MATLAB Simulation of an Electric Vehicle Charging Station Supplied by Photovoltaic Energy


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Abstract
Due to the important advantages of electric vehicles that beat conventional vehicles in terms of high efficiency and being environmentally friendly, Electric vehicle production and utilization are advancing rapidly. The integration of renewable energy sources such as photovoltaic energy and energy storage system plays a significant role to overcome the stress on the grid. However, the fluctuation of the output generated by PV can process by using batteries to meet the energy demand and improve the sustainability of the charging station. This paper introduces a MATLAB Simulation of a Standalone Electric Vehicle Charging Station Supplied by Photovoltaic Energy. A system has been proposed that consists of a PV array with a boost converter, an energy storage system buck controller to regulate the charging process in the electric vehicle, bidirectional controller to keep the stability of DC bus voltage. The results show that the charging process of the electric vehicle battery is exactly steady for all the PV variations. In addition, the charging/discharging of the energy storage battery responds perfectly to store and recover for PV energy variations.

Keywords: Standalone; electric vehicle; charging station; Photovoltaic; PI; MPPT; battery

1 INTRODUCTION
Greenhouse gases have a great effect on our planet and one of the ways to reduce it is by replacing the conventional internal combustion engine vehicles with electrical vehicles, nowadays all countries and companies around the globe are moving toward changing to electrical vehicles, governments are offering huge financial support, and companies are setting a deadline for the full transfer from conventional vehicles to electrical vehicles. Electrical vehicles have zero emissions and almost no sound which makes them environment friendly. [1]

To change from conventional vehicles to electrical vehicles means an increase in the electricity demand, and to overcome this problem we need to utilize renewable energy sources because they can be installed anywhere. By utilization of renewable energy sources like solar and wind…etc. we also get less usage of fossil fuel which means less greenhouse gas emissions. It can be installed at home or in the parking of a company where the cars are parked for a long period. [2]

As for our proposed system, we chose to go with Photovoltaic because of the weather nature in Saudi Arabia which is sunny most of the year, and the PV panels can be used in small regions like houses. And using a boost converter to supply the station from the PV panels, a bidirectional converter to charge and discharge the storage batteries, and a buck converter to charge the electrical vehicle. [3]

Nowadays, all countries moving toward reducing CO2 emissions to generate electricity. The high CO2 emissions are primarily due to the coal-based energy structure. Most people are interested now to convert their cars from petroleum cars to an EV. To solve this situation for generating electricity in charging stations, generate electrical by using PV cells which is a part of renewable energy. Many EVs increase the demand in power grids, which will harm the environment and the reliable operation of power systems.[4]

A charging station is connected upstream directly to the DC bus. It could have one or more charging cables equipped with a connector that is similar to a gas station nozzle and is used in the same way for feeding the car by electricity: it simply connects to the EVs to charge the lithium-ion battery. The station has lights indication to obtain the mode of station panel for charging or discharging operation for green or red color respectively. It's can have more information like an electronic payment system, card-controlled access system, energy meter, and Internet access.[5]

For safety, all charging stations are built-in with an earth fault detector to reduce the hazard. End users are never capable of dangerous voltages or currents. Furthermore, connector pins in a cable are not energized the EV until the pin is inserted properly in the EV charging socket and communication has been established between the vehicle and the charging station. In addition, the connector is completely isolated from the weather. In conclusion, a mechanical lock (latch) prevents accidental disconnection resulting from a pull hard on the cable.[6]

Now using electric vehicles (EV) instead of the vehicle that depend on internal combustion engines (ICE) increasing day by day, due to Global warming and the threat of vanishing fossil fuels in the next decades. But at the same time, extra loads are going to be applied to the grid system. So renewable energy sources especially Photovoltaic (PV) energy, which is abundantly available during office timing, is a preferable energy source for Electric Vehicle (EV) charging [7].

The idea that the EV is an environmentally friendly vehicle may not be accepted if charging stations rely primarily on grid power, which is typically generated from non-environmentally friendly sources such as fossil fuels. [8]

In this paper, will use a PV array to would be the main energy
source of the off-grid charging station. PV array is made up of solar cells, and by the series and parallel of combination can get a desired voltage and current and therefore the power needed to the loads. [9]

Solar PV has many advantages that make them at the forefront of renewable sources. PV panels provide clean energy. No harmful greenhouse gas emissions during electricity generation with PV panels there is thus solar PV is environmentally friendly. Easy to install, Solar panels can easily be installed on your place required and have no mechanically moving parts, except in cases of sun-tracking mechanical bases. Low Maintenance Costs, generally Solar energy systems don’t require a lot of maintenance. The basic and important component of the maintenance process is to clean the solar panels periodically to ensure get the maximum efficiency. Technology Development, Technology in the solar power industry is rapidly constantly advancing and improvements will increase in the future and make it more economical profit. [10]

Still the challenge the output of solar energy dependent on the local weather, variability can occur on short timescales where the times of generation may not necessarily correspond to that of the demand so energy storage systems (ESS) like batteries are needed to supply the loads when PV not available during night or poor output PV due to some weather conditions as clouds. [11]

In this paper simulation and performance improvement of an electric vehicle charging station and replacement from previous decently directly from the grid that causes more pollution and load and instead by built system standalone by using supply from renewable energy.

The paper structure is as follows: Section 2 proposed system structure, analysis and design of the charging station, and the charging converters modeling and design. The proposed control system is shown in Section 3. The simulation experimental results have been discussed in Section 4. Finally, Section 5 comes with the conclusions.

2. PROPOSED SYSTEM STRUCTURE.

The structure of the proposed electric vehicle charging station system is shown in Figure 1. The electric vehicle charging station system is an off-grid type that is powered by renewable energy and chooses solar energy that will be the main source. It is captured by a PV array that generates electrical energy for the electric vehicle charging station by falling radiation from the sun. However, the generated energy is unstable. Due to varying of output power from energy intermittence solar cells and environmental changes we install Energy Storage System by using batteries to store power in peak production from PV and later when needed. The output terminals of the PV are connected to a boost converter to step up the voltage to the DC bus limit and help in utilizing the maximum power point tracking (MPPT) condition of the PV panel. Buck converter connecting directly to DC bus to step down the voltage to charging EV battery (lithium-ion). In addition, the other converter namely bidirectional converters used in two ways, the first way using the converter as a boost converter to step up the voltage to charge the ESS battery (Lead-acid), and the second way using the converter as a boost converter to step up the DC voltage to energized the bus in regulating the DC bus voltage against the variations of the EV load and insolation level.

![Fig. 1: EV Charging Station Based on Stand Alone PV Power Supply](image1)

2.1 PV array

In our paper with an off-grid charging station, the main energy source is a PV array. Multiple modules can be wired together in series or parallel to deliver the voltage and current levels required to cover the load. The PV array is made up of solar cells, A typical solar cell has two layers of silicon, which is n-type at the top and p-type at the bottom. The strategy for modeling a PV module is similar to that of modeling a PV cell. It employs the same PV cell model. A current source (ISC), a diode (D), and a series resistance (Rs). comprise the model. The effect of parallel resistance (Rp) is very small in a single module, so it is not included in the model. It also includes temperature effects on the short-circuit current (Isc) and reverse saturation current of the diode to make a better model (Io). To achieve the best I-V curve match, it employs a single diode with the diode ideality factor (n) set. The equivalent circuit of a solar cell is depicted in Figure (2). [12]

![Fig 2: Equivalent circuit of solar cell](image2)

2.2 Boost Converter

A boost converter deal with DC-DC convertor that do increase the voltage from supply to the load. The boost convertor is classify switched-mode power supply which contain: semiconductor, transistor, diode and element to storage the energy such as inductor or capacitor or both.
2.3 Buck Converter

A buck converter is a type of DC-DC converter, it works to decrease voltage from supply to load. It is containing (a diode, transistor capacitor, and inductor) [14]. Figure (4) show the buck converter diagram.

2.4 Bidirectional converter

The Bidirectional DC-DC Converter Is a device that increases or decreases DC voltage in the two sides of the converter to the other, the increase or decrease depends on a controller attached and gate signal generator, its works as a boost converter in 1st mode and as a buck converter in the 2nd mode, in the buck mode it is used to lower the bus voltage to meet the batteries voltage to be charged, and in the boost mode, it used to raise the voltage and back to the bus. Bidirectional DC-DC converter is useful for switching between energy storage such as in electric vehicles. A PI controller is added to regulate the battery current during charge and discharge operations, and the reference value of the current is positive for charging operations, and negative value for discharging operations [15]. Figure (5) shows a Bidirectional converter diagram.

2.5 Energy storage system (ESS)

The ESS is used to store the excess energy of the PV array. Hence, the stored energy is utilized to supply the load during periods where the generated energy is not sufficient to supply the charging station.

In this system we choose lead acid based on the features listed in the following Table (1) [16].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Lead acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Density</td>
<td>30-50 W.h / kg</td>
</tr>
<tr>
<td>Charging/Discharging Efficiency</td>
<td>45-95 %</td>
</tr>
<tr>
<td>Specific Power</td>
<td>180 W / kg</td>
</tr>
<tr>
<td>Cycle Durability</td>
<td>350 Cycles</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>2.1 V</td>
</tr>
<tr>
<td>Life Time</td>
<td>15 Y</td>
</tr>
</tbody>
</table>

2.6 The EV battery

The EV charging station power to reduce the power consumption from the utility grid by charging directly from the energy produced by PV, and in the event of production stops, it is used ESS in EV use lithium-ion battery based on the feature listed in the following table (2) [17].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>lithium-ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Density</td>
<td>100-265 W.h / kg</td>
</tr>
<tr>
<td>Charging/Discharging Efficiency</td>
<td>80-93 %</td>
</tr>
<tr>
<td>Specific Power</td>
<td>250-350 W / kg</td>
</tr>
<tr>
<td>Cycle Durability</td>
<td>500-1,200 Cycles</td>
</tr>
<tr>
<td>Cell Voltage</td>
<td>3.2 V</td>
</tr>
<tr>
<td>Life Time</td>
<td>3-5 Y</td>
</tr>
</tbody>
</table>

3. CONTROL SYSTEM

Using Control techniques of the proposed system is very important due to the nature of the intermittent power generations of PV that can provide significant changes of the output during a day and maintain keep the almost constant voltage in DC bus voltage. So, to ensure get high performance of the proposed system will add controls in some main parts of the proposed system, in the boost used maximum power point (MPPT) to manage the fluctuations in the PV. moreover, the buck controller to regulates the charging process in the electric vehicle, and the bidirectional controller keeps the stability of DC bus voltage and regulates the process of charging/discharging the battery[8]. figure (6) shows the proposed system controllers that are used and in this chapter, we write a brief about each type.
Fig 6: The proposed system controllers: (a) MPPT controller, (b) EV charge controller, and (c) storage battery converter controller.

3.1 MPPT control

The MPPT controller is important for the PV module to track the fall radiation to reach the maximum power. The common technique is perturb and observe (P&O). This technique works by modifying the voltage by a little quantity from the array and measures power in this situation. If the power increases, the action changes the direction until the power stops increasing. It is referred to as the hill-climbing method because it depends on the height of the power-voltage curve below the MPPT, and the dip above that point. P&O method is the popular use in tracking MPPT because it is easy to execute. This method gives high efficiency, provided that the system is adapted to the method. Figure (7) shows the flow chart for P&O algorithm method. [18].

Fig 7: Flow chart of Perturb and Observe Algorithm

3.2 Bidirectional converter control

PI stands for Proportional, Integral. If you need for something to be constant like in our case the current, the way is to use a control loop feedback to ensure the output is what you want, you will set a constant value for the feedback and by this value, the output will be regulated till it meets the wanted value. A PI controller is added to regulate the battery current during charge and discharge operations, and the reference value of the current is positive for charging operations, and negative value for discharging operations [19]. Figure (8) shows a block diagram of the PI controller.

3.3 Buck Converter Control

The mission of the Buck Converter Controller is to control the charging process of the EV. In our system, the Constant Current/Constant Voltage (CC/CV) technique is utilized; because this method is an effective way to charge lithium batteries. Includes two stages; in the first stage, a constant current path flows through the battery until the voltage in battery reaches a amount voltage. We need to ensure that the charging current should be lower than the maximum charging current that the battery can accept. In the second stage, the voltage is constant and the current steps down until the battery reaches maximum charge. When the battery is fully charged, this step will be stopped.

A simple Proportion and Integral (PI) controller is suitable for this technique. The proportion and integral gains of the PI controller are satisfying using the Ziegler–Nichols method. The experimental Ziegler–Nichols tuning algorithm can be expressed as the following. First, in proportional part the value will be very low proportional gain. Although, ignore the integral part from the controller by adjusted the Integral gain (KI) to zero. The proportional gain (KP) is then steps up until continuous oscillations in the output signal are observed. After each gain increases, you should need to make a disturbance changing the set point to see if the loop fluctuate as represented in figure (6. b) [20].

4 RESULT AND DISCUSSION

The simulation parameters are listed in Table [3].

<table>
<thead>
<tr>
<th>PV</th>
<th>120W, 21.6V, 7.5A</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC bus voltage</td>
<td>25V</td>
</tr>
<tr>
<td>Charging converter Inductor</td>
<td>2mH</td>
</tr>
<tr>
<td>Boost Capacitor and Inductor</td>
<td>3.3mF, 5mH</td>
</tr>
<tr>
<td>EV &amp; storage battery voltage</td>
<td>15V, 12V</td>
</tr>
</tbody>
</table>

The proposed system is simulated using Matlab/Simulink toolbox as shown in Fig. 9.
Figure 9: The proposed system model using Matlab

Figure 10: (a) PV insolation level, (b) PV voltage, (c) PV current, and (d) DC bus voltage

Figure 11a represents the state of charge of the lead-acid battery bank. In the first second, the insolation is more than 90%. Hence, the generated power from PV panels is sufficient to charge the EV battery and store the remaining power in the lead-acid battery bank. However, the insolation at the second two is less than 30% which is not sufficient to supply the power to EV battery. Therefore, the storage battery in lead-acid will be discharged to compensate for fall down in PV power. Furthermore, the charging and discharging sequences follow and compensate for the insolation scale. Figure 11b shows the voltage of the lead-acid battery bank. In addition, the current of the battery follows its reference value from DC bus voltage controller, as represented in Figure 11c.

Figure 12a represents the state of charge of the EV battery. It’s continuous charging while power generated

The state of charge of the EV battery is shown in Figure 12a, it’s continuous charging while power generated power PV cell at full irradiance or form storage power at lead acid battery at low power period. Figure 12b represent the voltage of EV battery. It is continuously charging. The EV current follows the reference current from by the charge controller, as shown in Figure 12c.

Figure 13a represents the PV power, (b) EV charging power (c) lead-acid battery power

The state of charge of the EV battery is shown in Figure 12a, it’s continuous charging while power generated power PV cell at full irradiance or form storage power at lead acid battery at low power period. Figure 12b represent the voltage of EV battery. It is continuously charging. The EV current follows the reference current from by the charge controller, as shown in Figure 12c.
Figures 13 a,b and c show the PV power, the EV charging power, and the lead-acid battery power respectively. In the first second, the irradiation is more than 90%. Hence, the generated power from PV panels is sufficient to charge the EV battery and store the remaining power in the lead-acid battery bank. However, the insolation at the second number two is less than 30% which is not enough to supply the energy to the EV. Therefore, the storage battery in the lead-acid battery bank discharges to compensate for the drop in solar energy. In addition, the charging and discharging sequences follow and compensate for the insolation scale. Its voltage steps up with charging and steps down with discharging. The EV power is steady state at all cases, represented in Figure 13b.

5. CONCLUSION
A stand alone Electrical Vehicle charging station based on a Photovoltaic energy source is proposed. The system contains a PV panels, boost converter, buck converter, bidirectional converter, ESS batteries, and the Electrical Vehicle batteries. The control system is composition of four controllers, MPPT, EV charger, and the storage converter controller and A PI controller is added to regulate the battery current during charge and discharge operations, and the reference value of the current is positive for charging operations, and negative value for discharging operations. The system is built separately in MATLAB Simulink as every converter is been built and tested alone, and we got an excellent outcome for every single converter, the second we aggregate the components to a whole system the results went very far from accepted, we changed and calculated the capacitors, inductors, and resistors all over again till we got the desired output shown in this paper.

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REFERENCES
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