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Modeling and Control of a Multiport Converter based EV Charging Station with PV and Battery

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ABSTRACT

As an environmental friendly vehicle, the increasing number of electrical vehicles (EVs) leads to a pressing need of widely distributed charging stations, especially due to the limited on-board battery capacity. However, fast charging stations, especially super-fast charging stations may stress power grid with potential overload at peaking time, sudden power gap and voltage sag. This project discusses the implementation and modeling of space vector modulation to multiport converter based EV charging station integrated with PV power generation, and battery energy storage system. In this paper, the control scheme and combination of PV power generation, EV charging station, and battery energy storage (BES) provides improved stabilization including power gap balancing, peak shaving and valley filling, and voltage sag compensation. As a result, the influence on power grid is reduced due to the matching between daily charging demand and adequate daytime PV generation. Simulation results are presented to confirm the benefits at different modes of this proposed multiport EV charging circuits with the PV-BES configuration with SVM technique. Furthermore, SiC devices are employed to the EV charging station to further improve the efficiency.

INTRODUCTION

The continuous rise in gasoline prices along with the increased concerns about the pollutions produced by fossil fuel engines are forcing the current vehicle market to find new alternatives to reduce the fossil fuel usage. Along with the research on bio-fuel driven engines; different electric vehicles and hybrid electric vehicles are evolving as viable alternatives to replace, or at least reduce, the current fleet of fossil fuel driven vehicles. Although current manufactured electric/hybrid vehicles are being marketed as a way to reduce fossil fuel usage, several promising technologies are being demonstrated that can utilize power electronics to charge the battery from the utility using plug-in vehicles or act as a distributed resource to send power back to the utility with vehicle-to-grid capabilities. In this paper, different plug-in vehicle topologies are described to review the power electronics required for them. The newly evolving V2G technology is also discussed along with economics and compliance requirements to allow the vehicle to be connected to the grid. Before going into the details of power electronics required for the electric/hybrid vehicles, the common forms of these vehicles are described next to get accustomed with the terminologies.

Literature View:

Singaravelan and Kowsalya [1] presented fuzzy controller for voltage-frequency control scheme for microgrid in islanding operation. The proposed scheme of fuzzy based voltage-power/frequency-active power (VP/FQ) sets the real power output to regulate the microgrid voltage and the reactive power output to regulate the frequency. This supervisory control scheme allows the voltage source converter (VSC) with standard inductor interface and dqframe current control in islanding mode in the instantaneous synchronization operation. The results demonstrate that the proposed approach perfume well and has a significance for the control of inverters in microgrid. A high-frequency photovoltaic pulse charger for lead-acid battery guided by a power-increment-aided incremental-conductance maximum power point tracking was proposed by Hung-I Hsieh et al [2]. The PV-PC implemented by a boost current converter is to eliminate sulphating crystallization on the electrode plates of the LAB and to prolong the battery life. The BCC associated with the PV module is modeled to maximize the energy charging to battery under maximum power transfer. A duty-control guided by the PI-INC MPPT is designed to drive the BCC operating at MPP against the random insulation.

Arash Shafie et al [3] proposed a novel MPPT algorithm mainly for battery charging applications which were considered constant voltage type loads. This was achieved mainly with output current maximization. This technique benefits from advantages such as very simple current controller and also circuit topology independency. This provides high efficiency for energy conversion with low cost for low power, low cost applications. A new hybrid PV model was introduced for simulation purposes. Finally, simulation results will be provided confirming the validity of the algorithm. Jannik Schäfer [4] proposes a novel multi-port multi-cell (MPMC) topology, which allows to overcome the arising design challenges for converter systems in applications with highly different input and output voltage levels. Among other advantages, the MPMC topology reduces the cell-internal port voltage ratios, and therefore leads to beneficial characteristic impedances of the converter ports.

G. Sowmmiya [5], proposed a multiport fast charger for the electric vehicle based on the concept of the active power electronic transformer is designed and implemented. This concept offers the following benefits: power control; voltage control (compensation of voltage sags and peaks); current control (short-circuit current limitation).The multiport topology enables the reduction of power losses and the complexity of the power circuit and increases power density. The grid converter works as a synchronous rectifier supplying the multiport converter part with energy. Maximum power point Tracking is implemented by which the voltage obtained from PV module can produce maximum power.

ELECTRIC VEHICLES

A typical electric vehicle (EV) has a battery pack connected to an electric motor and provides traction power through the use of a transmission. The batteries are charged primarily by a battery charger that receives its power from an external source such as the electrical utility. Also during regenerative braking, the motor acts as a generator which provides power back to the batteries and in the process slows down the vehicle. The primary advantage of an EV is that the design is simple and has a low part count. The primary disadvantage is that the driving range of the vehicle is limited to the size of the battery and the time to re-charge the battery can be from 15 minutes to 8 hours depending on how far the vehicle was last driven, the battery type and battery charging method.

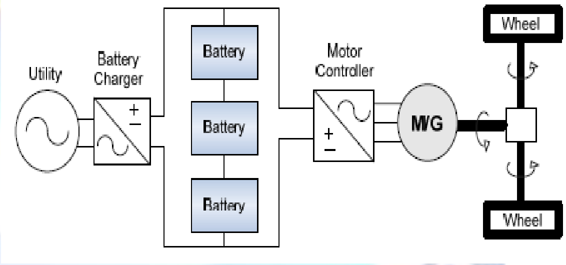

Figure 1: Typical EV configuration

Plug-In Vehicles:

According to the Electric Power Research Institute (EPRI), more than 40% of U.S. generating capacity operates overnight at a reduced load overnight, and it is during these off-peak hours that most PHEVs could be recharged. Recent studies show that if PHEVs replace one-half of all vehicles on the road by 2050, only an 8% increase in electricity generation (4% increase in capacity) will be required [2]. Most of the electric vehicles that are of plug-in type, utilize on-board battery chargers to recharge the batteries using utility power. The simplest form of a plug-in electric vehicle is shown in Fig. 1. This configuration consists of a battery system and a motor controller that provides power to the motor, which in-turn supplies power to the wheels for traction. Many of today's EVs use a permanent magnet electric motor that can also act as a generator to recharge the batteries when the brakes are applied. During regenerative braking, the motor acts as a generator that provides power back to the batteries and in the process slows down the vehicle. Friction brakes are used when the vehicle must be stopped quickly or if the batteries are at full charge.

The components that make up a typical HEV include a battery pack, motor controller, motor/generator, internal combustion engine, transmission and driveline components. The primary power electronics include a DC-AC motor controller which provides three-phase power to a permanent magnet motor. The Toyota Prius HEV configuration is given in Fig. 2. The Prius design uses two permanent magnet motors/generator, one of 10kW and the other of 50kW. The battery is connected to a booster and inverter before feeding to the motor/generators. The power electronics are bidirectional and used for both charging the battery and powering the motors. The motor/generators and gasoline engine feed into a planetary gear set. The system operates in a continuously variable transmission (CVT) mode where the gear ratio is determined by the power transfer between the battery, motor/generators and gasoline engine [3], [4]. The batteries can also be charged using regenerative braking of the large motor/generators. There is no provision to charge the batteries externally. For plug-in hybrid electric vehicles, batteries are charged when they are not being driven. This is normally accomplished through a utility connected AC-DC converter to obtain DC power from the grid. The batteries can also be charged directly from a solar resource using a DC-DC converter or from a wind source using an AC-DC converter. Energy flow is unidirectional as power is taken from the utility to charge the battery pack. A Toyota Prius configuration with PHEV conversion is shown in Fig. 2. The battery voltage for most converted PHEVs are maintained at the same level as the original design (typically 200-500 VDC) and battery modules are added in parallel to increase the energy capacity of the battery pack, thus allowing the electric motor to run more often than the original HEV design. Some of the PHEV conversion companies include: CalCars, Energy CS, Hymotion, Electrovaya, and Hybrids Plus, and most of them use lithium batteries.

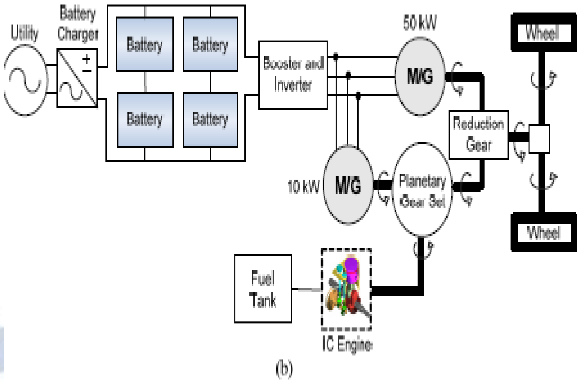

Figure 2: Configurations converted PHEV

PLUG-IN ELECTRIC VEHICLE CHARGER TOPOLOGY

The desirable characteristics for the charger are power bi-directionality (V2G and G2V), power factor equal to one, capability of performing power control, low PQ impact, construction and topology simplicity, and regular 16 A single-phase plug compatibility [6]. This charger does not allow performing fast charge, being 2.3 kW (10 A, 230 V) the advisable maximum power for a single-phase household-type plug. This power range is defined based on EU standards and power grid restrictions, since higher power ranges could represent a negative impact on the low voltage (LV) grid in terms of PQ and EMS requirements [22]–[24]. Regarding the voltage level of the battery pack, the proposed design is focused on L-category vehicles (two-, three- and four-wheel vehicles such as motorcycles, mopeds, quads, and minicars), as the one studied in [25], but could be extended to other voltage levels.

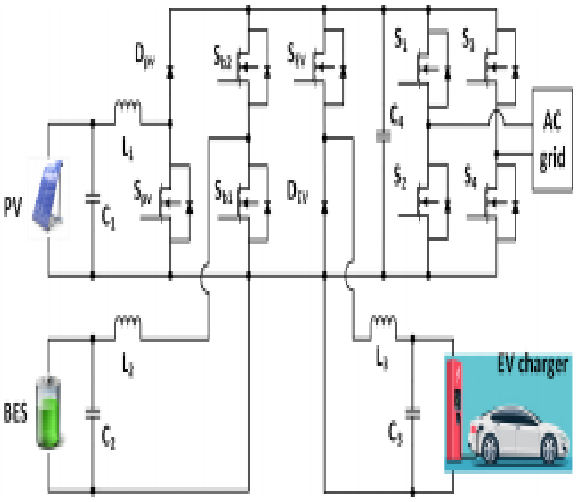

Figure 3: PEV charger topology

a. Photovoltaic Array Modeling:

In the PV network of electrical phenomenon, cell is the necessary part. For the raise in appropriate current, high power and potential difference, the sunlight dependent cells and their region unit joined in non-current or parallel fashion called as PV exhibit are used. In practical applications, each and every cell is similar to diode with the intersection designed by the semiconductor material. When the light weight is absorbed by the electrical marvel sway at the point of intersection, it gives the streams at once. The (current-voltage) and (Power-Voltage) attributes at absolutely unpredictable star intensities of the PV exhibit are represented in figure 4, whereas the often seen existence of most electrical outlet on each yield is shown in power diagram 5.

$$I = I_{ph} - I_D - I_{sh} \qquad (1)$$

$$I = I_{ph} - I_o \left[\exp\left(q V_D / nKT\right)\right] - \left(v_D / R_S\right) \qquad (2)$$

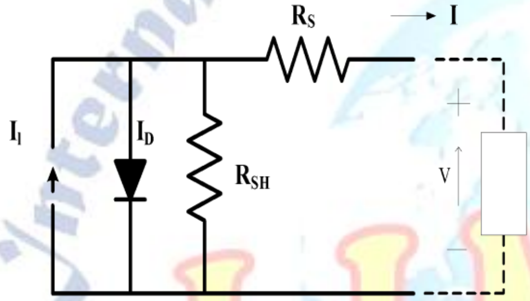

Figure 4: PV Electrical Equivalent circuit

Operation of Multi Stage Converter:

1. Mode 1: PV to EV:

In this mode, the switches Spv, Sb1, and Sb2 are turned off while SEV is turned on. Therefore, PV directly delivers power to the load, as shown in Figure. The differential equations in this stage can be expressed as follows:

$$i_{PV} = C_1 \frac{dv_{C1}}{dt} + i_{EV}$$

$$C_2 \frac{dv_{C2}}{dt} = \frac{v_{Bat} - v_{C2}}{r_b} - i_{L2}$$

$$i_{EV} = C_3 \frac{dv_{C3}}{dt} + \frac{v_{EV}}{R_{EV}}$$

$$v_{C1} - v_{C3} = L_3 \frac{i_{L3}}{dt}$$

$$L_2 \frac{i_{L2}}{dt} = -v_{C2}$$

2. Mode 2: BES to EV

When Spv and SEV are turned on while Sb1 and Sb2 are turned off, BES is discharged to the EV load, as shown in Figure. The differential equations in this mode can be expressed as follows:

$$i_{PV} = C_1 \frac{dv_{C1}}{dt}$$

$$L_2 \frac{i_{L2}}{dt} = v_{DC} - v_{C2}$$

$$v_{DC} - v_{C3} = L_3 \frac{i_{L_3}}{dt}$$

$$C_2 \frac{dv_{C2}}{dt} = \frac{v_{Bat} - v_{C2}}{r_b} - i_{L2}$$

$$i_{EV} = C_3 \frac{dv_{C3}}{dt} + \frac{v_{EV}}{R_{EV}}$$

SVPWM TECHNIQUE FOR TWO-PHASE INVERTER

In the SVPWM technique of three-phase inverter. A reference voltage vector V* is realized by computing the duty ratio for two space vectors which are adjacent to V* and by adjusting the switching time of two zero space vectors.

In this paper, the realization method for SVPWM technique of two-phase inverter is proposed without zero space vectors. Figure 5 shows the model sectors to determinate the switching times for the reference vector V* by adjusting four voltage space vectors.

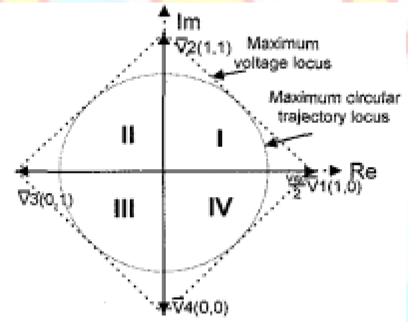

Figure 5: SVM Four possible space vectors

SIMULINK RESULTS

The experimental results have been obtained using a reduced scale setup (with power levels 5 times lower than the full scale). It is important to note that in this reduced scale setup the DCBUS voltage was stabilized around 108 V and P_{Max} was ±460W, being the "Advisable Energy Levels" used for sizing, simulation and further full-scale implementation. A PWM control and data logging purpose is also used, jointly with other laboratory equipment and several electronic components, as presented in Figure 5.

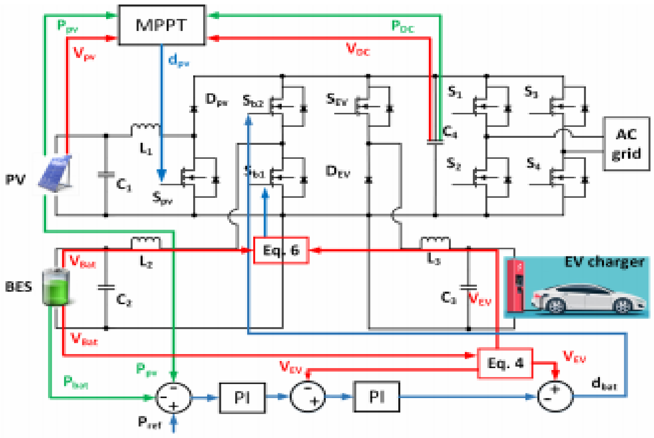

Figure 6: Simulation Diagram for PV based V2G System

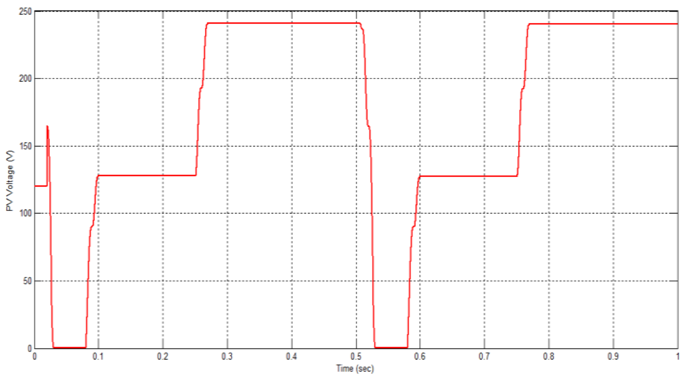

Figure 7: Simulation Waveform for PV Voltage

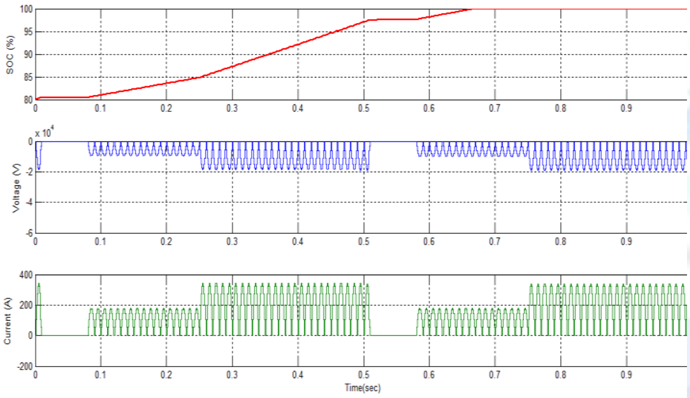

Figure 8: Simulation Waveform for Battery Parameters

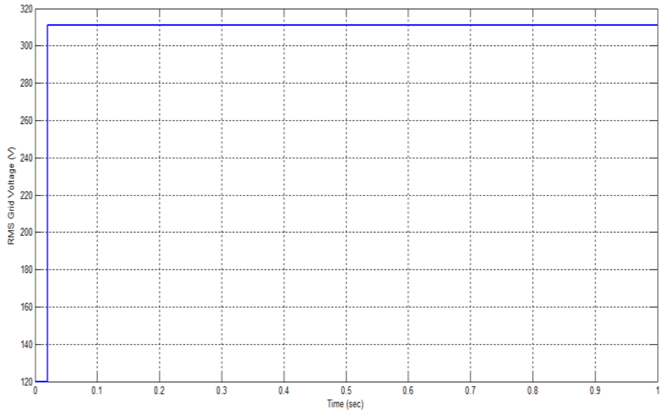

Figure 9: Simulation Waveform for Grid RMS Voltage

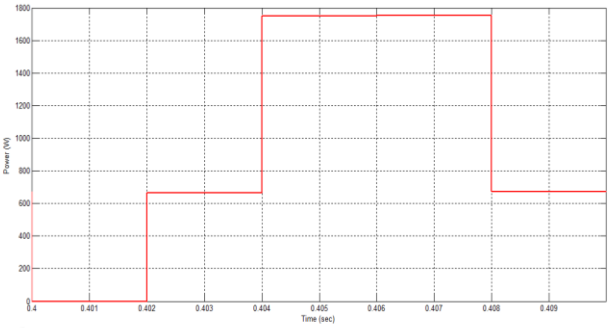

Figure 10: Simulation Waveform for Grid Power

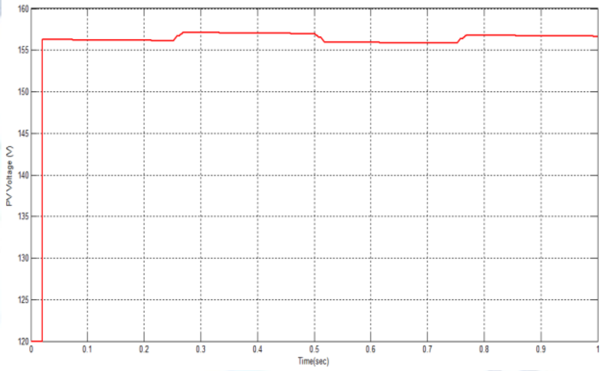

Figure 11: Simulation Waveform for PV Voltage with SVM Technique

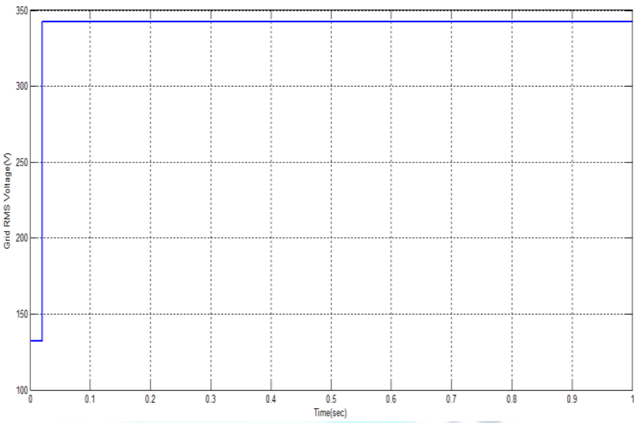

Figure 12: Simulation Waveform for RMS Voltage with SVM Technique

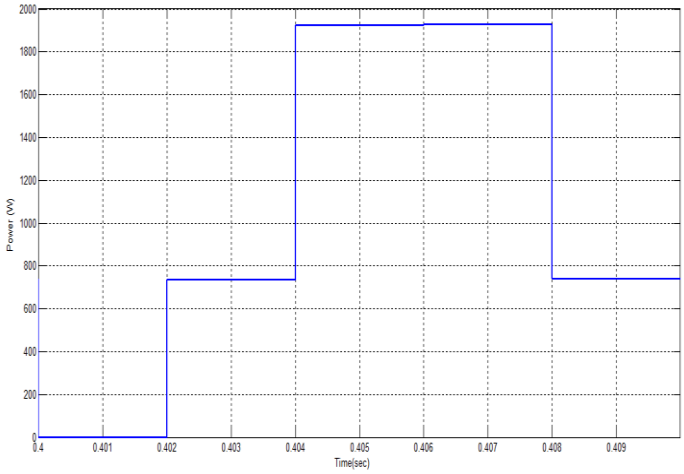

Figure 13: Simulation Waveform for Power with SVM Technique

CONCLUSION

A space vector modulated multiport converter based EV charging station with PV and BES is proposed. A BES controller is the proposed control design, BES starts to discharge when PV is insufficient for local EV charging, and starts to charge when PV generation is surplus or power grid is at valley demand, such as during nighttime. As a result, the combination of EV charging, PV generation, and BES enhances the stability and reliability of the power grid. Different operating modes and their benefits are investigated and then, simulation and thermal models of the multiport converter based EV charging stations and the proposed SiC counterpart are developed in Matlab/Simulation. Simulation results show that the efficiency can be improved for PV-to-EV mode, PV-to-BES, and BES-to-EV mode at nominal operating condition, compared to Si based EV charging stations under the same operating conditions.

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