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Intelligent Energy Management for Solar Powered EV Charging Stations

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ENERGY INNOVATIONS SMALL GRANT TRANSPORTATION PROGRAM

FINAL REPORT

Intelligent Energy Management for Solar Powered EV Charging Stations

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Nomenclature

AC	Alternative Current
API	Application Programming Interface
BMS	Battery Management System
CANBUS	Controller Area Network Bus
DC	Direct Current
EV	Electric Vehicle
MODBUS	A Serial Communication Protocol
PV	Photovoltaic
SOC	State of Charge
XML	Extensible Markup Language

Abstract

A solar PV powered battery buffered electric vehicle charging station with intelligent energy management was designed and demonstrated in UC Davis West Village, the largest planned zero net energy community in the United States. An on-site controller was introduced into a level 2 workplace charging system to control the power flow between the PV, grid, battery, and vehicle charger. The energy management approach introduced weather information and load demand statistics to optimize the use of solar and grid energy by the charging station. Hence, instead of immediately recharging the battery to a fixed state of charge after each EV charging, the target charge level of the buffer battery is optimized according to the estimated PV electricity generation and the projected EV charging load to maximize usage of solar energy and to minimize impacts of solar availability and electric vehicle charging on the utility grid. Weather information – cloud cover- is extracted from a weather forecast website to estimate the PV electricity. Historical EV charging data for the station are used to project the EV charging load by using the similar day of the week approach. This charging station management approach will simplify utility grid management from the load side during the initial stages of solar PV and EV introduction.

Key Words: Electric vehicle, charging station, energy storage, weather forecast, load projection, optimization, PV panel, bi-directional inverter

Executive Summary

Introduction

With rapid adoption of electric vehicles and continued extensive installation of solar power systems, especially in high PV and EV penetration areas, electric vehicle charging, especially fast charging, and solar power availability pose a challenge for the utility grid, which may lack the capacity to deliver the periodic high power required and to store surplus solar electricity when it is not needed. It may not be economical to upgrade the distribution infrastructure in the early stage to handle this higher power demand and surplus solar energy. An approach to enabling high penetration of electric vehicle charging and solar electricity into the present distribution infrastructure, while maintaining or improving PV system value, utility system reliability, and a reliable power supply for EV charging is to use solar powered charging stations equipped with battery storage. Only a few solar powered EV charging stations with battery buffers have been demonstrated and those stations immediately replenishes the battery after each EV charging. None of them have included the effects of PV electricity estimation and EV charging load projection in their energy management strategies. This project is concerned with the design and demonstration of an on-site controller and the development of a control strategy which will lower the impact of EV charging and PV generation on the utility grid.

Project Objectives

The goal of this project is to determine the feasibility of introducing real-time weather information and actual load statistics into the energy management of a solar powered electric vehicle charging station with buffered battery storage to maximize the use of solar electricity and minimize peak power demand spikes on local grid during vehicle charging. The project objectives include:

- Design a control system using a real-time on-site controller to communicate with the grid-tied inverter and the battery storage at the charging station. Develop a control strategy for controlling power flow between system components.
- Develop the control software using LabVIEW to control the charging system. Optimize the charge level of the battery and demonstrate the adjustment of the battery SOC between 0.5 – 0.9 based on the weather information and the historical charge station data.
- Simulate different EV charging station operation scenarios to verify that EV charging peak power request from the grid will be reduced by a factor of 2-3 compared to the conventional EV charging station.
- Operate the charging station with the on-site controller and the energy management approach to show the optimal battery SOC varies between 0.5-0.9.
- Demonstrate that the intelligent energy management can reduce the grid peak power demand for EV charging by at least a factor of 2.

Project Outcomes

- A control system was designed using the NI cRIO-9082 controller to communicate with the different system components. The power flow control was developed for both grid-tied operation and stand-alone operation.

- The control and monitoring software for the charging system was developed using LabVIEW. The software accomplished the functions of data monitoring and logging, power flow control, weather information extraction, PV electricity estimation, EV charging load projection, battery target SOC optimization, and projection of system operation.
- Simulations were performed for different scenarios. Compared to a charging station without optimal energy management, the grid peak power demand for the battery buffered charging station with optimized energy management was reduced by a factor of 2.
- The control hardware and software have been successfully installed. The test operation of the system showed that the controller can successfully extract weather information, estimate PV electricity, project EV charging load, and optimize the battery target SOC between 0.3-1 as instructed.
- Continuous operation of the charging station demonstrated that the intelligent energy management reduced the grid peak power demand for EV charging by at least a factor of 2

Conclusions

- The EV charging station with a buffer battery can significantly reduce the grid peak power demand, shift the grid power demand into off-peak time periods, and cut down on the energy exchange with the utility grid by a factor of 2-3.

- The estimated PV electricity based on the extracted weather information reflects the actual PV electricity generation. A linear fit of the historical EV charging load from the same day of the week over the latest six weeks is appropriate for extracting the charging pattern of a workplace EV charging station.

- Optimization of energy management based on the estimated PV electricity and the projected EV charging load is feasible. The battery target SOC is adjusted between 0.3-1 according to the estimated PV electricity and the projected EV charging load. Optimization of energy management can satisfy EV charging load requirements and at the same time almost eliminate the peak power demand for EV charging from the grid and cut down on energy exchange between the charging station and the utility grid by a factor of 2.

- The proposed power flow control and intelligent energy management can be integrated with current charging stations without installing additional devices and is best suited for charging systems having one big battery and multiple charging outlets.

Recommendations

- It would be advantageous to use a supervisory computer instead of the external on-site controller to communicate with present charging stations and perform optimization of the energy storage with no additional hardware cost.

- The intelligent energy management strategy used in this project is best suited for charging station systems having one large energy storage battery and multiple charging outlets, such as for workplace or commercial public charging stations. More complex PV electricity estimation modeling and more accurate load projection modeling for multiple charging outlets should be developed for those systems.

- As more experience is gained with the use of the charging station in West Village, further improvement of the models should be pursued to handle more extensive use of the system and more diverse weather conditions.

Public Benefits to California

- Reduced impacts of the EV charging system on the California electricity supply, transmission, and distribution system in terms of peak power demand and energy exchange. The charging station lowered the station's peak power demand and reduced the energy exchange with the utility grid by a factor of 2-3, and eliminated grid power demand during on-peak hours.

- Reduced electricity transmission and distribution losses for EV charging from the grid. Transmission and distribution losses of 5.4 – 6.9 % for EV charging were eliminated in the charging station.

- Benefited the charging station owner through the Time-of-Use rate plans by shifting EV charging from on-peak hours to off-peak time periods.

Introduction

With rapid adoption of electric vehicles and extensive installation of solar power systems, especially in high PV and EV penetration areas, electric vehicle charging, especially fast charging, and uncertain solar power availability pose a challenge for the utility grid, because it may lack the capacity to deliver the periodic high power demanded and/or to store surplus solar electricity. It may not be economical to upgrade the distribution infrastructure in the early stage to handle this higher power demand and surplus solar energy. An approach to enabling high penetration of electric vehicle charging and solar electricity into the present distribution infrastructure, while maintaining or improving PV system value, utility system reliability, and a reliable power supply for EV charging is to use solar powered charging stations equipped with battery storage. Only a few solar powered EV charging stations with battery buffers have been demonstrated in the U.S. and none of them have included the effects of weather forecasting and charging load request in their energy management strategies.

Presently there are three levels of charging stations, namely AC level 1, AC level 2 and high power DC charging. AC level 1 (1-2 kW) and level 2 (up to 10 kW) charging is used in residential houses. Currently AC level 2 and high power DC (up to 50 kW) charging are deployed in commercial and office areas. As of March 2013, California had 4,183 public charging stations (points) [1]. A few of the charging stations are connected to rooftop solar panel units at residences or parking garages and in most cases are without load management. In 2013, the first public fast EV charging system including solar power and battery energy storage was installed in Carmel, Indiana. A solar powered level 2 charging station with battery buffer is being demonstrated in the West Village, Davis, California this summer (2014). A detailed report on the vehicle charging station is given in [2]. The solar panel unit, the storage battery, and/or the grid can provide the electrical power for charging the electric vehicles. After the charging is complete, the buffer storage units are recharged from solar power and grid in a maximum duration of 1-2 hours. The solar powered charging stations with energy storage can reduce peak power demand from the grid, but can consistently require high power to recharge them without considering solar power availability and variability of the expected charging load demand.

The proposed intelligent energy management for EV charging stations with PV and batteries will stream/filter weather forecast information in XML format from major weather services via the internet to project solar energy available in the next day, and monitor and collect daily load demands to estimate the expected EV charging load. Energy management will calculate the optimal battery charge level and decide to charge/discharge batteries during off-peak/peak hours. The proposed approach can significantly mitigate the impact on the local grid of the peak power for electric vehicle charging and reduce the grid peak power request by a factor of 2-3 at the early stages of fast charging adoption (see Table 1). Compared to the current battery buffered solar charging station, the proposed approach imposes no extra hardware costs.

Table 1 Comparison of current EV charging station technologies

	Conventional Charging Stations	Solar Powered Charging Stations	Solar Powered Charging Stations with Energy Storage	Proposed Solar Powered Charging Stations with Energy Storage
Cost	Low	Medium	High (bat. Cost)	High (bat. Cost)
Impact on Grid	High	High	Medium	Low
Energy Management	No	No	Yes	Yes
Solar/Load Projection	No	No	No	Yes
Market Share (present)	High	low	Very low	Very low (nearly zero)

Project Objectives

The goal of this project is to determine the feasibility of introducing real-time weather forecast and actual load statistics into the energy management of a solar powered electric vehicle charging station with buffer battery storage to maximize the use of solar electricity and minimize power spikes on local grid due to vehicle charging. Uncertainty of charger usage, including fast charging, and solar power will be addressed by weather forecast and load projection via on-site or remote control of the electronics linking the PV, battery, and the grid. The project objectives are to:

1. Develop a control strategy for a solar powered EV charging station with buffer battery and the complete system diagram and control flowchart.

2. Develop software to implement the system control strategy, stream weather forecasting for solar energy projection, collecting EV charging data for load projection, optimizing the use of the battery storage, and demonstrating automatic adjustment of the charge level of the battery between 0.5 – 0.9 according to real-time weather forecast and historical EV charging load on a computer.

3. Simulate the proposed energy management that the peak power request from the grid will be reduced by a factor of 2-3 compared to the baseline present EV charging stations with PV system and buffer battery in which the buffer battery is replenished within 1-2 hours after each vehicle charge.

4. Design, setup, and operate the charging station with a real-time on-site controller and demonstrate the real-time weather forecast streaming from a major weather forecast website and load demand projection, and verify that the charge level of the battery varies between 0.5-0.9 accordingly.

5. Demonstrate that the proposed energy management will satisfy the project goal – compared to a present level 2 charging station with buffer battery to reduce the grid peak power demand of the EV charger by at least a factor of 2.

Project Approach

The research project was accomplished in five major tasks as originally planned. The control system was designed, along with the development of the system control strategy and its control flowchart, in the first task. The control interfaces and block diagrams for controlling and monitoring the charging system were programmed and the weather forecast streaming, solar electricity projection, and EV charging load projection were developed using LabVIEW in task 2. The PV powered charging stations without a buffer battery or with a buffer battery that is recharged immediately after each EV charging, and with optimized energy management were simulated and compared regarding their peak power request in task 3. The control strategy and optimization of the battery energy storage were integrated with the charging system and demonstrated on the modified charging system in task 4. The charging system with the developed control strategy and the proposed energy storage optimization has been operated for several months to demonstrate the proposed energy management approach in task 5. The project tasks are listed below, followed by the detailed description and development in each task.

Task 1: Hardware and software design of the proposed control system using a real-time site controller

The proposed system differs from previous systems developed [2] in many respects. The previous systems are like an uninterruptable power supply, as show in Figure 1. The battery is always full and acts as a backup power. When the battery voltage reaches the lower limit, the system tops off the battery to the upper voltage limit at full power from the PV panel and/or the utility grid without considering the off-peak periods. In the proposed system, an on-site controller and a supervisory computer will be introduced to communicate with the bi-directional inverter over the Modbus and the battery management system over the CANBUS, as shown in Figure 2. The on-site controller monitors the solar PV power, the battery status, the EV charging load, and the grid status to control power flow between different components depending on the status of the system (Figure 3). The supervisory computer extracts weather conditions from a weather forecast website to predict the available PV electricity and projects the expected EV charging load based on stored past use patterns of the station. Based on the projected PV electricity and EV charging load, an optimal battery SOC is calculated for charging the battery during off-peak periods, as shown in Figure 4.

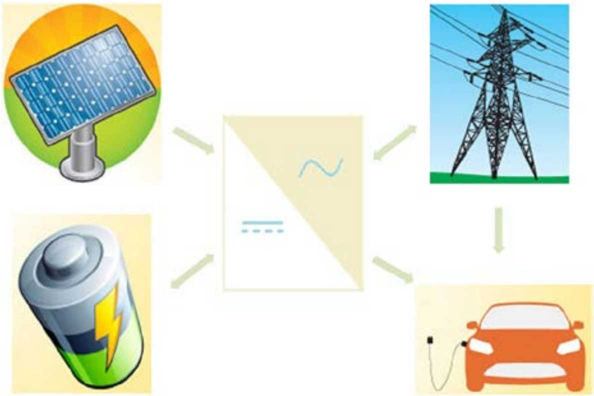


Figure 1: PV powered charging station equipped with energy storage

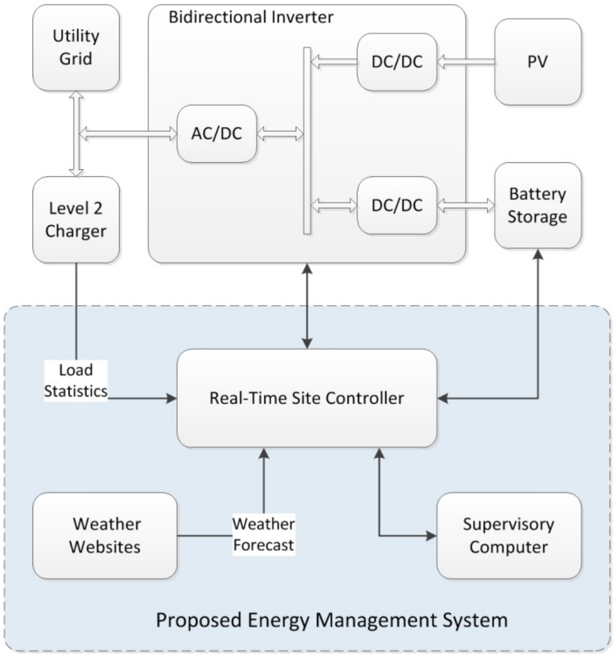
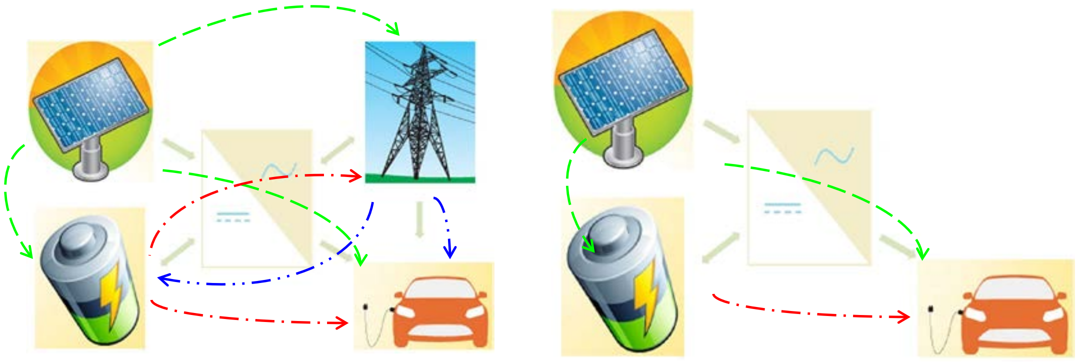


Figure 2: Integration of the proposed energy management with the charging station



Grid-tied Operation Stand-alone Operation

Figure 3: Operation Modes of the Charging Station

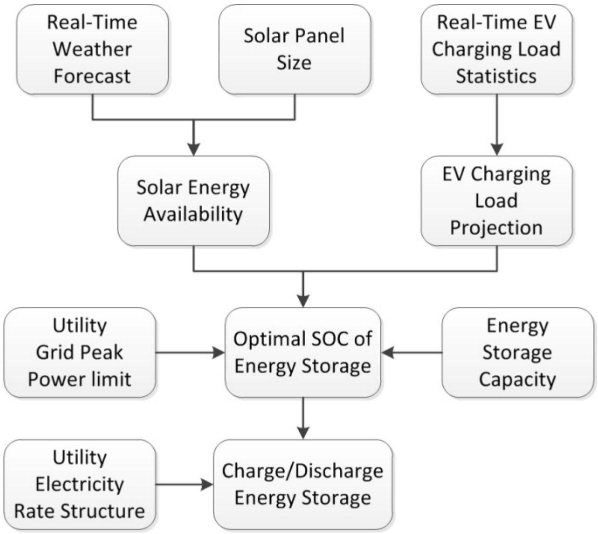


Figure 4: Control Strategy for Optimizing the SOC and Operation of Energy Storage

Task 2: Development of energy management strategy

To communicate with the energy storage and the bi-directional inverter, a monitoring and control interface was developed using LabVIEW. Some key information from each component is extracted and displayed on related tabs. Some major control variables and operation modes can be configured via the control interface. Power split and control strategies for both grid-tied operation and standalone operation have been developed. Weather information such as cloud cover is filtered and streamed from a weather forecast website for calculating the available PV electricity. The EV charging load is logged into a supervisory computer for projecting the load trends. Linear fit of the latest six-weeks of station load data is used to project the load using the same day of the week. The projected PV electricity and the projected EV charging load are used to calculate the optimal battery SOC. The optimal SOC is used as the target SOC in the control tab for topping off the battery during off-peak periods.

Task 2.1 Stream and filter real-time weather forecast into the controller to evaluate available solar energy

Solar power forecast information is essential for efficient use and management of the solar electricity. The solar power output depends on the incoming solar insolation and the solar panel characteristics. The incoming solar insolation varies spatially and temporally. The solar insolation on the assigned solar panel for a clear sky was calculated as a function of the day of year and the time of day, multiplied by the cosine of the angle between the normal to the panel and the direction of the sun from it. The actual solar insolation on the solar panel varies with the change of the state of the sky. Various complicated numerical weather forecast models have been developed for evaluating solar radiation for the management of the electric grid [3-6]. Solar energy forecasting for an EV charging station equipped with limited energy storage is different from that for the management of the electric grid.

In this research, only the most common indicator of the state of the sky, percent cloud cover, is taken into account in calculating the solar electricity. To simplify the forecasting, the percentage of cloud cover is regarded as the percentage attenuation of solar insulation compared to that for a clear sky on the solar panel. The estimated solar PV electricity generation can be obtained by summing up the actual solar insolation over time multiplied by the panel area and the PV conversion efficiency. This is described in the following equation.

$$E_{PV}^{P} = A\eta \int (1-c)G(d,t)dt$$

where E_{PV}^{P} (Wh/m^2) is the daily solar PV electricity, A (m^2) is the area of the solar panel, η is the PV panel conversion efficiency, c represents the fraction of the cloud cover, and G(d,t) (W/m^2) is the solar insolation received by the PV panel on a specific day on a clear sky. G(d,t) is a 2-D array, indexed by the day of the year and the time of the day. Figure 5 shows the calculated solar insolation for a tilt angle of 30 and 90 degrees.

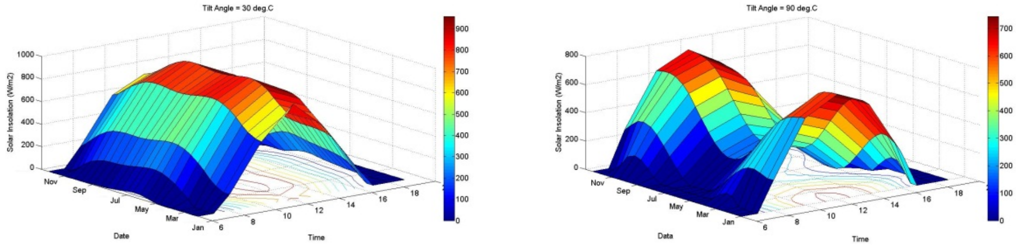


Figure 5: Calculated solar insolation for solar panels at West Village

The cloud cover can be obtained from weather application programming interfaces (API) provided by major weather forecast websites. There are many free weather APIs available on the internet, such as Weather Channel API, Weather Underground API, yr.no API, WeatherBug API, NOAA Weather Service API, and OpenWeatherMap API, etc. OpenWeatherMap provides free API access to cloud cover data and it is used in this research. A web request from the control interface that is sent to the server requires authentication in order to obtain the XML data. The XML is searched to find the cloud description and cloud cover value for the time and day of interest. The weather data for every three hours in XML format is streamed and the cloud cover is extracted to predict the solar insolation.

Task 2.2 Load projection based on real-time vehicle charging statistics

EV charging load forecasting is vitally important for the economic operation and optimum control of a solar powered battery buffered EV charging station. EV charging load estimation is needed to maximize the use of solar PV energy for EV charging, optimization of the SOC of energy storage, reduction of EV charging power spikes on the utility grid during peak hours, and maximization of the efficiency and economics of charging station operation. Electric load/demand forecasting is mature for the electric utility industry. Various short-term, medium, and long-term load forecasting approaches have been widely used for planning and operating utility grids [6-8]. Most methods use statistical techniques based on historical data including load, weather, date, and time factors. The weather, particularly ambient temperature, plays a key role on the variation of demand. However, EV charging as a highly variable load is dependent on driving pattern, charging habit, and time factors including the day of the week and holidays. The traditional load forecasting methods may not be suitable for forecasting EV charging load demand. It is not possible to accurately predict the EV charging events/power at a particular time, but for a community-used work place charging station, the number of EVs and the charging habit are relatively stable and average usage can be predicted. Hence the probability of EV charging and aggregated electricity demand on a certain day can be forecasted utilizing recent historical charger use data.

In order to simplify the EV charging load forecasts and to avoid the use of the unavailable information, a statistical model that determines the load model parameters from the historical use data of the latest six weeks has been developed. The linear fit of historical EV charging use data using the least squares method is employed to project the charger demand for each day of the week. The general least squares method is used to fit the historical data of charge station usage to a straight line of the general form

$$E_{EV}^{P} = an + b$$

where E_{EV}^{P} (kWh/day) is the projected EV charging load for week n, n is an integer representing the week number in the sequence of week data for a particular day of the week, a is slope, and b is intercept of the fitted model for week n=0. The values of a and b are the best fit of the historical charging use data for each day of the week, using usage data for the past six weeks. The slope of the linear model reflects the trend of charging demand over the last six weeks. The projected demand for the charging station is determined by setting n=7 in the best fit equation for each day of the coming week.

Task 2.3 Method to adjust the battery state of charge according to the weather forecasts and the charger use projections

Since most EV charging for a workplace charging station occurs in the early morning, and PV energy production is weak during this period, the available energy from the battery should be sufficient to meet the projected EV charging demand to avoid EV charging from the grid during peak hours. Hence the battery SOC to start the day should be maintained at a level dependent on the difference between the estimated PV energy generation and the projected EV charging demand for that day. If the current SOC is less than the projected SOC needed to meet the charge station demand, the battery should be charged from the grid during the off-peak hours. The targeted SOC to start the day is given by the following equation.

$$SOC^{P} = SOC_{mean} + \frac{k\Delta E_{ESS}^{P}}{E_{ESS}} \quad \left(SOC_{max} \geq SOC^{P} \geq SOC_{min} + \frac{kE_{EV}^{P}}{E_{ESS}}\right)$$

$$\Delta E_{ESS}^{P} = E_{EV}^{P} - E_{PV}^{P}$$

E_{PV}^{P}: projected solar electricity (kWh) during the next day
E_{EV}^{P}: projected EV charging demand (kWh) during the next day
$\Delta E_{ESS}^{P} = -(E_{PV}^{P} - E_{EV}^{P})$: projected energy deficit and surplus (positive: deploying; negative: charging)
E_{ESS}: Total battery storage capacity (kWh)
SOC_{min}: Minimum SOC (%)
SOC_{max}: Maximum SOC (%)
SOC_{mean}: Mean SOC (%) in the morning without over-night charging
SOC^{P}: Projected target of SOC to start the day

k : Correction factor to account for losses in the battery and electronics (k>1)

Task 3: Simulation of the operation of the charging station using the proposed energy management to confirm the mitigation of grid impacts from peak power of EV charging

To understand the impact of solar PV system and EV charging on utility grids, solar PV powered EV charging systems without and with a buffer battery has been simulated. For the charging station with a buffer battery, two scenarios of recharging the battery from the grid have been studied – (1) recharging the battery immediately after each EV charging event and (2) charging the battery to optimal the SOC during off-peak periods. Various operational situations such as no EV charging, no PV power generation, and multiple EV charging events are considered in the simulation.

A typical case to be simulated is shown in Figure 6. The PV power generation and EV charging load shown are representative of the present charging station. . The battery capacity is 35 kWh with the SOC operational window of 0.4-1.0. The PV output power through a day is represented by a sin curve between 10 am and 6 pm with the peak power of 3.6 kW. Since most EVs have either a 6.6 kW or a 3.3/3.6 kW onboard charger and EV owners charge their EVs when batteries are less than half their charge, the EV charging load of 6.6 kW for 2-2.5 hours or 3.3 kW for 4 hours is used in the simulation. These input assumptions are close to the actual operating conditions of our station, which makes comparison of the simulation results with actual operation of the charging station straight-forward.

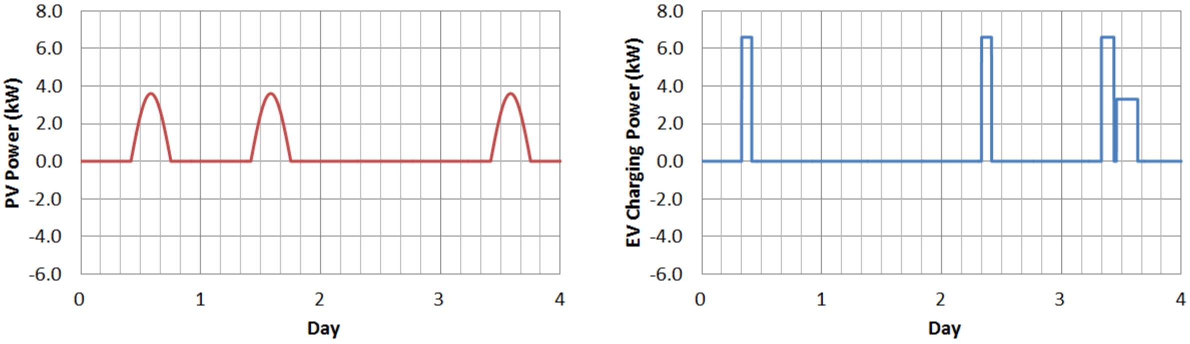


Figure 6: Simulation inputs of PV power and EV charging load

Two energy management approaches for PV powered EV charging stations with a buffer battery have been simulated. One approach is to recharge the battery immediately to prescribed level within 1-2 hours after each EV charging. A charging power of 5 kW and a fixed target SOC of 0.8 are used in the simulation. The other approach is to charge the battery to the optimal SOC during off-peak hours. The optimal SOC is calculated based on PV electricity estimation and EV load projection. Charging happens during off-peak hours from midnight to 7 am. The charging power is calculated by dividing the recharge energy by the charging time. Considering the efficiency of the bi-directional inverter, a minimum charging power of 3 kW is applied. For both scenarios, the grid power and the cumulative electricity exchange between the charging system and the utility grid are plotted for evaluating the impact of the two operating strategies on the utility grid.

Task 4: Integration of the proposed energy management approach with a present level 2 charging station at West Village

A schematic diagram of the West Village vehicle charging station has been shown previously in Figure 2. The requirements for the on-site controller are to monitor the voltage of the 220 cells and the 33 temperature probes in the 350V lithium battery and the status of the high voltage control box, collect PV output, EV charging load, battery power, and grid power data, and control the power flow between various system components. All the data are stored in a log file. A National Instrument NI Compact RIO-9082 high performance controller system was purchased and employed as the on-site controller for the above intense monitoring and control functions. The cRIO-9082 has 1.33 GHz dual-core i7 processor with 2 GB RAM and 32 GB storage, and can run on either LabVIEW RT OS or Windows Embedded 7 OS. A NI 9871 RS485 serial module and NI 9853 high speed CAN module are plugged into the Compact RIO for communicating with the bi-directional inverter (Princeton Power DRI-10) through Modbus and the battery management system through CAN bus, respectively. Dual power supply lines from the utility grid and the battery are designed to provide reliable power to the controller. Figure 7 is the diagram of the complete system setup.

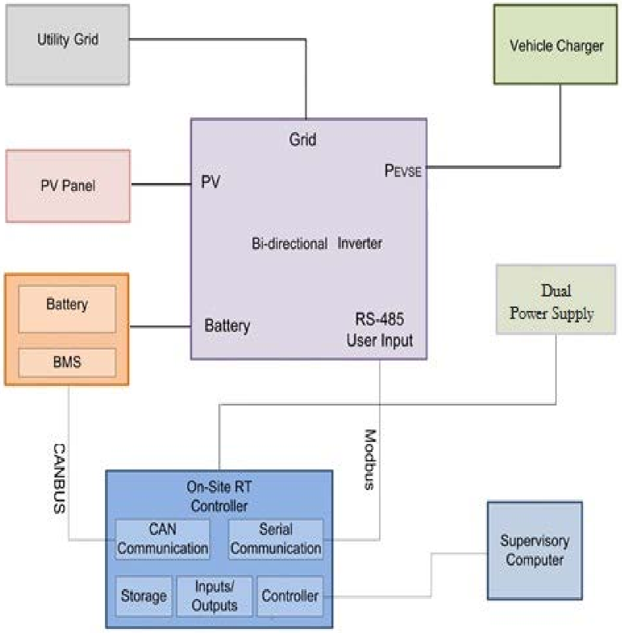


Figure 7: System wiring diagram

The NI LabVIEW software Datalogging and Supervisory Control (DSC) module is used to implement the communication interface and block diagram. A Modbus I/O server was created to read from or write data to the Modbus slave device – DRI-10 bidirectional inverter. An NI-XNET database was created for the CAN to communicate with the battery management system. Several NI-XNET sessions were created for cell voltages, temperatures, and status of the control box. The data are passed between the onsite controller and the supervisory computer by using the network-published shared variables. Once the shared data have been updated, the data are available to complete networked system.

Task 5: System operation for the level 2 charging station with different operational modes and data collection

The charging station was initially operated continuously without optimization of the battery storage to collect EV load data to be used for projecting the EV charging load. Six-week EV charging load data were collected. Then, the battery optimization function was turned on to optimize the battery SOC according to the estimated PV electricity and the projected EV load. The battery was recharged to the fixed SOC of 0.8 during off-peak hours between 9 pm and 7 am. The data of PV power, EV load, battery power and SOC, and grid power are collected every minute. The charging station is continuing to operate to collect data to validate the control strategy previously discussed.

Project Outcomes

The summary results of this project are (with respect to the project objectives):

Outcome 1: The control strategy, system diagram, and control flowchart were developed for a PV powered EV charging station with a buffer battery and an on-site controller.

a) System diagram

The work to design the real-time on-site controller and integrate it into the vehicle charging station in West Village has been completed. This work included all aspects of the integration of the controller with the lithium buffer battery and its management system and the grid-tied bi-directional inverter.

Figure 8 shows the detailed block diagram of the charging system. The charging system has a 5 kW Sunpower PV array, a 6.6 kW GE level 2 charging unit, a 35 kWh lithium iron phosphate battery pack from Lithium Force in China, and a 10 kW load response bi-directional inverter from Princeton Power. The on-site controller communicates with the bi-directional inverter through the Modbus serial port and with the battery management system through the CAN bus port. Dual power inputs from the grid and the inverter are adopted to provide reliable power for the controller.

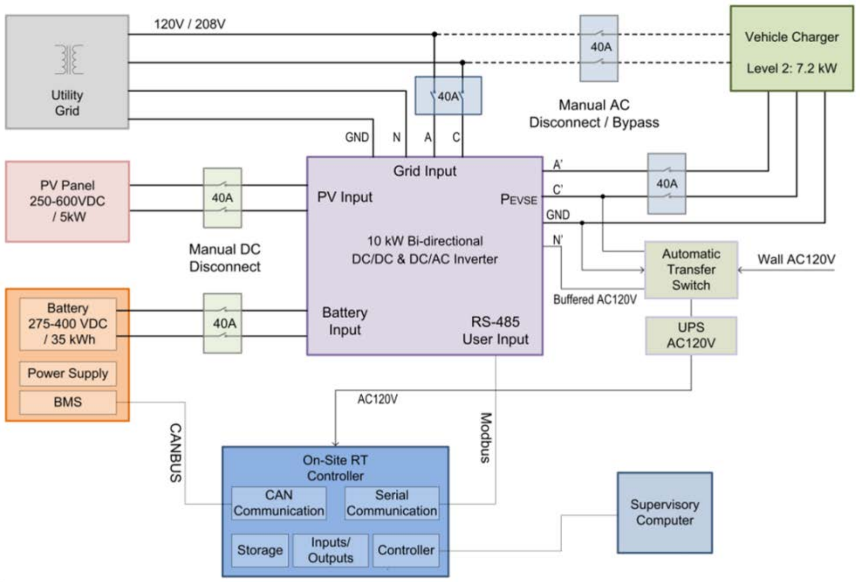


Figure 8: Block diagram of the EV charging system

b) Control flowchart

The control strategy for maximizing PV energy used for EV charging and reducing grid power demand has been developed. According to the availability of grid power, grid-tied operating and stand-alone operating modes have been designed for the charging station. In the grid-tied mode, the EV can be charged from PV, the battery, and/or the grid. In the case of a power outage, the system will automatically switch to standalone mode and be isolated from the grid. In the standalone mode, the EV is charged from PV and the battery. When the grid power is restored, the system will automatically switch to grid-tied operation. Figure 9 and Figure 10 show the control flowchart of the grid-tied operation and the stand-alone operation, respectively.

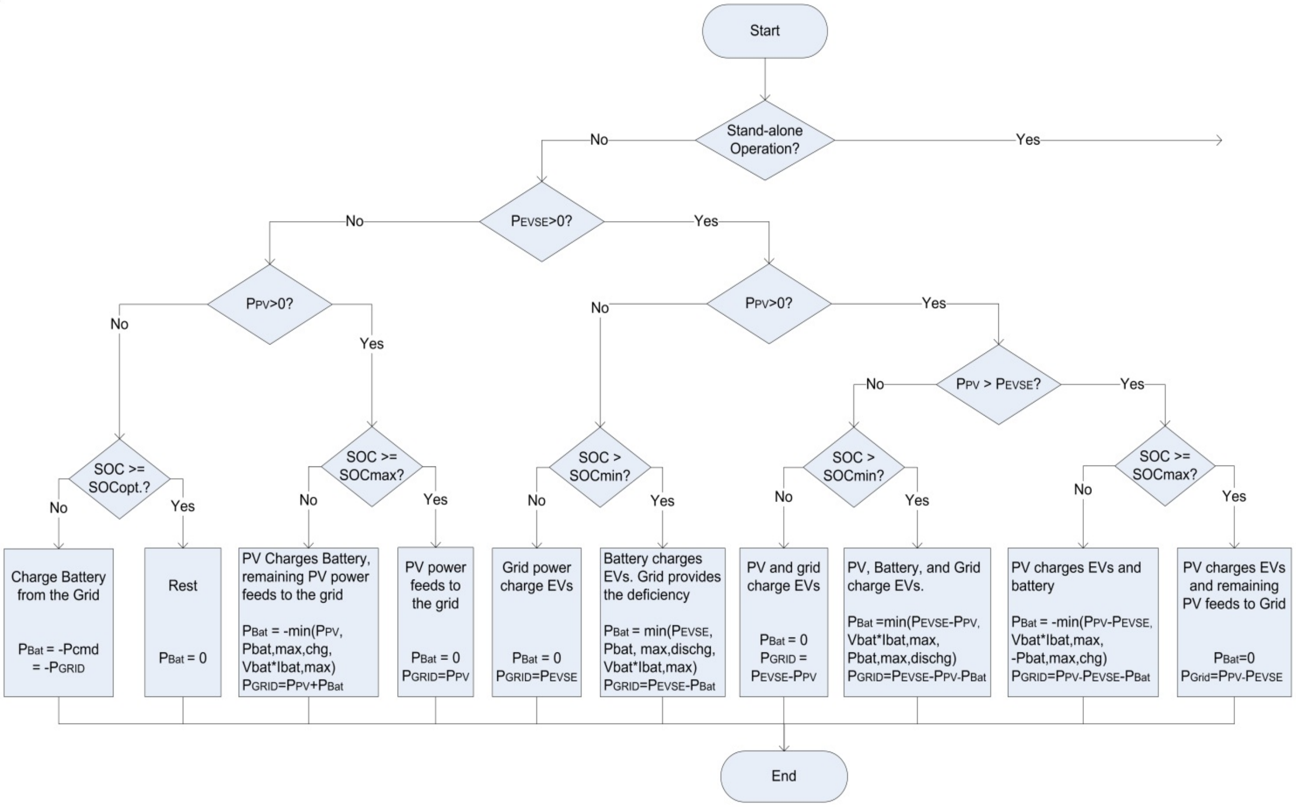


Figure 9: Control flowchart – grid-tied operation

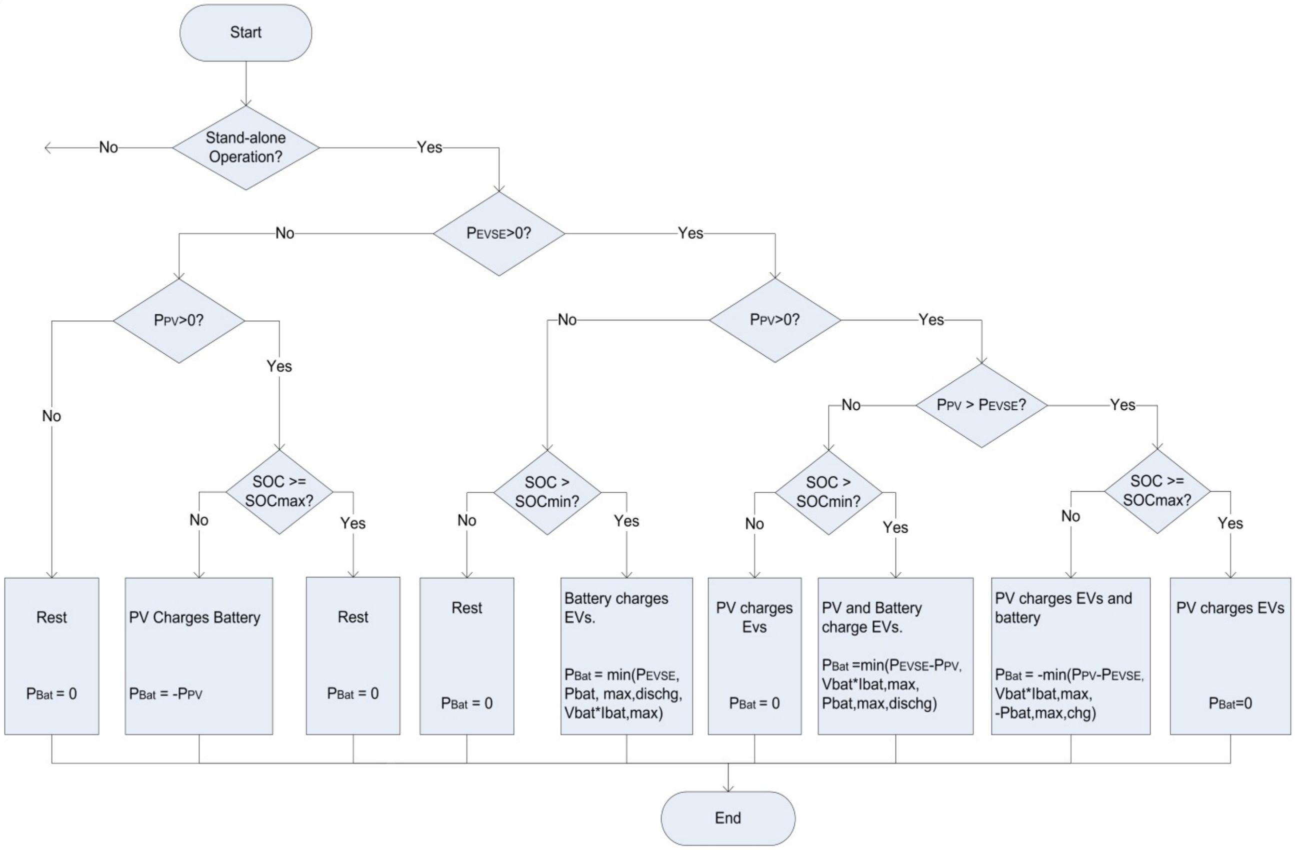


Figure 10: Control flowchart – standalone operation

In grid-tied operational mode, when an EV is plugged into the charger, PV power is used to charge the EV if it is available. If more power is needed, the remaining power is provided by the battery or/and the utility grid. If no electric vehicle is plugged-in, PV energy is stored in the battery and if the battery is completely charged, excess PV power flows into the utility grid. During off-peak hours, grid power can be used to bring the battery state-of-charge up to a specified level if the battery charge is low. Energy is never fed to the grid from the battery in the present system due to high EV charging requirements and low PV availability.

In the stand-alone mode, grid power is not available. The system can supply reliable, clean and cost-effective power to critical loads that cannot be supplied directly from the utility grid. Hence if PV is available, it will power the EV charger supplemented if needed by energy from the battery. If excess energy is available, the remaining PV power will be stored in the battery. By using the battery storage, the system is able to provide a reliable and constant power source from inherent intermittent solar PV power.

Outcome 2: The control software was developed to implement the system control strategy, stream weather forecasting, estimate PV electricity, collect EV charging data, project EV charging load demand, and optimize the battery SOC. The optimization of the battery SOC between 0.5-0.9 according to the PV estimation and the EV charging projection was demonstrated on a computer.

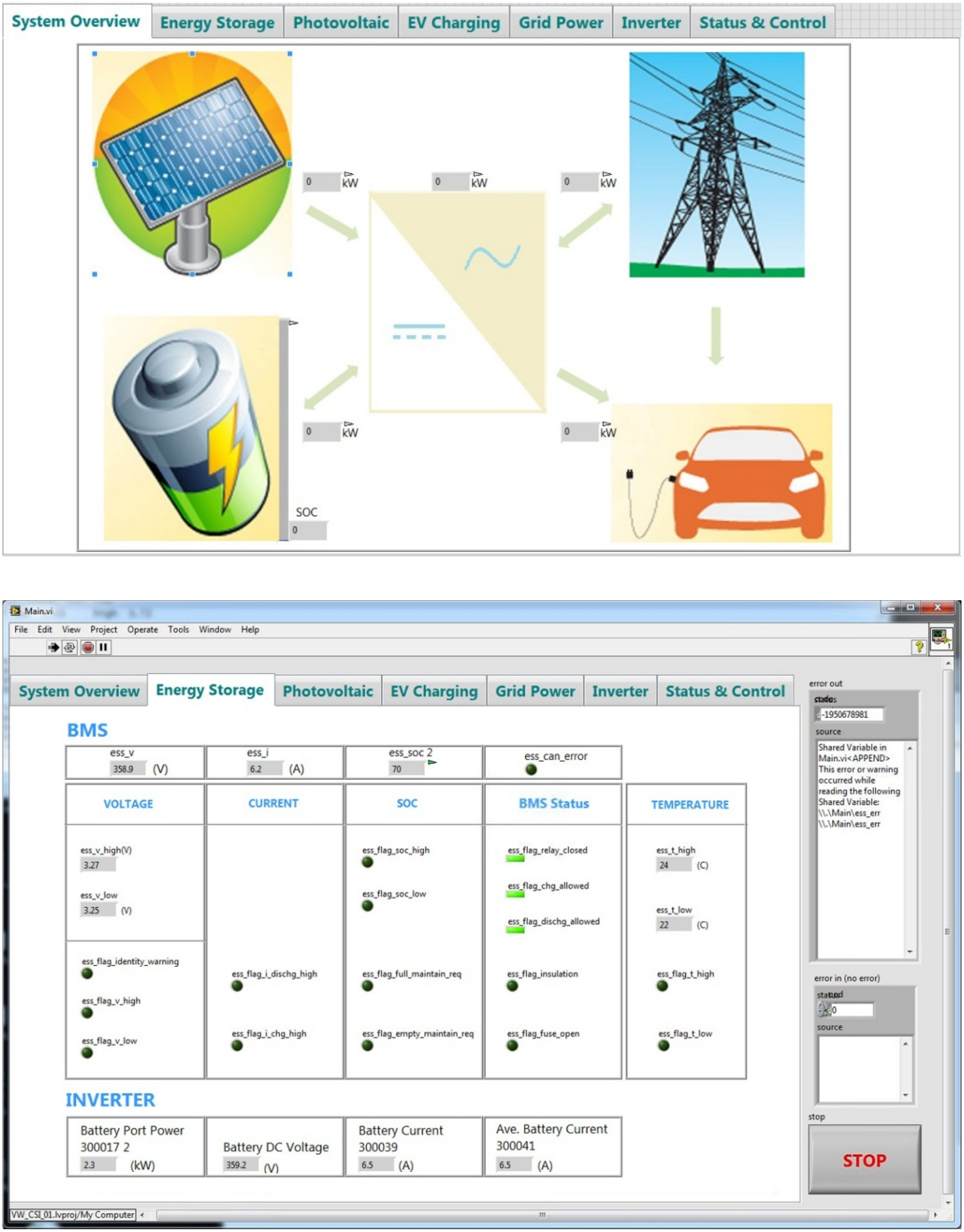
a) Control software

The control and monitoring software for the charging station was developed using LabVIEW software. The software accomplishes the following four major functions.

- **Monitoring**: Displays the measured parameters and status of each component of the charging system, and collects and logs system parameters (Figure 11).
- **Control**: Used to view and configure control parameters, carry out the power flow control strategies, and change the system operation (Figure 12).
- **Projection**: Used to detect system errors and status, and respond to the all events (Figure 13).
- **Optimization**: Streams weather information for estimating PV electricity generation (Figure 14), collects EV charging data and projects EV charging load (Figure 15), and optimizes and updates battery SOC target (Figure 16).

b) Demonstration of battery usage optimization

As shown in Figure 16, several 1-D arrays have been defined for storing actual and projected EV charging load, and actual and estimated PV electricity on a weekly basis. The contents of actual EV and actual PV arrays are updated on a daily basis at midnight. The estimation of the available PV electricity for the next day is performed three hours earlier. The EV load projection for the next week is done on the first day of the week using the method described in detail in Task 2.2 based on the latest six-week historical EV load data. The target SOC for starting each day is optimized according to weather information and EV load projection as discussed in Task 2.2. The target SOC of 0.809 in Figure 16 was calculated based on the estimated PV electricity of 15.8 kWh and the projected EV charging load of 16.05 kWh. All this data is shared with the controller for operation of the charging station.



SOC 0

ess_v 358.9 (V)

ess_i 6.2 (A)

ess_soc 2 70

ess_v_high(V) 3.27

ess_v_low 3.25 (V)

ess_t_high 24 (C)

ess_t_low 22 (C)

Battery Port Power 300017 2 2.3 (kW)

Battery DC Voltage 359.2 (V)

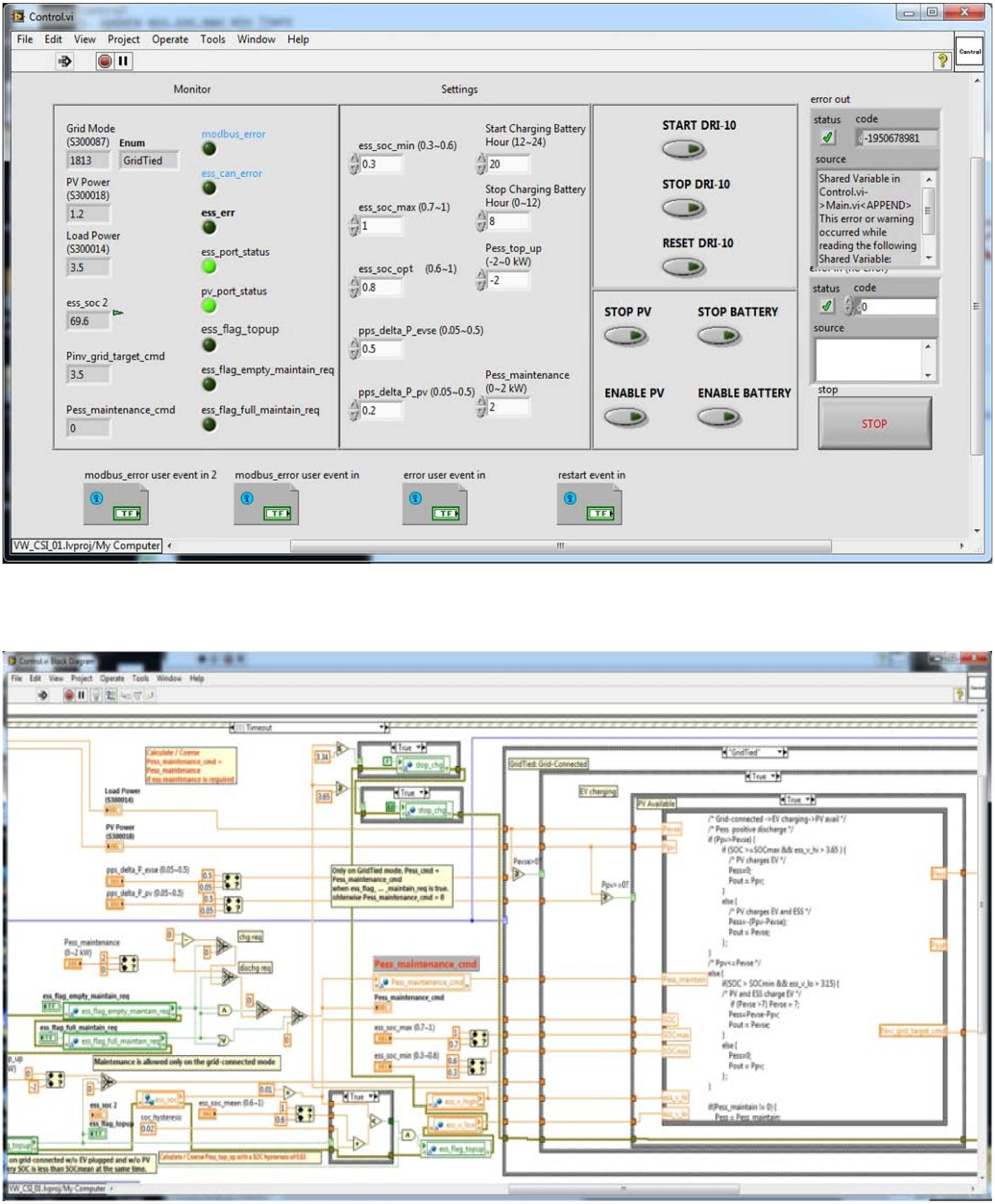
Battery Current 300039 6.5 (A)

Ave. Battery Current 300041 6.5 (A)

error out
status -1950678981
source
Shared Variable in Main.vi<APPEND> This error or warning occurred while reading the following Shared Variable: \\.\Main\ess_err \\.\Main\ess_err

error in (no error)
status 0
source

Figure 11: System monitoring interface with the taps for selecting each component



Grid Mode (S300087): 1813
Enum: GridTied
PV Power (S300018): 1.2
Load Power (S300014): 3.5
ess_soc 2: 69.6
Pinv_grid_target_cmd: 3.5
Pess_maintenance_cmd: 0
modbus_error
ess_can_error
ess_err
ess_port_status
pv_port_status
ess_flag_topup
ess_flag_empty_maintain_req
ess_flag_full_maintain_req
ess_soc_min (0.3~0.6): 0.3
ess_soc_max (0.7~1): 1
ess_soc_opt (0.6~1): 0.8
pps_delta_P_evse (0.05~0.5): 0.5
pps_delta_P_pv (0.05~0.5): 0.2
Start Charging Battery Hour (12~24): 20
Stop Charging Battery Hour (0~12): 8
Pess_top_up (-2~0 kW): -2
Pess_maintenance (0~2 kW): 2

error out
status ✓ code -1950678981
source: Shared Variable in Control.vi->Main.vi<APPEND> This error or warning occurred while reading the following Shared Variable:

status ✓ code 0
source:

Figure 12: Control interface and block diagram

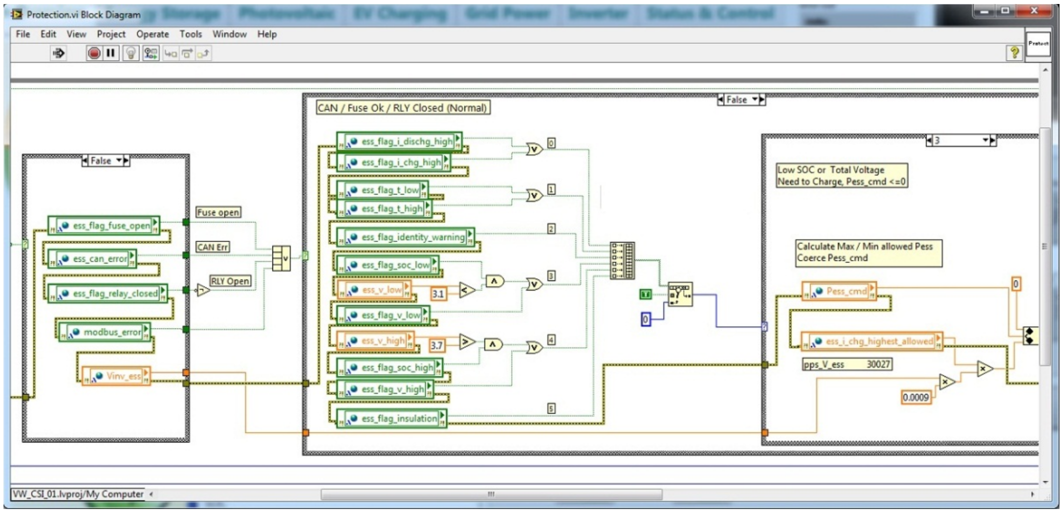
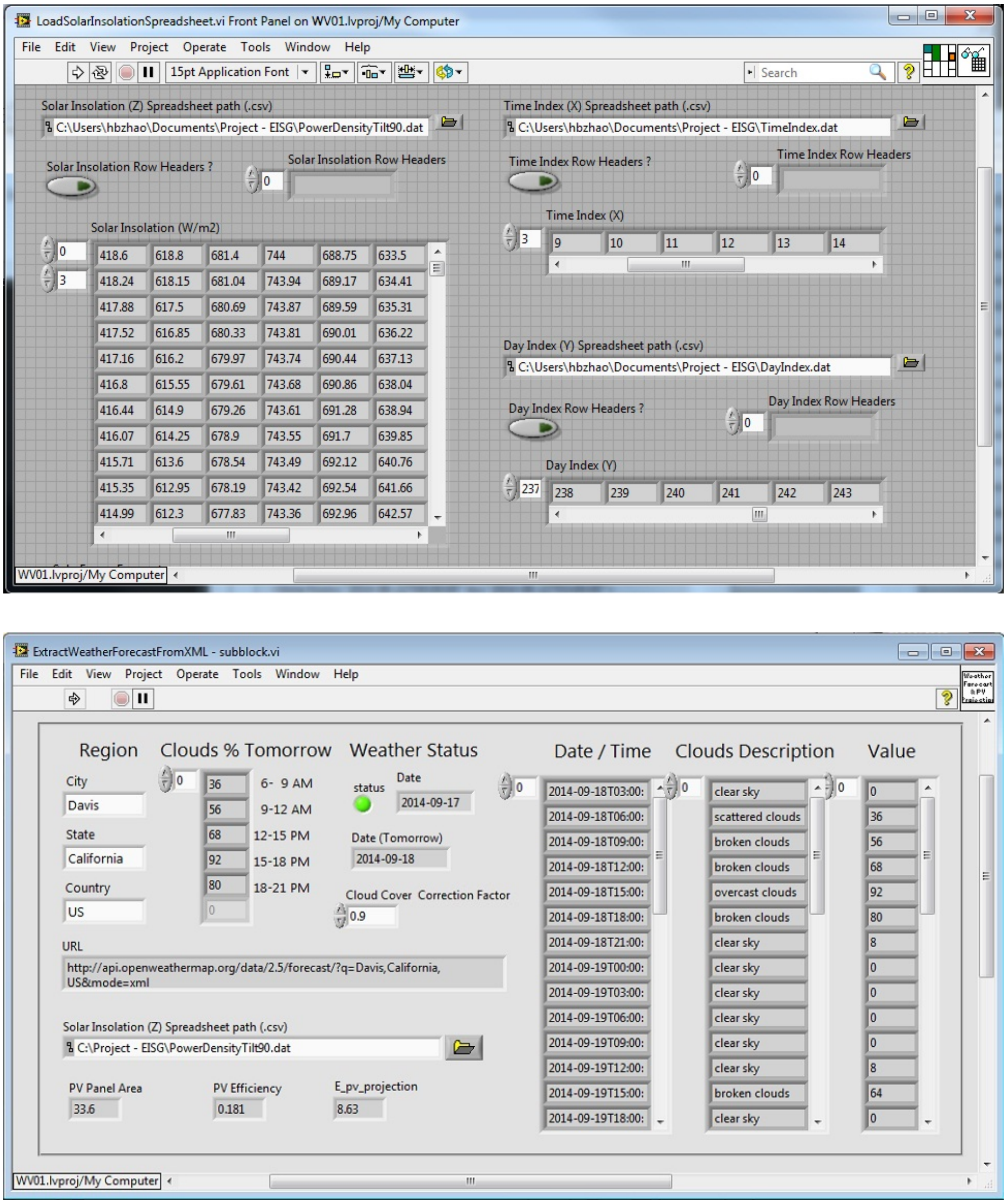


Figure 13: Protection block diagram



Solar Insolation (Z) Spreadsheet path (.csv): C:\Users\hbzhao\Documents\Project - EISG\PowerDensityTilt90.dat

Solar Insolation Row Headers ?

Solar Insolation Row Headers: 0

Solar Insolation (W/m2): 0, 3

418.6	618.8	681.4	744	688.75	633.5
418.24	618.15	681.04	743.94	689.17	634.41
417.88	617.5	680.69	743.87	689.59	635.31
417.52	616.85	680.33	743.81	690.01	636.22
417.16	616.2	679.97	743.74	690.44	637.13
416.8	615.55	679.61	743.68	690.86	638.04
416.44	614.9	679.26	743.61	691.28	638.94
416.07	614.25	678.9	743.55	691.7	639.85
415.71	613.6	678.54	743.49	692.12	640.76
415.35	612.95	678.19	743.42	692.54	641.66
414.99	612.3	677.83	743.36	692.96	642.57

Time Index (X) Spreadsheet path (.csv): C:\Users\hbzhao\Documents\Project - EISG\TimeIndex.dat

Time Index Row Headers ?

Time Index Row Headers: 0

Time Index (X): 3

9	10	11	12	13	14

Day Index (Y) Spreadsheet path (.csv): C:\Users\hbzhao\Documents\Project - EISG\DayIndex.dat

Day Index Row Headers ?

Day Index Row Headers: 0

Day Index (Y): 237

238	239	240	241	242	243

Region

City: Davis

State: California

Country: US

Clouds % Tomorrow: 0

36	6- 9 AM
56	9-12 AM
68	12-15 PM
92	15-18 PM
80	18-21 PM
0	

Weather Status

status

Date: 2014-09-17

Date (Tomorrow): 2014-09-18

Cloud Cover Correction Factor: 0.9

URL: http://api.openweathermap.org/data/2.5/forecast/?q=Davis,California, US&mode=xml

Solar Insolation (Z) Spreadsheet path (.csv): C:\Project - EISG\PowerDensityTilt90.dat

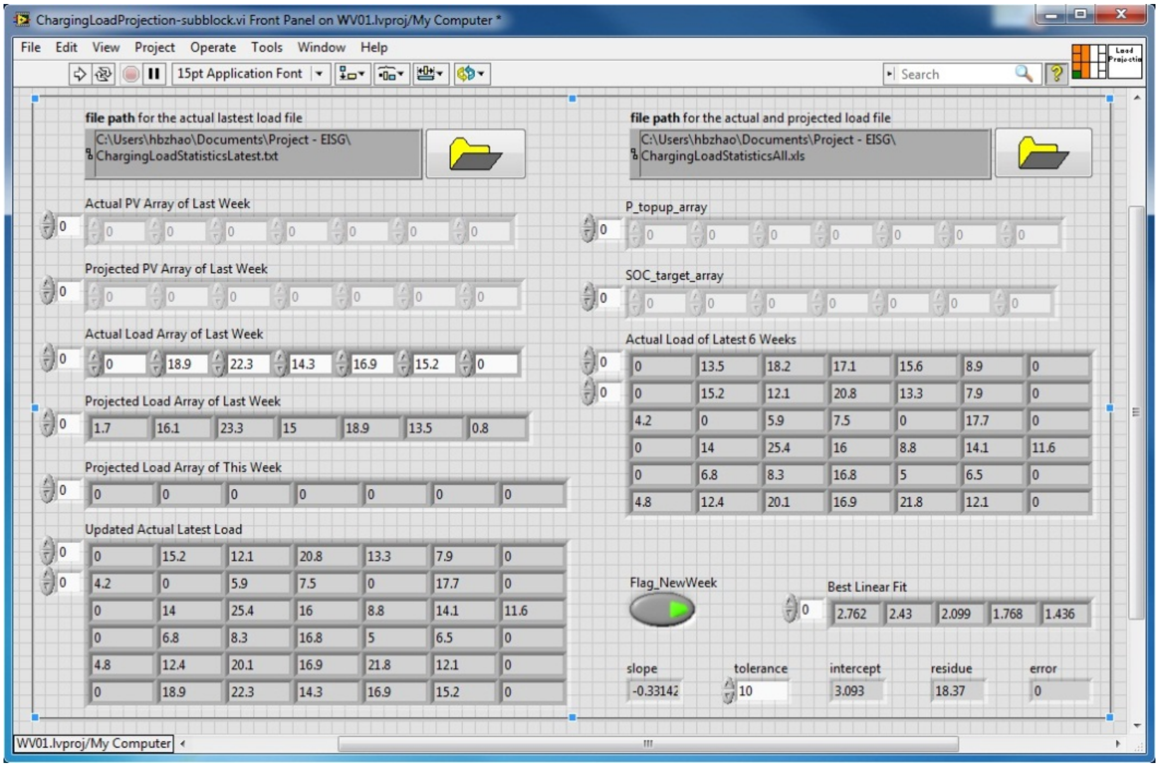
PV Panel Area: 33.6

PV Efficiency: 0.181

E_pv_projection: 8.63

Date / Time (0)	Clouds Description (0)	Value (0)
2014-09-18T03:00:	clear sky	0
2014-09-18T06:00:	scattered clouds	36
2014-09-18T09:00:	broken clouds	56
2014-09-18T12:00:	broken clouds	68
2014-09-18T15:00:	overcast clouds	92
2014-09-18T18:00:	broken clouds	80
2014-09-18T21:00:	clear sky	8
2014-09-19T00:00:	clear sky	0
2014-09-19T03:00:	clear sky	0
2014-09-19T06:00:	clear sky	0
2014-09-19T09:00:	clear sky	0
2014-09-19T12:00:	clear sky	8
2014-09-19T15:00:	broken clouds	64
2014-09-19T18:00:	clear sky	0

Figure 14: Solar insolation calculation, weather information extraction and PV electricity estimation



file path for the actual lastest load file

C:\Users\hbzhao\Documents\Project - EISG\ChargingLoadStatisticsLatest.txt

file path for the actual and projected load file

C:\Users\hbzhao\Documents\Project - EISG\ChargingLoadStatisticsAll.xls

Actual PV Array of Last Week

0	0	0	0	0	0	0

Projected PV Array of Last Week

0	0	0	0	0	0	0

Actual Load Array of Last Week

0	18.9	22.3	14.3	16.9	15.2	0

Projected Load Array of Last Week

1.7	16.1	23.3	15	18.9	13.5	0.8

Projected Load Array of This Week

0	0	0	0	0	0	0

Updated Actual Latest Load

0	15.2	12.1	20.8	13.3	7.9	0
4.2	0	5.9	7.5	0	17.7	0
0	14	25.4	16	8.8	14.1	11.6
0	6.8	8.3	16.8	5	6.5	0
4.8	12.4	20.1	16.9	21.8	12.1	0
0	18.9	22.3	14.3	16.9	15.2	0

P_topup_array

0	0	0	0	0	0	0

SOC_target_array

0	0	0	0	0	0	0

Actual Load of Latest 6 Weeks

0	13.5	18.2	17.1	15.6	8.9	0
0	15.2	12.1	20.8	13.3	7.9	0
4.2	0	5.9	7.5	0	17.7	0
0	14	25.4	16	8.8	14.1	11.6
0	6.8	8.3	16.8	5	6.5	0
4.8	12.4	20.1	16.9	21.8	12.1	0

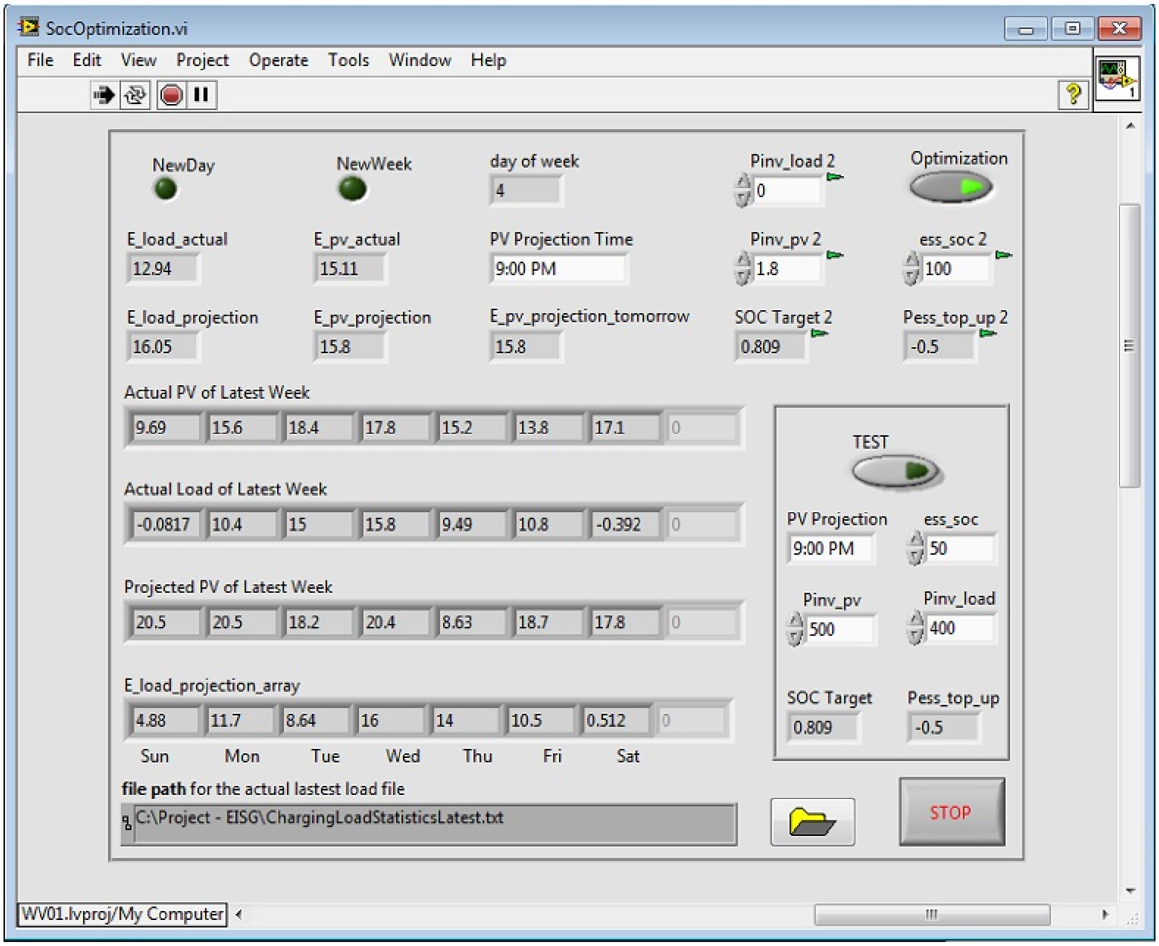
Flag_NewWeek

Best Linear Fit

2.762	2.43	2.099	1.768	1.436

slope	tolerance	intercept	residue	error
-0.33142	10	3.093	18.37	0

Figure 15: EV Charging load forecast from historical data



NewDay	NewWeek	day of week	Pinv_load 2	Optimization
●	●	4	0	

E_load_actual	E_pv_actual	PV Projection Time	Pinv_pv 2	ess_soc 2
12.94	15.11	9:00 PM	1.8	100

E_load_projection	E_pv_projection	E_pv_projection_tomorrow	SOC Target 2	Pess_top_up 2
16.05	15.8	15.8	0.809	-0.5

Actual PV of Latest Week

9.69	15.6	18.4	17.8	15.2	13.8	17.1	0

Actual Load of Latest Week

-0.0817	10.4	15	15.8	9.49	10.8	-0.392	0

Projected PV of Latest Week

20.5	20.5	18.2	20.4	8.63	18.7	17.8	0

E_load_projection_array

4.88	11.7	8.64	16	14	10.5	0.512	0
Sun	Mon	Tue	Wed	Thu	Fri	Sat	

TEST

PV Projection	ess_soc
9:00 PM	50

Pinv_pv	Pinv_load
500	400

SOC Target	Pess_top_up
0.809	-0.5

file path for the actual lastest load file

C:\Project - EISG\ChargingLoadStatisticsLatest.txt

Figure 16: Developed EV charging load forecast interface

Outcome 3: The simulations were performed for different operating scenarios. The simulation results show that compared to the charging station without intelligent energy management the peak power request from the grid was reduced by a factor 2-3.

Simulations of the charging station have been performed for different scenarios. The grid power and the cumulative grid electricity have been plotted. Figure 17 shows the results of the PV powered charging station without energy storage. The shaded areas in the grid power chart represent summer off-peak periods (9:30 pm – 8:30 am). Positive values mean power consumption from the grid and negative means power fed into the grid. In the cumulative grid energy chart, the blue curve denotes the cumulative electricity withdrawn from the utility grid, and the red curve represents the cumulative electricity fed into the utility grid. The simulation shows that EV charging for a workplace charging happens in the early morning and PV electricity is available in the afternoon, and PV power cannot be directly used for EV charging.

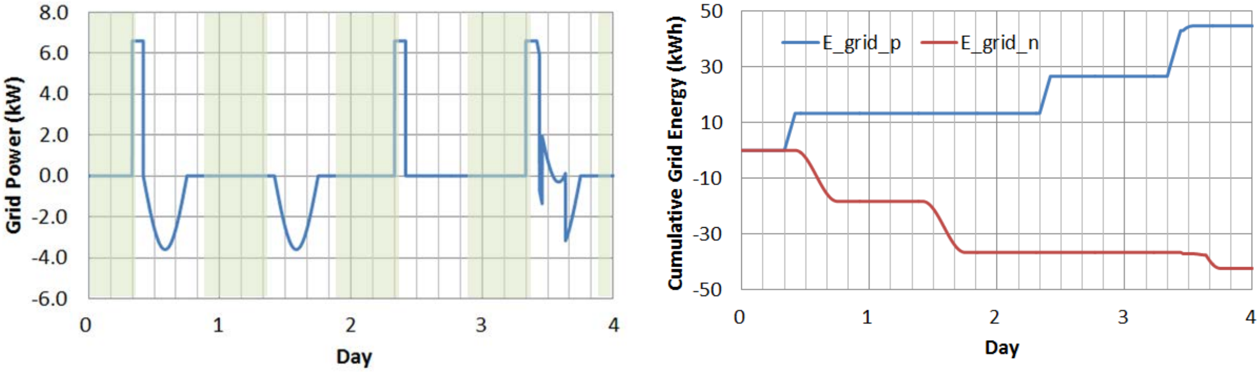


Figure 17: PV powered EV charging station without a buffer battery

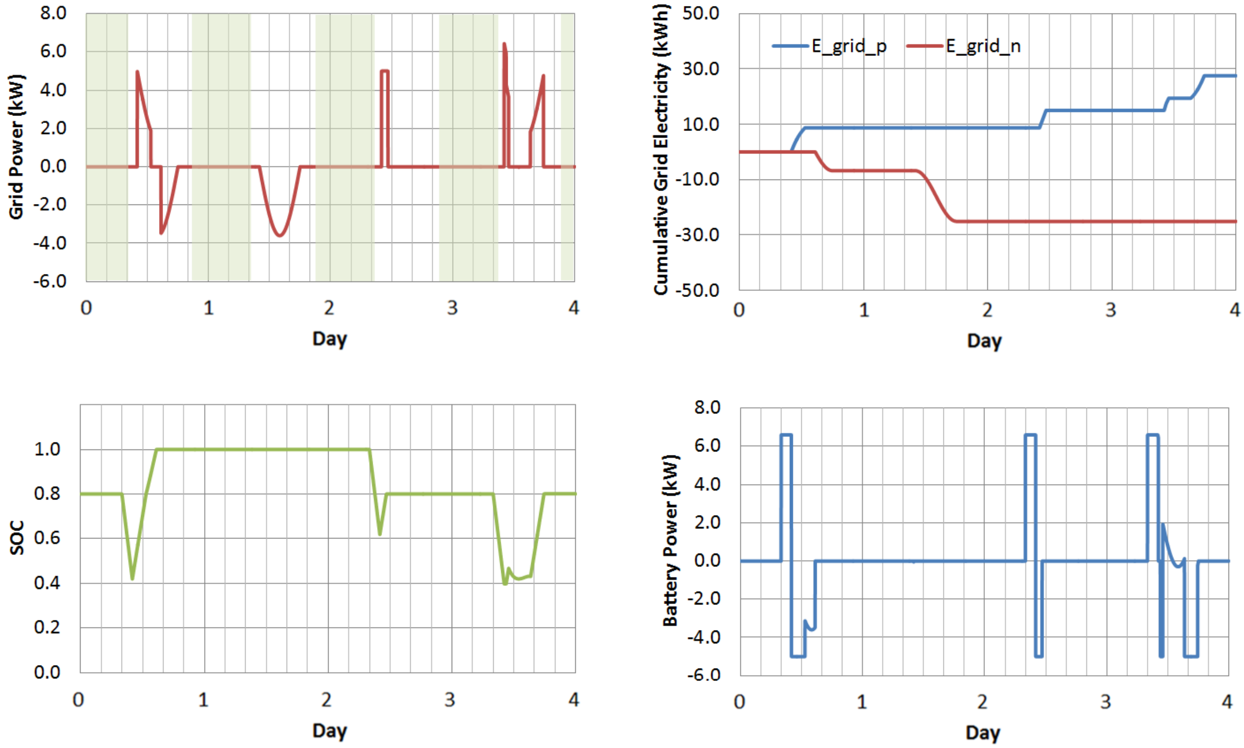


Figure 18: Charging station with buffer battery (recharged after each charging)

PV powered charging station with buffer battery which is immediately recharged after each charging event has been simulated. The battery is charged up to the SOC of 0.8 after each EV charging within 1-2 hours. The simulation results are shown in Figure 18. The simulation shows that battery recharging happens during partial-peak or on-peak periods.

Compared to the PV powered charging station without energy storage, the power demand spikes from the grid were only slightly reduced. However, the energy exchange between the charging system and the utility grid was reduced by a factor of 2-3.

The PV powered charging station with intelligent battery energy management was simulated using the same simulation inputs. Figure 19 gives the simulated grid power, battery power and SOC, and the cumulative grid electricity. The blue dotted line represents the optimal battery target SOC, which is updated at midnight according to the simulation input. The system compares the actual battery SOC with the target SOC to decide if recharging the battery is needed during off-peak periods. Compared to the charging station without optimal battery management, the power demand peak was reduced by a factor of 2. The battery recharging power demand was shifted away from the on-peak time periods to the off-peak time periods. Since all business customers will transition eventually to time-of-use rate plans as required by the California Public Utilities Commission, the charging station with intelligent energy management will benefit from less energy use during peak periods when time-of-use rates are higher.

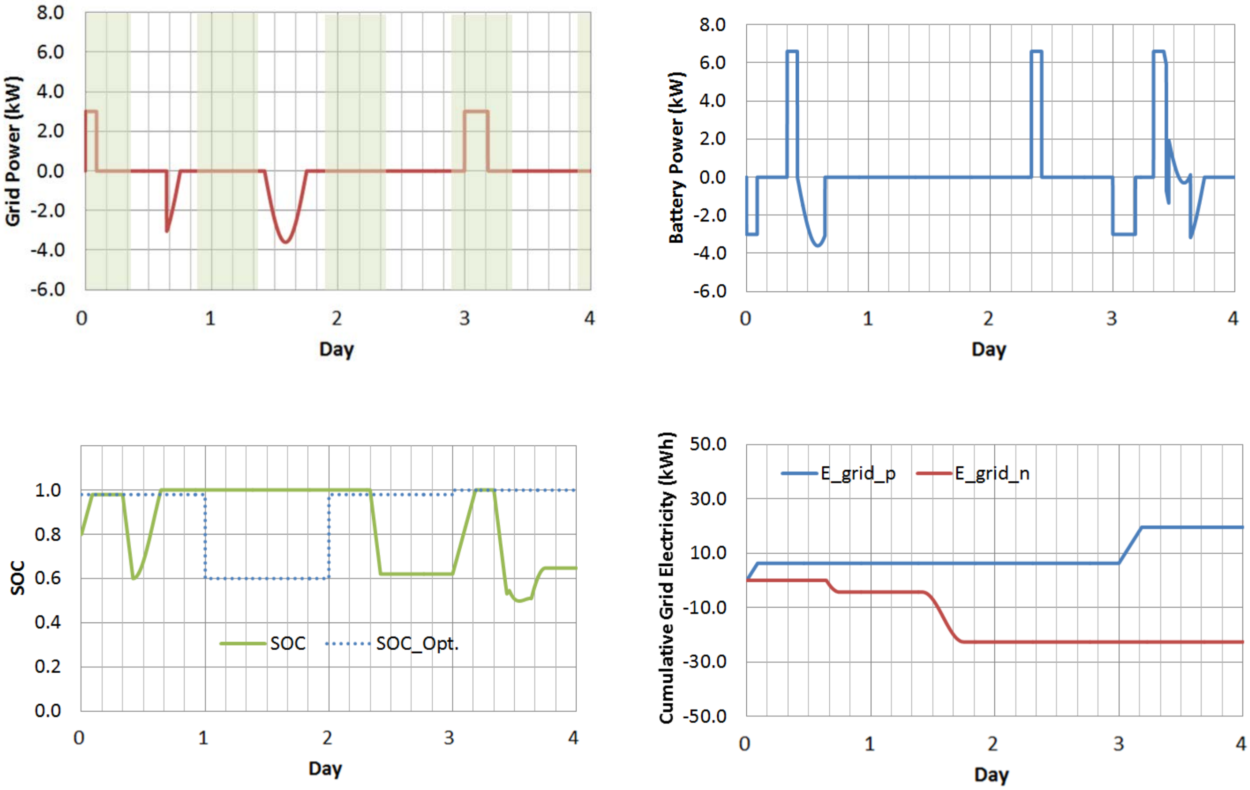


Figure 19: Charging station with intelligent energy management

Outcome 4: The EV charging station with the on-site control was designed, set up and operated. The weather information streaming, PV electricity estimation, and the load demand projection were demonstrated on the charging station. The optimization of the battery SOC between 0.5-0.9 was verified.

a) System setup and integration

The on-site controller and the supervisory computer have been installed in the electrical room which accommodates the battery storage and the bi-directional inverter. The communication between the controller and the inverter, the controller and the battery management system, and the controller and the supervisory computer was established. Figure 20 shows the setup of the control system. The controller manages the power flow between the different components and optimizes the battery storage according to the estimated PV electricity and the projected EV load.

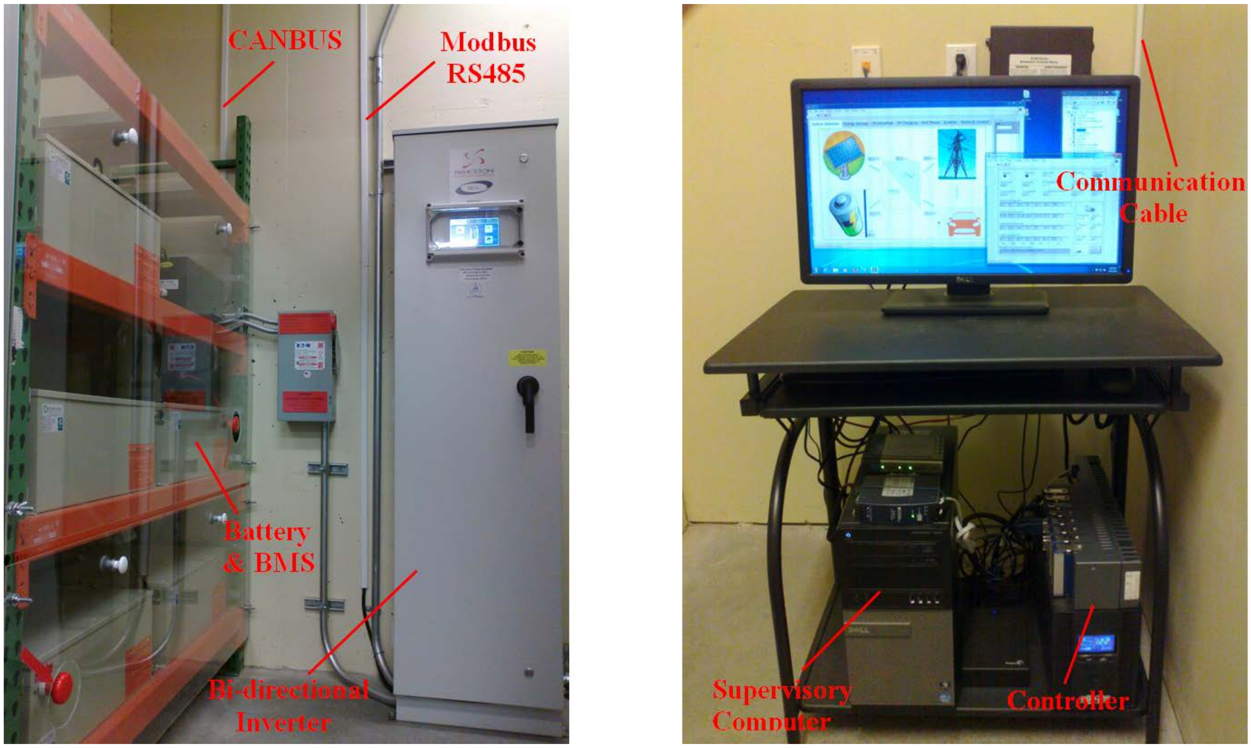
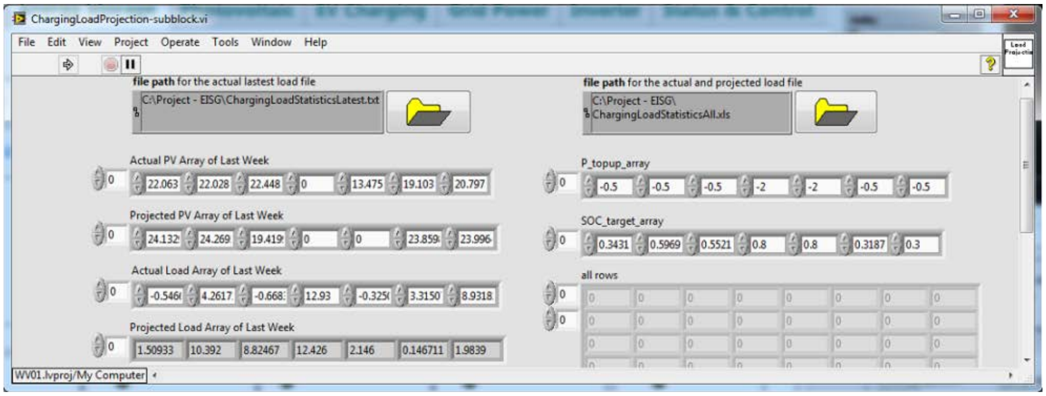


Figure 20: Charging system and controller setup

b) Verification of PV electricity estimation, EV charging load projection, and battery SOC optimization

The test operation of the system demonstrated that the controller can successfully extract weather information, estimate PV electricity, project EV charging load, and optimize the battery target SOC between 0.3-1, as shown in Figure 21.



file path for the actual lastest load file: C:\Project - EISG\ChargingLoadStatisticsLatest.txt

file path for the actual and projected load file: C:\Project - EISG\ChargingLoadStatisticsAll.xls

Actual PV Array of Last Week: 0 | 22.063 | 22.028 | 22.448 | 0 | 13.475 | 19.103 | 20.797

Projected PV Array of Last Week: 0 | 24.132 | 24.269 | 19.419 | 0 | 0 | 23.859 | 23.996

Actual Load Array of Last Week: 0 | -0.546 | 4.2617 | -0.668 | 12.93 | -0.325 | 3.3150 | 8.9318

Projected Load Array of Last Week: 0 | 1.50933 | 10.392 | 8.82467 | 12.426 | 2.146 | 0.146711 | 1.9839

P_topup_array: 0 | -0.5 | -0.5 | -0.5 | -2 | -2 | -0.5 | -0.5

SOC_target_array: 0 | 0.3431 | 0.5969 | 0.5521 | 0.8 | 0.8 | 0.3187 | 0.3

all rows: 0 | 0

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Figure 21: Optimization of battery SOC target

Outcome 5: The charging station with intelligent energy management was demonstrated. The continuous operation shows that compared to a charging station without intelligent energy management the proposed

energy management satified the project goal – reduce the grid peak power demand of the EV charging station by a factor of 2.

The charging station was operated for six days without intelligent energy management with the battery being recharged during off-peak time (9:30 pm to 8:30 am) when the SOC became low. Figure 22 shows the measured PV power and EV charging load. The grid power for the charging system with and without a buffer battery is plotted in Figure 23. The results show that for a workplace charging station, solar PV power cannot be directly used for EV charging and the charging station with the buffer battery can significantly reduce the peak power demand. The battery power and SOC, and the cumulative grid electricity are given in Figure 24. Compared to the charging station without a buffer battery, the energy exchange between the charging system and the grid was reduced by a factor of 2.

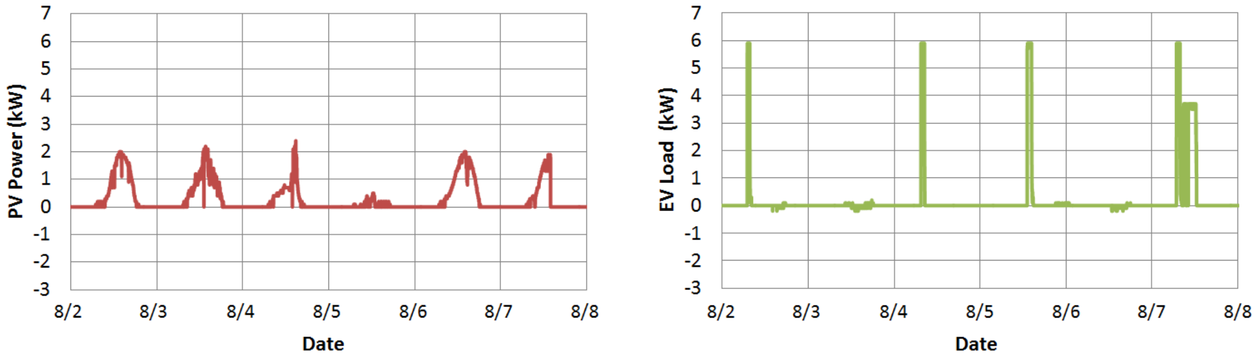
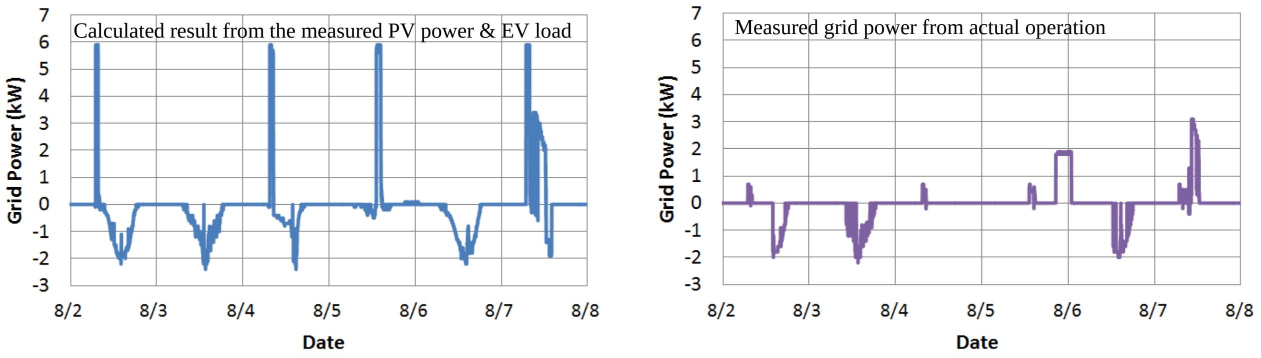


Figure 22: Measured PV power and EV charging load



Charging station without a buffer battery

Charging station with a buffer battery

Figure 23: Grid power for the charging system with and without a buffer battery

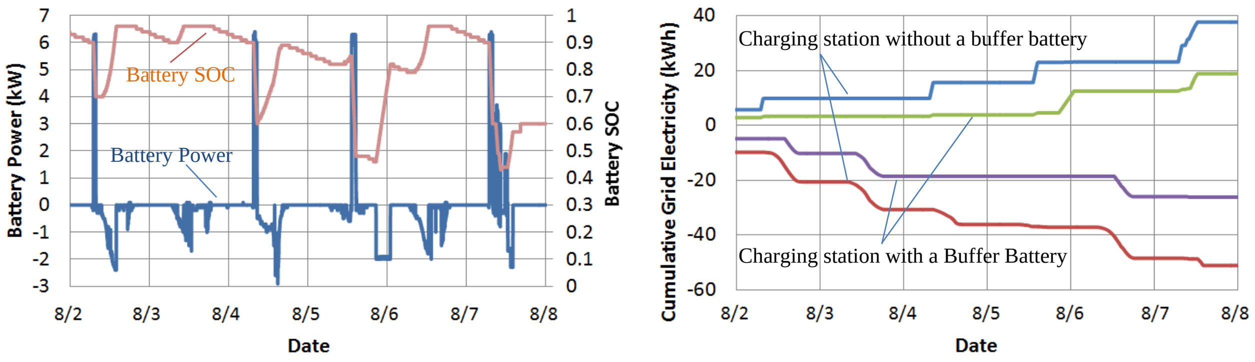


Figure 24: Battery power and SOC and cumulative grid electricity

The charging station was run continuously for a time without optimization of battery storage to collect data for the EV charging load projection. Then the intelligent energy management was activated. Figure 25 shows the estimated PV electricity and the actual PV electricity generation. Most of the time, the estimated PV electricity is 14-17% higher than the actual PV electricity generation, which may be caused by the actual conversion efficiency of the panels being lower than claimed on their datasheet or by the hazy conditions due to the forest fires. On several cloudy days, the estimated PV electricity is far lower than the actual generation, which was caused by the inaccurate cloud cover information.

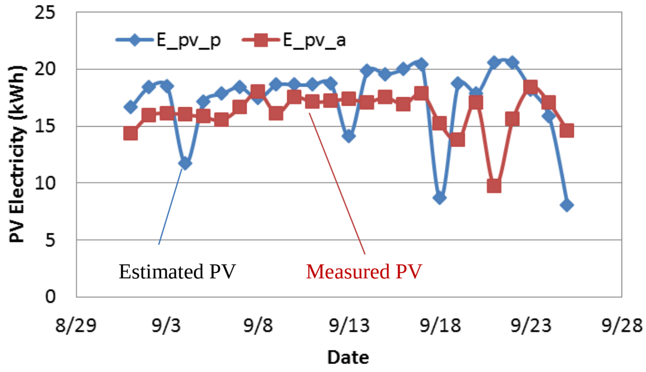


Figure 25: Estimation of PV electricity generation

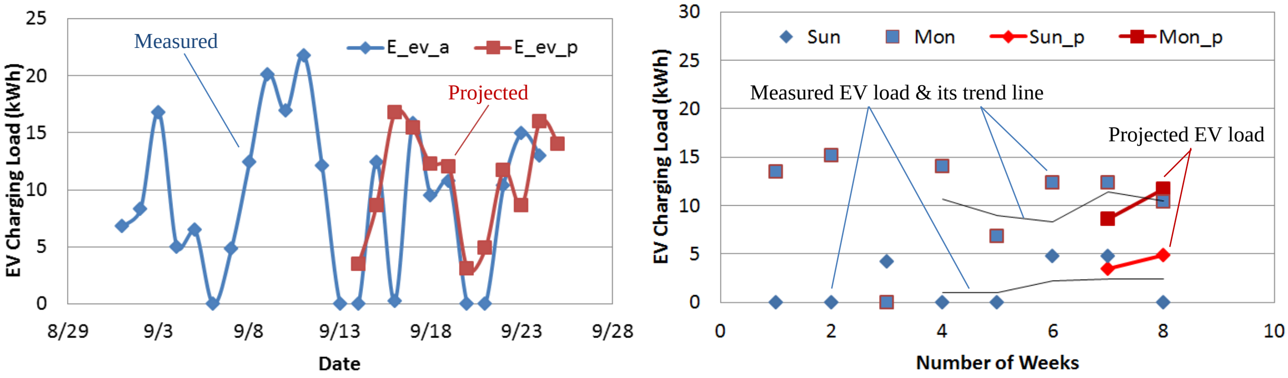


Figure 26: EV charging load projection

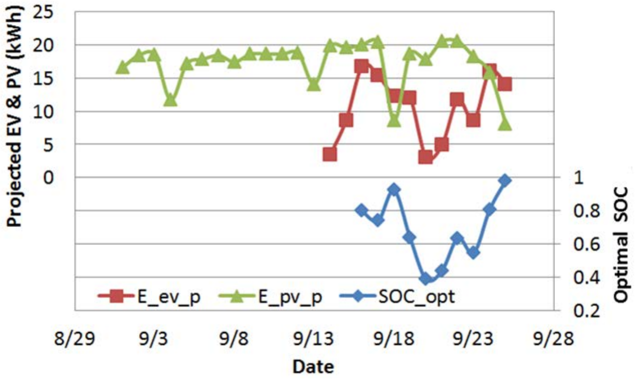


Figure 27: Optimization of battery SOC target

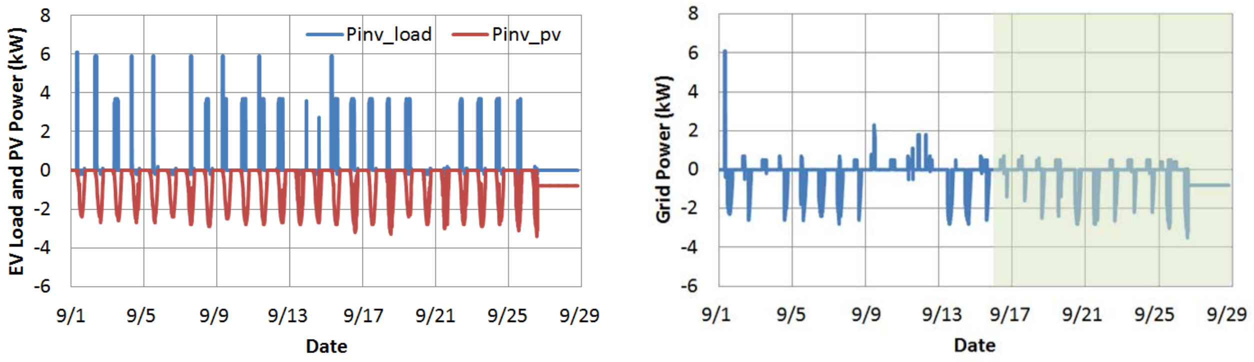


Figure 28: Measured EV load, PV power, and grid power

The measured EV charging load and the projected load on a daily basis are plotted in Figure 26. The projected EV charging load approximately reflects the actual charging variation. The actual and projected load for Sunday and Monday are also given on a weekly basis in Figure 26. The projected EV charging load approximately matched the trend lines of the actual load.

The battery SOC target was optimized based on the estimated PV electricity and the projected EV charging load. The battery is recharged during off-peak time periods if the battery SOC is less than the optimal SOC target. Figure 27 shows the estimated PV electricity, the projected EV load, and the optimized SOC target on a daily basis. The charging system was activated on 9/1, the EV was charged from the grid. On 9/2 the on-site controller took control of the charging system and on 9/16 the function of optimizing energy storage was turned on. The EV charging load, the PV power, and the grid power are plotted in Figure 28. The demonstration shows the intelligent energy management can almost eliminate the charging station peak power demand for EV charging from the utility grid.

Conclusions

The proposed intelligent energy management has been successfully demonstrated on a workplace charging station at UC Davis West Village. All the project tasks have been completed. The charging station has been operative since early August except for two system shutdowns due to the failure of a power supply in the bi-directional inverter. The charging system is routinely used by 2-3 EV users. Data are being continuously collected from the system and the data will continue to be examined on a regular basis as part of ongoing research.

The individual conclusions from each objective and outcome are:

1. The system diagram describing the integration of the on-site controller with the present charging station was designed. The control flowcharts reflecting the power flow control strategy for the grid-tied operational mode and the stand-alone operational mode were completed. It is particular important to for different devices to use the same communication port types and protocols, which will simplify system design and control.

2. The control interfaces for executing the control strategy, filtering weather information, estimating PV power, projecting EV charging load, and optimizing the battery SOC were developed using LabVIEW. The optimization of the battery SOC between 0.5 – 0.9 according to weather forecast and load

projection was demonstrated. The free three-hour weather information was used for the PV electricity estimation. More accurate hour-by-hour weather information could be purchased to improve the accuracy of the estimated PV electricity.

3. Simulations of the charging station were performed for different scenarios. Compared to the PV powered charging station without energy storage, the grid power demand spikes was reduced slightly for a charging station with buffer battery which is immediately recharged after each charging event. However, the energy exchange between the charging system and the utility grid was reduced by a factor of 2-3. Compared to the charging station without optimal energy management, the optimal energy management can reduce power demand peak by a factor of 2. For the charging station with intelligent energy management, the minimum battery recharging power was set to 3 kW considering the inverter is more efficient at higher power levels.

4. The charging station with the integrated on-site controller was successfully operated. The real-time weather forecast streaming and filtering and the EV charging load projection were demonstrated. The charge level of the battery was optimized between 0.5-0.9 based on the estimated PV generation and the projected EV load demand.

5. The charging station was continuously operated for a time with and without intelligent energy management. Compared to the charging station without a buffer battery, the energy exchange between the charging system and the grid was reduced by a factor of 2. The intelligent energy management can almost eliminate the charging station peak power demand for EV charging from the utility grid.

Broader conclusions and considerations from this research are:

1. The actual operation of the charging station indicates that for a workplace charging station most of the time EV charging occurs in the early morning before solar energy is available and PV power cannot be used directly for EV charging. An EV charging station equipped with a buffer battery and with intelligent energy management can lower the station's peak power demand and reduce the energy exchange with the utility grid by a factor of 2-3. The battery recharging power demand was shifted away from the on-peak time periods to the off-peak time periods. Since all business customers will transition eventually to time-of-use rate plans as required by the California Public Utilities Commission, the charging station with intelligent energy management will benefit from less energy use during peak periods when time-of-use rates are higher.

2. The estimated PV electricity based on the extracted weather information reflects the actual PV electricity generation. More complicated PV electricity forecasting models with more accurate hour-by-hour weather information could improve the accuracy of the estimated PV electricity. The linear fit of the historical EV charging load data for each day of the week for the latest six-week period seems appropriate for extracting the charging pattern of a workplace EV charging station. Since the current charging station has only one outlet, the uncertainty and contingency will affect the result of the load demand projection. The intelligent energy management strategy is best suited for charging station systems having one large energy storage battery and multiple charging outlets.

3. The proposed energy management could be easily integrated with current PV powered charging station with a buffer battery. For a public charging system with one large energy storage battery and multiple charging outlets, the power flow control strategy could be executed by the microprocessor in the bi-directional inverter, and the estimation of PV electricity generation and the projection of EV

charging load can be performed by the supervisory computer instead of using an external on-site controller. More complicated PV electricity estimation and EV load demand projection methods can be run on a desktop computer. However, the same communication port type and protocol must be adopted between different devices.

4. The research was done at a public university and commercialization was not a goal, but the researchers will make an effort to make system integrators aware of our findings and share our experiences with charging station manufacturers.

Recommendations

This project demonstrated the feasibility of optimizing energy management using real-time weather information and actual EV charging data statistics to reduce peak power demand from the utility grid and energy exchange between the charging station and the grid. Instead of using an external on-site controller, a supervisory computer could be used to estimate PV electricity generation, project EV charging load, optimize the battery storage, and communicate with the bidirectional inverter through the internet or the serial port. More complex PV electricity estimation models could also be run on the supervisory computer for accurate PV estimation. This would make it easier to integrate the buffer battery with present charging stations with no additional hardware cost.

The charging station with intelligent energy management was demonstrated on a workplace charging station with the limited PV panel, the small battery storage, and one charging outlet. Since the EV charging data from one charging outlet is contingent, charging data from multiple charging outlets will deliver high EV load prediction accuracy. The intelligent energy management strategy used in this project is best suited for charging station systems having one large energy storage battery and multiple charging outlets, such as workplace or commercial charging station systems.

Running the optimization of the energy storage on the supervisory computer eliminates the requirement for a high performance controller which limits the complexity of the optimization algorithm. A more complex PV electricity estimation model using more accurate weather information can/should be developed for the optimization of the energy storage on the supervisory computer. The EV charging load projection for treating more charging outlets also will need to be developed.

The research team are continuing to collect data from the charging station in West Village and improving the models based on actual operation with the station. Operating scenarios for larger EV charging loads will be simulated and analyzed in the future. As more experience is gained with the use of the charging station in West Village, the researchers should/will present their research at appropriate conferences on renewable energy and contact EV charging station manufacturers to promote the intelligent energy management approach. The researchers will also be in a position to recommend to other groups in California how they can best utilize PV charging and the value of battery buffering as part of their system.

Public Benefits to California

The intelligent energy management using weather information and actual load statistics on a workplace level 2 charging station with limited PV power, small battery storage, and one charging outlet can be applied to large distributed public commercial or workplace EV charging station systems which will become more important in California as the number of EVs and PV systems in California continues to increase. The benefits of using intelligent energy management on those charging systems will become increasing important. The public benefits to California derived from this EISG project, which demonstrated intelligent energy management for a PV powered EV charging station with a buffer battery include:

- Reduced impacts of the EV charging system on the California electricity supply, transmission, and distribution system in terms of peak power demand and energy exchange.
- Reduced electricity system losses and improved the value of the charging station.
- Benefit the charging station owner through the Time-of-Use rate plans.

An EV charging station equipped with a buffer battery and with intelligent energy management can lower the station's peak power demand and reduce the energy exchange with the utility grid by a factor of 2-3, and eliminate grid power demand during on-peak hours at early EV adoption stage. According to California Energy Demand 2014-2024 Preliminary Forecast [9], electric consumption by EVs in the PG&E planning area is projected to reach up to 2, 800 GWh and peak impacts are estimated to be up to 121 MW by 2024 with assumption that most charging would occur during off-peak hours. Therefore, battery buffered EV charging stations with intelligent energy management may eliminate the growing electricity demand of 121 MW from EV charging in the PG&E planning area during on-peak time periods. The intelligent energy management for the PV powered EV charging station with a buffer battery will ease the challenge faced by the utility grid to upgrade the distribution infrastructure in the early stage to handle high EV charging power demand, especially fast EV charging, and surplus PV solar energy.

Both simulation and demonstration show that a workplace PV powered, battery buffered EV charging station with intelligent energy management could reduce energy exchange with grid by a factor of at least 2. Considering the California average transmission and distribution losses of 5.4 – 6.9 % during 2002 to 2008 [10] and the projected electric consumption of up to 2,800 GWh by EVs in the PG&E planning area in 2024, 75.6-96.6 GWh electricity losses can be avoided in the PG&E planning area in 2024 by using PV powered EV charging stations with intelligent energy management.

With transition to time-of-use rate plans required by the California Public Utilities Commission, the charging station with intelligent energy management will benefit from much less energy use during on-peak periods when time-of-use rates are high. For example, the summer electric rate is $0.566/kWh during on-peak periods and $0.148 during off-peak hours for a PG&E A-6 small commerical / general Time-of-Use service in 2014 [11]. At the same time, the chariging station with intelligent energy management can help the overall balancing of the grid as more PV power and unpredictable EV charging loads come on line on the user side.

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Development Status Questionnaire

California Energy Commission **Energy Innovations Small Grant (EISG) Program** **PROJECT DEVELOPMENT STATUS**	**Questionnaire**

Answer each question below and provide brief comments where appropriate to clarify status. If you are filling out this form in MS Word the comment block will expand to accommodate inserted text.

Please Identify yourself, and your project: **PI Name** Hengbing Zhao **Grant #** 13-02T

Overall Status	
Questions	**Comments:**
1) Do you consider that this research project proved the feasibility of your concept? Yes	*The proposed intelligent energy management has been successfully demonstrated on a workplace charging station at UC Davis West Village.*
2) Do you intend to continue this development effort towards commercialization? No	*The research was done at a public university and commercialization was not a goal, but the researchers will make an effort to make system integrators aware of our findings.*
Engineering/Technical	
3) What are the key remaining technical or engineering obstacles that prevent product demonstration?	*Suitable bi-directional battery charging electronics are at an early stage of development. Also there is a need for better integration of the various components and system software.*
4) Have you defined a development path from where you are to product demonstration?	*NA.*
5) How many years are required to complete product development and demonstration?	*NA.*
6) How much money is required to complete engineering development and demonstration?	*NA*
7) Do you have an engineering requirements specification for your potential product?	*NA*
Marketing	
8) What market does your concept serve?	*Commercial EV charging stations*
9) What is the market need?	*Residential and commercial PV powered charging stations with a buffer battery storage are becoming important.*
10) Have you surveyed potential customers for interest in your product?	*NA.*
11) Have you performed a market analysis that takes external factors into consideration?	*NA.*

12) Have you identified any regulatory, institutional or legal barriers to product acceptance?	*No*
13) What is the size of the potential market in California for your proposed technology?	*It is likely that this concept will be applied in future market developments*
14) Have you clearly identified the technology that can be patented?	*NO. we are not concerned about IP.*
15) Have you performed a patent search?	*A self-search has been done. No similar approach has been applied to EV charging stations.*
16) Have you applied for patents?	*No*
17) Have you secured any patents?	*No*
18) Have you published any paper or publicly disclosed your concept in any way that would limit your ability to seek patent protection?	*A conference paper has been accepted by IEVC 2014.*
Commercialization Path	
19) Can your organization commercialize your product without partnering with another organization?	*No. we would be happy to have any EV charging station manufacturer develop and use this approach.*
20) Has an industrial or commercial company expressed interest in helping you take your technology to the market?	*No*
21) Have you developed a commercialization plan?	*NA.*
22) What are the commercialization risks?	*No commercialization risk for EV charging station developers and integrators.*
Financial Plan	
23) If you plan to continue development of your concept, do you have a plan for the required funding?	*NA*
24) Have you identified funding requirements for each of the development and commercialization phases?	*NA*
25) Have you received any follow-on funding or commitments to fund the follow-on work to this grant?	*No. This work was a follow on to a California Solar Initiative project. We will seek additional funding to continue to research the system at West Village.*
26) What are the go/no-go milestones in your commercialization plan?	*NA*
27) How would you assess the financial risk of bringing this product/service to the market?	*NA*
28) Have you developed a comprehensive business plan that incorporates the information requested in this questionnaire?	*NA*
Public Benefits	
29) What sectors will receive the greatest benefits as a result of your concept?	*The concept will benefit PV companies, charging station owners and utility/ grid companies.*
30) Identify the relevant savings to California in terms of kWh, cost, reliability, safety, environment etc.	*Intelligent management of PV/battery systems can lead to large cost savings for charging station and EV owners as well as electric utilities as a result of larger shifts of electricity demand to PV solar at optimum times of the day.*

31) Does the proposed technology reduce emissions from power generation?	*Yes. It maximizes the use of solar PV for EV charging.*
32) Are there any potential negative effects from the application of this technology with regard to public safety, environment etc.?	*No*
Competitive Analysis	
33) What are the comparative advantages of your product (compared to your competition) and how relevant are they to your customers?	*Our approach to PV/battery management would benefit all system suppliers and integrators of battery buffered PV charging systems*
34) What are the comparative disadvantages of your product (compared to your competition) and how relevant are they to your customers?	*NA*
Development Assistance	
The EISG Program may in the future provide follow-on services to selected Awardees that would assist them in obtaining follow-on funding from the full range of funding sources (i.e. Partners, PIER, NSF, SBIR, DOE etc.). The types of services offered could include: (1) intellectual property assessment; (2) market assessment; (3) business plan development etc.	
35) If selected, would you be interested in receiving development assistance?	*We are interested in additional funding to develop our system to accommodate more EVs in West Village*