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Solar PV based charging station for electric vehicles (EV)

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Abstract. Electric Vehicles (EV) have been rapidly gaining attraction owing to their use of clean energy. The use of renewable energy sources, such as solar energy, is readily available to a wider community because of the falling costs of installing PV panels per watt. Saudi Arabia's Vision 2030, a sustainable vision for the future of Saudi Arabia focuses on new environmental and sustainable policies that are being developed to reduce carbon emissions, and to achieve that, there is a strong motivation to use clean energy and resources such as solar and wind energy. This paper presents the design of a stand-alone solar PV charging station for EV which includes additional features that allow the users to monitor the charging status of an EV via a smartphone application.

Introduction

Global warming is a fact, and the weather is becoming increasingly unpredictable as air is getting highly polluted. It is concerning that the world will address the climate situation too late, resulting in irreparable consequences. The dependence on non-renewable energy has been the major contributor of climate change since it results in the emission of greenhouse gasses [1,2].

Global electricity demand and cost is growing more rapidly as compared to renewables, driving a strong increase in the consumption of fossil fuels. According to EIA (Energy Information Administrations), the demand in energy keeps increasing higher than the global population, resulting in a rise in the average amount of power consumed for each person [3,4]. Another problem is the existing charging systems are overloading the grid, if several EV's are charged at the same time in the same place the power system may face excessive demands because the modern EV's consume more power equivalent to 10 homes [5,6].

The implementation of an off-grid power generation system can help resolve the problem of grid overloading as well as provide power in remote locations, where grid connectivity is an issue. Enhancing energy efficiency and lowering the grid energy demand are commonly regarded as the most valuable, quickest, least expensive, and safest way to fight climate change. EV charging reduces on-grid energy consumption by using solar panels and other renewable energy sources.

Shatnawi et al. presented a work of battery charging technologies and recent EV charging approaches and discussed the technical challenges in this field. The paper illustrated the importance of integrating renewable energy resources, particularly solar energy in the UAE and the Arab World, to provide clean and cost-effective public and private EV charging stations [7]. Another work conducted by Madhu et al. to design a smart charging station using Arduino and a range of sensors brings numerous advantages and functionalities. Through the integration of comprehensive sensors such as current, voltage, and temperature sensors, the charging station becomes capable of effectively monitoring and regulating the charging process, ensuring optimal battery conditions and charging safety [8].

A work done by Ballaji et al. investigated the simulation of an EV charging system. The system considered the EV battery as load and studied the effect of changing conditions in the environment due to varying irradiance throughout the day [9].

This paper presents the design of a stand-alone solar photovoltaic (PV) based charging station for an electric vehicle (EV) with multiple functions and fearures. It allows monitoring of the charging status through a mobile phone application with automated charging to prolong EV`s battery life. It also monitors solar irradiance and related weather parameters such as ambient temperature and relative humidity that may affect the overall performance of the system. The proposed system has efficient maintenance and troubleshooting characteristics as different hardware modules of the system can be isolated for safety purposes, which can be handled by hardware means or through the mobile application.

The proposed system

The block diagram of the proposed system is shown in Fig. 1 which illustrates the overall design of the EV charging station. The proposed system consists of solar panels, a battery bank (battery storage system), an EV charger, and a DC/AC inverter.

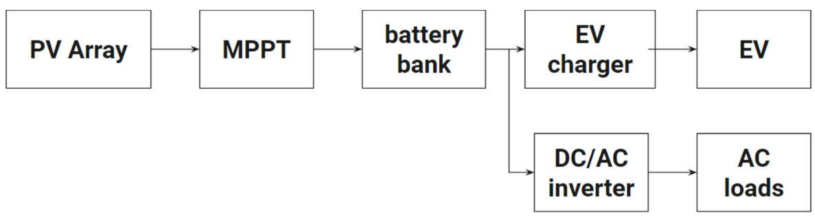

Figure 1: Overall Block Diagram of EV Charging Station System

The flow of the system shown in Fig. 1 above starts with the PV array connected to an MPPT charge controller that draws maximum power from the solar panels to be fed on to the battery bank. The battery bank acts as a solar energy storage system that provides a backup source of power on cloudy days or at night and to overcome the variation of power being produced by solar systems. It is necessary to include a battery bank especially when using a grid-independent (Off-grid) system. The system includes two types of loads, a DC load (EV battery) and an AC load (electrical appliances in the station). The EV charger consists of a DC-DC boost converter which operates as a step-up converter. Lastly, the system incorporates a DC/AC inverter that converts the DC output of the solar panels and battery bank to AC in order to power up appliances that are plugged in the station.

The EV charger is provisioned in the carport structure. The EV charger uses voltage and current sensors to measure the charging current and voltage in order to calculate the charging power. Additionally, the EV charger includes a battery monitoring system that displays to the user the charging status of the EV. The carport mounted solar panels provides an optimized fixed angle of 26 degrees for maximum sunlight collection.

System implementation

In order to design the system, it is essential to identify the loads first. The station is designed to charge an EV of 48V 7Ah and power up AC loads up to 150W minimum.

Storage batteries are needed because PV modules can generate power only when it is exposed to sunlight. They store the energy that is being generated by the PV modules during periods of high irradiance and make it available at night as well as during overcast periods. The batteries selected are two Lead-calcium batteries 12V 60Ah each, and they are connected in series as shown in Fig. 2. All the batteries used in a battery bank are the same type, same manufacturer, same age, and are maintained at equal temperature. Furthermore, the batteries have the same charge and

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discharge properties under these circumstances. If the above characteristics do not match, there is a high probability of huge energy loss within the battery bank.

Figure 2: Storage battery connection

MPPT charge controller is used to maximize the power transfer from the PV array to the battery bank. Next is a DC to AC inverter which is a 24V 3 kVA pure sine wave inverter as shown in Fig. 3.

Figure 3: (left) and MPPT

The EV charger is a DC to DC boost converter that will boost the voltage of the battery bank and match it to the voltage of the EV batteries and decrease the current to the rated charging current of the EV batteries. The design is developed using LM2588 5-A Flyback Regulator [10].

The method that was used for charging was the constant voltage (CV) charging method because it is the optimal method to get the most out of the batteries in terms of service life and capacity, as well as a reasonable recharge time and cost. A DC voltage between (50.1 V) and (50.4 V) is applied to the input terminals of the CV charge controller and the output terminals are connected to a (48V 7 Ah) lead acid battery to charge it.

To start wiring the components within the system, a wiring diagram and wire sizing are made in order to visualize the connection of the system components. The wiring diagram of the system is shown in Fig. 4.

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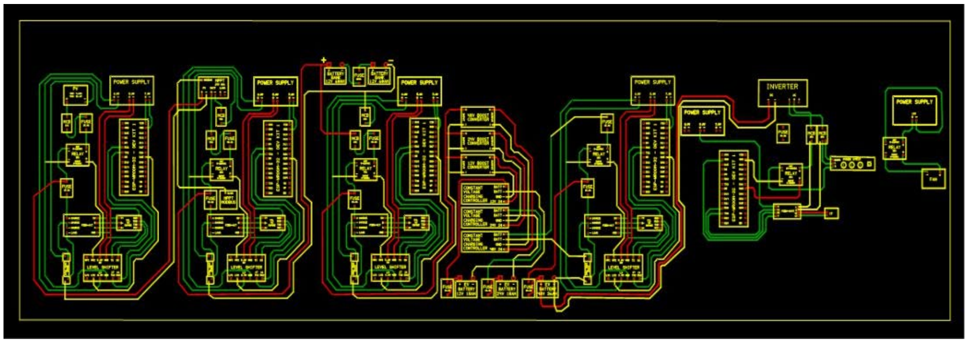

Figure 4: Wiring diagram

To display the charging status of the EV through a mobile application, a Raspberry Pi processor was used as a central server to record all the sensor readings and display the on the mobile platform to be accessed at any given time. The Raspberry Pi together with a home automation software as a server can also send data to the cloud which enables the user to view all sensor readings and to control the different parameters in the system even outside the local area network as shown in Fig. 5.

Figure 5: Mobile application user interface

Another set of parameters that was monitored in the system was the sensor outputs. The sensors include a light sensor, humidity and temperature sensor, pressure sensor, and an accelerometer sensor as shown in Fig. 6. The light sensor used is a BH1750 that measures the illuminance level of the light going to the solar panels. The humidity and temperature sensor used is DHT22 that will measure the humidity and temperature to be displayed to the user. In addition, a barometric pressure sensor BMP280 was used that detects the atmospheric pressure for weather forecasting. Lastly, an accelerometer & gyroscope (3-axis) sensor was used to measure the angle at which the solar panels will be adjusted to for maximum power.

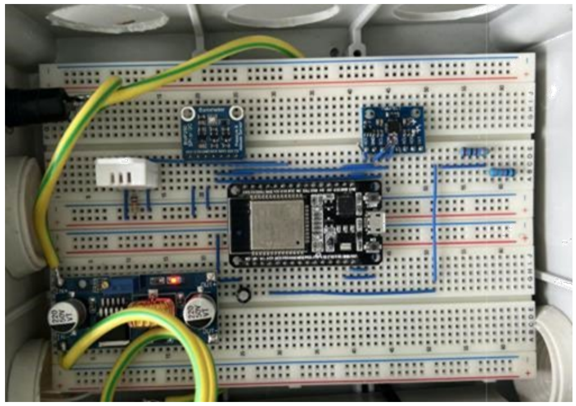

Figure 6: Sensors Circuit

Finally, the structure of the charging station and electrical enclosure which is designed using Solid Works software and a ventilation system is added to maintain the ideal working temperature for the electronic components. Dimensions are 0.81 m in height, 1.76 m in width, and 0.3 m depth. All components were placed within a factory fabricated electrical enclosure as in Fig. 7. After that, the structure of the charging station was made whose dimensions are 2.47 m in height, 2 m in width, and 1.5 m depth, as shown in Fig. 8. The solar panels were placed at an angle of 26 degrees.

Figure 7: Electrical Enclosure

Figure 8: Charging Station & Carport

Testing and Results

The angle on which the PVs are mounted is a critical consideration on any solar power system installation. After positioning the panels at different angles during months of March and April, different output ratings were obtained as shown in Table 1. It was found that the optimum tilt angle for our location is 26 degrees to pull out every single watt hour out of the system.

Table 1: Test result of solar panels

Angle	Voltage (V)	Current (A)
22°	21.5	3.64
23°	21.5	3.67
24°	21.5	3.72
25°	21.5	3.77
26°	21.5	3.81

For the boost converter, all of the specifications stated previously have been met. The output voltage across the output capacitor is 54 V with no load and 50 V with load connected. To get the efficiency, the test was performed using 4 wire measurement method to get accurate data. All DC measurements were taken using a multimeter and electronic DC load tester as well as an infrared thermometer was used to get the temperature output of the circuit shown in Fig. 9. The below tables show the result of the boost converter when testing with a fan and without a fan.

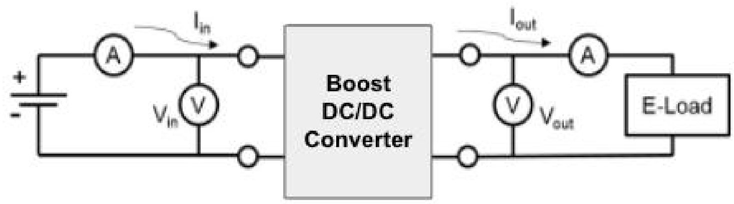

Figure 9: Testing converter

The results of the boost converter testing with a fan and without a fan were recorded as shown in Table 2 and Table 3 which show only the minimum and maximum readings recorded.

Table 2: Results of testing converter with fan

Vin(V)	In (A)	Pin (W)	Temp (C)	Vout (V)	Iout (A)	Iset (A)	Pout(W)	EFF %
24	0.37	8.88	25.4	50.4	0.15	0.15	7.56	85.13
24	1.45	34.8	24.4	50.4	0.65	0.65	32.76	94.13

Table 3: Results of testing converter without fan

Vin(V)	In (A)	Pin (W)	Temp (C)	Vout (V)	Iout (A)	Iset (A)	Pout(W)	EFF %
24	0.24	5.76	25.5	50.3	0.1	0.1	5.03	87.32
24	2.1	50.4	27.8	49.6	1	1	49.6	98.41

The converter with fan reached a maximum efficiency of 94.13%, and minimum of 85.13%. On the other hand, the converter without fan reached the maximum efficiency of 100.98%, and minimum of 100.87%. However, the converter without a fan is not efficient, it will stop working at some point as temperature increases the output voltage will decrease, and will not be able to give the desired output as well as the ICs will get damaged. The result shows the addition of a small fan played a very important role as the heat sink alone gets hot during operation and this

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can damage the ICs without a fan. The efficiency vs output current graph was generated as shown in Fig. 10 with average efficiency of converter of 92.47%.

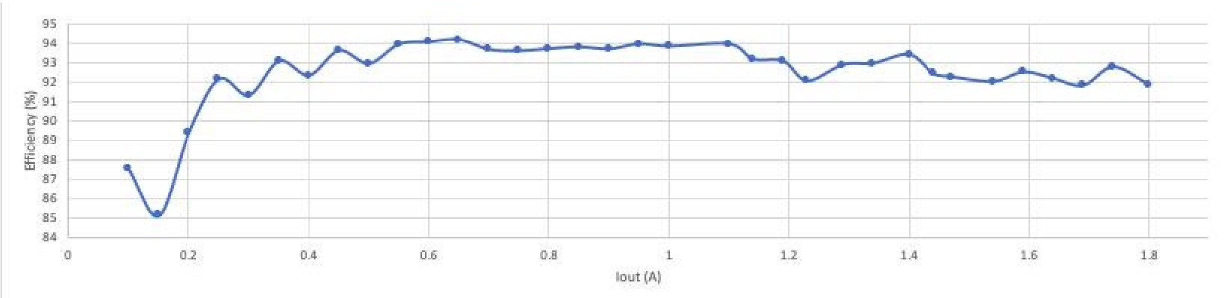

Figure 10: Efficiency Vs Output Current

The last part of the system is hardware and software integration. The circuits for all the parameters that should be monitored in our system were completed. Later, the sensors and communication modules were programmed to display the information to the user wirelessly.

Testing the battery status of the EV battery when charged, gave us accurate voltage readings for the battery used which was around 50.1 V as illustrated in Fig. 11 (a).

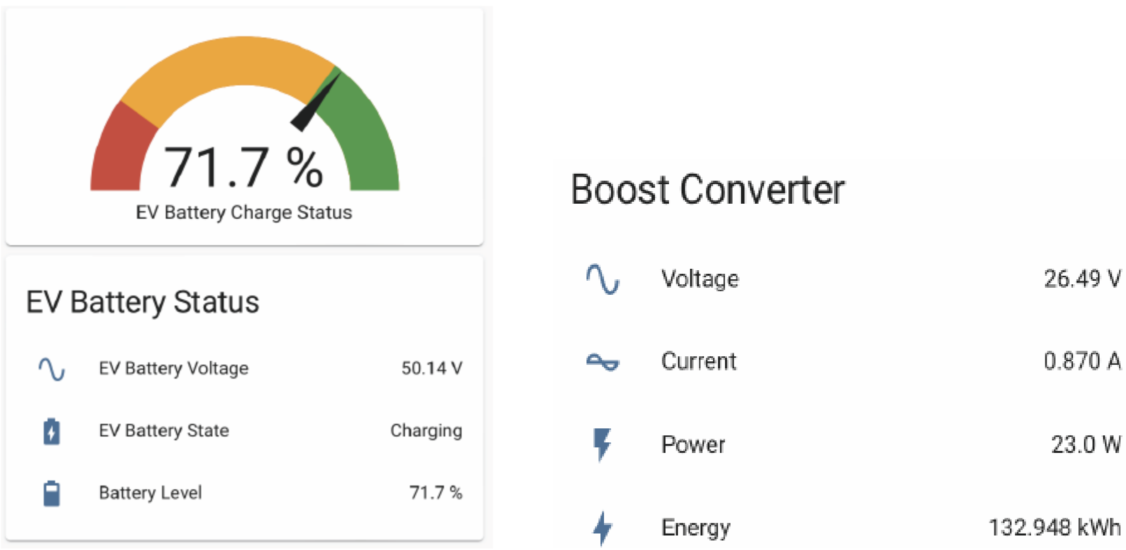

Figure 11: (a) EV Battery Status, (b) Boost Converter Energy Monitoring

The boost converter readings display the input coming from the battery bank entering the boost converter. Theoretically, the voltage of the boost converter should be 24 V. However, considering that 12 V batteries can go as high as 13.2 V when fully charged, when two 13.2 V batteries are connected in series as in our case it will give us a maximum output of 26.4 V, which can be observed in Fig. 11 (b) above.

Summary

The project involved building an off-grid solar based charging station for electric vehicles by fabricated the whole system design of the charging station as well as building the user interface of mobile application. Some important features that we included in our project is the monitoring of the charging status of the EV battery as well as the power consumption within the system. It also allows control of components and displays readings of the illuminance levels, temperature and humidity, etc.

For future work, the team will look to extend the current charging time of project which is around 3.7 hours to charge an EV to include fast charging methods for the battery to charge in a shorter period of time.

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