Renewable energy powered DC charging system for electric vehicle

P Jyothi, P Saketh, Ch Vignesh and V S Kirthika Devi

Department of Electrical and Electronics Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India.

E-mail: jyothi0282@gmail.com, saketh.potti@gmail.com, ch.vigneshyuv@gmail.com, s_kirthika@blr.amrita.edu

Abstract. Recently, Electric Vehicles (EV) have pulled in a great deal of consideration attributable to the utilization of clean energy. However, the challenge is that developing number of EVs implies request in charging is tremendous which will aggregate the power grid load. In this paper, a renewable based DC charging system is introduced which integrates power from sun, wind and battery energy storage system (BESS) to provide an uninterruptible power supply for the load. Variable irradiance and wind speeds are considered for this study. Incremental conductance method with boost converter and hill climb method with buck converter are implemented in solar and wind respectively to maximize the system efficiency. Three phase uncontrolled diode bridge rectifier is used to convert the AC power output of wind to DC power. Surplus amount of power generated is preserved in the battery storage system which is retrieved in the absence of renewable sources. A bidirectional converter is designed to allow the forward and reverse flow of power. A controller is designed using PID to limit the discharge current of the storage system. Modelling and validation of proposed system is done using MATLAB Simulink platform.

Keywords: EV, Solar, Wind Energy Conversion System (WECS), BESS

1. Introduction
Increasing pollution and rapid depletion of fossil fuels (petroleum, diesel, etc.) has paved a way for the entry of EVs in the market. A huge advancement in lithium-ion battery has impelled the improvement of EVs. But charging of EVs through conventional energy sources will violate the purpose of pollution free transportation. To take advantage of EVs, power generated from renewable sources like solar, wind and hydro should be used to for charging. Unfortunately, renewable sources are erratic and uncontrollable which makes it incapable of supplying continuous loads. Therefore, it is preferred to integrate more than one form of energy to make the system more reliable and productive. Usually, solar panels and wind turbines are integrated for better performance due to their easier implementation irrespective of location and space availability and their compactness and simplicity (unlike other renewable sources like geothermal, hydro, biomass or tidal energy systems).
To get the proper power and voltage levels from this integrated system power electronic interface is mandatory. In order to model the solar based power generation, ideal circuit model of solar cell, mathematical model of PV panel and its characteristics are understood [12]. The power and current curves of a solar panel with respect to voltage are non-linear in nature. The nonlinear nature of solar panel shows the requirement for the use of MPPT algorithm. The maximum power occurs at different voltage values for changing irradiance. Some of the popular MPPT algorithms which are used for extracting maximum power output from converters employed for solar photovoltaic system are P&O, Incremental Conductance (IC), MPPT using fuzzy logic, etc., [1,11]. Among all the MPPT techniques IC method gives better results under rapidly varying solar radiation. This algorithm uses a search strategy that adjusts converter duty ratio so that voltage of solar panel varies and hunts for the condition at which maximum power point occurs and searching will end when desired point is reached. [2,10].

Renewable based charging station can be of two types one is grid connected system and the other is standalone system. In case of stand alone system, an additional storage system is very essential for providing continuous power supply. A bidirectional converter and has to be designed for the BESS which stores the excess energy produced from renewables in the day time and to discharge during the night time to charge EVs. Current controller is required to control the duty ratio of the switch in the bidirectional converter circuit. Battery current can be controlled using Proportional-Integral-Derivative (PID) controller to avoid overheating [3,4]. Charge and discharge behaviour of a battery is nonlinear and a thorough knowledge of its characteristics is required for modelling of battery as they have direct influence on EV performance. When SOC of the battery is less than 20% charging happens at high currents and voltage gradually increases. When the threshold value of voltage is met, battery current is limited and the voltage is almost constant [5].

Like solar cells, energy from wind turbines can also be converted to usable power. In many cases solar and wind are connected with traditional power to create a hybrid system. The variable speed operation of the WECS is essential for current scenario. Horizontal axis wind turbine along with permanent magnet synchronous generator (PMSG) and uncontrolled diode bridge rectifier is used in this study [6]. Output power of PMSG, DC bus voltage and the rotor speed are related in such a way that the initial value of rotor speed. And the DC bus voltage should be high to get maximum power for high wind speeds [7].

The control of wind turbines generally aims at maximum power point tracking (MPPT) by adjusting the electrical generator speed. Popular MPPT methods include Tip-speed ratio (TSR), P&O method, power signal feedback, Fuzzy Logic Control, etc. When TSR, P&O and fuzzy control methods are analyzed on three turbines of different sizes and ratings i.e. small, medium and large turbines it is observed P&O algorithm gives good results for all types of turbines [8].
2. System Description

The main aim of this work is to provide DC power for the fast charging of electric vehicles because oil-based transportation will not support world in decades ahead. The proposed system comprises of a PV panel and a wind energy conservation system. The power output generated from the PV panel is in the form of DC and a boost converter is used to increase the voltage which is provided with IC MPPT algorithm which optimizes the circuit. WECS generates AC output which will be converted to DC using an AC-DC converter (Rectifier), followed by a DC-DC converter to get the required output voltage. BESS is added to the proposed system which helps to give steady power output from the system. There are three modes in which BESS should be able to operate. Controller decides the mode of operation of BESS.

Mode 1: No load
   BESS should work in charge mode
Mode 2: No power supply
   BESS should operate in discharge mode
Mode 3: Both Load and power supply are available
   BESS is isolated

3. Simulation model

In this section, the block diagram shown in the figure 1 is implemented using MATLAB Simulink software. Figure 2 shows the complete MATLAB model of proposed methodology. Solar PV, WECS and battery storage system are designed using Sim power systems toolbox.

3.1. Solar and wind integrated system

Solar and wind systems are designed for a power rating of 100kW each. DC power is generated from this integrated system using power electronic converters and is fed to the EV. By considering the ratings of the system IGBT switches are used as they are best suited for medium power applications. Both solar and wind power systems are designed for same output voltages and are connected in parallel. Design parameters of complete MATLAB model are mentioned in Table.1

Figure 1. Block diagram of battery charging system.
Figure 2. MATLAB model of the proposed system.

Table 1. Specifications of system components.

| Simulation block         | Parameter specification                                                                 |
|--------------------------|-----------------------------------------------------------------------------------------|
| Solar PV subsystem       | Power rating =100kW, Voltage=273.5V, Current=368.28A                                   |
| Boost Converter          | $V_{in} = 273.5V, V_{out} = 500V, L= 4.5 \times 10^{-3} \text{ H}, C= 6.04 \times 10^{-3} \text{ F}, f=5\text{kHz}, \text{current ripple} =1.5\%, \text{voltage ripple} =0.6\%$ |
| Bidirectional converter in solar | $V_L=273.5V, V_H=500V, L=3.38\times10^{-5}\text{ H}, C_H=6\times10^{-3}\text{ F}, C_L=6.7 \times 10^{-3} \text{ F}, f=5\text{kHz}, \frac{\Delta V_H}{V_H} = 0.6\%, \frac{\Delta V_L}{V_L} = 1\%$ |
| Wind Turbine and generator | Power rating=100kw, rated wind speed=12m/sec, DC link voltage=1100V, DC link capacitor=5000μF, rated rotor speed=1000rpm, Stator Phase Resistance=2.875Ω, Inertia=0.8e-3Kgm$^2$, Torque constant=12Nm/Apeak, Pole pairs=8 |
| Buck Converter           | $V_{in}=1100V, V_{out}=500V, L=0.06 \text{ H}, C=4.545\times10^{-6}\text{ F}, f=5\text{kHz}, \frac{\Delta V_{out}}{V_{out}} = 1\%, \frac{\Delta I_L}{I_L} = 1\%$ |
| Bidirectional converter in wind | $V_L=500V, V_H=1100V, L=1.6216\times10^{-4}\text{ H}, C_H = 6.16\times10^{-4}\text{ F}, C_L=1.056\times10^{-3}\text{ F}, f=5\text{kHz}, \frac{\Delta V_H}{V_H} = 1\%, \frac{\Delta V_L}{V_L} = 1.5\%$ |
| EV Battery               | BatteryEnergy=100kWh, voltage=500V, Capacity=200Ah                                     |
3.2. Solar PV subsystem model

The system is designed in two stages (PV and boost converter) along with BESS and MPPT controller. The simulation model of solar subsystem is shown in figure 3. Suitable solar module is chosen in the PV array (MATLAB block) and the number of modules in series and parallel are considered to meet the required power rating. Irradiance and temperature are taken as inputs to the PV array.

![Figure 3. MATLAB model of Solar subsystem.](image)

BESS include a battery, bidirectional converter and a controller to provide gate pulses for switches. Simulation model of BESS is shown in figure 4. Battery in BESS charges when switch S2 is ON and discharges when S1 is ON. A PID controller is implemented to limit the discharge current of the battery.

![Figure 4. BESS for solar.](image)

Boost converter is utilized to step up the output voltage of solar. And it is controlled using MPPT controller. The circuit representation of the boost converter is shown in figure 5. Designing
parameters of the converter are calculated using formulas given in equations 1, 2 and 3 where $V_{in}$ is the input voltage. $V_{out}$ is the output voltage, $L$, $C$ and $F$ are the inductance, capacitance and switching frequency respectively.

$$V_{out} = \frac{V_{in}}{1-D}$$  \hspace{1cm} (1)

$$L = \frac{V_{in} + D}{\Delta I/L + F}$$  \hspace{1cm} (2)

$$C = \frac{D}{R \times \frac{\Delta V_{out}}{V_{out}}}$$  \hspace{1cm} (3)

**Figure 5.** Circuit diagram of Boost converter.

Gate pulses for the switch (S) are provided by the MPPT controller. Here, IC algorithm is adopted which compares the incremental conductance with the instantaneous conductance and uses the maxima theorem in calculus to adjust the duty ratio for tracking the point where maximum power occurs. Voltage and current are given as inputs for the controller. equations 4 to 6 represent set of rules based on which MPP is found.

$$\frac{dP}{dV} = 0 \text{ at } P_{max} \text{ where } P = V \times I$$  \hspace{1cm} (4)

$$\frac{dP}{dV} = V \frac{dI}{dV} + I = 0$$  \hspace{1cm} (5)

$$\frac{dI}{dV} = -\frac{I}{V}$$  \hspace{1cm} (6)

The derivative of power with respect to voltage is zero at the point where the maximum power is produced, the slope of the curve is greater than zero on left side of the MPP and slope of the power vs voltage curve on right side of MPP is less than zero. Based on the calculated value of slope the voltage is either increased or decreased. Figure 6 shows the PV curve of a solar panel.

**Figure 6.** Power Vs Voltage curve of PV panel.

### 3.3. Wind energy conversion system

In this section, WECS is discussed, which is designed in three stages along with BESS and MPPT. The simulation model of the WECS is shown in figure 7. In WECS wind turbines take wind speed, pitch angle and generator speed as inputs and convert kinetic energy of wind into mechanical power.
The torque output of wind turbine is given to PMSG which converts mechanical power to electrical power. Three phase AC power is generated by PMSG but the solar power output is in the form of DC, to couple both solar and wind, rectifier is introduced in WECS.

Circuit representation of bidirectional converter and its controller in WECS are shown in figure 8. Switch $S_1$ gets activated when the load is disconnected during this condition rectifier output is connected to the BESS and if wind power output is zero $S_2$ is activated, during this condition BESS is connected to load.

A buck converter is designed to reduce the DC link voltage. High value of inductor is to have less ripples in the output current. The circuit representation of buck converter is given in the figure 9. And the designing can be done using formulas given in equations 7 to 9.

\[
\begin{align*}
V_{\text{out}} &= V_{\text{in}} 
V_{\text{out}} = D 
V_{\text{in}} &\quad (7)
L &= \frac{\Delta I_s + P}{V_{\text{out}} (1 - D)} \quad (8)
C &= \frac{1 - D}{B \frac{V_{\text{out}}}{V_{\text{in}}} L + F^2} \quad (9)
\end{align*}
\]
Figure 9. Circuit diagram of Buck converter.

Gate pulses for the switch (S) is provided by MPPT controller. P&O technique is considered for this study because of its simplicity. For this method power output of PMSG and angular speed of rotor are the given as inputs and output is the duty ratio. Figure 10 depicts that to track the MPP angular speed angular speed has to be adjusted. Output voltage is proportional to rotor speed [9]. Thus, for changing rotor speed voltage of generator has to be adjusted. And this can be done by changing duty ratio of buck converter. equations 10 to 12 give the conditions to check if MPP is achieved or not.

\[
\frac{dP}{dw} = 0 \text{ at } P_{\text{max}} \quad (10)
\]

\[
\frac{dP}{dw} > 0 \text{ (left side of } P_{\text{max}} \text{ in figure 10) } \quad (11)
\]

\[
\frac{dP}{dw} < 0 \text{ (right side of } P_{\text{max}} \text{ in figure 10) } \quad (12)
\]

Figure 10. Power Vs angular speed curve of wind turbine.

3.4. Battery energy storage system

The purpose of having a storage system in EV charging system is to make use of the excess energy generated which can be retrieved when the irradiance of solar is less or when the wind speed is very low. A bidirectional converter is utilized for this purpose which functions as buck converter in one direction and boost converter in reverse direction. Figure 11 gives the circuit representation of bidirectional converter. Equations 13 to 17 are used for the design of the converter.

\[
D_{\text{Buck}} = \frac{V_H}{V_L} \quad (13)
\]

\[
D_{\text{Boost}} = 1 - \frac{V_L}{V_H} \quad (14)
\]
\[ L = \frac{V_s + D}{\Delta I_L + F} \]  
\[ C_L = \frac{D_{Boost}}{R_H + \frac{AV_H + F}{V_H}} \]  
\[ C_H = \frac{1 - D_{Buck}}{B + \frac{2V_L}{V_L + L + F^2}} \]

**Figure 11.** Circuit representation of bidirectional converter.

While charging EV through BESS if there is any excess current flowing, the components may get damaged. So, to avoid this situation current controller has to be designed. Here PID is used to limit the discharge current. It is one of the most commonly used feedback controllers. PID estimates the error value by measuring the difference between setpoint and the actual output. Setpoint is the desired value at which the system should operate. Output of the PID is a constant value which is compared with the carrier signal to generate gate pulses for the switch in the bidirectional converter. By adjusting the duty ratio of gate pulses discharge current of the battery is limited.

### 4. Results and analysis

The simulation results of the proposed approach are discussed in this section. Waveforms for different power system parameters like voltage, current and power are analysed. Figure 12 shows the output voltage of the integrated system.

**Figure 12.** Output voltage of solar wind integrated power system.

Figure 13 shows the power generated from solar and it can be observed that power output is proportional to the irradiance and temperature because irradiance will affect the current output of the PV panel. Solar panel is open circuited for some time during this condition BESS operates in mode2 (open circuit means the power output is zero so BESS will discharge).
Waveform of the active power generated from wind is given in the figure 14. Here, the variations in the output power is due the change in wind speed and the power is less than rated value because wind turbine will not be able to convert all the wind speed to useful power, along with this there will be mechanical losses and copper losses in PMSG.

Figure 13. Output Power of PV panel.

Figure 14. Active Power generated from PMSG.

Figure15, 16 compares the output power of PV panel and WECS with and without MPPT controller, this proves that the power extracted can be increased by the implementation of MPPT techniques. And the overall efficiency of the system can be increased.

Figure 15. Solar power with and without MPPT.
From the Figure 16 the values of the wind power at different wind speeds are tabulated. Table 2 shows the analysis of power with and without MPPT. It is noticed that at different wind speeds increase in the efficiency is different.

Table 2. Comparison of wind power with and without MPPT.

| Wind Speed (m/s) | Wind Power without MPPT | Wind power with MPPT |
|------------------|--------------------------|-----------------------|
| 12               | 67kW                     | 70kW                  |
| 11.5             | 60.5kW                   | 62kW                  |
| 11.3             | 58kW                     | 59kW                  |

Current waveforms of battery in storage system are given in Figure 17(a), 17(b). All the three modes of BESS can be observed. The negative current indicates that the battery is in charge mode and vice versa. In the period 0.5sec to 1sec BESS is in the charge mode, from 1.5sec to 2sec BESS is in discharge mode of operation. And in the remaining time BESS is isolated.
Based on the power generated from the system two EVs each of 100kWh energy capacity can be connected at the output side. Figure 18 shows the current output of EVs. It is observed that the current is negative which means the EVs are charging and from the period 0.5sec to 1sec the load is open circuited so the current is zero. Voltage of solar wind integrated system is maintained constant at a value of 500V and the current is equally divided among two EVs.

### 5. Conclusion

Simulation model for charging of electric vehicle through energy generated from solar and wind integrated system with storage system is presented in this paper. Incremental conductance method which controls boost converter and P&O technique which controls buck converter are used to extract maximum power. Variable irradiance and different wind speeds are given as input parameters for the system. BESS stores the energy generated when there is no load connected. Bidirectional converter is used which provides suitable path for charging and discharging of the storage system with the help of controller.

### References

[1] Sivaprasad A, Kumaravel S and Ashok S., 2016, "Integration of solar PV/battery hybrid system using dual input DC-DC converter," 2016 Biennial Int. Conf. on Power and Energy Systems: Towards Sustainable Energy (PESTSE), Bangalore, pp. 1-5

[2] P. K. Vineeth Kumar and K. Manjunath, 2017, "Analysis, design and implementation for control of non-inverted zeta converter using incremental conductance MPPT algorithm for SPV applications," 2017 Int. Conf. on Inventive Systems and Control (ICISC), Coimbatore, pp. 1-5
[3] T. S. Biya and M. R. Sindhu, 2019, "Design and Power Management of Solar Powered Electric Vehicle Charging Station with Energy Storage System," 2019 3rd Int. conf. on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, pp. 815-820

[4] Z. Chen, H. Lin, B. Li and R. Qi, 2011, "A novel bidirectional battery energy controller for Plug-inHybrid Electric Vehicle," 2011 IEEE Int. Conf. on Automation and Logistics (ICAL), Chongqing, pp. 173-177

[5] Sheng Chen, A. Saber and T. Khandelwal, 2016, "General battery modeling and simulation using non-linear open circuit voltage in power system analysis," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, pp. 1-5

[6] D. Zhang and K. J. Tseng, 2014, "Design and modelling of grid-connected PMSG-based wind energy conversion through diode rectifier, DC/DC and DC/AC converters," 2014 Australasian Universities Power Engineering Conf. (AUPEC), Perth, WA, pp. 1-5

[7] T. Tafticht, K. Agbossou, A. Cheriti and M. L. Doumbia, 2006, "Output Power Maximization of a Permanent Magnet Synchronous Generator Based Stand-alone Wind Turbine," 2006 IEEE Int. Symposium on Industrial Electronics, Montreal, Que., pp. 2412-2416

[8] R. Rathi and K. S. Sandhu, 2016, "Comparative analysis of MPPT algorithms using wind turbines with different dimensions & ratings," 2016 IEEE 1st Int. Conf. on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, pp. 1-4

[9] A. Shahi and C. Bhattacharjee, 2018, "A study & analysis of fuzzy based P&O MPPT scheme in PMSG based wind turbine," 2018 Technologies for Smart-City Energy Security and Power (ICSESP), Bhubaneswar, pp. 1-4

[10] Remya O C, V S Kirthika Devi and S G Srivani, 2018, ‘‘Performance Analysis of Single Phase Closed Loop System for Cascaded H-Bridge Multilevel Inverter Using Renewable Source’, Journal of Engineering and Applied Sciences (ISSN 1816-949X) Vol-13, Number-7, pp.1757-1766.

[11] V S Kirthika Devi, and S G Srivani. 2016, "Performance assessment of PV energy conversion system with Buck-Boost and Cuk converter for cascaded H-Bridge inverter," 2016 Biennial Int. Conf. on Power and Energy Systems: Towards Sustainable Energy (PESTSE), IEEE.

[12] V S Kirthika Devi and S G Srivani Iyengar, 2015 “Modeling of a High Performance Photovoltaic system using MPPT Algorithm for seven level Asymmetric H-Bridge Inverter”, Int. Journal of Applied Engineering Research (IJAER) ISSN 0973-4562 Vol 10, Number 15 (2015), pp-35296-35302.