Solar Charging Station for Education and Research

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Abstract

Many energy efficiency projects have been performed in Weber State University campus in the past years. The achievement is remarkable. This paper will address the design of a pilot project, Solar Charging Station, through student's senior project for education and research. Students will learn the theory of solar Photovoltaic (PV) systems and to build an experimental solar charging station to charge the electric bikes and electric bikes. The integrated system will be used as the demonstration for the two new courses, Renewable Energy and Solar PV Systems, at the Weber State University. The project is supported by Energy and Sustainability Office (ESO) of the university. If the pilot project is successful, many more solar charging stations will be installed on campus. The goals of this project are to educate the students of the Weber State University with the concept of sustainability, the theory and hands-on experience of solar energy applications and to promote the sustainability on campus by utilizing renewable energy.

Through the project, students will be able to learn the theory of how the solar PV systems work, how to design the system (capacity and the specifications) for PV modules, charge controller, inverter and the battery bank with hands-on experience. Besides charging the electric bikes and electric motorcycles, the solar charging station can also be designed to charge electric cars. By monitoring the system performance, collecting data and conducting performance analysis, students will also learn how to improve the solar charging systems. This paper will demonstrate the system design and performance analysis as well as how the system will be used in the classes for students' learning.

Keywords *- photovoltaic; solar panel; solar module; solar system; solar PV system; electric bike; electric motorcycle; solar charging*

I. Introduction

Many studies revealed the supply of fossil fuels such as coal, natural gas and oil has its limit. Researches have also been done to discuss the limitations and the impacts of using fossil fuel energy and its possible impact on global climate change. The demand for energy is increasing as the world population grows and the economic growth in many developing countries as well as the developed countries. The energy crisis can be anticipated in the near future, may be in the next century if not in 40 or 50 years. The alternative energy or renewable energy to the fossil fuels ought to be actively explored earlier rather than late. The renewable energy such as solar energy can provide a long term solution and minimize climate change.

The Solar Charging Stations for charging electric bikes and electric motorcycle is a fundamental and practical application of using solar energy for sustainability. The Solar Charging Stations utilize solar PV modules to convert solar energy to DC voltage. The DC energy can be stored to battery bank by a charge controller. An inverter is employed to convert the DC voltage from the battery bank to 110 volt AC at 60 Hz frequency that is identical to the power from the electric outlet on the wall. This project will enable students to acquire an essential foundation towards how to design and build the solar PV systems for various applications. The students will also learn the code compliances required by National Electric Code (NEC) during the system design process.

Based on the available components, the target of this pilot project is to build two solar charging stations with different capacities. One station is for charging electric bikes and the other is for charging electric motorcycle. The capacity for electric motorcycles is larger than that of electric bikes. The design consideration will be discussed in the following sections. If the pilot project is successful, many more solar charging stations will be installed on campus.

II. Project Motivation

Weber State University encourages all faculty, staff and students to utilize the public transportation and bikes for their transportation between the train transit station and the campus to reduce the use of automobiles. However, the long uphill (about 4 miles) from the train transit station to the campus will be a challenge to the bikers. Riding electric bikes will be helpful to mitigate the burden and encourage the utilization of the public transportation and improve the environment. But if the electric bike is charged from the electric outlet on the wall, it will not be sustainable because the power from the electric outlet is generated by burning the fossil fuel such as coal at the power company (not green energy) that generates carbon dioxide (CO_2) during the process of power generation.

The idea of this project is to build "Solar Charging Stations" that will provide free electricity that is generated from the solar Photovoltaic (PV) system for charging the electric bikes and electric motorcycles on campus instead of charging them from the electric outlet on the wall. If the electric vehicle is charged with the electricity generated from solar energy, the operation will be sustainable because the renewable energy (green energy) is used as the power source. For education, students benefit from this project by learning the theory and hands-on experience of the system design. It also provides a platform for research in solar energy and its application.

III. System Designs and Components

The basic theory of the Solar Charging Station is to harvest the solar energy and convert it to AC electricity that can be used to charge electric bikes and electric motorcycles. The Solar Charging Stations utilize solar PV modules to convert solar energy to DC voltage. The DC energy can be stored to a battery bank by charge controller. An inverter is employed to convert the DC voltage from the battery bank to 110 volt AC at 60 Hz frequency for charging the electric vehicles. Two separate charging stations with different capacities are built in order to efficiently monitor the system performance separately.

1. Solar Charging Station # 1 – For electric bikes

Solar charging system #1 is built for charging electric bikes. We have two electric bikes for this project. The loads of each electric bike is 230 Wh (Watt-hours) and 360 Wh individually. Figure 1 shows the block diagram of the system for charging the electric bikes. For simplicity, the combiner box, Ground-Fault Protection Device (GFPD), the overcurrent protection devices (the circuit breakers) and system grounding wires are not shown in the figure.

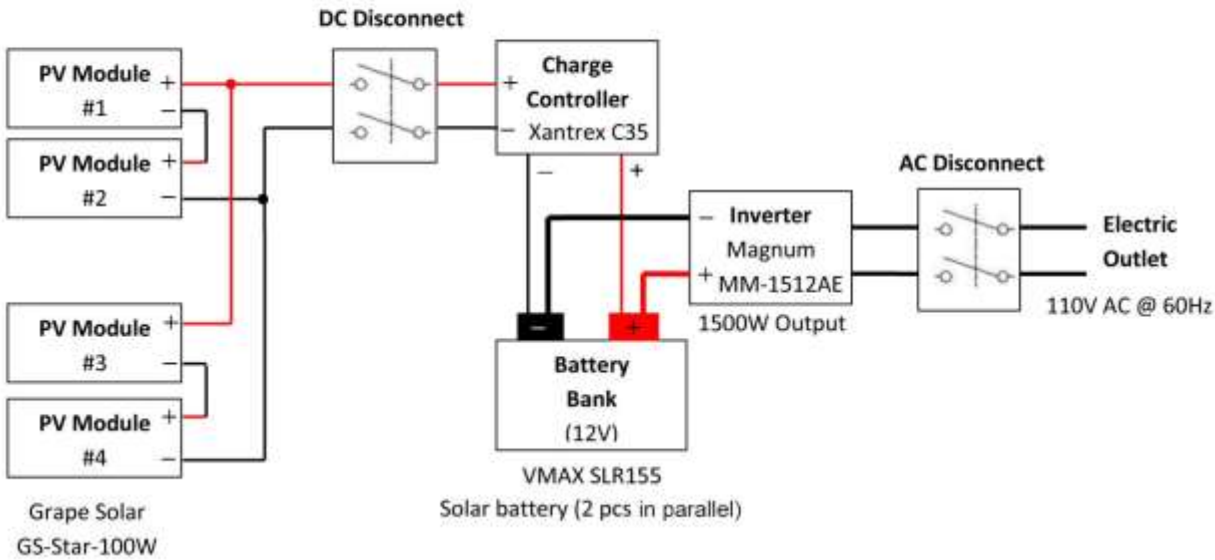

Figure 1. Solar charging station # 1 system block diagram – For electric bikes

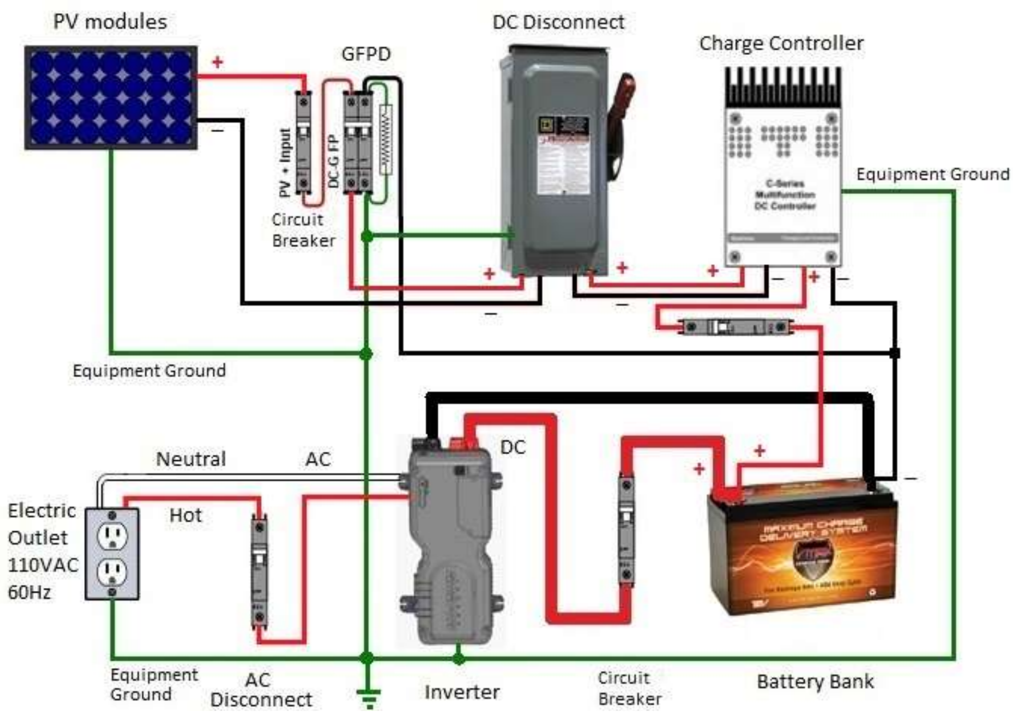

Figure 2. Wiring diagram of solar charging station # 1 for electric bikes

Figure 2 demonstrates the wiring diagram and components detail of the system. The components used in charging station #1 are listed in Table 1. The following subsections describe their functions, specifications and the design considerations.

Table 1. Components for solar charging station #1

Component	Qty	Specifications
PV modules	4	Grape Solar GS-Star-100W
GFPD	1	MidNite Solar MNDC-GFP63
DC Disconnect	1	Square D Disconnect HU361RB, 3P, 600V, 30A
DC circuit breaker	2	MidNite Solar MNEPV 150V DC, 30A
Charge controller	1	Xantrex C35, Input voltage < 55V DC, Output voltage 12V/24V DC, Load current 35A, PWM charging process
Battery bank	2	VMAX SLR155, 12V, 155Ah
DC circuit breaker	1	Xscorpion CB200A, 12V DC, 200A (for battery output)
Inverter	1	Magnum MM-1512AE, 1500VA, Input 12V DC, Output 120V AC @ 60Hz Modified Sine Wave
AC circuit breaker	1	Square D QO 20 Amp Single-Pole Circuit Breaker

A. PV Modules

PV modules consist of many PV cell circuits, normally in series, sealed in an environmentally protective laminate and are the fundamental building block of PV systems. The PV cells convert sunlight into DC current electricity. The PV modules used in charging station # 1 are Grape Solar's GS-Star-100W. Four modules are used and each module has 100 watts nominal output. The total maximum power output is 400 watts.

(a) The range of DC output voltage from PV modules

The PV array in charging station #1 is configured with 2 strings of 2 PV modules in series. It is known that the output voltage of a PV module is influenced by the ambient temperature. The temperature data from American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) is normally used along with open-circuit voltage (V_{oc}) and temperature coefficient of V_{oc} (TC_{Voc}) to calculate the range of the output voltage from the PV module. The calculations are shown in the following equations [1].

From the Electrical Specifications of GS-Star-100W at STC (Standard Test Conditions):

Open-circuit voltage V_{oc} = 21.9 V
Temperature coefficient of V_{oc} = – 0.32% / ºC

The low temperature history at Hill Air Force Base, Ogden [2]:
ASHRAE Extreme Annual Mean Minimum Design Dry Bulb Temperature = – 16 ºC

T_{min} = – 16 ºC – 25 ºC = – 41 ºC
$V_1 = V_{oc}$ x { 1 + [(– 41 ºC) x (– 0.32% / ºC)]}
= 21.9 x 1.1312 = 24.77 V

There are two PV modules in series per string. Therefore, the maximum output voltage from PV modules after temperature correction will be 49.55 V that is within the input voltage specification of Xantrex C35 charge controller.

2 modules in series → V_{max} = 24.77 x 2 = 49.55 V

(b) The maximum output current from PV modules

Short-circuit current I_{sc} of GS-Star-100W = 6.13A
Temperature coefficient of I_{sc} = 0.04 % / ºC
ASHRAE 2% High Temperature = 34 ºC

T_{max} = 34 ºC – 25 ºC = 9 ºC
$I_1 = I_{sc}$ x { 1 + [9 ºC) x (0.04% / ºC)]} = 6.13 A x 1.0036 = 6.15 A
2 strings of PV modules in parallel → I_{max} = 6.15 x 2 = 12.3 A

B. Ground Faults Protection Device (GFPD)

For the electrical industry, ground fault is the undesirable condition of current flowing through the grounding conductor. The cause of this undesirable current flow is an unintentional electrical connection between a current-carrying conductor in the PV system and the equipment grounding conductor (EGC) [3]. NEC Article 690.5 specifies the ground-fault protection requirements for grounded dc photovoltaic arrays. Ground fault protection is also required for ungrounded PV systems; these requirements are detailed in 690.35(C). The specified purpose of a ground-fault protection device (GFPD) as part of a PV power system is to reduce the risk of fire associated with a ground fault. The ground fault is a kind of shorted circuit, the fault current can be very high that could create a significant fire hazard as bare metal is heated by the current flow. In addition, the ground fault causes a safety hazard [3].

The ground fault protection device (GFPD) is connected between grounded conductor and system ground. If the current flows through GFPD is larger than the rated current (for example, 1 amp), the protection device will trip and disconnect the DC ungrounded conductor, i.e. the wire between PV positive and charge controller that is connected through the GFPD. As shown in Figure 2, the GFPD is protecting the ungrounded conductor between DC disconnect and charge controller.

C. **DC Disconnect and AC Disconnect**

DC disconnect is used as PV power source disconnect to comply disconnecting means required by NEC 2011, Sections 690.13, 690.14(c), and 690.15 [4]

NEC 2011, Sections 690.13 indicates: PV power source disconnect, specifically referring to DC power portion of the system. In our system, the DC disconnect works as the PV power source disconnect.

NEC 2011, Sections 690.14(c) requires PV system disconnect so that the system can be safely and easily shutdown and disconnected from building wiring. The AC disconnect in Figure 2 is utilized as the PV system disconnect.

NEC 2011, Sections 690.15 also requires PV equipment disconnect so that all sources of power can be disconnected to service or remove individual components in the system. For inverter, the DC disconnect and the AC disconnect in our system work as the PV equipment disconnect.

D. **DC Series Fusing**

DC circuit breakers are used to protect the wires from overcurrent. On the PV power source side, the circuit breaker with rating of 30A @ 150V DC is used. For the circuit between battery bank and inverter, 200A @ 12V DC circuit breaker is installed.

E. Charge Controller

The charge controller receives and regulates the input voltage from PV power source and stores the energy by charging the battery bank. The charge controller charges the battery bank with a 3-stage charging process as demonstrated in Figure 3 [5].

The charging control settings for Bulk and Float stages for lead acid battery are shown below, as specified in the user's manual of Xantrex C35 charge controller [5].

Bulk: 13.0 V ~ 15.0 V DC

Float: 12.5 V ~ 14.5 V DC

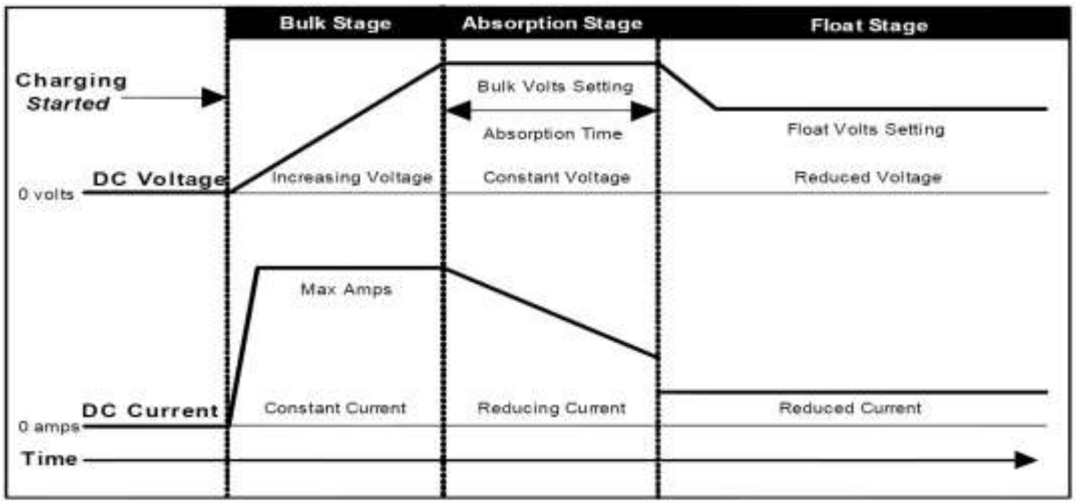

Figure 3. 3-Stage battery charging Process [5]

F. Battery Bank

Two 12-volt VMAX SLR155 AGM deep cycle solar battery are connected in parallel as the battery bank. Each battery has the capacity of 155 Ah (Amp-hour). This battery bank provides 3720 watt-hour of energy storage (155 Ah x 12 V x 2 = 3720 Wh) which is sufficient to energize the two electric bikes with total loads of 590 Wh.

G. Inverter

The Magnum MM-1512AE inverter is rated 1500 W output power. It takes 12 VDC electricity from the battery bank and converts it to 120 VAC, 60 Hz electricity. The AC electricity is fed to the electric outlet for charging the electric bikes.

H. Equipment Ground

Non-current-carrying conductive materials such as the metal enclosure or case of all the components of the PV system need to be properly grounded (connected to earth) to reduce the risk of electric shock.

I. Electric Outlet

The electric outlet provides the receptacles for the charger of electric bikes. It is the only device installed outdoor. So it needs to be an outdoor electric outlet.

J. Safety Practices

The PV system can generate a high DC and AC voltage during the operation. Proper personal protection equipment (PPE) such as helmet, safety goggles, electric gloves, and footwear, etc.

should be used when the system is energized. Students will learn the importance of safety practices and operate in a safe condition [6].

2. Solar Charging Station # 2 – For electric motorcycles

Solar charging system #2 is constructed for charging electric motorcycle. The load of electric motorcycle in our project is estimated about 2500 Wh. In order to accommodate the load of electric motorcycle, some components with larger capacity are used in compare with charging station #1. Table 2 shows the component list of charging station #2. System wiring diagram for charging the electric motorcycles is demonstrated in Figure 4.

Table 2. Components - Solar charging station #2

Component	Qty	Specifications
PV modules	3	SolarWorld Sunmodule Plus SW 265 mono, 265W
GFPD	1	MidNite Solar MNDC-GFP63
DC Disconnect	1	Square D Disconnect HU361RB, 3P, 600V, 30A
DC circuit breaker	2	MidNite Solar MNEPV 150V DC, 30A
Charge controller	1	MidNite Solar The KID, Input voltage < 150V DC, Output voltage 12V~48V DC, Load current 30A, MPPT
Battery bank	4	Deka 8A27, 12V, 92Ah
DC circuit breaker	1	Xscorpion CB200A, 12V DC, 200A (for battery output)
Inverter	1	Xantrex PROWatt SW 2000, 1800W, Input 12V DC, Output 104V~127V AC @ 60Hz True Sine Wave
AC circuit breaker	1	Square D QO 20 Amp Single-Pole Circuit Breaker

A. PV Modules

The PV modules used in charging station # 2 are SolarWorld's Sunmodule Plus SW 265 mono. The output power of each PV module is rated 265 W. Three PV modules are connected in series that provides total maximum power output of 795 watts.

(a) The range of DC output voltage from PV modules

As demonstrated in station #1, similar calculation can be performed for station #2. From the Electrical Specifications of Sunmodule Plus SW 265 at STC:

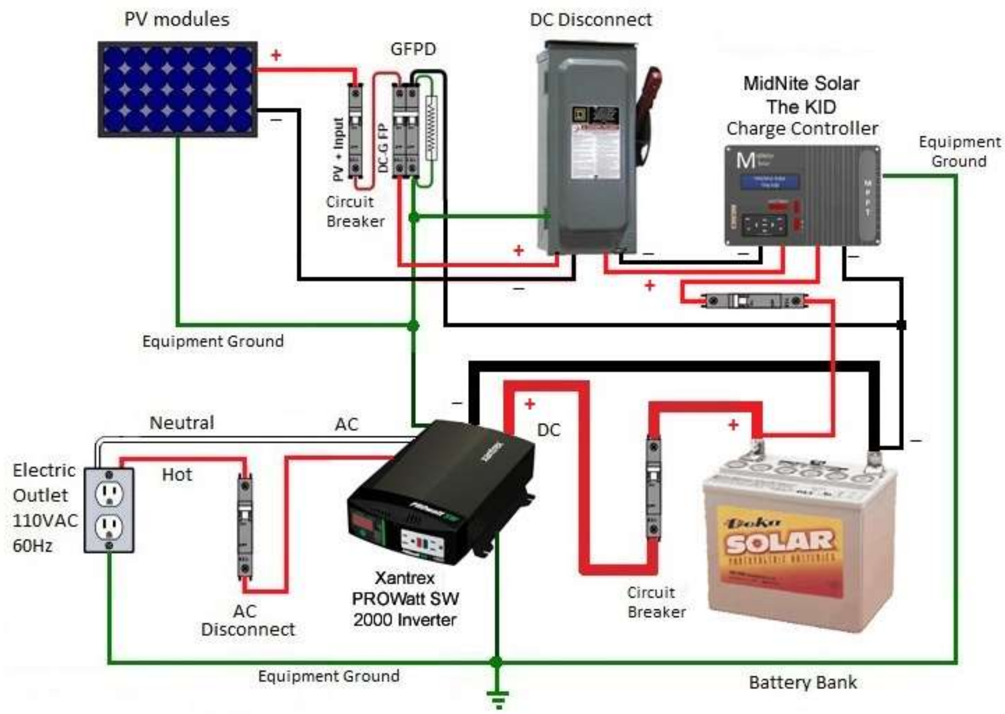

Figure 4. Wiring diagram of solar charging station # 2 for electric motorcycle

Open-circuit voltage V_{oc} = 39 V
Temperature coefficient of V_{oc} = – 0.30% / ºC

T_{min} = – 16 ºC – 25 ºC = – 41 ºC
$V_1 = V_{oc} \times \{ 1 + [(-41\ ºC) \times (-0.30\% / ºC)]\}$
$= 39 \times 1.123 = 43.8$ V

V_{max} = 43.8 V x 3 = 131.4 V < 150 V (The input voltage of The KID charge controller)

(b) The maximum output current from PV modules

Short-circuit current I_{sc} of Sunmodule Plus SW 265 = 9.31A
Temperature coefficient of I_{sc} = 0.04 % / ºC
ASHRAE 2% High Temperature = 34 ºC

T_{max} = 34 ºC – 25 ºC = 9 ºC
$I_{max} = I_1 = I_{sc} \times \{ 1 + [9\ ºC) \times (0.04\% / ºC)]\} = 9.31\ A \times 1.0036 = 9.34\ A$

B. Battery Bank

Four 12-volt Deka 8A27 AGM deep cycle solar batteries are connected in parallel as the battery bank. Each battery has the capacity of 92 Ah (Amp-hour). This battery bank provides 4416 watt-hour of energy storage (92 Ah x 12 V x 4 = 4416 Wh) which is capable of supplying sufficient energy for charging the electric motorcycle (2500 Wh load).

C. Inverter

Station #2 is equipped with Xantrex PROWatt SW 2000 inverter. It provides 1800W continuous power under normal condition. The output is 110 V @ 60 Hz true sine wave AC electricity.

IV. System Implementations and Test Phase

The installation of PV modules needs qualified professionals to complete the job. This project is collaborated with Energy and Sustainability Office of Weber State University. The office takes cares of the task of mounting the PV modules on the roof of the building above the lab. Subject to the cold weather in this area, the installation of PV modules is scheduled to be completed in February. Except for the PV modules, the rest of the components will be mounted on a movable cart. Besides doing the research, the cart is designed to be able to transport and demonstrate the system configurations for the class of Solar PV Systems which is taught in our department. The loads in this project are two electric bikes (230 Wh and 360 Wh respectively) and one electric motorcycle with 2500 Wh capacity.

Students use the platforms discussed above for their senior projects throughout the Spring semester 2015. The two charging stations are scheduled to complete and commissioning in March 2015 (Note: System prototype has been done and has been verified that the system is functional on February 13, 2015. A complete system installation will be finished followed by system data collection by the end of April). After the systems are running, data will be monitored and collected including the charging records and the measurement of voltage, current and power on both DC and AC sides. These data will be used for system performance analysis. The related test conditions such as temperature, irradiance, and the road tests of electric bikes and electric motorcycle will also be taken into account during the performance analysis. The results will be demonstrated in the conference.

V. Outcomes and Future Developments

The Solar Charging Stations project involved multidiscipline from electrical, electronics, and mechanical engineering technologies. For educational purpose, students benefit from this project by learning the theory and hands-on experience of a practical example of solar energy. Several students who are taking the course Solar PV Systems are doing their senior project with this topic. Students working on this project acquire an essential foundation towards how to design and build the solar PV systems for various applications. These students will also learn the code compliances required by National Electric Code (NEC) during the system design process.

More research will be performed based on this platform to develop a more efficient system for further applications. Students and faculty will be working on collecting data for system performance analysis through entire semester. In addition, this project is a pilot experiment for promoting the sustainability and reducing carbon footprint on campus. More charging stations are expected to be built on campus if this pilot project works successfully. This will promote the concept of sustainability on campus and encourage the school members including students, faculty and staff to use public transportation and electric vehicles that are charged from solar energy.

Reference

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