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# Bidirectional EV Charging for Frequency and Voltage Support in Smart Grids

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## ABSTRACT

The rapid growth of electric vehicles (EVs) is changing the electrical characteristics of distribution networks. Conventional charging mainly draws energy from the grid, whereas bidirectional charging enables controlled power transfer in both directions between an EV battery and the grid. This work investigates Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operation as flexible resources for frequency regulation and voltage support in smart grids. The proposed framework combines a bidirectional power converter, battery state-of-charge monitoring, grid measurements, communication, and a supervisory energy-management controller. During periods of excess generation or low system frequency, suitable EVs can inject active power into the grid. During surplus generation or when charging is beneficial, the controller can increase G2V charging within user and battery constraints. Reactive-power control can also be coordinated to assist voltage regulation. The framework is intended to improve grid flexibility while maintaining EV mobility requirements, battery operating limits, and charging quality.

**Keywords:** Bidirectional EV Charging, Vehicle-to-Grid, Grid-to-Vehicle, Frequency Regulation, Voltage Support, Smart Grid, Active Power, Reactive Power, Energy Management.

## I. INTRODUCTION

The increasing adoption of electric vehicles is creating a large and controllable electrical load. As the number of connected EVs grows, charging behavior can influence feeder loading, transformer utilization, voltage profiles, and system frequency. These effects become more important when many vehicles begin or stop charging at similar times. Instead of treating EVs only as passive loads, smart-grid operation can use their batteries as distributed energy resources when drivers permit controlled energy exchange.

Bidirectional charging extends conventional charging by allowing energy to move from the grid to the vehicle during G2V operation and from the vehicle back to the grid during V2G operation. The direction and magnitude of power exchange can be adjusted through a power-electronic converter. This controllability creates an opportunity to respond to short-term grid conditions without installing a separate stationary storage device at every location.

Frequency support can be achieved by adjusting EV active power in response to frequency deviations. When system frequency falls below its reference, selected EVs can reduce their charging demand or discharge stored energy. When frequency rises because generation exceeds demand, charging power can be increased within predefined limits. Voltage support can similarly use active and reactive power control to reduce local voltage deviations and improve power quality.

A practical system must balance grid-service objectives with EV-user requirements. The controller therefore needs information about battery state of charge (SOC), vehicle availability, requested departure time, allowable charging power, battery limits, and

local grid conditions. The proposed framework combines these constraints in a coordinated control strategy so that grid support is delivered only when adequate energy and user flexibility are available.

The study focuses on the architecture, control logic, and evaluation of a bidirectional EV charging framework for smart grids. The approach can be implemented in a simulation environment and later extended to hardware-in-the-loop testing and field deployment. The resulting system provides a foundation for coordinated EV participation in frequency regulation, voltage management, peak reduction, and renewable-energy integration.

## II. LITERATURE SURVEY

Early studies on EV-grid interaction established that uncontrolled charging can increase peak demand and alter distribution-network operating conditions. Research on coordinated charging subsequently introduced scheduling methods that consider network constraints, charging requirements, and power losses. These studies provide the basis for treating EV charging as a controllable grid load rather than a fixed demand.

Vehicle-to-grid research has investigated the ability of EV fleets to provide ancillary services. V2G can supply or absorb active power depending on system conditions, while the aggregate capacity depends on the number of connected vehicles, battery SOC, charger ratings, and user availability. Economic and technical analyses have also examined battery degradation, energy prices, and compensation for grid services.

Power-electronic converter research has enabled efficient bidirectional AC/DC and DC/DC power transfer. Grid-connected converters can regulate active and reactive power, synchronize with the grid, and operate under current and voltage constraints. These capabilities are essential for combining frequency response with voltage support in a single charging interface.

Recent smart-grid approaches increasingly combine forecasting, optimization, and real-time control. Forecasts of EV availability, renewable generation, and grid demand can be used to reserve battery capacity for anticipated disturbances. Optimization methods can simultaneously consider user convenience, energy cost, network constraints, battery degradation, and ancillary-service requirements.

The proposed work builds on these research directions by integrating frequency and voltage support within one bidirectional charging framework. Rather than using EVs only for scheduled energy exchange, the controller continuously evaluates grid measurements and available EV flexibility, then determines appropriate charging or discharging commands while respecting operating constraints.

## III. EXISTING SYSTEM

Conventional EV charging stations normally operate in a unidirectional manner. Electricity flows from the utility supply through the charging equipment to the vehicle battery, and the vehicle cannot return power to the grid. Charging schedules are usually designed around user demand rather than real-time grid requirements.

Some smart-charging systems can delay, accelerate, or modulate charging power to reduce peak demand. Although this provides useful flexibility, the EV remains a controllable load and cannot supply stored energy back to the network. Consequently, the available support is limited when the grid requires additional active power.

Separate stationary batteries and conventional voltage-control devices can provide grid services, but their installation adds equipment, cost, space, and maintenance requirements. Coordinating existing EV batteries with the grid can create an additional distributed storage resource when suitable bidirectional chargers and communication infrastructure are available.

A unified control framework is therefore required to coordinate EV charging and discharging with grid frequency, voltage, battery SOC, and user mobility requirements. Such a framework should distinguish between normal charging, frequency-response operation, voltage-support operation, and protective fallback states.

### Disadvantages of Existing System

Unidirectional charging cannot return stored EV energy to the grid.
Conventional charging may increase peak demand when many EVs charge simultaneously.
Limited coordination between EV charging and real-time frequency conditions.
Voltage fluctuations may remain unaddressed when charging power is controlled only from the user side.
Separate stationary storage may be required for some grid-support functions.
Uncoordinated bidirectional operation could increase battery cycling and conflict with driver mobility requirements.

## IV. PROPOSED SYSTEM

The proposed system introduces a bidirectional EV charging station connected to a smart grid through a controllable power-electronic interface. The main components are the utility grid, bidirectional AC/DC converter, EV battery, battery-management system, communication layer, grid measurement unit, and supervisory energy-management controller. The controller receives frequency, voltage, power-flow, SOC, and availability information before determining the operating mode.
During G2V operation, the controller supplies charging power according to the EV request while observing grid constraints. Charging can be increased when renewable generation is abundant or system frequency is above its reference. It can be reduced or temporarily paused when the grid approaches a demand or voltage limit.
During V2G operation, the EV battery supplies active power to the grid when sufficient SOC and driver authorization are available. The controller can use frequency deviation as a fast signal for active-power adjustment. A droop-like relationship or another response law can convert frequency error into a charging or discharging reference, subject to converter and battery limits.
Voltage support can be implemented through coordinated reactive-power control and, where appropriate, active-power modulation. The controller monitors the local voltage and generates a reactive-power reference when voltage moves away from its desired range. Priority logic can prevent simultaneous commands from exceeding converter current limits.
The supervisory controller also enforces user and battery constraints. Minimum and maximum SOC limits, requested departure time, maximum charging rate, reserve energy, battery temperature, and communication status are considered before a grid-support command is accepted. This allows EV participation without treating mobility needs as secondary to grid operation.

## V. SYSTEM ARCHITECTURE

The architecture contains five main functional layers: the electrical grid, bidirectional charging interface, EV battery subsystem, communication and measurement layer, and supervisory control layer. The grid supplies or receives active power and can exchange reactive power through the converter. The charging interface controls the direction and magnitude of power flow.
The EV battery subsystem contains battery modules and a battery-management system. The BMS monitors voltage, current, temperature, SOC, and protection status. Only the available energy above the required mobility reserve is exposed to the grid-service controller, helping to limit excessive discharge and protect battery operation.
The measurement and communication layer transfers grid frequency, voltage magnitude, active power, reactive power, charger status, and EV availability to the controller. Communication can be implemented using suitable smart-grid protocols. The controller should also detect stale or invalid measurements and move the charger to a safe fallback state when communication is lost.
The supervisory controller is the central decision layer. It combines grid-service requirements with EV constraints and determines charging, discharging, and reactive-power references. A hierarchical strategy can assign fast frequency response to the inner converter loop while slower scheduling functions manage SOC, user requirements, and economic objectives.

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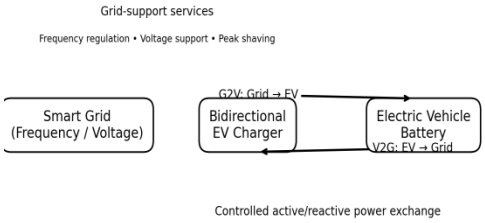



Fig 5.1: Concept of Bidirectional EV Charging in a Smart Grid

## VI. IMPLEMENTATION

The proposed framework can be implemented using MATLAB/Simulink, PSCAD, Python-based power-system simulation, or another suitable engineering platform. The model contains the grid, bidirectional converter, EV battery, measurement blocks, control logic, and communication delay. Time-series profiles can be created for grid frequency, voltage, EV availability, and charging demand.

The implementation begins by defining EV and grid parameters. Each EV is represented using battery capacity, initial SOC, minimum and maximum SOC, charging and discharging power limits, arrival time, departure time, and mobility reserve. Grid parameters include nominal frequency, nominal voltage, feeder limits, and allowable voltage and frequency bands.

At every control interval, the energy-management algorithm evaluates frequency and voltage deviations together with EV availability. If the grid requires support and an EV has sufficient flexible energy, the controller calculates an active- or reactive-power reference. The bidirectional converter then tracks the reference while enforcing current, voltage, and power constraints.

Battery SOC is continuously updated from measured power and time. A reserve SOC is maintained so that an EV remains capable of meeting its expected mobility requirement. The controller can also impose a maximum cumulative discharge energy or battery-throughput limit to reduce unnecessary cycling.

The system is evaluated using frequency-deviation reduction, voltage-deviation reduction, peak-grid power, energy exchanged through V2G, charging-completion rate, SOC compliance, converter utilization, and response time. Baseline cases such as uncontrolled G2V charging and smart unidirectional charging can be compared with the proposed bidirectional strategy.

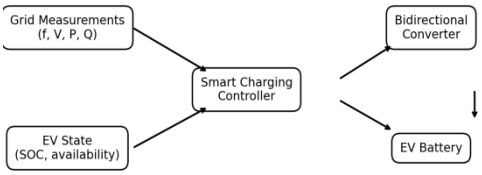



Fig 6.1: Smart-Grid Bidirectional Control Block Diagram

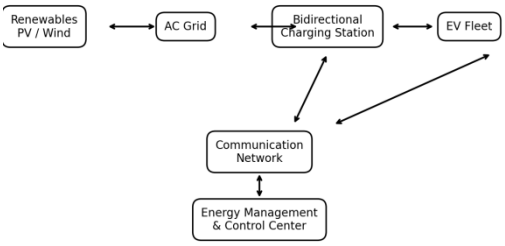



Fig 6.2: Integrated System Architecture

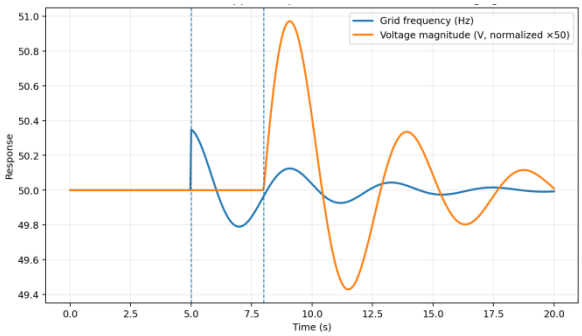



Fig 6.3: Illustrative Frequency and Voltage Support Response

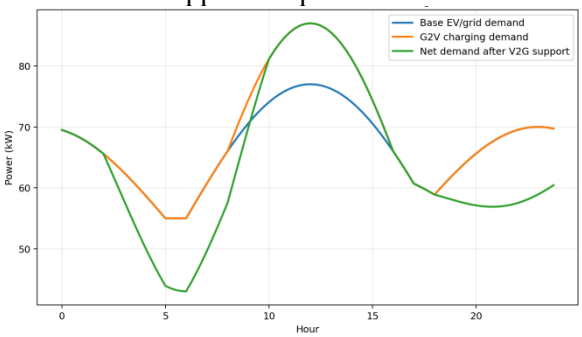



Fig 6.4: Illustrative Bidirectional Power Scheduling

## VII. CONCLUSION

The proposed bidirectional EV charging framework demonstrates how EV batteries can become controllable resources for smart-grid operation. By combining G2V and V2G capabilities with real-time grid measurements, the system can adjust active-power exchange according to frequency conditions and use reactive-power control to assist local voltage regulation.

The approach also emphasizes practical constraints. EV mobility requirements, SOC limits, converter ratings, communication reliability, and battery operating conditions must be incorporated into the control process. With appropriate coordination, EV fleets can provide grid flexibility while continuing to serve their primary transportation purpose.

Overall, bidirectional charging provides a promising technical pathway for integrating distributed storage into future smart grids. Further validation using detailed network models, hardware-in-the-loop experiments, and real charging infrastructure is required to quantify performance under diverse operating conditions.

## VIII. FUTURE SCOPE

Future work can incorporate short-term forecasting of EV availability, renewable generation, electricity demand, and grid disturbances. Predictive control could reserve sufficient EV energy for mobility while allocating the remaining flexibility to frequency and voltage services.

Multi-objective optimization can jointly consider frequency quality, voltage deviation, charging cost, battery degradation, user satisfaction, and renewable-energy utilization. Distributed optimization may also allow large EV fleets to participate without relying on a single centralized controller.

Advanced converter controls can investigate simultaneous active and reactive power support, unbalanced-network compensation, harmonic mitigation, and fast frequency response. Integration with vehicle-to-building and vehicle-to-home operation can further extend the usefulness of bidirectional charging.

Future research should also address cybersecurity, communication delays, battery aging, interoperability standards, aggregator coordination, and field validation. Hardware-in-the-loop testing and pilot-scale demonstrations can help establish practical operating limits and quantify the long-term impact of frequent grid-service participation.

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