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Implementation of quasi-z source inverter for grid connected PV based charging station of electric vehicle

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ABSTRACT

In recent trends, the use of electric vehicles is taking a sudden hike as they seem to be a much more friendly for the environment as compared to the conventional vehicles that run on combustion engines for a mode of transportation. With the increasing popularity of electric vehicles, the demand on the utility grid is also increasing. To overcome this problem, other alternative sources of energy need to be considered. Photovoltaic energy as the solution is finding its place in the EV charging systems. However, the total amount of energy that can be generated from the PV system is constrained, based on many parameters such as solar radiation, availability of space for Solar power plant development, maintenance of the system, etc. Hence, to maintain the continuity of the system, it needs to be integrated with the grid as well. This offers a smooth charging operation for the electric vehicles. In this paper, a new method is introduced for the integration between the solar inverter system and the utility transmission grid. Quasi-Z-source topology is proposed for the system integration. This topology facilitates a bidirectional flow of power between the PV source, the storage unit and the utility grid. The greatest advantage of this topology is its flexibility with different voltage levels of the solar inverter DC connection and the storage battery which requires no circuit alteration for charging batteries of different ratings. The hardware for the system is also fabricated. The results demonstrate that the proposed topology fits the generalized requirements.

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1. INTRODUCTION

The intense need for eco-friendly technology and energy shortage being faced by world these days has contributed to the increase in popularity of hybrid and electric vehicles. As such, vehicles run partially or fully on electricity, building a good charging infrastructure without increasing load on the utility grid is a matter of concern. Using Solar energy for designing the charging infrastructure has a lot of merits, keeping the load demand on the utility transmission grid lower also reducing the cost of operation that the utility service provider has to bear especially in various business operations and promoting a clean and green environment. Though the PV system has a lot of advantages, it still faces a lot of shortcomings as the PV output entirely depends on the level of the sun irradiation available, temperature, space available for setting up the system, etc. Hence, the system anyhow needs to be connected to the power grid to maintain a smooth operation of the system.

The methods that are widely used these days make use of a DC bus for power sharing and vehicle charging as the output produced by the PV panel is also DC power. Hence integration of PV panels and DC bus is an easy operation as depicted in [1], [2]. The various power sources that are available may be in various forms such as the utility grid, renewable power sources such as solar panel and wind turbine generator and DC energy storage units such as batteries. The integration of the entire system requires a lot of AC-DC rectifiers, DC-AC inverters and DC-DC converters to finally convert the energy into usable form. Then, before finally feeding power to the vehicle batteries from the DC bus, another DC-DC converter has to be employed so as to match the battery specifications of the vehicle. All these numerous stage conversions lead to increased system complexity, increased cost and size, and finally reduce the efficiency of the system. This finally opposes the goal of cost reduction for the utility service provider.

The quasi-Z-source inverter (qZSI) [3], [4] which has been created from the conventional Z source inverter (ZSI) [4] has various advantages for its usage in a Solar PV inverter system. The quasi-Z-source inverter uses the shoot through the state to boost the DC voltage by gating, both its switches on the same leg and hence produce a higher voltage as compared to the available voltage. This arrangement is more reliable as it prevents migrating and hence saving the circuit from getting short circuited. Hence it provides single stage DC-DC-AC conversion, further reducing the number of components also giving a higher DC-DC boost capability with lower cost as compared to a conventional voltage source inverter (VSI). When the PV source is the alternative source of energy, the energy storage capability is one of the significant elements in the electric vehicle charging station infrastructure. In order to reduce the dependence on the grid for energy, the extra energy from the PV system is stored. In relation to quasi ZSI, there are basically two options for the installation of battery storage to the circuit. This can be seen as proposed in [5]-[11]. However, connecting the battery directly across the capacitor leads to the requirement of designing the battery voltage at a higher value in the series in order to integrate the operating range of the PV terminal and the DC link voltage about the inverter switch. Since the charging voltage required by the vehicle varies according to the car manufacturer, a storage system with more flexibility is demanded.

The management of the bi-directional battery storage can be extended to be adapted in the concept of charging station for the electric vehicle. The system feasibility is proved by carrying out verification with MATLAB simulation and on the basis of the result, the proposed design passes the feasibility test. Further, the hardware of the proposed system is fabricated and verified through practical application.

2. CIRCUIT ANALYSIS OF QZSI INVERTER

A traditional voltage fed ZSI and the proposed qZSI are shown in Figures 1 and 2 respectively. The qZSI has two types of operating states similar to the traditional ZSI. These are (i) Non-shoot-through state and (ii) Shoot through the state. In the non-shoot through the state, the inverter bridge acts as a current source from the DC side. In the traditional VSI, the shoot through the state is forbidden as it causes the short circuit of the voltage source and also damages the device. In order to allow the shoot through the state, the operation of the circuit is modified by connecting a unique network of LC and diode to the inverter bridge in the qZSI and ZSI. On the occurrence of shoot through, the proposed network helps in protecting the circuit from damage and the DC link voltage is boosted by the quasi-Z-source network using the shoot through the state.

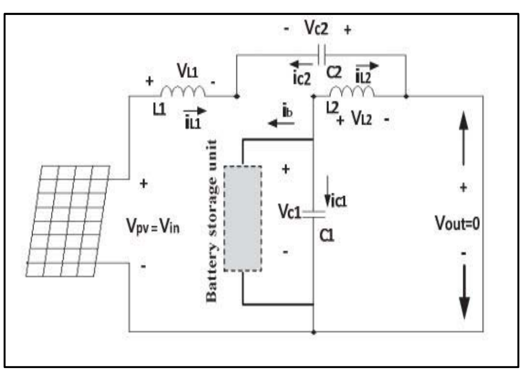

Figure 1. Equivalent circuit of shoot through state

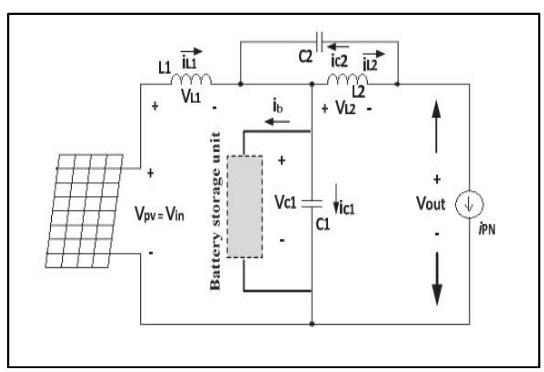

Figure 2. Equivalent circuit of non-shoot through state

3. VEHICLE CHARGING STATION

The electric vehicle charging station having 680V DC bus, which is connected to the backup battery parallelly as shown in Figure 3. Also, the charger 1-4 consist of buck converter (DC-DC) which delivers the energy requirement to the vehicle during the charging process. In order to control the current delivered to the EV battery, a controller used inside the buck converter (DC-DC). This controller is used to vary the current based on the time required to obtain a certain level of SoC [12]. Flow chart of charging mode of operation as shown in Figure 4.

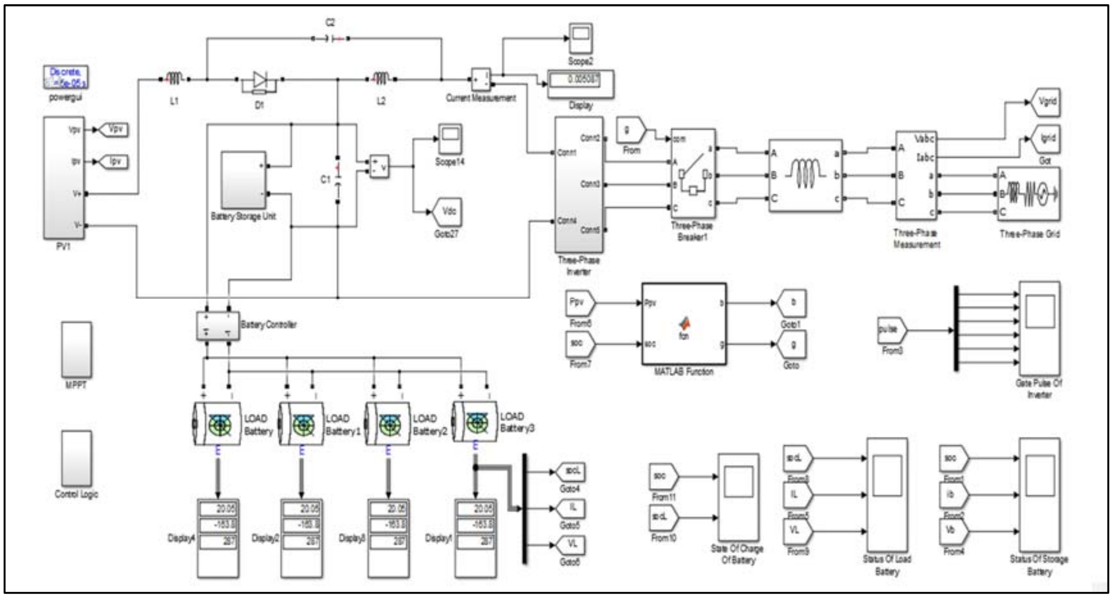

Figure 3. Overall MATLAB circuit diagram for bidirectional vehicle charging station using qZSI PV inverter

3.1. Modes of operation

The 3 major parameters which define the mode of operation of the system are:

a. PV array output power (P_{pv})
b. Charging vechicle battery power demand (P_{charge})
c. SoC of the storage battery

The flowchart depicting the power management of the system as shown in Figure 6 can be summarized as follows:

a. **Mode 1:** When the output of the PV panel is sufficient enough to meet the load demand, the load is fed directly from the PV power. The storage battery is also charged in this mode.
b. **Mode 2:** When the PV plant output low and is not sufficient to meet the load demand, but the SoC of the storage battery is sufficient, the storage battery goes into discharging mode and supports the PV output in meeting the load demand.
c. **Mode 3:** When the output from the PV panel is low and the SoC of the storage battery is also low, the Grid power used to meet the load demand.

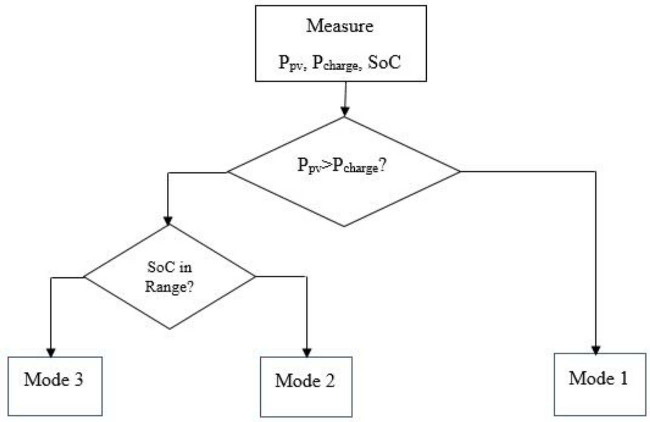

Figure 4. Flow chart of charging mode of operation

4. RESULT AND DISCUSSION

In order to verify the workability of the proposed design, the same design simulated in MATLAB Simulink. Because of the memory constraint of the computer, simulation is conducted for 10 sec. One simulation can only show 2 modes of operation at a time. Hence, the simulation is carried out twice in order to analyze all the 3 operating modes. Figure 5 shows the output power of the PV module. It depends directly on the step irradiation that is given to the panel. The irradiation is varied from 1000W/m^2 to 100W/m^2 in steps. Hence, the output power also decreases accordingly. As shown in Figure 6, from 0s to 2s, when the output of the PV panel is sufficient enough to meet the load demand (Mode 1), both the storage battery as well as the load battery gets charged. From 2s to 8s, when the PV panel output is not enough to meet the load demand, but the SOC of the storage battery is high (Mode 2), the load batteries are charged from the storage battery, hence the storage battery begins to discharge whereas the load batteries still charge, but at a slower rate. From 8s to 10s, the output of the PV panel increases again and the system operates in Mode 1. With the reference of Figure 7, from 0s to 6s, when the output power of the PV panel is low and the SoC of the storage battery is also low, the system operates in Mode 3 and the load batteries draw power from the grid whereas the storage battery remains disconnected. Hence, the SoC of the storage battery remains constant throughout, whereas the source of the load battery increases. From 6s to 10s, the output of the PV panel increases, hence the system switches back to Mode 1.

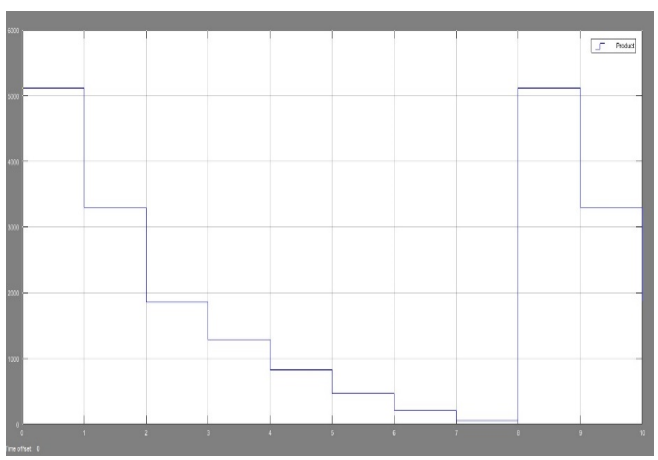

Figure 5. Power output of PV panel

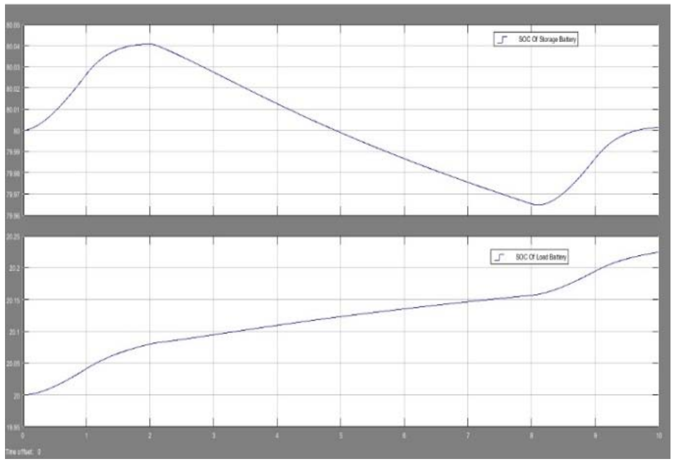

Figure 6. SoC of batteries in mode 1 and 2

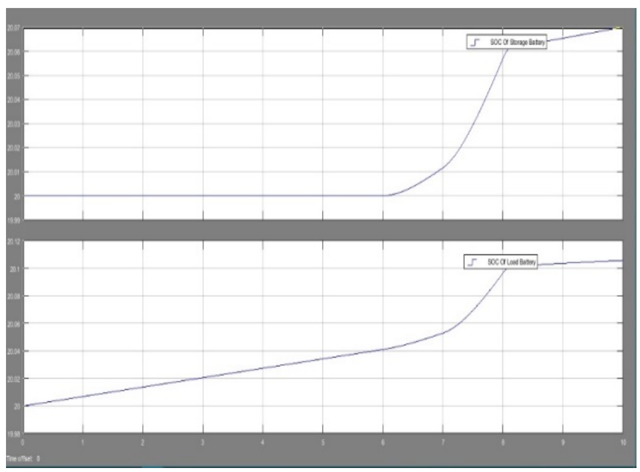

Figure 7. SoC of batteries in Mode 3

Figure 8 depicts various waveforms of the storage battery while operating in various modes. In Mode 1, from 0s to 2s, when the storage battery is charging, the SoC of the battery increases. The current in the battery is negative, which means that the current is entering into the battery. The voltage of the battery also increases at the same time. In Mode 2, from 2s to 8s, when the battery begins to discharge, the SoC of the battery begins to drop, whereas the current becomes positive which means that the current is being drawn from the battery. The voltage of the battery also begins to drop and after 8s, the battery again operates in mode 1. Figure 9 depicts various waveforms of the load battery while operating in various modes. In Mode 1, from 0s to 2s, when the output of the PV panel is high, the SoC of the load battery increases. The current in the battery is negative, which means that the current is entering into the battery. The voltage of the battery also increases at the same time. In Mode 2, from 2s to 8s, when the power from the PV panel becomes low, the SoC of the battery still increases, but at a slower rate as compared to that in Mode 1. The current remains negative, which means that the current is still being fed to the load battery. The voltage of the battery also continues to rise. After 8s, the battery again operates in mode 1. Figure 10 depicts the various waveforms of the storage battery when it operates in Mode 3. As the power is drawn from the grid in mode 3, the storage battery remains disconnected from the system. Hence, the SoC, current as well as the voltage remains constant till the system switches back to Mode 1 after 6s. Figure 11 depicts the various waveforms of the load battery when it operates in Mode 3. As the power is drawn from the grid in mode 3, the load battery continues to charge. Hence, the source increases and current remain negative. The voltage also increases with time. The system switches back to Mode 1 after 6s.

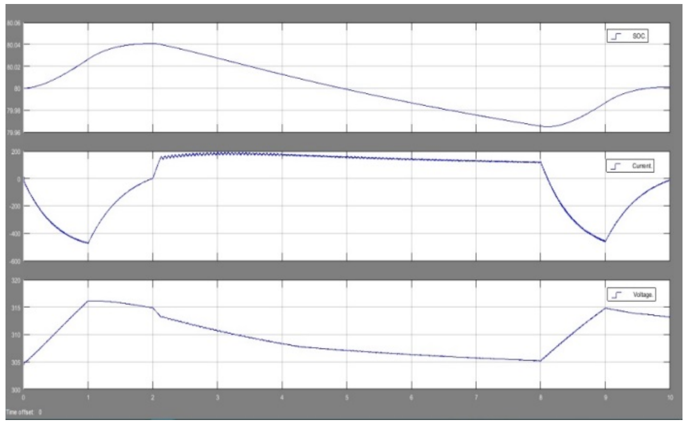

Figure 8. Waveforms of storage battery

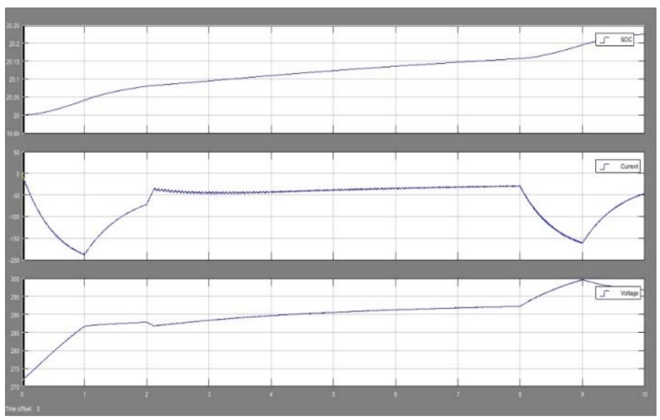

Figure 9. Waveforms of Load battery

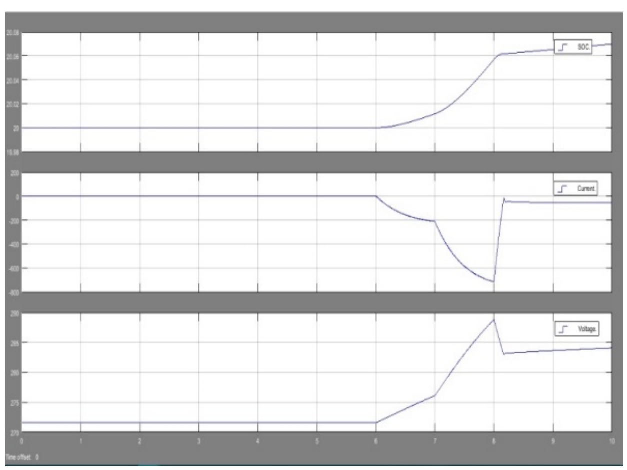

Figure 10. Waveforms of storage battery in Mode 3

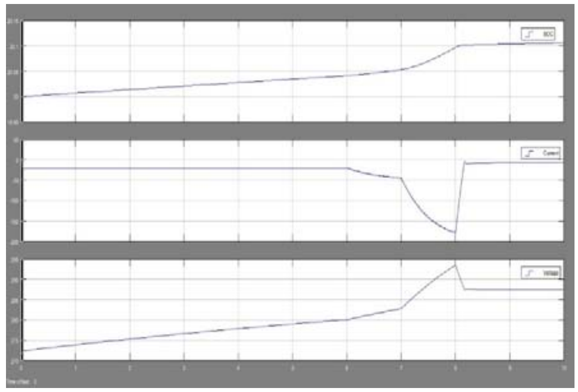

Figure 11. Waveforms of Load battery in Mode 3

Figure 12 describes the hardware implementation of the proposed circuit. It also has terminals for a storage battery and 2 load batteries. Current is fed to the batteries through a battery controller circuit. It consists of 2 Mosfets, one capacitor and one inductor which together form a circuit that is capable of acting both as buck and boost converter. It acts as a buck converter during the charging operation of the battery. On the other hand, it works as a boost converter during the discharging operation of the battery. The inverter part consists of 6 Mosfets. It is also connected to a single-phase AC supply through a 230/12V single tap transformer. Gate pulses are required for each of the mosfets used in the circuit. It is generated by a microcontroller. The controller circuit consists of a microcontroller circuit which is powered from one of the taps of a 230/12V 7 tap transformer through an IC7805 as the microcontroller runs on a constant 5V power supply. The microprocessor takes feedback from the PV panel and SoC of the storage battery to generate the clock signal for the Mosfets. The mosfets need a signal of at least 9V to perform the switching operation. But the signal generated by the microcontroller is a 5V signal. Hence a driver circuit is required that may act as an amplifier to amplify the 5V signal to 12V signal before feeding it to the mosfet. The driver circuit consists of 8 numbers of IC TLP250, one for each of the mosfet. Each of them is powered from the 230/12V transformer through a rectifier circuit. A capacitor is also put in the rectifier circuit that acts as a filter to smoothen the supply being fed to the IC. Finally, the switching operation is done according to the mode in which the system is working.

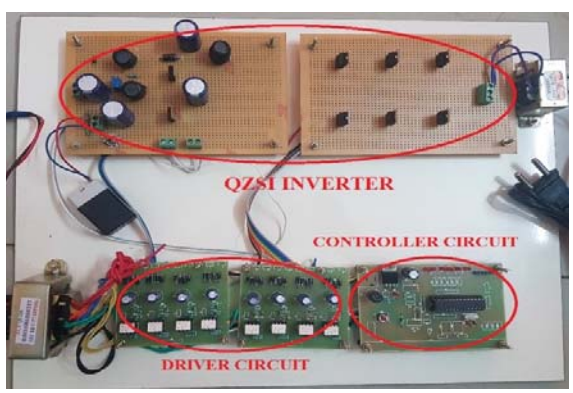

Figure. 12. Hardware Design

5. CONCLUSIONS

The efficient power management system using QZSI inverter is addressed in this paper. The result, emphasis the bi-directional power flow between PV to grid and grid to PV with different voltages which match the practical requirement. Modeling and control strategy have been developed for a better understanding of the control strategy. Hardware implementation of the circuit has also been done successfully and is verified with the simulation results. The proposed model ensures faster charging of electric vehicle and the portability of PV system makes charging station easily adaptable in smaller places. The robust controller controls the bi-direction power flow PV to grid and grid to PV with different operating voltages.

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Appendix

DESIGN Parameter:

	Parameters	Values
1.	PV Plant maximum power	5kWp V_{mpp} = 235.9 I_{mpp} = 21.36A
2.	PV System bus voltage(DC)	680 V_{ave} , 1124.1 V_{pk}
3.	Switching frequency	10 kHz
4.	Grid configuration	3-phase secondary network 415 V_{rms} (240 V_{rms} per phase)
5.	Grid injection (AC power)	5kVA
6.	Switching frequency	10 kHz
7.	Standard / reference	AS4447 Grid Connection of Energy Systems via Inveerters IEEE 1547 Standard on Interconnecting Distibuted Resources with Elec. Power Sys.
8.	Storage battery capacity (Kwh/Ah)	96 kWh at 300V, 320 Ah
9.	Traction Battery unit	24 kWh at 300V, 80 Ah
10.	Controller	DSP-30F2010
11.	Driver TLP250	Input threshold current I_f=5mA Supply current I_{cc}= 11mA Supply voltage V_{cc}= 10-35V Output current I_o= 1.5A