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

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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.

I INTRODUCTION

Up-to-date, the world has undergone a challenge in terms of providing electricity and ensuring global energy requirements. The challenge is mainly due to the shortage of primary energy resources from conventional fossil fuels like natural gas, coal and oil [1]. As a result, there is a great tendency to integrate the renewable energy resources and the use of plug-in electric vehicles (PEVs) on the smart grid in order to minimize reliance on conventional energy resources, satisfy the energy demands and consequently decreasing concerns related to global warming effects as well as the ones related to energy crisis [2e5].

The excessive electricity consumption causes intense surges in demand during peak hour which can cause undesirable impacts and harm the stability of the existing network. That's why; some researchers are working on ways to minimize load power variance by using renewable energy sources. In Ref. [6], a stochastic multiobjective daily volt/var control based on hydro-turbine, fuel cell, wind turbine, and photovoltaic power plants are investigated.

A study in Ref. [7] has developed a new control strategy that involves wind and photovoltaic generation subsystems. Energy storage systems are important components of a micro-grid as they enable the integration of intermittent renewable energy sources. Electric vehicle (EV) batteries can be utilized as effective storage devices in micro-grids when they are plugged-in for charging. Most personal transportation vehicles sit parked for about 22 hours each day, during which time they represent an idle asset. EVs could potentially help in micro-grid energy management by storing energy when there is surplus (Grid-To-Vehicle, G2V) and feeding this energy back to the grid when there is demand for it (Vehicle-To-Grid). V2G applied to the general power grid faces some challenges such as; it is complicated to control, needs large amount of EVs and is hard to realize in short term [1].

In this scenario, it is easy to implement V2G system in a micro-grid. 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 the dc bus can be used for integrating renewable generation sources into the system. In majority of the previous studies, V2G concept has been applied in the general power grid for services like peak shaving, valley filling, regulation and spinning reserves [2]. The V2G development in a micro-grid facility to support power generation from intermittent renewable sources of energy is still at its infancy. 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. 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.

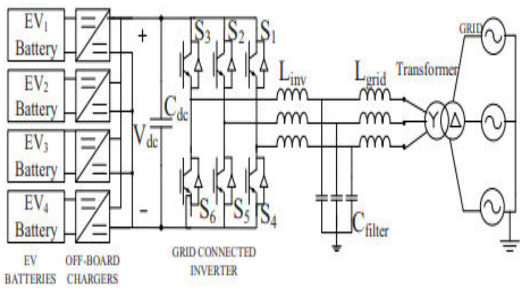


Fig 1: EV charging station for fast dc charging

II MICRO-GRID TEST SYSTEM CONFIGURATION

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

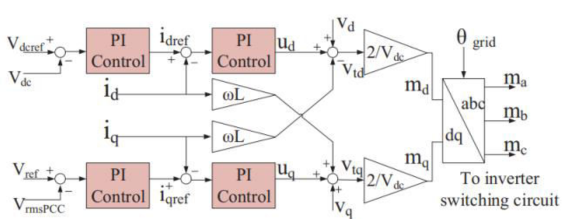


Fig 2: Inverter control system

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.

III SIMULATION MODELS AND RESULTS

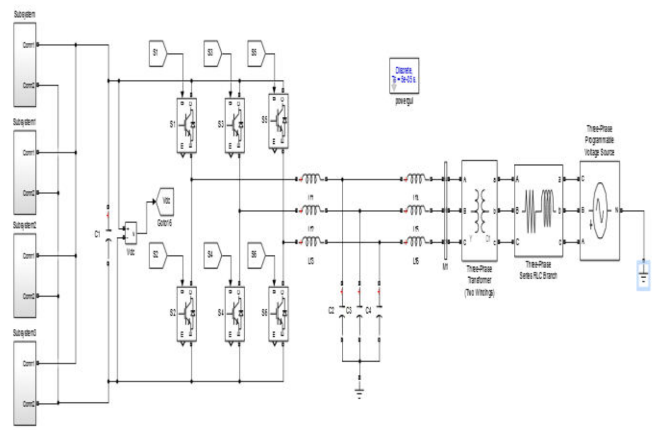


Fig 3: Block diagram

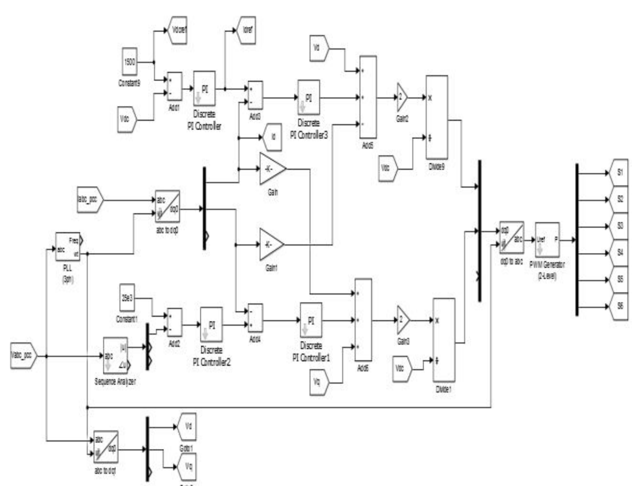


Fig 4: Control scheme diagram

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 25o C 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 respectively.

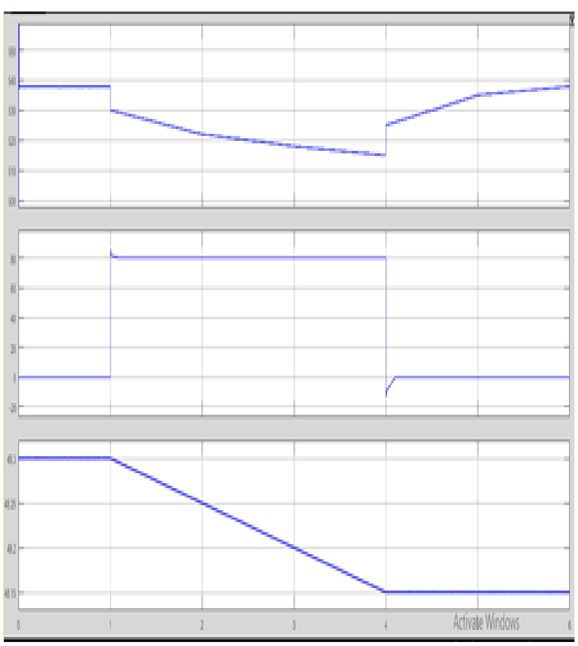


Fig 5: Voltage, current, and SOC of EV1 battery during V2G operation

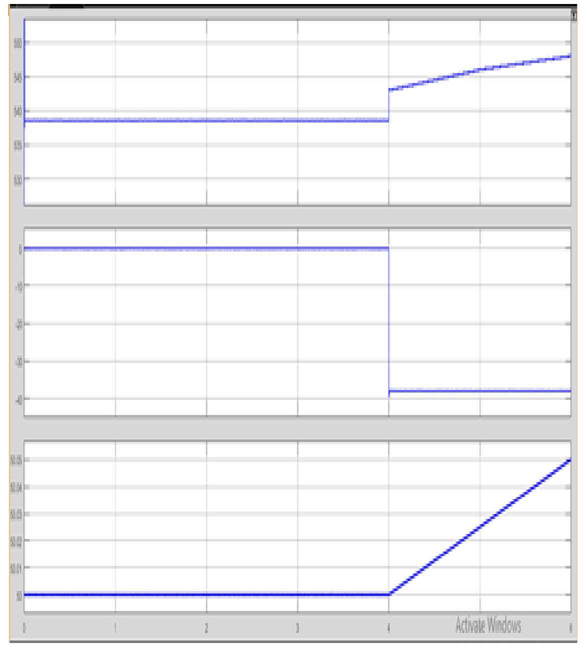


Fig 6: Voltage, current, and SOC of EV2 battery during G2V operation

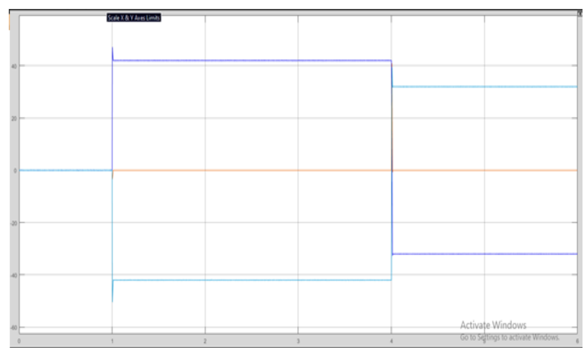


Fig 7: Active power profile of various components in the system

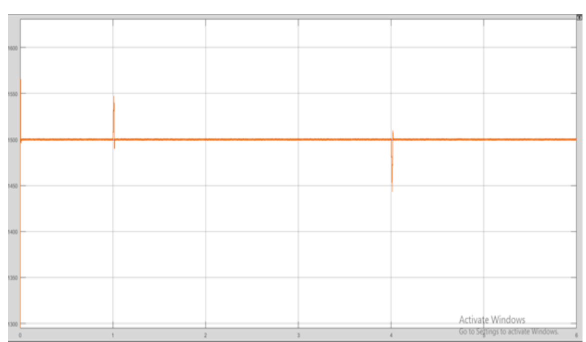


Fig 8: Variation in dc bus voltage

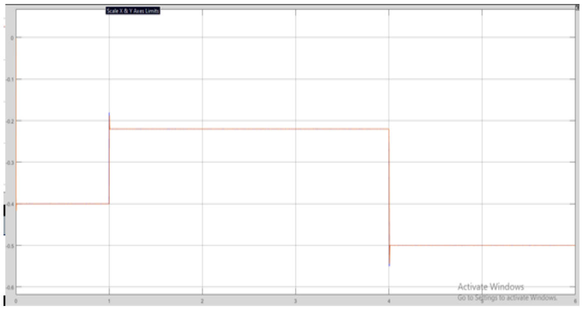


Fig 9: Reference current tracking by inverter controller

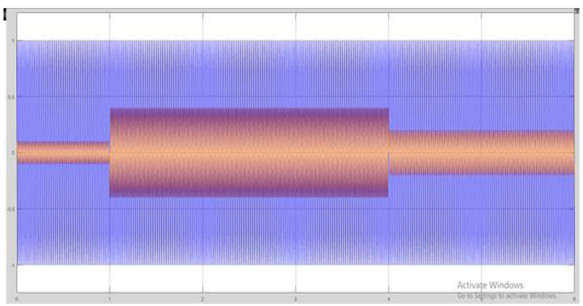
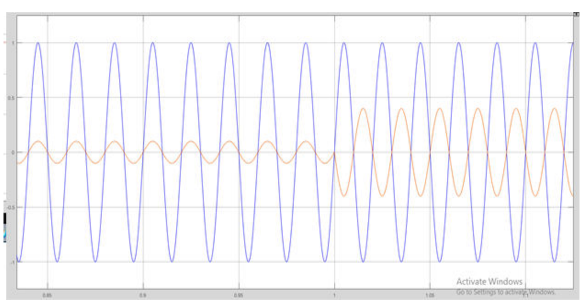
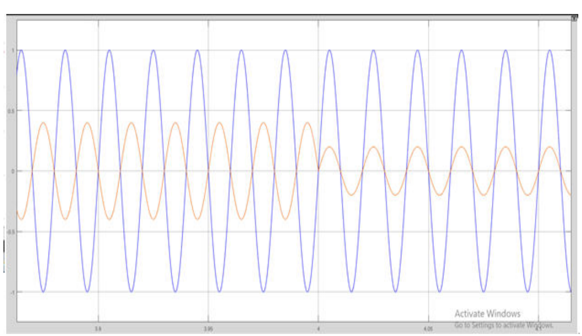


Fig 10: Grid voltage and grid injected current during V2G-G2V operation





IV CONCLUSIONS

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.

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.

The grid voltage and current at PCC are shown in Fig. 11. Voltage and current are in phase during G2V operation and out of phase during V2G operation showing the reverse power flow.

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 grid injected current is obtained as 2.31 % and is achieved by the judicious design of LCL filter.

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