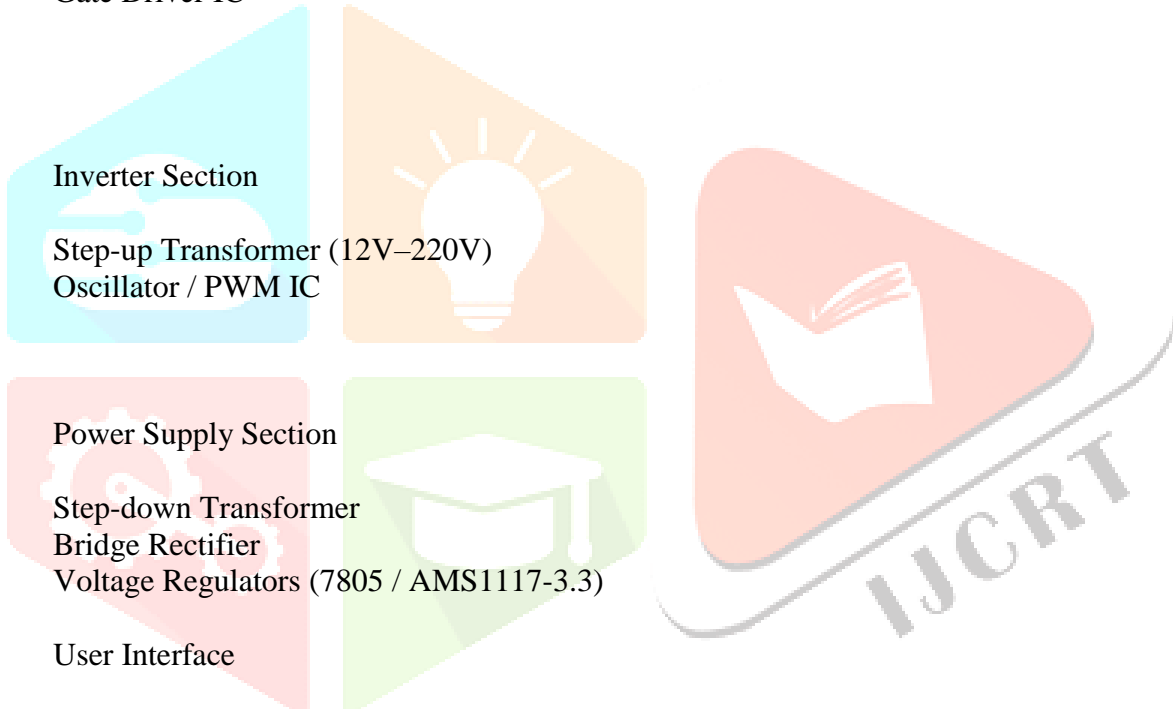
The battery gets charged by the grid in G2V operation when the grid is considered as a source. In V2G operation, the grid takes on the role of a load, receiving power from the battery. The two-way AC-DC converter guarantees flawless interaction between the grid and the DC bus. This converter works as an active rectifier in G2V mode, resulting in a sinusoidal current and Unity Power Factor (UPF). Conversely, it functions as an inverter in V2G mode, modeling Constant Current Source (CCS) to give the required energy back to the grid.

The bi-directional DC-DC converter manages the power interchange between the DC bus and the battery. It acts in buck mode to bring the grid voltage down to the battery voltage while controlling the current and voltage through the charging stages during G2V mode. The same converter works in boost mode during V2G mode, elevating the battery voltage to coincide with the DC bus voltage.

A lithium-ion battery with a voltage rating of 170V and a current rating of 12A is specified, which can be classified as a battery of an electric vehicle. In G2V mode, the battery gets power and in V2G mode, it discharges and thus supplies power. The controller in the bi-directional converter for V2G and G2V operation is used to control the energy flow between the EV and the grid.

III. COMPONENT USED :-

1. Main Controller
 - ESP32 Development Module
2. Measurement and Sensing
 - Units INA219 Current Sensor Module
 - PZEM-004T Energy Meter Module
 - AC Mains Detection Circuit
3. Power Switching Components
 - DPDT Relay
 - 12V Power Relay
 - Charging Relay
 - Power MOSFETs
 - Gate Driver IC
4. Inverter Section
 - Step-up Transformer (12V–220V)
 - Oscillator / PWM IC
5. Power Supply Section
 - Step-down Transformer
 - Bridge Rectifier
 - Voltage Regulators (7805 / AMS1117-3.3)
6. User Interface
 - 20x4 I2C LCD Display
 - Buzzer
 - Toggle Switches
7. Protection Components
 - Fuse, Diodes
 - Current Limiting and Biasing Resistors



IV. HARDWARE IMPLEMENTATION:-

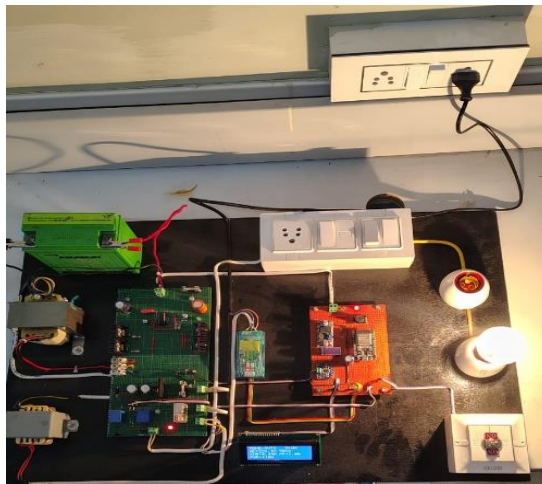


Fig no. 1

From here, power flows when the main grid connects and switches on. Instead of sitting idle, that incoming current gets managed through circuitry first. Then, it moves toward a rechargeable pack meant to act like an EV's built-in storage. Rather than waiting, the stored capacity begins filling up as long as connection stays active.

The lamp lights up because AC power is feeding the circuit. When mains electricity flows, it runs the device while topping up the battery at once. This picture shows both things happening together – energy going into storage and powering what's attached.

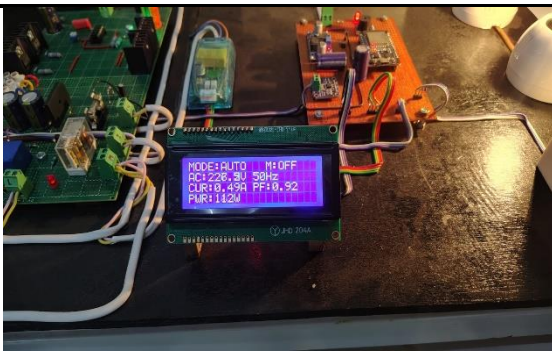


This picture shows how V2G works when discharging. With no AC power available, the battery takes over as main provider. Energy held inside powers the circuit instead. Operation keeps going without grid connection because of that flow.

Because of this, the light stays on, showing electricity moves from the battery to the device. Power flows backward here - battery sends energy out instead of storing it. That kind of discharge helps keep devices running when the grid fails or usage spikes. Vehicle-to-grid setups work like this when supply gets tight.

1. Control and Monitoring Unit:-

The system operates through its main component which is an ESP32 development module that handles system management together with PWM signal production and relay operation and real-time data collection. The controller continuously monitors voltage, current, and power parameters and executes logical decisions for charging and inverter modes.



The system uses an INA219 current sensor to measure DC-side current and the PZEM-004T energy meter module to measure AC-side voltage and current and power and energy parameters. The sensing units deliver feedback which enables safe operation while testing system performance..

2. Inverter and Power Conversion Stage

The inverter stage is implemented using power MOSFETs configured in a switching topology and driven by a gate driver circuit. A PWM-based switching technique is used to generate a controlled alternating waveform from the DC battery source.

The 12 V DC input is stepped up to 220 V AC using a step-up transformer. Proper isolation between low-voltage control circuitry and high-voltage AC section is maintained to ensure operational safety. Relay-based switching using DPDT and 12 V power relays enables bidirectional power flow. The system can operate in:

- a. Charging Mode – Grid supplies power to charge the battery
- b. Inverter (V2G) Mode – Battery supplies power to the AC load

Smooth transition between modes is achieved through controlled relay activation.

3. Power Supply and Regulation:-

The dedicated auxiliary power supply system employs a step-down transformer together with a bridge rectifier system and filter capacitors and two linear voltage regulators which include 7805 and AMS1117-3.3. The system provides two regulated output voltages of 5 V and 3.3 V which power the ESP32 and sensor modules

The system uses appropriate filtering capacitors which help control ripple effects while maintaining proper DC voltage output during different load scenarios.

4. Protection and User Interface

The system includes protection components which consist of fuses and diodes together with current-limiting resistors to protect against both overcurrent and reverse polarity situations.

The system displays real-time parameters through a 20×4 I2C LCD display which shows both voltage and current together with operational mode information. Users can select manual mode through toggle switches while the buzzer provides sound alerts to signal both switching activities and fault situations.

5. Prototype Validation

The developed hardware prototype confirms its ability to perform controlled DC-to-AC power conversion and real-time energy monitoring and stable bidirectional switching operations. The experimental setup proves that a microcontroller-based V2G interface can be implemented at low cost for small-scale residential and smart grid applications.

V. CONCLUSION

In this work, a microcontroller-based bidirectional vehicle-to-grid (V2G) prototype was successfully designed and implemented using an ESP32 controller, MOSFET-based inverter topology, relay-assisted switching network, and real-time energy monitoring modules. The system enables controlled power flow between the battery and AC side, supporting both charging mode and inverter (V2G) mode operation.

The developed hardware prototype demonstrates stable DC–AC conversion, effective voltage step-up to 220 V AC, and reliable mode transition using relay control. Real-time monitoring through INA219 and PZEM-004T modules ensures accurate measurement of voltage, current, and power parameters. The integration of sensing, control, and protection circuits enhances system safety and operational reliability.

Overall, the proposed design demonstrates the viability of low-cost V2G interfacing using embedded control techniques and provides a scalable platform for further improvements in grid synchronization, power quality enhancement, and intelligent energy management

VI. REFERENCES

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This appears to be an IEEE journal or magazine article covering the broader Vehicle-to-X space, including Vehicle-to-Home (V2H)