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Bi-Directional DC Converter for Grid Connected EV-PV System

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ABSTRACT
The solar energy and Electric Vehicle when work in sync has substantial potential. Although Photo-Voltaic (PV) solar energy is a significant worldwide energy source, energy storage is necessary to balance periods of high and low production because of its unpredictability. The transition from internal combustion engines to Electric Vehicles (EVs) is also a global movement in the transportation sector. Since cars are actually immobile 95% of the time, the EV battery can use Vehicle-To-Grid (V2G) technology to control the intermittent PV source when the car is linked to the grid. This paper presents the performance analysis of grid connected EV-PV system and the affect of EV-battery under variable solar generation. A bi-directional DC-converter with dual switch topology is presented to facilitate the charging and discharging of the battery. The effect of EV-PV system on grid voltage stability and power is also presented with harmonic analysis. The system has been designed in MATLAB software.
Keywords – DC-Converter, Electric Vehicles (EVs), Photo-Voltaic (PV), Vehicle-To-Grid (V to G) technology.

I. INTRODUCTION

Electric Vehicles (EVs) have achieved notable milestones, including the first vehicle to exceed 62mph (100kmh) in 1899. However, due to the infrastructural constraints and matured technology of Internal Combustion Engine (ICE) based vehicle won overall adoption battle [1]. The reason is simple, as electric cars were constrained by distance range, it was just few miles during 1890. With development of electric motor starter for ICE powered automobiles, eradicating their traditional disadvantage. Hence, it was determined that petrol vehicles were the superior choice to EV due to its low cost [2].

Electric vehicles became simpler and more efficient over the course of the twentieth century, Hence, over next decade they can become “Standard Vehicle” in near future. Over the last decade, there has been a surge in interest for electric vehicles. It can significantly reduce environmental footprint of our ICE based transportation system. But in the path of wide spread use of EV the main hurdle is charging station [3]. It required DC charging station which can be additional burden to the grid. This problem can be resolved by employing PV based charging system. PV generates DC and its output fluctuates as per the availability of solar irradiations. Hence Evand PV can efficiently overcome their mutual hurdles. When solar power is available in abundant, EV charging station can store that bulk power in the form of battery storage. These batteries can be discharged to meet the grid demand via solar inverter and the power goes on vice-versa from vehicle to grid (V to G) and grid to vehicle (G to V). This work presents the performance analysis of PV connected EV charging station under variable solar irradiations and its impact on grid voltage stability. The system has been designed in matlab simulink software. The results are presented for 154MW-34.5kV grid integrated bidirectional dual switch DC converter.

II. BI-DIRECTIONAL DC-CONVERTER

The electronic circuitry dedicatedly designed to transform the DC-voltage of one level to the another with reduced losses is DC-Converters (DCC). Apart from conventional topologies like buck converter, boost; buck-boost converter, flyback and forward converters; there are numerous other topologies designed by the researcher to harbor the best out of DC-DC conversion system [4]. DDC has a wide range of classification depending upon several factors as the type of input and output (buck/boost and both, flyback, CUK), the number of phases (single/multi-phase), the mode of operation (continuous and discontinuous), the switching frequency (low, high and medium), and the topology used (Forward, Push-pull, Half-bridge, Full-bridge, Resonant and Quasi-resonant converters) [5]. Also, they are classified as isolated and non-isolated type [6]. In isolated type structure, a transformer is used to change the level of voltage at the output terminal and also it isolates the input and output structure which can also provide the least magnetic interfacing. In this type of topology, the high voltage gain can be obtained by adjusting the conversion ratio of the transformer windings [7, 8].

In this paper, a High Frequency (HF), isolated structure DCC with two power switches is designed for PV-EV applications. The designed structure has bidirectional capability and can also be applied for charging and discharging purpose which can find applications in EV also. A voltage controller is designed to generate the gate pulses of the switches using conventional PID controller. The schematic diagram of the proposed converter is shown in figure 1. The Proposed DDC has simple design with only two switches (S1 and S2). The RC and RL branches helps in regulating the input and output voltage as per the requirement. There are two states of the switches which form the operating principle of DCC. If S1 is ON, the DCC will operate in boost mode. If S2 is ON, the DCC will operate in buck mode.

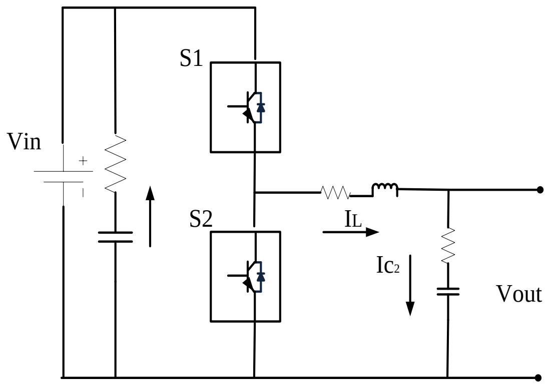

Fig. 1 The single line diagram of proposed DC-DC converter

III. PROPOSED WORK

The PV connected EV charging infrastructure not only enhances battery life but also decreases charging expenses [9]. PV systems produce DC output and is particularly well-suited for DC grid and battery charging purposes [10]. EV technology can both draw power from and contribute power to DC microgrids/nano-grids. The integration of PV with EV charging systems and battery storage reduces the strain on the utility grid and reduces dependency on non-renewable resources [11]. Developing a bidirectional off-board charger allows for fast charging as well as support for V to G or G to V. Building a charging station requires multiple converter stages [12]. In general, each charging station uses at least four power converter stages, with a DC/DC converter to connect photovoltaic (PV) systems to the DC bus.

Dedicated boost converters are used by PV systems for a variety of residential and commercial EV charging applications. Power transfer from DC G to V and V to G operations are two benefits of using bidirectional DC/DC converters [13,14]. These converters power functions as a boost converter when it moves from the low voltage side to the high voltage side. The two-quadrant non-isolated buck/boost converter is a popular option for many applications due to its simple design with two switches, affordable price, and effective performance. In this paper, DCC power flow with in EV to PV and PV to EV depending upon the demand and availability of solar irradiations. Also, the EV-PV system works in interconnected mode with the grid facilitating V to G and G to V power flow. The schematic of the proposed topology is shown in figure 2. DC- bus is installed with PV-EV charging station and an interface with the AC grid is achieved with dual stage DC-DC transformation to attain stability in the grid with the DC-power.

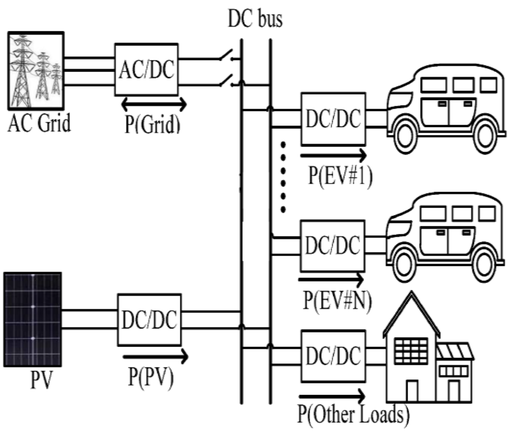

Fig. 2 Schematic diagram of STATCOM control

IV. SIMULATION MODEL AND RESULT

This research addresses the issue of voltage balance when EV-charging station is integrated to the AC grid. Voltage stability is an essential factor to when dealing with DC loads such as charging stations for electric vehicles or PV generated power. Control of the voltage on both the DC buses and the AC buses in addition to a seamless handoff when migrating from the AC microgrid to the DC microgrid and back again is required. Additionally, in order to get the most out of the cycle life of the battery, both the minimum and maximum levels that are stored in the battery storage unit has to be verified.

The battery system is connected with Bidirectional DC (BDC), converter and with the solar system boost converter is connected at the DC-bus. The matlab simulation model of the proposed system is shown in figure 3. The performance of the system is limited by output power rating of connected sources. In the proposed design, modeling of whole battery system and its components is carried out. The function of inverters is to perform dc to ac conversion of dc generated output by solar panels. Generally, the inverters have higher efficiency, and hence, the performance of PV system is not affected much. The design parameter for the complete system is shown in table-1.

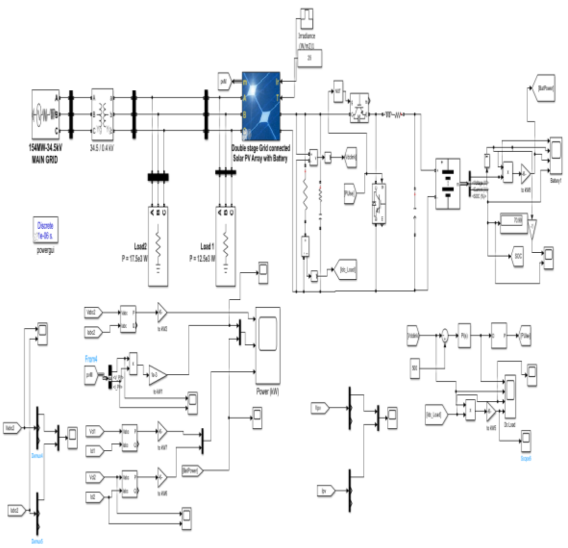

Fig. 3 Schematic diagram of STATCOM control

The proposed grid interfaced EV-PV charging station is analysed for variable solar irradiation whose graph has been presented in figure 4. As solar irradiance changes, output across solar also changes and DC-battery compliments it. When solar radiations reduces, Solar power reduces and battery power increases. When Solar output increases, battery output reduces this is shown in figure 5.

Table-1 Design parameter

Parameter	**Value**
Grid parameter	154MW; 34.5kV
AC loads	15.5 KW; 12.5 KW
PV-array; Parallel - 10, Series - 5	
PV power rating	33.6 kW
Voltage generated	33.18 V
Current generated	78.35 A
Resistance and capacitor across solar PV array	R =1 mΩ and C = 1mF
Boost converter	
RL Branch	R = 0.1 Ω , L = 1 mH
RC Branch	R = 0.1 Ω, C = 100 µF
Boosted voltage	48.06 V
Switching parameters	
Unit delay: sample time	1e-4 s
Duty cycle	Dmax = 0.48, Dinit = 0.05
PI controller gain upper	KP = 1, KI = 30,
Saturation limit	0.95
Bidirectional converter	
RC branch	R = 0.1 Ω, C = 1 µF
RL branch	R = 0.1 Ω, L = 1mH
PI controller	KP = 0.005, KI = 10
PWM DC-DC generator switching frequency	10e3 Hz
sample time	5e-6 s

The combined EV-PV system will results in constant DC bus voltage as shown in figure 6. Also, AC bus voltage is constant as shown in 7. Hence voltage stability is retain under variable EV-PV generation. The harmonic at the AC voltage is also negligible with 0.03 % as shown in figure 8.

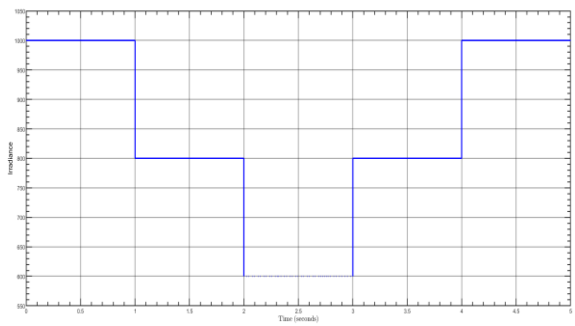

Fig. 4 Variable solar irradiation graph

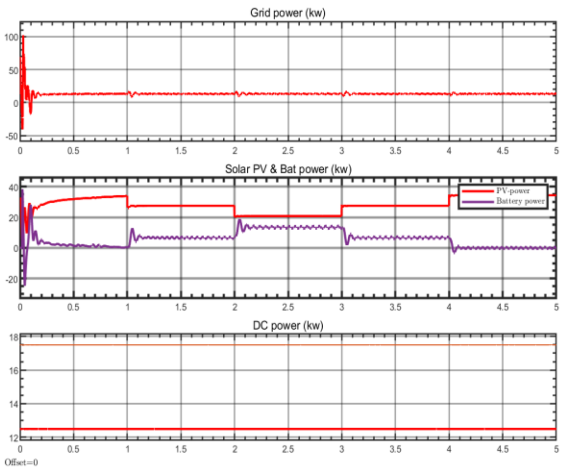

Fig. 6 Power curve for AC-bus, PV-system, Battry and DC-bus power

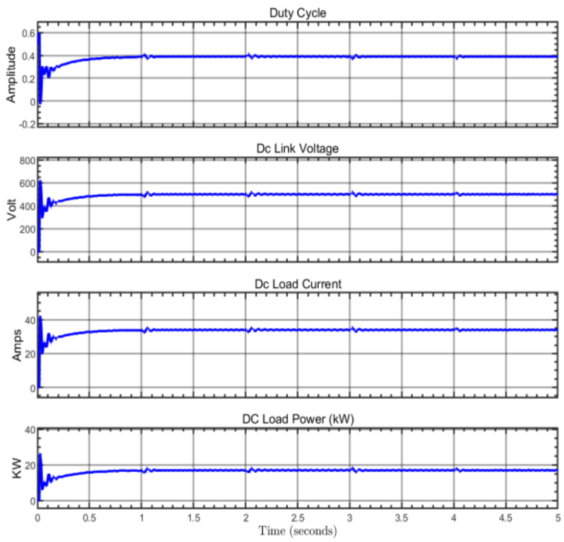

Fig. 6 Interfacing DC-bus for combined EV-PV system

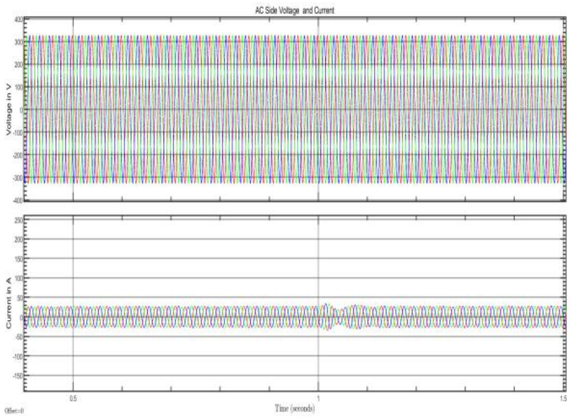

Fig. 7 AC-bus voltage and current

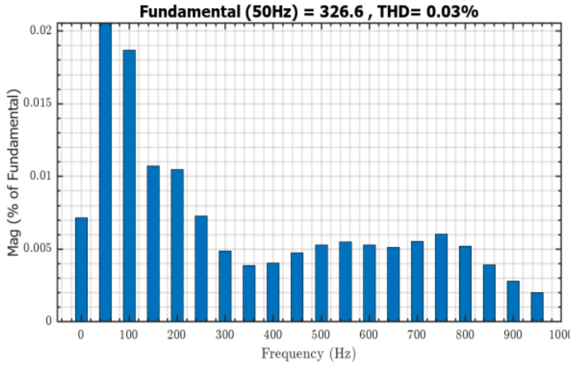

Fig. 8 THD of AC-bus voltage

V. Conclusion

In contrast to traditional charging stations, the study proposes a combination converter that improves bidirectional system feasibility, offering an innovative strategy for PV-powered EV charging stations. The BDC, which enables power transmission between the DC bus and the energy storage system, is an essential part of energy storage systems. The interfacing of PV based EV charging station presents a promising solution for power management of grid. Also, it helps in regulating the EV power demand.

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