FESC
Florida Energy Systems Consortium

Thrust Area 4: Solar (PV Integration)

PV Power Generation Using Plug-in Hybrid Vehicles as Energy Storage

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Description: The objective of this project is to develop and demonstrate an alternative PV power generation architecture that uses plug-in hybrid vehicle as the energy storage and transfer element with a total system cost target of $3.50/W. The tasks include developing efficient, reliable, and inexpensive maximum power tracking DC/DC battery chargers and 3-phase converters. A 10kW demonstration solar carport charging station was built on UCF campus. A plug-in hybrid vehicle with a 25kWh battery bank (battery-only driving range of 50-100 miles) and onboard bidirectional AC charging system will be demonstrated

Budget: $380,816
Universities: UCF
External Collaborators: City of Tavares, FL

Progress Summary

Research Objectives for Current Reporting Period: The main research objectives for the current reporting period include the development of power electronics hardware and fine tuning of control software.

Progress Made Toward Objectives During Reporting Period: A 10kW smart solar plug-in electric vehicle charging station was constructed on UCF campus. The PHEV Smart Solar Carport is configured as two 5 kilowatt systems providing a total power output of 10 kilowatts. Most PHEVs currently available today are configured to receive standard "household" 120 volt Alternating Current (AC), so an inverter converts the DC into the required AC power for the vehicle chargers. The new system not only offers this feature but also facilitate future deployment of experimental technologies that will interface the DC produced by the photovoltaic modules directly with the DC batteries in the electric vehicles. This would allow direct DC transfer to the vehicle batteries, thereby eliminating losses associated with converting the DC to AC, and then back to DC power. A unique control strategy is implemented, allowing efficient energy transfer while reducing the conversion stages between the source and the load. All of the pedestals are reconfigurable and include provisions to accommodate future vehicle charging configurations. The solar carport system is "grid interactive" in that the inverters produce AC voltage that is synchronized with the electrical grid. This means that power produced from the PV panels in excess of what is

needed to charge the electric vehicles will "go back" into the University's electrical grid. This allows the campus grid to act as an energy "bank" in which the excess capacity from the solar carport can be used to power other electrical demands on the campus. The interactive system also allows for non-sunlit period vehicle charging. On an annual net metering basis, the carport is anticipated to be a net exporter of power to the grid as there will be a significant number of sunlit hours during a year when the majority of electric vehicles parked at the facility are fully charged, and during semester breaks and weekends. A communication link will be established between the system and the power grid to facilitate intelligent control.

Several hardware prototypes have been built to facilitate the three-way energy flow control. Final prototyping for the DC/DC converter is shown here. Each converter consists of a power board, a power supply board, and a controller board. The power supply board is designed to supply 12V from an input between 100V and 400V. The controller board is a generalized design with built-in sensing amplifiers. These boards are mounted vertically in the power board of each DC/DC converter included in the carport charging station. In order to increase the efficiency, soft switching was implemented in both converters (1.2kW solar DC/DC and 4kW DC/DC converters). These prototypes operate at a high overall efficiency (above 95%). Research activities for the next reporting period will focus on fine tuning of the hardware and the software control algorithms, and make efficiency comparison between the new system and the convention configuration over a wide range of conditions.

2011 Annual Report

I. Introduction

Photovoltaic modules have become a viable renewable energy source for energy systems in communications, commercial, and residential applications. Plug-in electric or hybrid vehicles appear in the market as an emerging technology to reduce carbon emissions and improve energy efficiency. PV modules and electric vehicles interact with the power grid as energy source and energy sink elements, respectively. However, little was reported on energy conversion systems featuring a three-way energy flow among the power grid, PV modules, and electric vehicles. The research described in this report examined the concept and devised a system to test and demonstrate the concept.

II. System Overview

This three-port system is designed as a carport, providing shade for two parking spaces. This prototype system consists of four strings of six 200W panels each. Each string yields a maximum power of 1.2 kW, while the whole system yields a maximum solar power of 4.8 kW. The system supports up to two 4 kW electric vehicle chargers in the system. Any surplus or deficit of power is accounted for by the grid through a grid-tied inverter or rectifier, respectively. This overall system is shown in Figure 1. The carport could be used to charge any electric vehicle with a battery bank less than 216V.

The different modules of the carport system are all connected through a common DC bus.

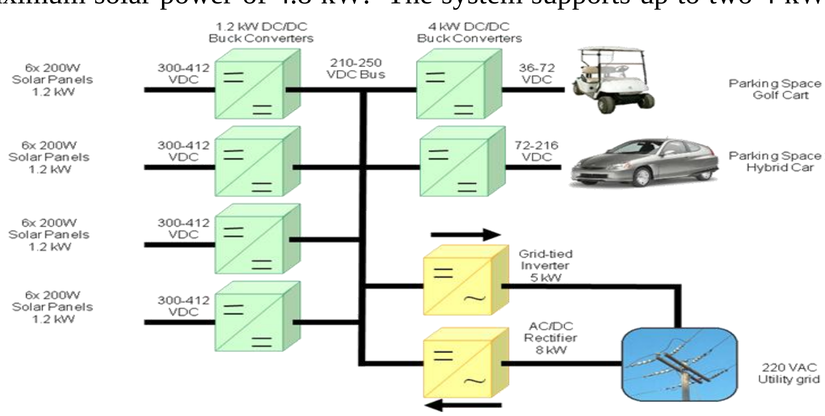

Figure 1: System Overview of the multiport solar carport

This bus is both a means of transmitting power, and control. The DC bus voltage is allowed to change depending on the power supply and consumption in the system. Each module is programmed to interact with the bus, varying its power with the bus voltage. For example, this droop behavior causes the battery chargers to reduce their output if the bus voltage falls, and causes the inverter to pull power from the bus if the voltage rises far enough.

III. Progress Overview

Recent progress in the solar carport project was in hardware, software, and testing of both together. Hardware progress includes testing the solar converters and battery chargers in series, and prototyping the Ground Fault Interrupter system. A safe GFI is necessary to protect people and equipment

Software progress includes development and testing of the droop control algorithm. This algorithm regulates all power electronics in the carport system. The droop control algorithm has been simulated in MATLAB. Control laws have been implemented and tested for the solar converters and battery chargers.

IV. Hardware Progress

The power converters in the solar carport have been designed, built and tested. First the solar and battery charger converters were tested at various power levels, and then they were tested in series. These tests were conducted to measure the total system efficiency.

Vin	Iin	Vout	Iout	Pin	Pout	Ploss	Efficiency
329.94	0.32	208.17	0.38	110	79	28	73.83
329.91	0.56	208.39	0.76	190	159	26	85.95
329.89	0.8	208.37	1.14	270	237	28	89.43
329.88	1.05	207.64	1.5	350	311	34	90.14
329.87	1.29	207.22	1.87	430	387	39	90.85
329.86	1.51	207.05	2.21	500	457	42	91.58
329.84	2	206.74	2.99	660	618	42	93.64
329.82	2.45	206.41	3.73	810	770	37	95.42
329.82	2.47	206.36	3.77	820	778	37	95.46
329.82	2.48	206.34	3.78	820	780	37	95.47
329.8	2.93	206.49	4.53	970	934	34	96.49
329.8	3.21	206.44	4.97	1060	1025	32	96.97
329.78	3.69	206.82	5.7	1220	1178	38	96.88
329.78	3.72	206.82	5.74	1230	1188	38	96.9
329.77	3.96	206.97	6.1	1310	1262	43	96.7

Table 1: Solar Converter Efficiency

Testing the solar converter alone yielded the efficiency data in Table 1. This shows a peak efficiency of 96.76% with 1060W in, 1025W out. Similar data was collected for the battery charger, but only at the same power levels. Full 4kW testing has not been performed yet.

The buck topology of these two converters makes use of Zero-Voltage Transition PWM soft-switching. This auxiliary circuit provides an alternative power path that reduces switching losses and voltage ringing, even under high power situations. Simulations in Pspice showed that there is approximately a 5% increase with the ZVT topology over the standard buck converter.

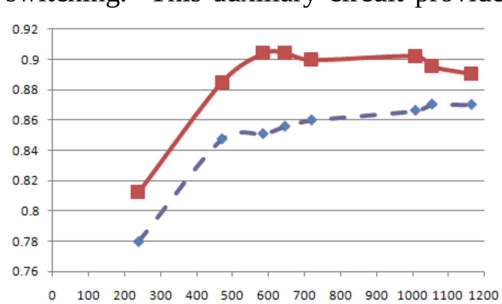

Figure 8: Efficieny curve of cascaded converters (top) vs typical setup (bottom)

Cascading the two converters allowed for testing of the efficiency and of the algorithm effectiveness. The efficiency results have been compared to a COTS grid-tie inverter and grid-tie battery charger. This experimental carport project exceeds the efficiency of a COTS system at all power levels. These preliminary results show that this DC/DC/DC conversion yields a significant increase in efficiency over the traditional DC/AC/DC conversion.

V. Controls Progress

Most of the control loops have been tested. On the solar converter, maximum power point tracking has been implemented. It has been tested to be resilient to noise and false readings. In addition to solar MPPT, the droop control laws have been tested on the solar converter and charger. The laws allow stable current sharing between converters. One additional control feature is phase interleaving in the charger.

Solar MPPT was tested using a solar array simulator configured as a 54W solar panel. MPPT runs at 10Hz with 1.0V step size. These values were optimized through testing so that the algorithm doesn't misstep on the power curve.

Droop control was tested similar to the cascaded hardware test. Two chargers were connected to the output of a solar converter to demonstrate current sharing. The solar converter was supplied by a solar array simulator and MPPT was enabled. Several tests were performed to verify current sharing between two loads. The test displayed here, in Figure 3, demonstrates what happens when a load is suddenly reduced. Battery 1 current, in orange, is reduced to zero. As a result, the bus voltage increases. Consequently the battery 2 current, in green, rises. This test demonstrates that multiple loads can share a limited amount of renewable energy using the droop control algorithm.

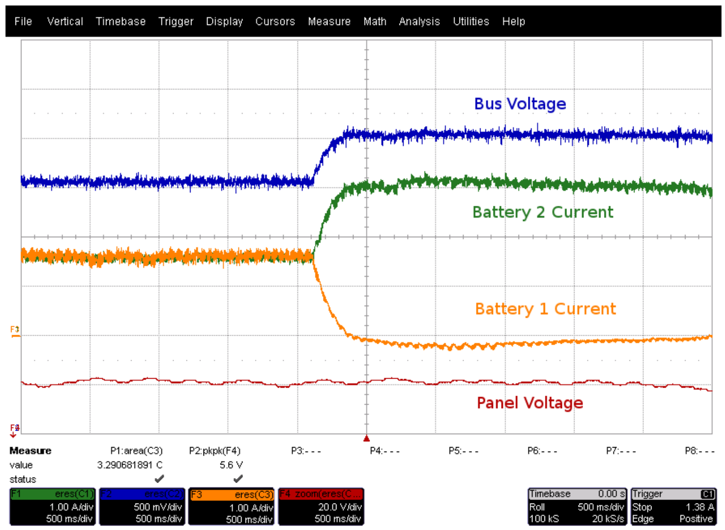

Figure 3: Droop Current Sharing

The 4kW chargers are each two buck converters in one, which allows the use of the same PCB for two solar converters. In the 4kW charger, the two buck converters can be individually controlled. This allows interleaving which reduces overall voltage and current ripple in the system. Effectively, this eliminates harmonics at the 50kHz switching frequency, only leaving those above it.

VI. Conclusion

This solar carport system has been tested at the module level. The solar converters and EV chargers are capable of safe and controlled operation with the droop algorithm and common DC bus. Additional research is necessary to develop a bidirectional DC/AC inverter, or to further the research in having a separate rectifier and inverter setup. These components would all need to have the droop control laws programmed and tested.