VEHICLE-TO-GRID TECHNOLOGY IN A MICRO-GRID USING DC FAST CHARGING

A PROJECT REPORT

submitted in partial fulfilment of the requirements

for the award of the degree of

BACHELOR OF TECHNOLOGY in ELECTRICAL AND ELECTRONICS ENGINEERING

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December 2021

CERTIFICATE

This is to certify that the project work titled **"VEHICLE-TO-GRID TECHNOLOGY IN A MICRO-GRID USING DC FAST CHARGING"** submitted by **TANYA (19BEE1199), LALITHA KALA (19BEE1093), KAVETI MANASA (19BEE1135), ANISHMA(19BEE1214)** is a record of bona fide work done under my guidance for

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ACKNOWLEDGEMENT

We wish to express our sincere thanks and deep sense of gratitude to our project guide, **Dr Jayapragash,** Assistant Professor Senior, School of Electrical and Electronics Engineering, for her consistent encouragement and valuable guidance offered to us in a pleasant manner throughout the course of the project work.

We thank our parents, family, and friends for bearing with us throughout the course of our project and for the opportunity they provided us in undergoing this course in such a prestigious institution.

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VEHICLE-TO-GRID TECHNOLOGY IN A MICRO-GRID USING DC FAST CHARGING ARCHITECTURE

ABSTRACT

Electric Vehicle (EV) batteries can be utilized as potential energy storage devices in micro-grids. They can help in micro-grid energy management by storing energy when there is surplus (Grid-To-Vehicle, G2V) and supplying energy back to the grid (Vehicle-To-Grid, V2G) when there is demand for it. Proper infrastructure and control systems have to be developed in order to realize this concept. Architecture for implementing a V2G-G2V system in a micro-grid using level-3 fast charging of EVs is presented in this paper. A micro-grid test system is modeled which has a dc fast charging station for interfacing the EVs. Simulation studies are carried out to demonstrate V2G-G2V power transfer. Test results show active power regulation in the micro-grid by EV batteries through G2V-V2G modes of operation. The charging station design ensures minimal harmonic distortion of grid injected current and the controller gives good dynamic performance in terms of dc bus voltage stability.

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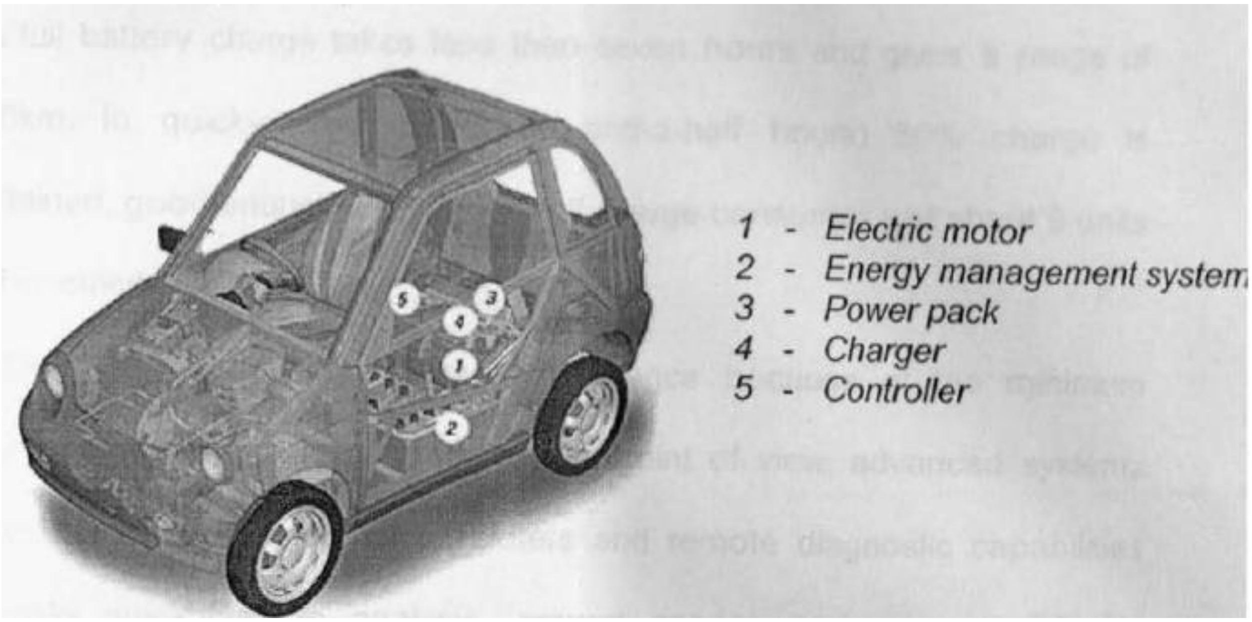
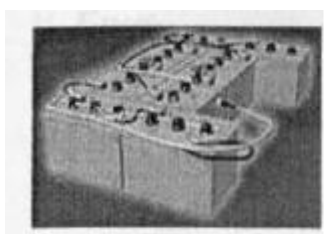
Need Of Electric Vehicle

Electric Vehicle (EV) technology is gaining ground and popularity rapidly. With depletion of oil reserves and a world characterized by smog, noise and all kinds of pollutants, governments and communities are awakening to the several b~nefits of EV technology. Zero emission vehicles are almost noiseless and can be charged at home or work, saving commuters endless queues at petrol stations. Charging at night when consumption is low, allows for efficient use of electricity. EVs are easier to service and maintain due to the absence of spark plugs, clutch and gears. Ideal for "stop - start" city driving conditions, EVs are extremely reliable and easy to drive. With the innumerable advantages of EVs, companies in developed countries have spent huge amounts to develop electric cars that can travel longer distances, providing high levels of comfort. In spite of this technology being available now, the cost of electric vehicles to suit driving requirements in these developed countries is prohibitively high.



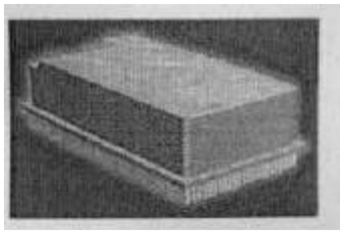
Power Pack

I) I REVA's Power Pack consists of eight 6-Volt EV tubular type lead acid batteries that attain 80% state of charge (quick-charge mode) in under 2.5 hours. A complete charge is achieved in less than seven hours and gives a range of * 80km. The Power Pack is housed beneath the front seats, which lowers the center of gravity, thus increasing the safety of passengers. Charging REVA is a safe and easy process - just plug into a 220 Volt, 15 Ampere socket - at home or at work. A full charge consumes just about 9 units of electricity.



Charger

REVA has an on-board Charger, which converts AC into DC power to charge the power pack. The charger is computer controlled with an in-built stabilizer and auto shut-off mechanism. The smart charger's output is connected to the Power Pack and ensures that optimum current and voltage is maintained at all times.



Ems

The brain of REVA is the Energy Management System (EMS) that monitors and controls all vital functions. The EMS is a computer-based system that optimizes charging and energy output of batteries to maximize operating range and improve performance. The system also predicts available range for a given state of battery charge and is a standard feature on the REVA. The EMS also maintains an electronic log of the vehicle performance, enables service personnel to run diagnostic checks on the car to give service information about the car

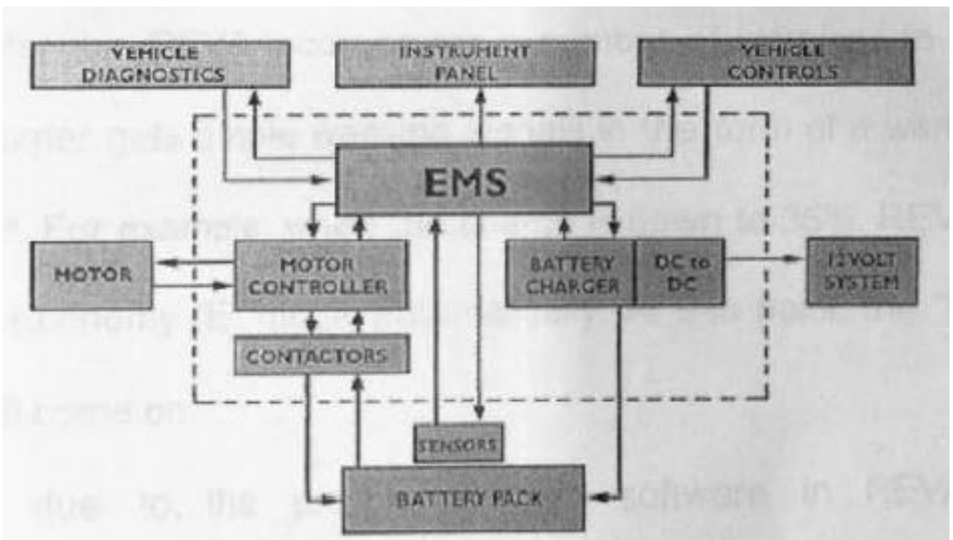


Fig Energy management system

MICROGRID

A microgrid[1] is a decentralized group of electricity sources and loads that normally operates connected to and synchronous with the traditional wide area synchronous grid (macrogrid), but can also disconnect to "island mode" and function autonomously as physical or economic conditions dictate.[2][3] Microgrids are best served by local energy sources where power transmission and distribution from a major centralized energy source is too far and costly to execute. In this case the microgrid is also called an autonomous, stand-alone or isolated microgrid.[4][5] In this way, microgrids improve the security of supply within the microgrid cell, and can supply emergency power, changing between island and connected modes.[2] They also offer an option for rural electrification in remote areas and on smaller geographical islands. As a controllable entity, a microgrid can effectively integrate various sources of distributed generation (DG), especially renewable energy sources (RES).[4] Control and protection are difficulties to microgrids, as all ancillary services for system stabilization must be generated within the microgrid and low short-circuit levels can be challenging for selective operation of the protection systems. A very important feature is also to provide multiple end-use needs simultaneously, such as heating, cooling, and electricity, since this allows energy carrier substitution and increased energy efficiency due to waste heat utilization for heating, domestic hot water, and cooling purposes (cross sectoral energy usage)

A typical scheme of an electric based microgrid with renewable energy resources in grid-connected mode

Basic Components In Micro grids

Local generation A microgrid presents various types of generation sources that feed electricity, heating, and cooling to the user. These sources are divided into two major groups – thermal energy sources (e.g,. natural gas or biogas generators or micro combined heat and power) and renewable generation sources (e.g. wind turbines and solar).

Consumption

In a microgrid, consumption simply refers to elements that consume electricity, heat, and cooling, which range from single devices to the lighting and heating systems of buildings, commercial centers, etc. In the case of controllable loads, electricity consumption can be modified according to the demands of the network.

Energy storage

In micro grid, energy storage is able to perform multiple functions, such as ensuring power quality, including frequency and voltage regulation, smoothing the output of renewable energy sources, providing backup power for the system and playing a crucial role in cost optimization. It includes all of chemical, electrical, pressure, gravitational, flywheel, and heat storage technologies.

When multiple energy storages with various capacities are available in a micro grid, it is preferred to coordinate their charging and discharging such that a smaller energy storage does not discharge faster than those with larger capacities. Likewise, it is preferred a smaller one does not get fully charged before those with larger capacities. This can be achieved under a coordinated control of energy storages based on their state of charge.[6] If multiple energy storage systems (possibly working on different technologies) are used and they are controlled by a unique supervising unit (an energy management system - EMS), a hierarchical control based on a master/slaves architecture can ensure best operations, particularly in the islanded mode.

Point of common coupling (PCC)

This is the point in the electric circuit where a micro grid is connected to a main grid.[27] Microgrids that do not have a PCC are called isolated micro grids which are usually present in remote sites (e.g., remote communities or remote industrial sites) where an interconnection with the main grid is not feasible due to either technical or economic constraints.

Primary control

The primary control is designed to satisfy the following requirements: To stabilize the voltage and frequency To offer plug and play capability for DERs and properly share the active and reactive power among them, preferably, without any communication links To mitigate circulating currents that can cause over-current phenomenon in the power electronic devices The primary control provides the setpoints for a lower controller which are the voltage and current control loops of DERs. These inner control loops are commonly referred to as zero-level control.[45]

Secondary control

Secondary control has typically seconds to minutes sampling time (i.e. slower than the previous one) which justifies the decoupled dynamics of the primary and the secondary control loops and facilitates their individual designs. The set point of primary control is given by secondary control[46] in which, as a centralized controller, it restores the micro grid voltage and frequency and compensates for the deviations caused by variations of loads or renewable sources. The secondary control can also be designed to satisfy the power quality requirements, e.g., voltage balancing at critical buses.

Tertiary control

Tertiary control is the last (and the slowest) control level, which considers economical concerns in the optimal operation of the micro grid (sampling time is from minutes to hours), and manages the power flow between micro grid and main grid.[45] This level often involves the prediction of weather, grid tariff, and loads in the next hours or day to design a generator dispatch plan that achieves economic savings.[33] More advanced techniques can also provide end to end control of a micro grid using machine learning techniques such as deep reinforcement learning.[47] In case of emergencies such as blackouts, tertiary control can manage a group of interconnected micro grids to form what is called "micro grid clustering", acting as a virtual power plant to continue supplying critical loads. During these situations the central controller should select one of the micro +grids to be the slack (i.e. master) and the rest as PV and load buses according to a predefined algorithm and the existing conditions of the system (i.e. demand and generation). In this case, the control should be real time or at least at a high sampling rate.

DC Fast Charging

DC Fast Charging bypasses all of the limitations of the on-board charger and required conversion, instead providing DC power directly to the battery, charging speed has the potential to be greatly increased. Charging times are dependent on the battery size and the output of the dispenser, and other factors, but many vehicles are capable of getting an 80% charge in about or under an hour using most currently available DC fast chargers. DC fast charging is essential for high mileage/long distance driving and large fleets. The quick turnaround enables drivers to recharge during their day or on a small break as opposed to being plugged in overnight, or for many hours, for a full charge. Older vehicles had limitations that only allowed them to charge at 50kW on DC units (if they were able to at all) but newer vehicles are now coming out that can accept up to 270kW. Because battery size has increased significantly since the first EVs hit the market, DC chargers have been getting progressively higher outputs to match – with some now being capable of up to 350kW.

Currently, in North America there are three types of DC fast charging: CHAdeMO, Combined Charging System (CCS) and Tesla Supercharger. All major DC charger manufacturers offer multi-standard units that offer the ability to charge via CCS or CHAdeMO from the same unit. The Tesla Supercharger can only service Tesla vehicles, however Tesla vehicles are capable of using other chargers, specifically CHAdeMO for DC fast charging, via an adapter.

COMBINED CHARGING SYSTEM (CCS)

The Combined Charging System (CCS) is based on open and universal standards for electric vehicles. The CCS combines single-phase AC, three-phase AC and DC high-speed charging in both Europe and the US – all in a single, easy to use system. The CCS includes the connector and inlet combination as well as all the control functions. It also manages communications between the electric vehicle and the infrastructure. As a result, it provides a solution to all charging requirements.

CHAdeMO

CHAdeMO is a DC charging standard for electric vehicles. It enables seamless communication between the car and the charger. It is developed by CHAdeMO Association, which is also tasked with certification, ensuring compatibility between the car and the charger. The Association is open to every organization that works for the realization of electro mobility. The Association, established in Japan, now has hundreds of members from around the globe. In Europe, CHAdeMO members based in the branch office in Paris, France, actively reach out to and work with the European members.

Tesla Supercharger

Tesla has installed their own proprietary chargers throughout the country (and the world) to provide long distance driving capability to Tesla vehicles. They are also placing chargers in urban areas that are available for drivers through their daily lives. Tesla is currently has over 1,600 Supercharger stations across North America

INTRODUCTION

The Society of Automotive Engineers defines three levels of charging for EVs. Level 1 charging uses a plug to connect to the vehicle's on-board charger and a standard household (120 V) outlet. This is the slowest form of charging and works for those who travel less than 60 kilometers a day and have all night to charge. Level 2 charging uses a dedicated Electric Vehicle Supply Equipment (EVSE) at home or at a public station to provide power at 220 V or 240 V and up to 30 A. The level 3 charging is also referred to as dc fast charging. DC fast charging stations provide charging power up to 90 kW at 200/450 V, reducing the charging time to 20-30 mins. DC fast charging is preferred for implementing a V2G architecture in micro-grid due to the quick power transfer that is required when EVs are utilized for energy storage.

Also, level 1 and level 2 ac charging is utilized for V2G technology in most of the works reported [3]. These ac charging systems are limited by the power rating of the on-board charger. An additional issue is that the distribution grid has not been designed for bi-directional energy flow. In this scenario, there is a research need for developing technically viable charging station architectures to facilitate V2G technology in micro-grids.

This work proposes a dc quick charging station infrastructure with V2G capability in a micro-grid facility. The dc bus used to interface EVs is also used for integrating a solar photo-voltaic (PV) array into the micro-grid. The proposed architecture allows high power bi-directional charging for EVs through off-board chargers. Effectiveness of the proposed model is evaluated based on MATLAB/Simulink simulations for both V2G and G2V modes of operation.

DC FAST CHARGING STATION CONFIGURATION FOR V2G

The configuration for dc fast charging station to implement V2G-G2V infrastructure in a micro-grid is shown in Fig. 1 [4]. EV batteries are connected to the dc bus through off-board chargers. A grid connected inverter connects the dc bus to the utility grid through an LCL filter and a step-up transformer. The important components of the charging station are described below.

A. Battery Charger Configuration

For dc fast charging, the chargers are located off-board and are enclosed in an EVSE. A bidirectional dc-dc converter forms the basic building block of an off-board charger with V2G capability. It forms the interface between EV battery system and the dc distribution grid. The converter configuration is shown in Fig. 2. It consists of two IGBT/MOSFET switches that are always operated by complimentary control signals. 1) Buck mode of operation (charging mode): When the upper switch (Sbuck) is operating, the converter acts as a buck converter stepping down the input voltage (Vdc) to battery charging voltage (Vbatt)During the on state, current flows through the switch and inductor to the battery. This is the charging operation, where the power flow is from the grid to vehicle (G2V).

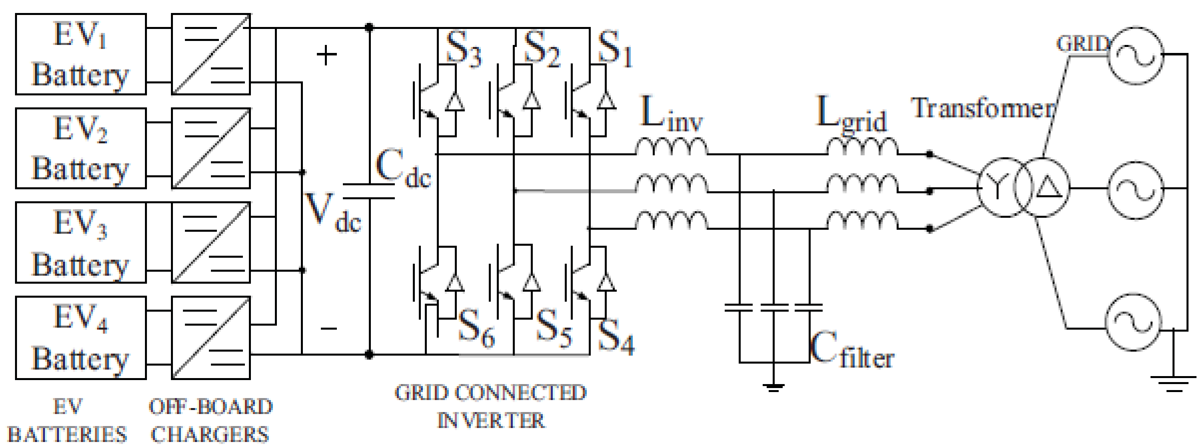
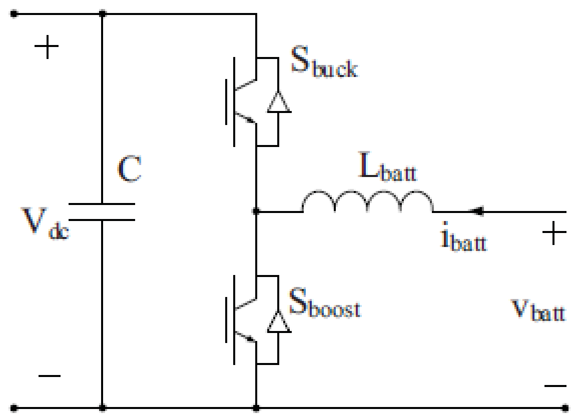


Fig. 1. EV charging station for fast dc charging

When the switch is off, the current takes its return path through the inductor and diode of lower switch and completes the circuit. If is the duty ratio of the upper switch, the battery voltage is given by:

Fig.2. Battery charger configuration



$$V_{batt} = V_{dc} * D \quad (1)$$

2) Boost mode of operation (discharging mode): when the lower switch ($Sboot$) is operating, the converter acts as a boost converter stepping up the battery voltage (Vbatt) to the DC B bus voltage (Vdc).When the switch is in on state, current continues to flow through the inductor and completes its circuit through the anti-parallel diode of the upper switch, and the capacitor. The net power flow in this case is from the vehicle to the grid (V2G) and the battery operates in the discharge mode. If the capacitor is large enough to provide a constant dc voltage, the output voltage during boost mode of operation is given by

$$V_{dc} = \frac{V_{batt}}{1 - D'} \quad (2)$$

()where D’ is the duty cycle of the lower switch.

B. Grid Connected Inverter and LCL Filter

The grid connected inverter (GCI) converts the dc bus voltage into a three phase ac voltage and also allows the reverse flow of current through the anti-parallel diodes of the switches in each leg (Fig. 1). An LCL filter is connected at the output terminals of the inverter for harmonic reduction and obtaining a pure sinusoidal voltage and current. The design procedure for determining the LCL filter parameters for this work is adapted from [4].

CONTROL SYSTEM

A. Off-Board Charger Control

A constant current control strategy [5] using PI controllers is implemented for charge/discharge control of the battery charger circuit and is shown in Fig.3. The controller first compares the reference battery current with zero, in-order to determine the polarity of the current signal, to decide between charging and discharging modes of operations. Once the mode is selected, the reference current is compared with the measured current and the error is passed through a PI controller to generate the switching pulses for S_{buck}/S_{boost}. S_{boost} will be turned off throughout the charging process and S_{buck} will be turned off throughout the discharging process

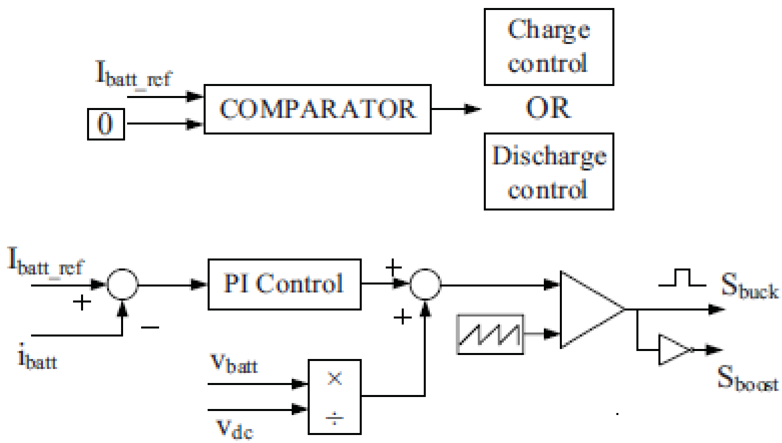


Fig. 3. Constant current control strategy for battery charger

B. Inverter Control

A cascade control in synchronous reference frame is proposed for the inverter controller. The conventional standard vector control using 4 PI controllers in a nested loop is shown in Fig. 4 [4]. The control structure consists of two outer voltage control loops and two inner current control loops. The d-axis outer loop controls the dc bus voltage and inner loop controls the active ac current. Similarly, the q-axis outer loop regulates the ac voltage magnitude by adjusting the reactive current, which is controlled by the q-axis inner current loop. Also, dq decoupling terms L and feed-forward voltage signals are added to improve the performance during transients.

MICRO-GRID TEST SYSTEM CONFIGURATION

The micro-grid test system configuration with the dc fast charging station is shown in Fig. 5. A 100 kW wind turbine (WT) and a 50 kW solar PV array serve as the generation sources

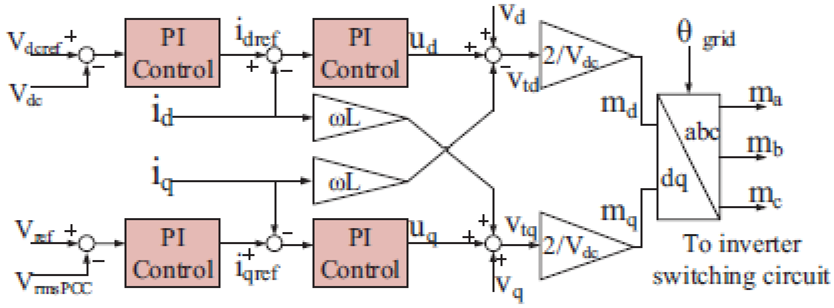


Fig. 4. Inverter control system in the system.

The EV battery storage system consists of 4 EV batteries connected to a 1.5 kV dc bus of the charging station through off-board chargers. The solar PV is also connected to this dc bus through a boost converter which has a maximum power point tracking (MPPT) controller. The utility grid consists of a 25 kV distribution feeder and a 120 kV equivalent transmission system. The wind turbine driven doubly-fed induction generator is connected to the micro-grid at the point of common coupling (PCC). Transformers are used to step up the voltages and connect the respective ac systems to the utility grid.

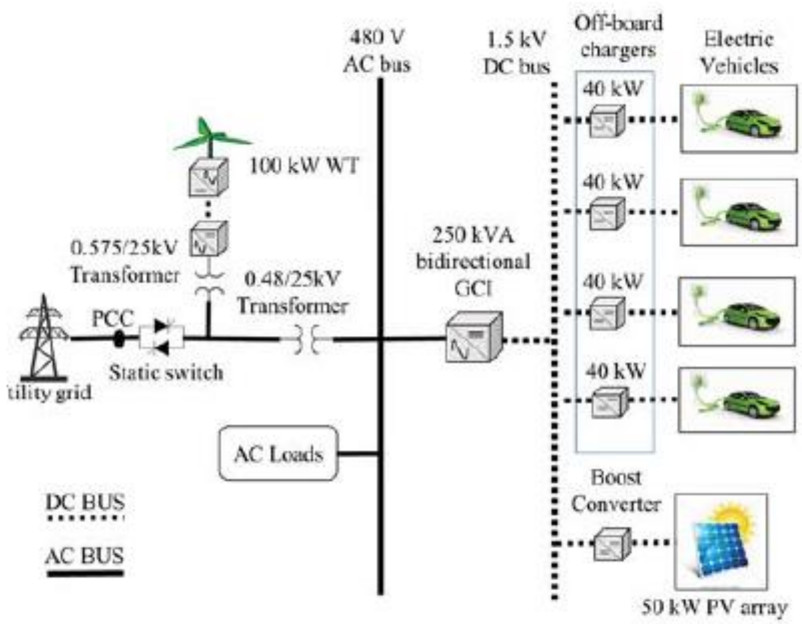


Fig. 5. Proposed microgrid test system configuration

SIMULATION RESULTS

The charging station design procedure is adapted from [4] and the obtained parameter values are given in Appendix. 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 25oC temperature) giving 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 (Fig. 1) are operated to perform the V2G-G2V power transfer. The current set-points given to the battery charging circuits of EV1 and EV2 batteries are shown in Table I and the results are shown in the subsequent figures. The battery parameters when EV1 is operating in V2G mode and EV2 operating in G2V mode are shown in Figs. 6 and 7, respectively.

TABLE I. CURRENT SET-POINTS TO EV BATTERIES

Time range (s)	0 to 1	1 to 4	4 to 6
Current set-point to EV_1 battery (A)	0	+80	0
Current set-point to EV_2 batter y(A)	0	0	-40

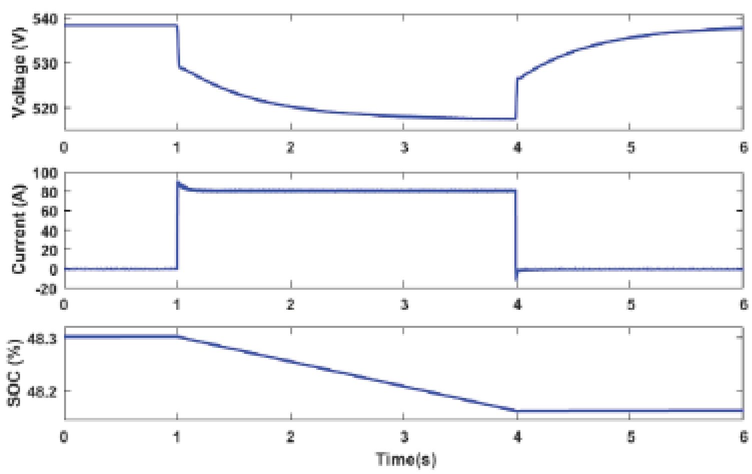


Fig. 6. Voltage, current, and SOC of EV1 battery during V2G operation

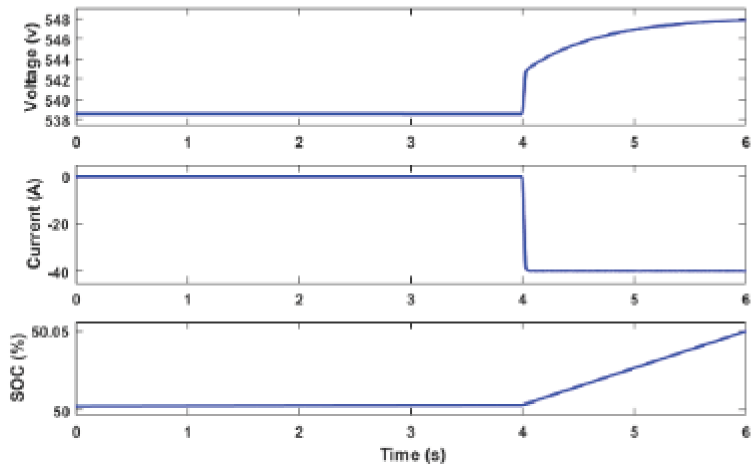


Fig. 7. Voltage, current, and SOC of EV2 battery during G2V operation

The active power contribution from various components of the system is shown in Fig. 8. The grid power changes to accommodate the power transferred by the EVs. The negative polarity of the grid power from 1s to 4s shows that the power is being fed to the grid from the vehicle. The change in polarity of grid power at 4s shows that the power is supplied by the grid for charging the vehicle battery. This demonstrates the V2G-G2V operation. Also, the net power at PCC is zero showing an optimal power balance in the system.

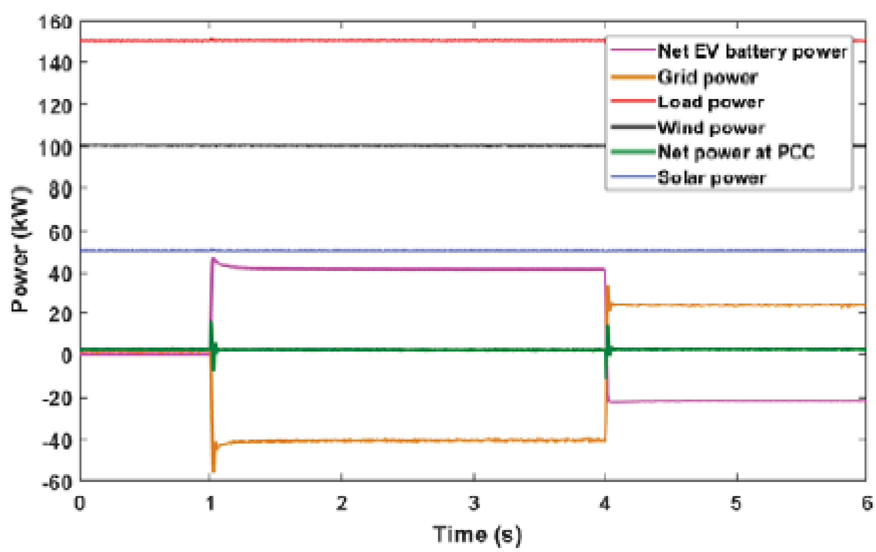


Fig. 8. Active power profile of various components in the system

The dc bus voltage is regulated at 1500 V by the outer voltage control loop of the inverter controller and is shown in Fig. 9. This in turn is achieved by the inner current control loop tracking the changed d-axis reference current as shown in Fig. 10.

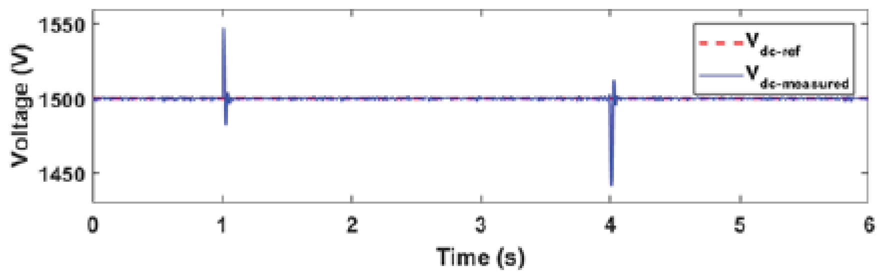


Fig. 9. Variation in dc bus voltage

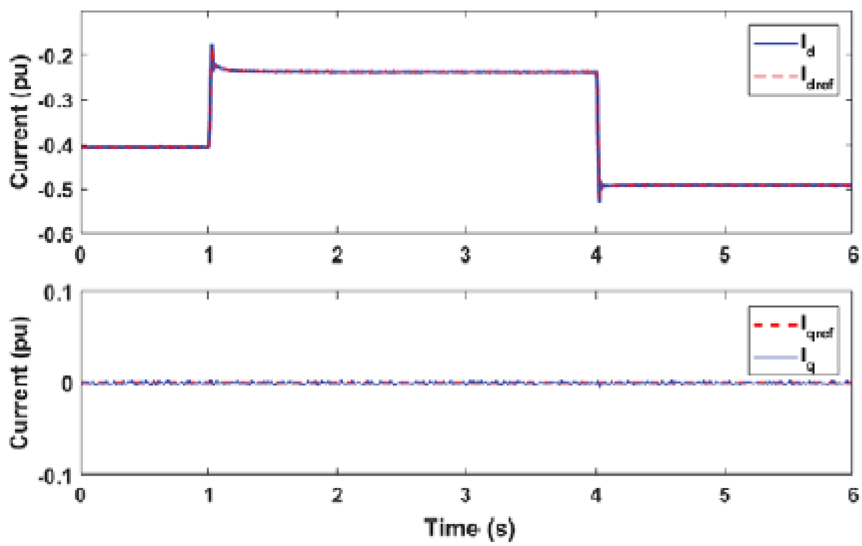


Fig. 10. Reference current tracking by inverter controller

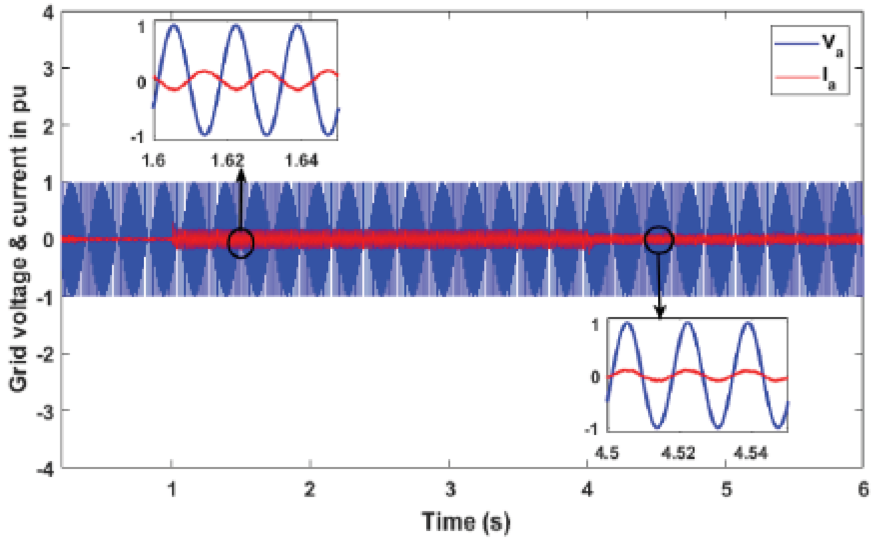


Fig. 11. Grid voltage and grid injected current during V2G-G2V operation

Total harmonic distortion (THD) analysis is done on the grid injected current and the result is shown in Fig. 12. According to IEEE Std. 1547, harmonic current distortion on power systems 69 kV and below are limited to 5% THD. The THD of gridinjected current is obtained as 2.31 % and is achieved by the judicious design of LCL filter.

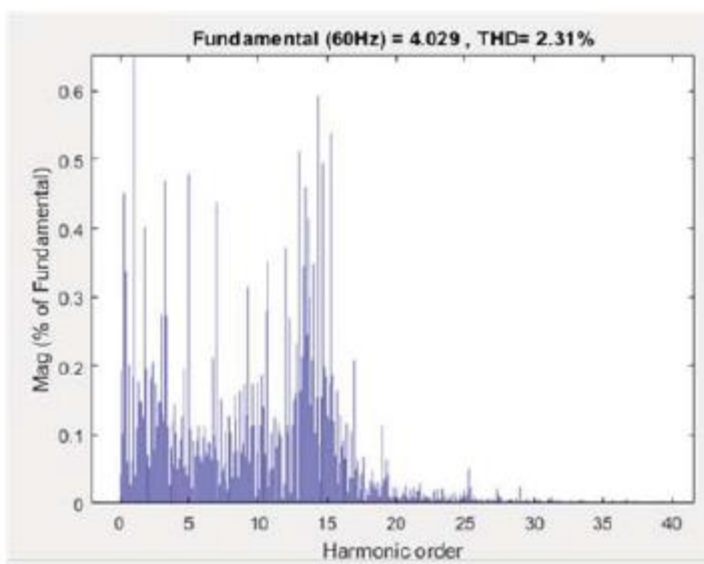


Fig. 12. Harmonic spectrum and THD of grid-injected current

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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