PV to Vehicle, PV to Grid, Vehicle to Grid, and Grid to Vehicle Micro Grid System Using Level Three Charging Station

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Abstract— This paper makes use of electric vehicles (EVs) that are simultaneously connected to the Photovoltaic Cells (PV) and the power grid. In micro-grids, batteries of the electric vehicles (EVs) used as a source of power to feed the power grid in the peak demands of electricity. EVs can help regulation of the power grid by storing excess solar energy and returning it to the grid during high demand hours. This paper proposes a new architecture of micro-grids by using a rooftop solar system, Battery Electric Vehicles (BEVs), grid connected inverters, a boost converter, a bidirectional half-bridge converter, output filter, including L, LC, or LCL, and transformers. The main parts of this micro-grid are illustrated and modeled, as well as a simulation of their operation. In addition, simulation results explore the charging and discharging scenarios of the BEVs.

Keywords— PV to vehicle, PV to grid, Grid to vehicle, Vehicle to grid, Micro-grid, Demand Side Management

I. Introduction

It goes without saying that the world's population will continue to grow each year, resulting in a rise in the number of cars on the earth. The question is oil and gas will not be able to keep up with the demand, therefore the only option is electricity and various types of electric vehicles [1]. Furthermore, electric vehicles (EVs) can benefit the environment by lowering pollution levels in the air [2]. Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicle (PHEVs), and Hybrid Electric Vehicles (HEVs) are the three types of electric cars on the market [3]. Both BEVs and PHEVs are fed by power grid and the number of batteries in BEVs and PHEVs has been increased. Typical BEV battery capacities vary from 40 to 80 kWh, while some are now available with batteries as large as 200 kWh [4]. Charging electric vehicles using renewable energy is an excellent way to minimize vehicle emissions while also providing a clean supply of electricity. The EV as a dispersed energy storage system will become an essential element of the smart grid if the idle EV battery is utilized to feed the power grid [5]. The common storage batteries fitted on EVs are lithium-ion battery storage systems [6]. For EVs, there are three charging levels. A plug connects to the (120 V) outlet for Level 1 charging. This method is not fast and is suitable for low mileage traveling. In Level 2 of the charging, a specialized outlet provides power at 240 V and up to 30 A. Finally, DC fast charging (Level 3) delivers up to 90 kW of charging power at 400 V, which will charge the EVs batteries less than one hour [7]. Although the usage of electric cars benefits the environment and the economic viability of all the countries, it also has some negative consequences for the power grid. The high charging loads associated with fast level 3 charging stations causes several problems including, shortage of the electricity, peak demand spikes, voltage instability, and reliability issues for the power grid [8, 9]. Therefore, all the countries should consider using renewable energy sources like solar and wind energy to reduce the stress of using electric vehicles on the power grid [10]. In this paper, the proposed microgrid system utilize photovoltaic cells to charge the Battery Electric Vehicles (BEVs) via a level 3 station. Fig. 1 indicates the DC fast charging station using solar energy to charge the batteries of the electric cars.

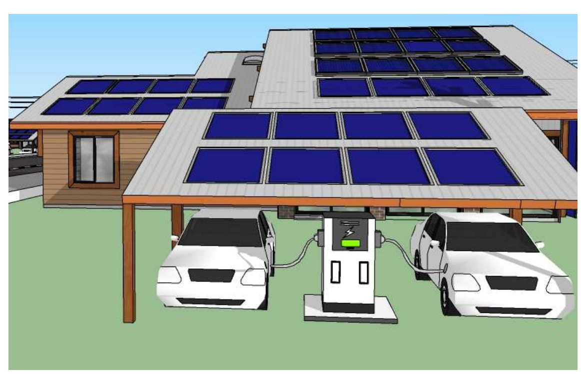

Fig. 1. DC fast charging station using PV to Vehicles

Therefore, as it can be seen from Fig. 1, the high-power bi-directional charging for EVs is possible for PV to BEVs, PV to power grid, BEVs to power grid and power grid to vehicle [11]. This paper will be presented as follow: In Section 2, the structure of the proposed micro-grid system is illustrated. Section 3 explains DC fast charging method. Section 4 demonstrates half bridge DC-DC converter and charging/discharging modes of the batteries. Section 5 and 6 illustrate boost converter and LCL filter. Section 7 contains the simulation and results of the proposed system. At the end, Section 8 is the conclusion.

II. Structure of the proposed micro-grid system

The proposed micro-grid system is equipped with rooftop photovoltaic system, a transformer, Battery Electric Vehicles (BEVs), DC fast charging station, and the necessary power converters. The structure of the proposed microgrid system is describes in Fig. 2.

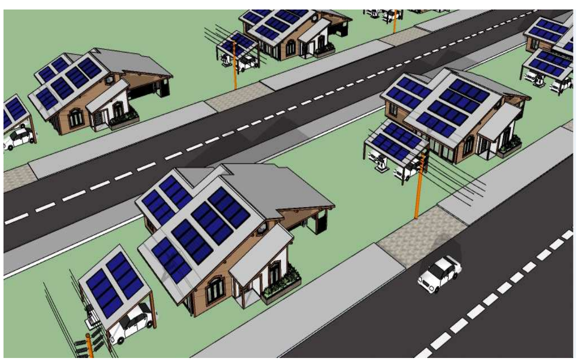

Fig. 2. Structure of the presented microgrid system

The proposed microgrid system can operate in four different ways, including PV to Vehicle, PV to Grid, Vehicle to Grid, and finally Grid to Vehicle. In the first part, when there is enough sun radiation and solar power, the PV system can charge the batteries of the BEVs. Moreover, in the second part, when the batteries are fully charged, the energy come from solar PV system can be utilized for the national power grid [12]. In the third part, in cloudy days and night time, when there is no sun radiation, the power grid can charge the BEVs through a DC fast charging station in one or two hours. Finally, in the fourth part, in the peak demand of electricity, to prevent the shortage of power and prevent the shedding down, the power utility companies can use the stored energy of the BEVs to feed the power grid by a demand side management system [13, 14]. The presented micro-grid system with all four different modes of operation can be seen from Fig. 3.

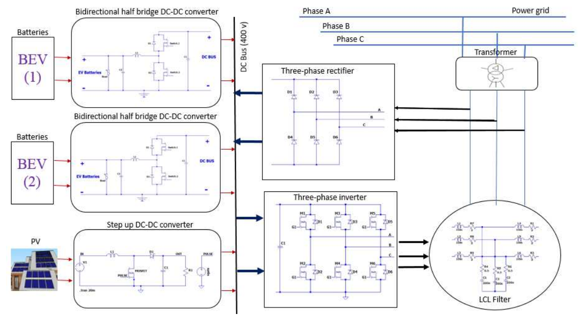

Fig. 3. PV to Vehicle; PV to Grid; Vehicle to Grid; Grid to Vehicle, using a DC fast charging station

As it can be seen from Fig. 3, all parts of the system are connecting to DC bus of the DC fast charging station. In this way, the system is used to generated power for the grid in a lower time and also the power grid is able to charge the BEVs in less than one hour [15].

III. DC fast charging

A DC fast charging system contains four main parts, including the EV batteries, voltage converters, there-phase inverters, and a LCL filter. A voltage converter is used to step up the output voltage of the batteries to the DC bus before the inverter [16]. Then, an inverter converts the dc voltage of the DC bus to three phase AC voltage. The output voltage of the inverter has some level of harmonics and has to be lowered via using a LCL filter to have a pure sinusoidal waveform. Finally, the AC output voltage of the inverter must be boosted by using a step-up transformer to be injected to the power gird. Although the usage of electric cars benefits the environment and the economic viability of all the countries, it also has some negative consequences for the power grid [17]. The high charging loads associated with fast level 3 charging stations causes several problems including, shortage of the electricity, peak demand spikes, voltage instability, and reliability issues for the power grid. Also, the power utility companies should install fast dc level 3 charging stations on the stronger buses to prevent the peak demands. If the level 3 charging stations will be installed on weak buses, the severe voltage drops would happen which results in increasing power losses. So, power companies should specify the strong and weak buses in each area and build the level 3 charging station on the stronger buses [18].

IV. Half-bridge dc to dc converter

A bi-directional half-bridge is mostly utilized in EVs, where it can be used as a step-down converter (to charging the batteries) or a step-up converter (to feed the power grid by discharging the batteries) with the same configuration [19]. Fig. 4 demonstrates the bidirectional half bridge dc to dc converter.

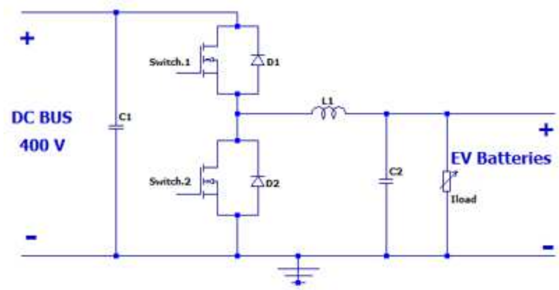

Fig. 4. Bidirectional half-bridge dc-to dc converter

According to Fig. 4, because of having two switches (Q upper and Q lower), the diagram can be used as a step-down or step-up converter. In addition to switches, there are two freewheeling diodes which are parallel to switches, which can be used to transfer current across the switches [20]. There are two modes of operation for this converter.

A. Step-down mode: charging the batteries

In the step-down mode, only switch 2 is operating and the batteries can be charged by either the solar system or the inductor. Therefore, the output voltage of the solar system is stepping down to charge the batteries [21].

Mode 1: In this case, switch 1 is on and switch 2 is off. Therefore, the energy from the DC bus feeds the batteries through the inductor L, causing the inductor current to grow as it can be seen from Fig. 5.

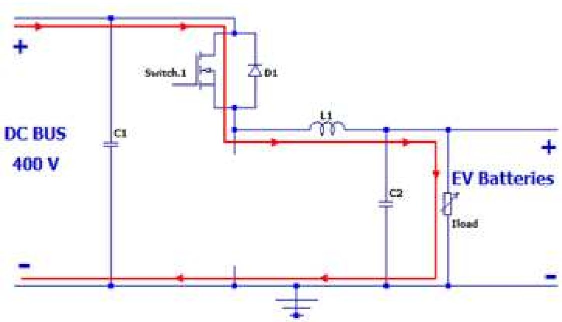

Fig. 5. Mode 1: charging the batteries by solar modules

Mode 2: In this mode, according to Fig. 6, both of the switches are off. Therefore, the stored energy of the inductor L will feed the batteries.

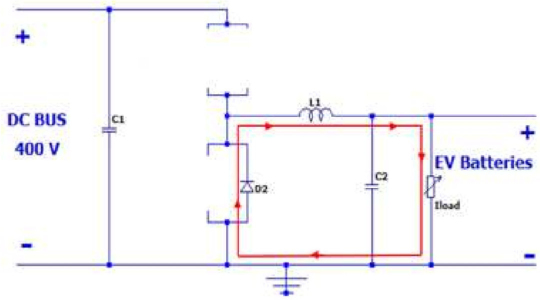

Fig. 6. Mode 2: Charging the batteries by stored energy of the inductor

B. step-up mode: discharging the batteries

In the step-up mode, only switch 1 is operating and the batteries can be discharged to feed the power grid. Therefore, the output voltage of the batteries is stepping up to feed the power grid [22].

Mode 3: In this case, switch 2 is on and switch 1 is off. Therefore, the batteries are discharging through the inductor L and the energy of the inductor will be increased as it can be seen from Fig. 7.

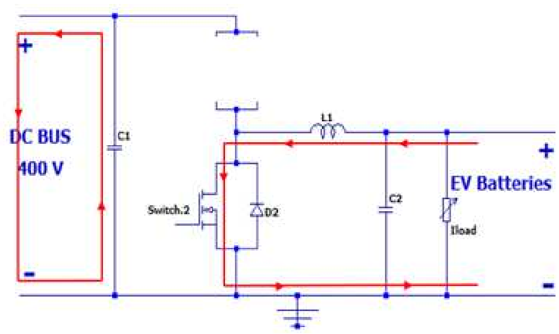

Fig. 7. Mode 3: Discharging the batteries by storing energy in the inductor

Mode 4: In this mode, both switches are off. Therefore, both the batteries and the stored energy of the inductor feed the power grid which is shown in Fig. 8.

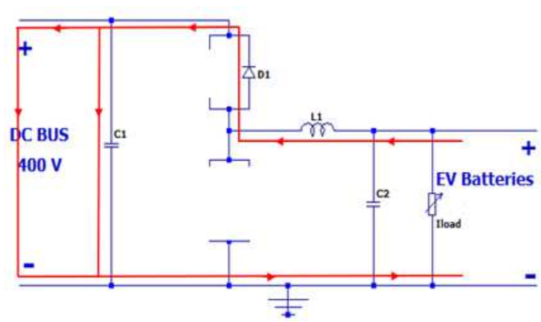

Fig. 8. Mode 4: Discharging the batteries by feeding the power grid

V. Step up DC-DC converter

To step up the voltage of the PV system to 400 V of the DC bus, a step-up converter is utilized. Fig. 9 describes the diagram of the step up converter.

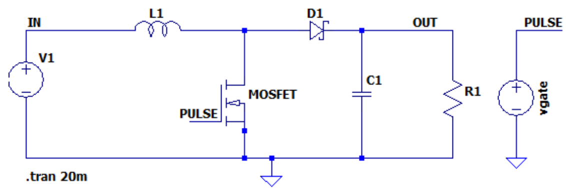

Fig. 9. Step up converter

The step up converter has two modes of operation as it can be seen from Fig. 10.

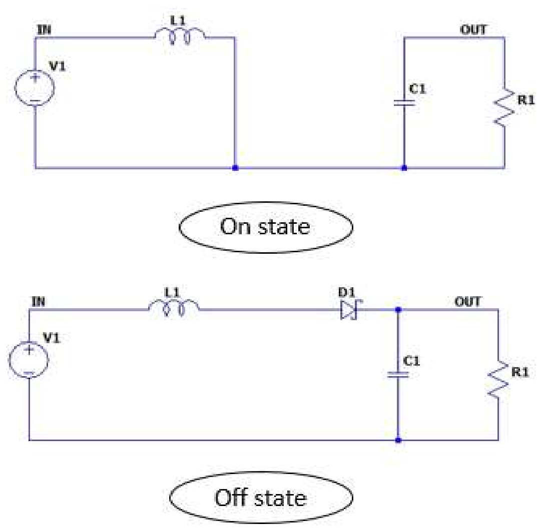

Fig. 10. Two different modes of operation

According to Fig. 10, when switch is on, the inductor L1 will be charged by the dc voltage of the PV. Therefore, the current of the inductor will increase. Also, when switch is off, the stored energy of the inductor as well as the energy comes from PV will feed the DC bus [23].

VI. LCL filter

It is obvious that the output signal of the inverter has some harmonics. So, the usage of a filter is required. The filter that is utilized after the inverter is LCL filter because it has lower voltage drop and can be used at low switching frequency, 60 Hz of the power grid [24, 25]. Eq. (1), (2), and (3), demonstrate the base impedance, base capacitance, and the LCL filter capacitance.

$$Z_{base} = \frac{{V_{ph}}^2}{S_{base}} \quad (1)$$

$$C_{base} = \frac{1}{w_g . Z_{base}} \quad (2)$$

$$C_{filter} = 10\ \%\ C_{base} \quad (3)$$

In the above equations, Z_{base} is base impedance, V_{ph} is the phase's voltage, C_{base} is the base capacitance, w_g is grid angular velocity. In addition, for calculating the inductor in the inverter side of the system, the peak to peak ripple output current must be specified [26, 27]. Eq. (4) and (5), indicates the peak to peak output ripple current and the inductor of the inverter side.

$$\Delta I_{L.max} = 20\ \%. I_{output} \quad (4)$$

$$L_{inverter} = \frac{V_{dc}}{6. f_{switching} . \Delta I_{L.max}} \quad (5)$$

Where, $L_{inverter}$ is the first side inductor, $f_{switching}$ is switching frequency of the system, V_{dc} is DC bus voltage. The attenuation factor and the second side inductor are given by Eq. (6), (7), and (8).

$$Attenuation\ factor = K_a = 20\ \% \quad (6)$$

$$\omega_{switching} = 2. \pi. f_{switching} \quad (7)$$

$$L_{power-grid} = \frac{1 + \sqrt{\frac{1}{K_a^2}}}{C_{filter} . \omega_{switching}^2} \quad (8)$$

Where, $L_{powergrid}$ is power-grid side inductor.

VII. Simulation results

In both the step down (charging) and step up (discharging) modes, LTSPICE software is used for simulation. In addition, the converter is set up to work in Continuous Conduction Mode (CCM). In the charging mode of operation, the input voltage is 400 V equal to DC bus, and the output voltage is 250 V, which is equal to voltage of the batteries. Fig. 11 demonstrates the buck mode of the system.

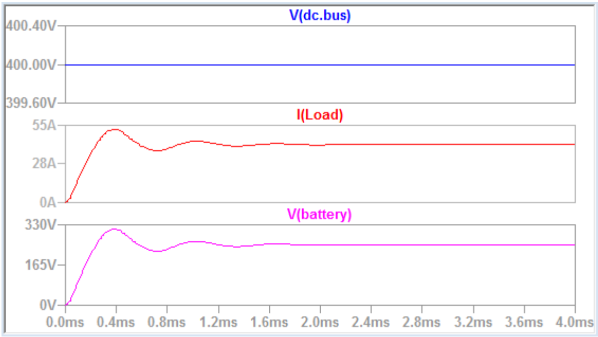

Fig. 11. Buck mode

According to Fig. 11, the output voltage across the batteries is 250 V, which charges the storage system of the BEV. Also, Fig. 12 shows the voltage across switch 1 and current through the inductor.

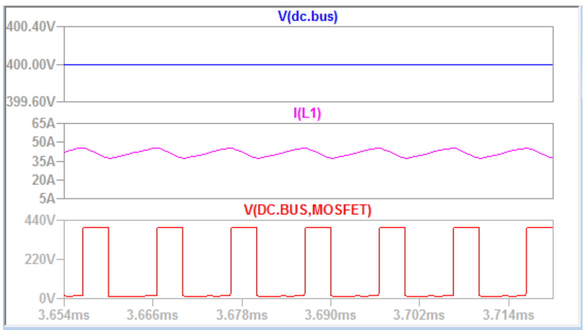

Fig. 12. Voltage across switch 1 and current through the inductor

Based on Fig. 12, when switch 1 is off, the voltage of the mosfet is 400 V and the stored energy of the inductor L1 feeds the battery. Moreover, when switch 1 is on, the voltage of the mosfet is zero and the power from the DC bus feeds the battery through the inductor L1, and increase the inductor current. Fig. 13 demonstrates the discharging mode of operation in which the batteries of the BEV feed the DC bus in order to feed the power grid.

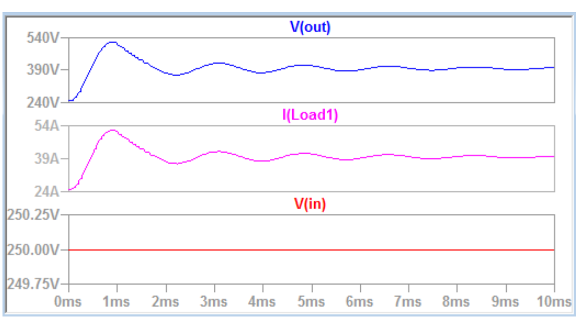

Fig. 13. Boost mode

As it is shown in Fig. 13, the output voltage across the DC bus is 400 V, which feeds the power grid. Also, Fig. 14 shows the voltage across switch 2 and current through the inductor L1 in this mode of operation.

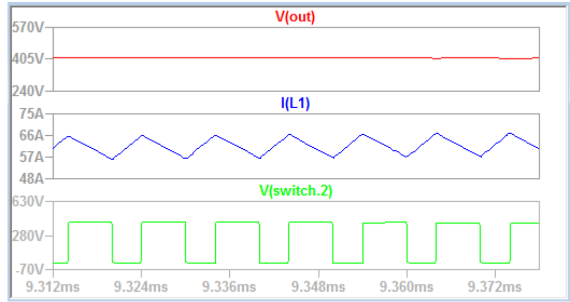

Fig. 14. Voltage across switch 2 and current through inductor L1

According to simulation in Fig. 14, when switch 2 is off, the voltage across the switch is 400 V and both the energy from the batteries as well as the stored energy of the inductor L1 feed the power grid. Moreover, when switch 2 is on, the voltage across the switch is zero and the power from capacitor C1 feeds the DC bus. Plus, the energy from the batteries increases the inductor current through L1. Fig. 15 shows the output three-phase line to line voltage of the inverter which can be injected to the power grid.

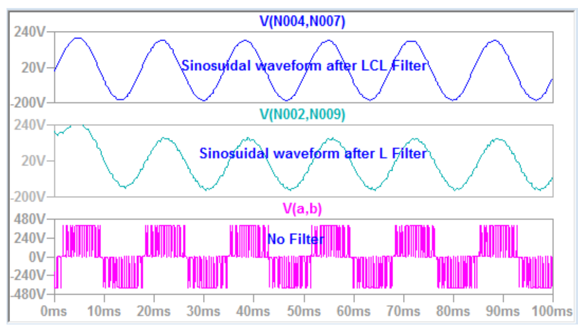

Fig. 15. The output three-phase line to line voltage of the inverter

As it can be seen from Fig. 15, by using grid connected inverter with LCL filter the three-phase output voltage of the proposed system are sinusoidal.

VIII. Conclusion

In this paper, BEVs storage sources are integrated into the power grid. This paper presents the PV to EVs, PV to the power grid, EVs to the power grid, and the power grid to EVs topologies in a micro-grid system using a level 3 charging station operations for buildings with electric vehicles and solar panels. The voltage converter and grid-connected inverter provide a power flow between BEVs and the power grid in both directions. The acquired findings clearly show that the suggested method produces satisfactory outcomes under various conditions and can be implemented in the micro-grid system. In addition, by integrating this system with demand response, peak-time demands can be solved using BSS of each electric car to transfer demands from peak time to off-peak time.

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