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V2G-Enabled DC Fast Charging in PV -Based Microgrids

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ABSTRACT

The increasing demand for electrical energy and depletion of fossil fuels necessitate advanced solutions in modern power systems. This paper investigates the integration of renewable energy sources and plug-in electric vehicles within a microgrid framework to enhance grid stability. High peak-load demand introduces significant power fluctuations, which can be mitigated using coordinated energy management strategies. Electric vehicles are modeled as distributed energy storage systems enabling bidirectional power flow through Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. The proposed approach facilitates peak load shaving, efficient energy utilization, and improved power balance. Simulation results demonstrate the effectiveness of EV-assisted micro-grids in stabilizing the grid and supporting sustainable energy integration.

I.INTRODUCTION

The increasing global demand for electricity and the depletion of conventional fossil fuel resources such as coal, oil, and natural gas have created significant challenges in modern power systems. To address these issues, there is a growing emphasis on integrating renewable energy sources and plug-in electric vehicles (PEVs) into smart grids. However, high electricity consumption during peak hours can lead to load fluctuations, adversely affecting grid stability.

Micro-grids incorporating renewable sources like solar and wind energy, along with energy storage systems, offer a promising solution. In this context, electric vehicles (EVs) can function as distributed energy storage units, as they remain idle for extended periods. Through Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations, EVs can store surplus energy and supply it back during peak demand.

Despite its potential, large-scale V2G implementation in conventional grids faces challenges such as control complexity and infrastructure limitations. This paper proposes a DC fast charging station with V2G capability integrated into a micro-grid. The system enables efficient bidirectional power flow and incorporates a photovoltaic (PV) array via a common DC bus. The proposed model is validated through MATLAB/Simulink simulations under both G2V and V2G operating modes.

II .LITERATURE SURVEY

Vehicle-to-Grid (V2G) and Vehicle-Grid Integration (VGI) technologies have been extensively analyzed at site, utility, and system levels to assess their technical and economic potential. Early work by Tomic and Kempton [1], [2] demonstrated that electric vehicle (EV) fleets can generate annual revenues ranging from $70 to $1,030 per vehicle by participating in frequency regulation markets such as NYISO and CAISO.

A large-scale demonstration at the Los Angeles Air Force Base [3], [4] evaluated real-world V2G performance using plug-in electric vehicles (PEVs) for grid frequency regulation. Although the project delivered significant energy support, profitability was inconsistent due to market fluctuations and operational costs.

Demand response (DR) strategies have also been explored in projects such as the Honda Smart Charge initiative [5], which showed that EV users respond effectively to incentive-based charging programs. Similarly, SDG&E pilot studies [6], [7] demonstrated that time-of-use pricing can shift up to 94% of EV charging to off-peak periods.

Furthermore, the JUMP Smart Maui project [8] highlighted the potential of V2G systems to mitigate peak demand and support renewable energy integration through controlled charging and discharging.

Overall, these studies indicate that while V2G and VGI provide promising grid services, challenges related to market access, scalability, and operational complexity persist.

III.WORKING METHODOLOGY

A. Pulse Width Modulation (PWM) Principle

The proposed system utilizes Pulse Width Modulation (PWM) to operate power electronic converters in switched mode, ensuring high efficiency by minimizing switching losses. The output voltage is controlled by varying the pulse width of switching signals. The modulation index m is defined as:

$$m = \frac{V_{control}}{V_{tri}}$$

This expression defines the Modulation Index **(m)**, where the peak amplitude of the reference (modulating) wave—typically a sine wave—and represents the peak amplitude of the high-frequency triangular carrier wave. The ratio between these two amplitudes determines the width of the output pulses and controls the fundamental voltage magnitude of the converter.The switching frequency fs is maintained significantly higher than the fundamental frequency f1, with the frequency modulation ratio given by:

$$m = \frac{f_s}{f_1}$$

B. Sinusoidal PWM for Inverter Control

A sinusoidal PWM (SPWM) technique is implemented by comparing a sinusoidal reference signal with triangular carrier waveforms. The inverter output voltage is expressed as:

$$V_{Ao} = \begin{cases} \frac{V_{dc}}{2}, & V_{control} > V_{tri} \\ \frac{-V_{dc}}{2}, & V_{control} < V_{tri} \end{cases}$$

For a three-phase system, the reference voltages are defined as:

$$V_a^* = m\frac{V_{dc}}{2}\cos\theta,$$
$$V_b^* = m\frac{V_{dc}}{2}\cos(\theta - \frac{2\pi}{3}),$$
$$V_c^* = m\frac{V_{dc}}{2}\cos(\theta + \frac{2\pi}{3})$$

C. Multilevel PWM Techniques

To improve output waveform quality, level-shifted carrier-based PWM techniques such as In-Phase Disposition (IPD), Phase Opposition Disposition (POD), and Alternate Phase Opposition Disposition (APOD) are employed. These methods utilize multiple carrier signals to reduce Total Harmonic Distortion (THD) and enhance voltage levels.

D. PI Controller Design

A Proportional–Integral (PI) controller is implemented to eliminate steady-state error and improve system stability. The control output is given by:

$$u(t) = K_p e(t) + K_i \int e(t)dt$$

where e(t)=SP−PV represents the error signal.

E. Phase-Locked Loop (PLL)

A Phase-Locked Loop (PLL) is used to synchronize the output with the reference signal. The phase error is minimized as:

$$e_\theta(t) = \theta_{ref} - \theta_{out}$$

This ensures frequency and phase alignment for stable operation. The proposed methodology enables efficient power conversion, reduced harmonics, and reliable performance in micro-grid applications.

IV. RESULTS:

The control block diagram is shown in Figure 1 and the block diagram of the overall system is shown in Figure 2**.** The wind turbine is operated at rated speed giving an output maximum power of 100 kW. The solar PV is operated at standard test conditions (1000W/m2 irradiance and 25^o C temperature) giving 60 the maximum power output of 50 kW. A 150 kW resistive load is connected to the 480 V ac bus. The reactive current reference to GCI is set to zero for unity pf operation. The initial state of charge (SOC) of the EV batteries is set at 50%. Once the steady state conditions are reached, batteries of EV1 and EV2 are operated to perform the V2G-G2V power transfer. The current set-points given to the battery charging circuits of EV1 and EV2 batteries. The battery parameters when EV1 is operating in V2G mode and EV2 operating in G2V mode.

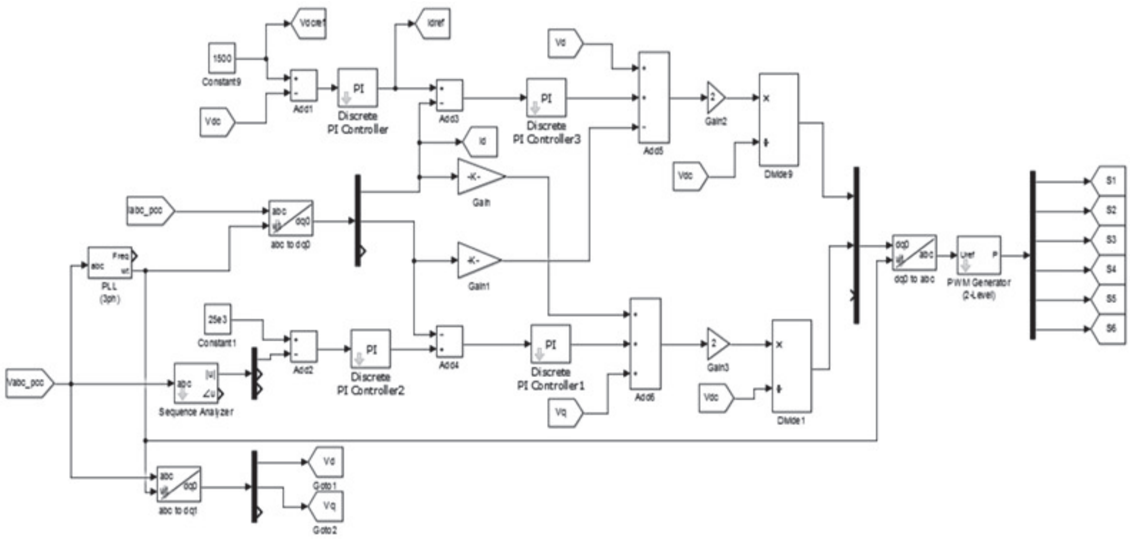

Fig 1. Control block diagram to generate pulse for converter.

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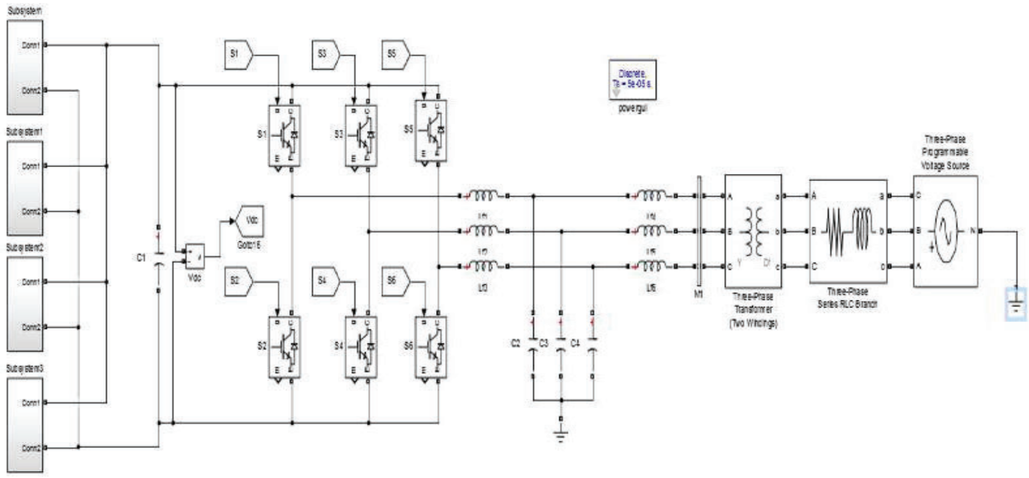

Fig.2. Simulation model of the plant considered for study.

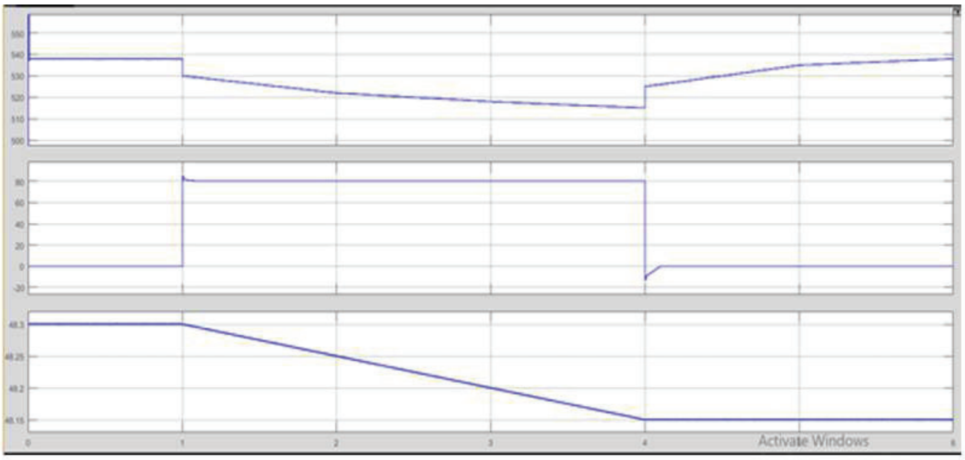

Fig.3. Voltage, current, and SOC of EV1 battery during V2G operation

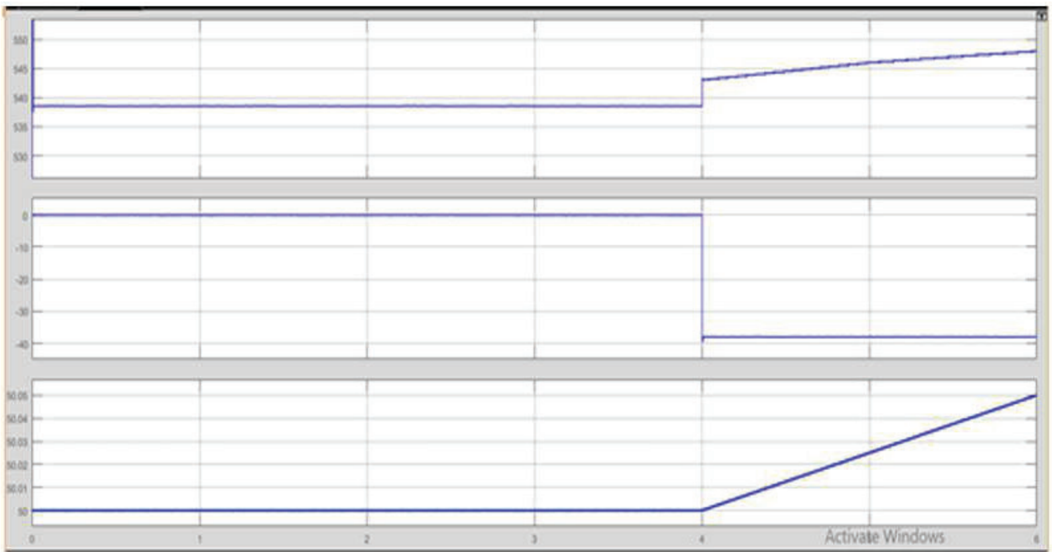

Fig.4. Voltage, current, and SOC of EV2 battery during G2V operation

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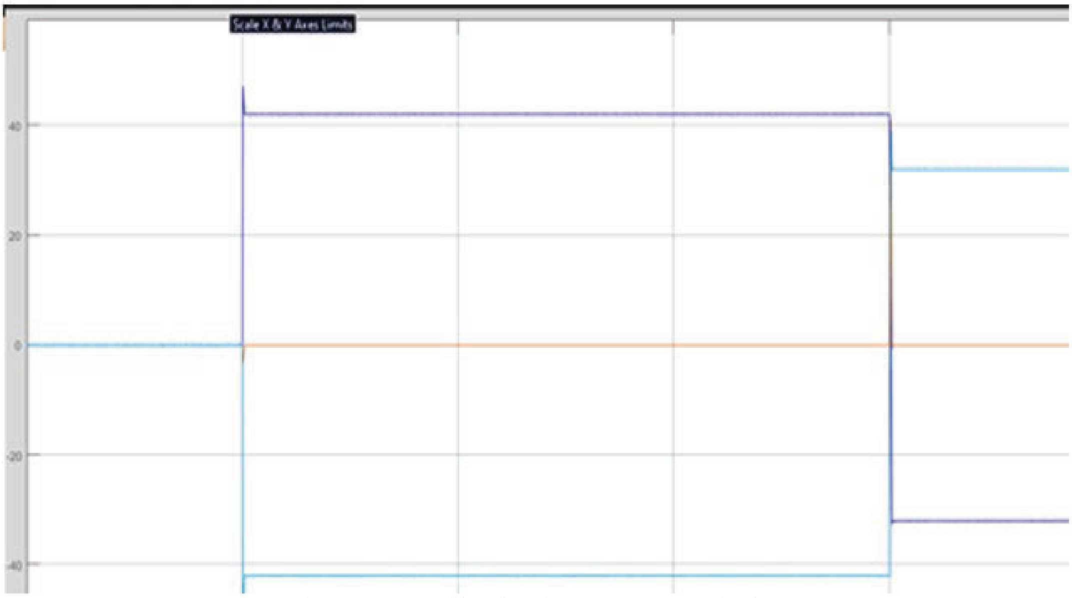

Fig. 5. Active power profile of various components in the system.

The grid power varies according to the power exchanged with EVs. From 1 s to 4 s, the negative grid power indicates V2G operation, where power is fed back to the grid. After 4 s, the polarity reversal represents G2V mode, with the grid supplying power to charge the EV battery. The net power at The PCC remains zero, confirming effective power balance. The voltage, current, and SOC of EV1 battery during V2G operation is shown in Figure 3. The voltage, current, and SOC of EV2 battery during G2V operation is shown in Figure 4 respectively. The active power profile of various components in the system is shown in Figure 5. The DC bus voltage is regulated at 1500 V using an outer voltage control loop, supported by an inner current control loop that tracks the d-axis reference current. At the PCC, grid voltage and current are in phase during G2V operation and out of phase during V2G operation, indicating bidirectional power flow. Further, the THD of the grid-injected current is measured as 2.31%, which complies with the IEEE 1547 limit of 5% for systems below 69 kV. This is achieved using a properly designed LCL filter.

V . CONCLUSION

Modeling and design of a V2G system in a micro-grid using dc fast charging architecture is presented in this paper. A dc fast charging station with off-board chargers and a grid connected inverter is designed to interface EVs to the microgrid. The control system designed for this power electronic interface allows bi-directional power transfer between EVs and the grid. The simulation results show a smooth power transfer between the EVs and the grid, and the quality of grid injected current from the EVs adheres to the relevant standards. The designed controller gives good dynamic performance in terms of dc bus voltage stability and in tracking the changed active power reference. Active power regulation aspects of the microgrid are considered in this work, and the proposed V2G system can be utilized for several other services like reactive power control and frequency regulation. Design of a supervisory controller which gives command signals to the individual EV charger controllers is suggested for future research.

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