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Vehicle to Grid Technology in a Micro Grid Using DC Fast Charging Architecture

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Abstract:

Batteries from electric vehicles (EVs) have the potential to be used in microgrids as energy storage devices. By storing energy when there is excess (Grid-to-Vehicle, or G2V) and returning it to the grid (Vehicle-to-Grid, or V2G) when needed, they may aid in micro-grid energy management. The development of appropriate control systems and infrastructure is necessary to make this idea a reality. This study presents an architecture for establishing a V2G-G2V system in a micro-grid employing level-3 rapid charging of EVs. An EV interface is provided via a dc rapid charging station in a modeled micro-grid test system. V2G-G2V power transmission is shown via simulation research. According to test findings, EV batteries are actively regulating power in the microgrid via G2V-V2G modes of operation. The controller provides excellent dynamic performance in terms of dc bus voltage stability, and the charging station design assures low harmonic distortion of grid injected current.

Keywords: DC fast charging, Electric vehicle, Grid connected inverter, Micro-grid, Off-board charger, Vehicle-to-grid

I. INTRODUCTION

A microgrid's energy storage systems are crucial parts because they make it possible to include sporadic renewable energy sources. When plugged in for charging, electric vehicle (EV) batteries may be used as efficient storage devices in micro-grids. The majority of personal transportation cars are idle assets since they are typically parked for 22 hours per day. By storing energy when there is excess (Grid-To-Vehicle, or G2V) and returning it to the grid when there is demand (Vehicle-To-Grid), EVs may be able to assist with micro-grid energy management. V2G when applied to the general power grid has many difficulties, including being difficult to manage, requiring a significant number of EVs, and being difficult to implement quickly [1]. In this case, setting up a V2G system in a micro grid is simple. Three different EV charging levels are specified by the Society of Automotive Engineers. A plug is used for Level 1 charging, which connects the car's onboard charger to a regular home (120 V) outlet. For people who travel less than 60 kilometers per day and have all night to charge, this is the slowest method of charging. Power at 220 V or 240 V and up to 30 A is supplied for level 2 charging using a specialized Electric Vehicle Supply Equipment (EVSE) at home or at a public station. DC rapid charging is another name for level 3 charging. DC fast charging stations cut the charging time down to 20–30 minutes by providing charging power of up to 90 kW at 200/450 V. Because EVs need to transmit power quickly when used as energy storage devices, DC rapid charging is the recommended method for establishing a V2G architecture in micro-grids.

The system may also include renewable energy sources via the usage of the DC bus. The V2G idea has been used in the general electricity grid for services including peak shaving, valley filling, regulation, and spinning reserves in the majority of earlier studies [2]. We are continuing in the early stages of V2G development in a micro grid facility to support power production from intermittent renewable energy sources. Most of the reported works also use level 1 and level 2 ac charging for V2G technology [3]. The on-board charger's power rating sets a restriction on these ac charging solutions. The distribution grid's lack of bidirectional energy flow architecture is another problem. In this case, research is required to create technically workable charging station designs that will enable V2G technology in micro-grids.In a micro-grid facility, this paper suggests a dc rapid charging station architecture with V2G functionality. The micro-grid may include a solar photo-voltaic (PV) array using the same DC bus that interfaces EVs. With off-board chargers, the suggested design enables high power, bi-directional EV charging. MATLAB/Simulink simulations are used to assess the effectiveness of the proposed model for both V2G and G2V modes of operation.

II. DC FAST CHARGING STATION CONFIGURATION FOR V2G

Fig. 1 [4] depicts the setup for a DC fast charging station used to construct V2G-G2V infrastructure in a micro-grid.Off-board chargers are used to link EV batteries to the DC bus. The dc bus is linked to the utility grid via a grid connected inverter, which passes via a step-up transformer and an LCL filter. The following is a description of the charging station's key parts. A. Setup of Battery Charger The chargers are housed in an EVSE and are off-board for DC rapid charging. The fundamental component of an off-board charger with V2G functionality is a bidirectional DC-DC converter. It serves as the link between the DC distribution grid and the EV battery system. Fig. 2 displays the converter arrangement. Two IGBT/MOSFET switches make up this system, and they are always driven by complementary control signals. 1) Charging mode, or the Buck mode of operation: The converter functions as a buck converter, stepping down the input voltage (Va) to the battery charging voltage (Va) while the top switch (Wasege*buc*k) is in operation. When the switch is in the on position, current travels to the battery via the inductor and switch. In this charging process, electricity is transferred from the grid to

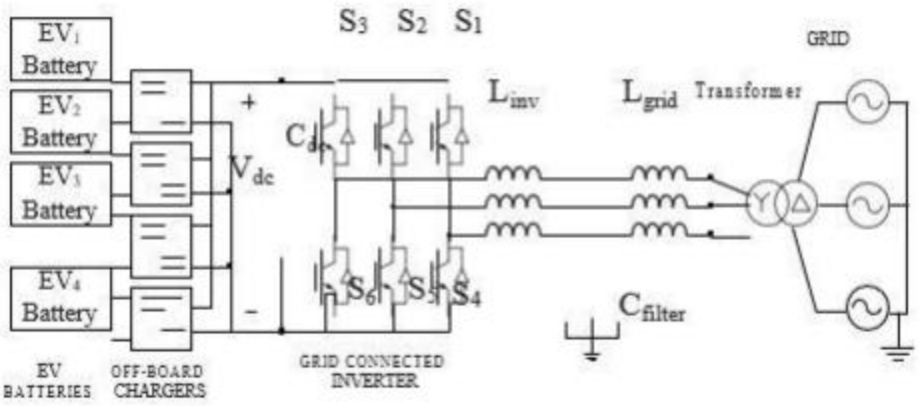


Fig. 1. EV charging station for fast dc charging

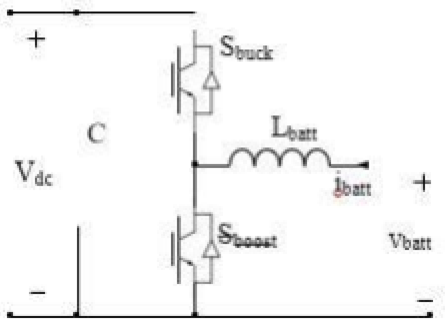


Fig. 2. Battery charger configuration

automobile (G2V). The circuit is completed when the switch is off because the current follows its return route via the lower switch's diode and inductor. Assuming that the higher switch's duty ratio is D, the battery voltage may be calculated using:

III.CONTROL SYSTEM

A. Off-Board Charger Control

Fig. 3 illustrates the implementation of a constant current control technique [5] that uses PI controllers to manage the charge and discharge of the battery charger circuit. To choose between the charging and discharging modes of operation, the controller first compares the battery current difference with zero to ascertain the polarity of the current signal. After the mode is chosen, the difference current and the measured current are compared, and the error is then sent via a PI controller to produce the switching pulses for k/oo. Throughout the charging process, $Sbooct$ will be turned off, and during the discharging phase, $Sbuc$k will be turned off.

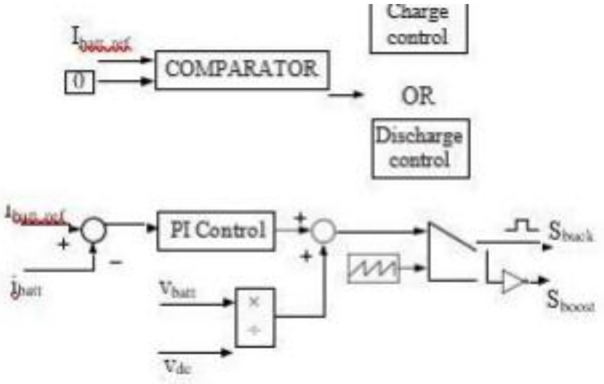


Fig. 3. Constant current control strategy for battery charger

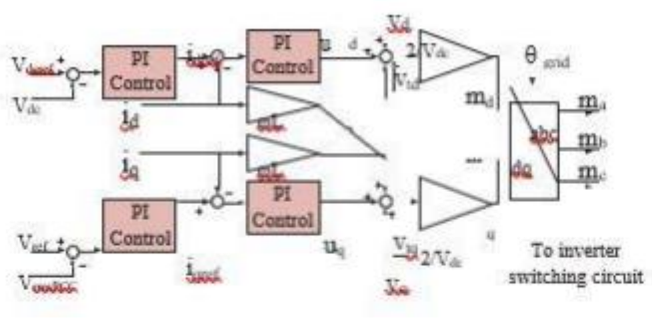


Fig.4 The control structure consists of two outer voltagecontrol loops and two inner current control loops. The d-axis

B. Grid Connected Inverter and LCL Filter

In addition to allowing current to flow in the opposite direction via the anti-parallel diodes of the switches in each leg, the grid connected inverter (GCI) transforms the dc bus voltage into a three phase ac voltage (Fig. 1). The inverter's output terminals are linked to an LCL filter in order to reduce harmonics and provide a pure sinusoidal voltage and current. This work's design process for figuring out the LCL filter settings is taken from [4]. The inner loop regulates the active ac current, while the outside loop manages the dc bus voltage. Similar to this, the q-axis inner current loop controls the reactive current, which in turn controls the ac voltage magnitude via the q-axis outer loop. Moreover, feed forward voltage signals and dq decoupling terms ωL are included to enhance performance during transients. inside the framework. Four EV batteries are part of the EV battery storage system, which is linked via off-board chargers to the charging station's 1.5 kV dc bus. Through the use of a boost converter with an MPPT controller, the solar PV is also linked to this DC bus. A 120 kV equivalent transmission system plus a 25 kV distribution feeder make up the utility grid. At the point of common connection (PCC), the micro-grid is linked to the doubly fed induction generator powered by a wind turbine. Transformers are used in order to link the corresponding ac systems to the utility grid and increase the voltages.

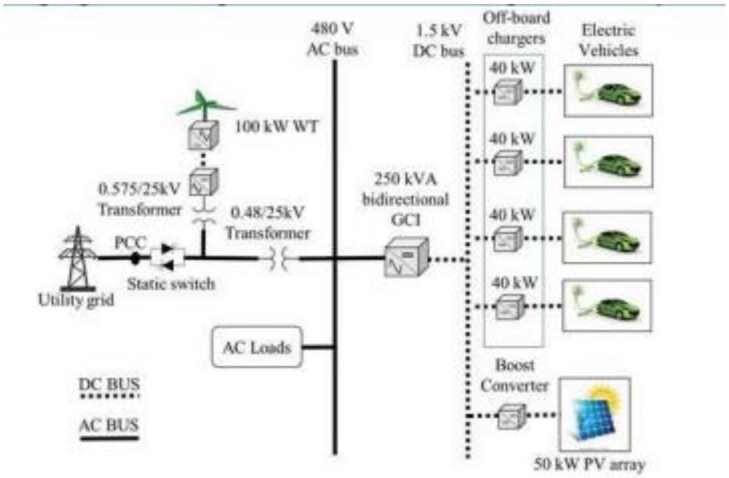


Fig. 5. Proposed microgrid test system configuration

SIMULATION RESULTS

The process for designing charging stations is taken from [4], and the appendix contains the parameter values that were determined. When the wind turbine is running at its rated speed, it may provide up to 100 kW of electricity. When the solar PV is run under typical test circumstances (1000W/m2 irradiance and 25°C temperature), it can produce up to 50 kW of electricity at its maximum. The 480 V ac bus is coupled to a resistive load of 150 kW. For a unity pf operation, the reactive current reference to the GCI is set to zero. The EV batteries' initial state of charge (SOC) is fixed at 50%. The V2G-G2V power transfer is carried out by operating the batteries of EV1 and EV2 (Fig. 1) after the steady state criteria are met. Table I displays the current set-points provided to the EV1 and EV2 battery charging circuits. The next figures display the outcomes. The battery characteristics in V2G mode for EV1 and G2V mode for EV2 are shown in Figs. 6 and 7, respectively.

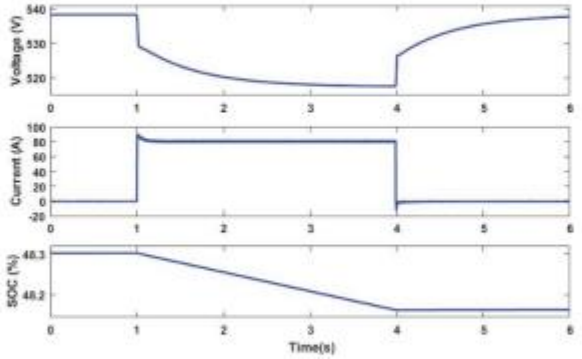


Fig. 6. Voltage, current, and SOC of EV1 battery during V2G operation

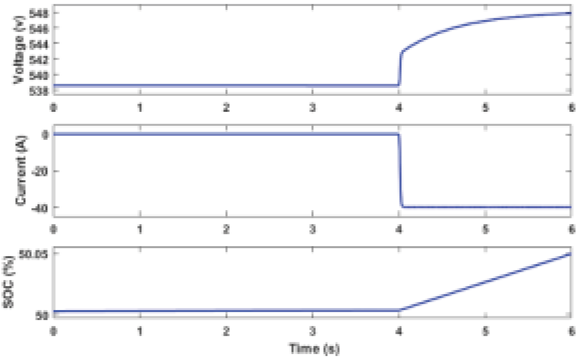
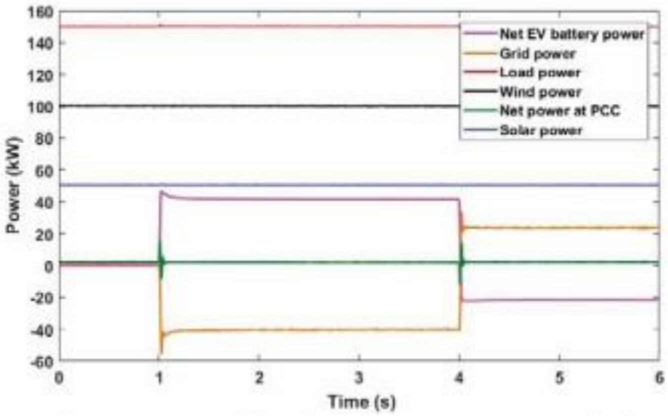


Fig. 7. Voltage, current, and SOC of EV2 battery during G2V operation

Fig. 8 displays the active power contribution from each system component. In order to handle the power delivered by the EVs, the grid power adjusts. The grid is receiving electricity from the car, as seen by the negative polarity of the grid power from 1 to 4 seconds. The polarity of the grid electricity changes at 4 s, indicating that the grid is supplying the power to recharge the car battery. This illustrates how V2G-G2V works. Additionally, PCC's net power is zero, indicating that the system's power balance is ideal.



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 looptracking the changed daxis reference current as shown in Fig. 10.

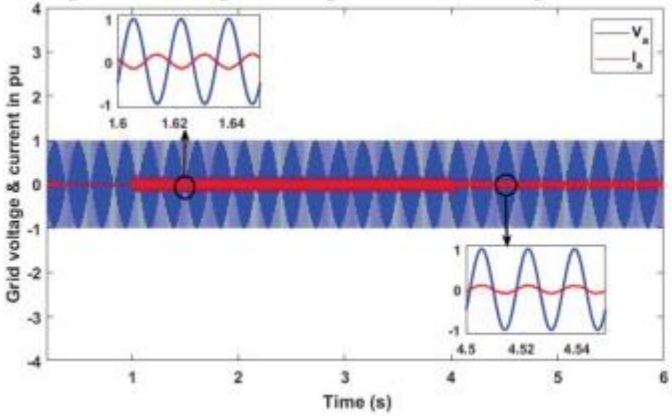


Fig. 11. Grid voltage and grid injected current during V2G-G2V operation

Total harmonic distortion (THD) analysis is done on the gridinjected current and the result is shown in Fig. 12. According toIEEE Std. 1547, harmonic current distortion on power systems69 kV and below are limited to 5% THD. The THD of grid- injected current is obtained as 2.31 % and is achieved by the judicious design of LCL filter.

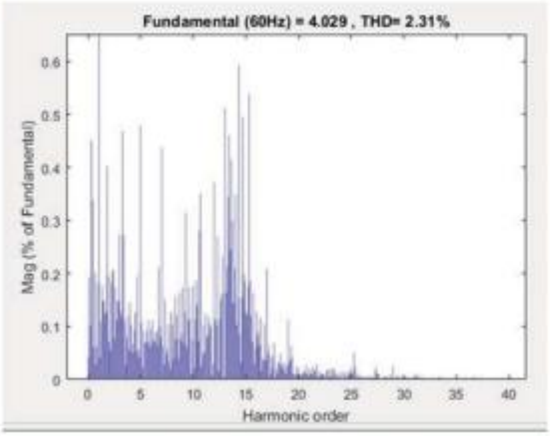


Fig. 12. Harmonic spectrum and THD of grid-injected current

CONCLUSIONS

This study presents the modeling and design of a V2G system on a micro-grid employing dc rapid charging architecture. To link EVs to the microgrid, an adc fast charging station with off-board chargers and a grid-connected inverter is constructed. Electric vehicles and the grid may transmit power in both directions thanks to the control system built for this power electronic interface. The simulation findings demonstrate a seamless power transfer between the EVs and the grid, and the EVs' grid-injected current quality complies with applicable regulations. In terms of monitoring the altered active power reference and dc bus voltage stability, the developed controller performs well dynamically. This paper examines the micro-grid's active power regulation features. Reactive power control and frequency regulation are only two more services that may be provided by the suggested V2G system. Future research is advised to focus on designing a supervisory controller that issues commands to each individual EV charging controller.

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