Journal of Green Engineering (JGE)

Volume-10, Issue-12, December 2020

Off-Grid Solar Photovoltaics Powered Charging Infrastructure for Electric Vehicles

[1]Appalanaidu Chowdary and [2]Sura Srinivasa Rao

[1]Research Scholar, Department of Electrical, Electronics and Communication Engineering, Gandhi Institute of Technology and Management (Deemed to be University), Visakhapatnam, Andhra Pradesh, India.
[2]Assistant Professor, Department of Electrical, Electronics and Communication Engineering, Gandhi Institute of Technology and Management (Deemed to be University), Visakhapatnam, Andhra Pradesh, India.
E-mail:121960502501@gitam.in

Abstract

With the emergence of electric vehicles in the transport sector, concerns over charging infrastructure were raised. The charging infrastructure is mainly used for powering electric vehicles, like how the gas stations work. Recently, alternative options such as solar, wind, etc., were suggested for developing charging stations. In this paper, a solar power charging station is modeled and analyzed. An off-grid system is considered for the EV load, and the simulation is carried out. Results of this study include the power generation potential, supply, and load mismatch relationships. In addition, analysis is extended considering the weather parameter influence on power produced. We believe this study could be useful for planning EV charging stations.

Keywords: Electric vehicles, Charging stations, Solar for EVs, Off-grid charging infrastructure, HOMER tool, PV plant feasibility.

1 Introduction

The decarbonization of the transport sector has become a feasible and addressable issue with the latest technology developments. The most promising option is the use of electricity as fuel to power vehicles. The use of electricity mostly eliminates the use of fossil fuels like petrol and diesel [1].

Journal of Green Engineering, Vol. 10_12, 12721-12728.

The recently developed electric vehicles are mostly run by electricity that is generated onsite or offsite. Due to this, concerns over charging infrastructure were raised. At present, the road infrastructure we have mostly had conventional stations where they don't provide electric charge stations. The charging infrastructure is mainly used for powering electric vehicles, like how the gas stations work [2]. In the charging stations, either fast DC or AC charging equipment is available, and sometimes battery banks are also. When these systems have evolved for the first time, they mainly use conventional fuels for powering or energy from the grid. Recently, alternative options such as solar, wind, etc., were suggested for developing charging stations, see in Table 1 [3].

Table 1 Renewable Energy Options for Electric Vehicle Charging Infrastructure

Renewables	Description
Solar	This source can be widely used for charging infrastructure. Also, the favorable aspect of installation on-site, especially as rooftop, façade is well suited.
Wind	The small scale wind turbine is suitable. However, the concerns over wind speed limitation rise and become little unfavorable deployment conditions in the charging stations. This can only be limited to few locations where wind potential is high.
Biogas	This is applicable and can be used in any location as long as there enough feedstock.

To understand the potential options, a literature review has been carried out. Integrated power systems are also developed for use as charging infrastructure on a commercial level [4]. And the impact of large scale electric vehicle integration is investigated in ref. [5]. A study by Niveditha et al. explored the renewable options and suggested that renewable alone can be used as an off-grid mode for electric vehicle charging. Hence, the off-grid mode of charging is considered in this research. A biogas-based electric vehicle charging station is investigated in a study, and it was found that renewable energy-based systems are reliable in providing power to the electric vehicle [6]. In another study, Kumar et al. explored the new options for using solar as charging infrastructure, i.e., solar trees. Their study developed a three-layer solar tree for use as an electric vehicle charging infrastructure [7].

From the above literature, it is understood that solar energy is most promising for electric vehicles due to its favorable conditions in terms of power generation at any location [8]. Hence, in this study, we chose solar energy deployment for electric vehicles.

This study's main objecti ve is to design and analyze the off-grid solar photovoltaics powered charging infrastructure for electric vehicles. As per the goal, simulation is carried out to understand the solar power charging stations' feasibility.

2 Description and Modelling of Off-grid Solar PV for EV

In Figure 1, a schematic view of the solar-powered off-grid charging station is shown. The proposed charging infrastructure consists of solar panels, charging station equipment that is inbuilt with the chargers and a storage device. This provision will allow electric vehicle owners to charge their vehicles directly.

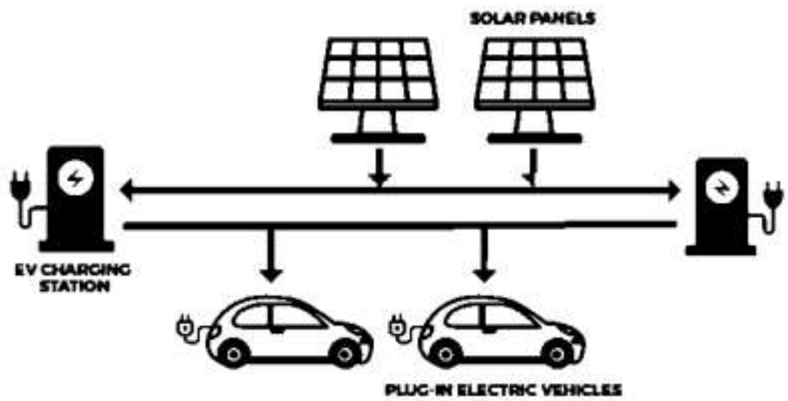

Figure 1 Off-Grid Solar-Powered Electric Vehicle Charging Infrastructure

Modeling of the charging station components is done below. At first solar photovoltaic power outputs were modeled using the below Equation (1) [9].

$$E_{PV} = A \times eff_{PV} \times I \times PR \tag{1}$$

At the same time, during the solar array modeling, the conditions that affect the system performance and power outputs were considered. These include area (A), efficiency (eff_{PV}), solar irradiance (I), temperature, performance ratio (PR) [9].

The solar array's output energy is fed to the battery present in the charging station, which is continuously charging as long as there is enough power from the solar. At the same time, it will discharge energy whenever the electric vehicle is connected to it.

The energy storage device modeling is as follows. The total energy present in the battery is calculated using Equation (2). In addition, as we mentioned earlier, there is a battery bank, which means series and parallel configuration of batteries are possible. Hence, it is recommended to consider the system voltage, as per Eqations (3) and (4) [10,11].

$$E_{Bat} = \frac{E_{Total} \times \eta_a}{V_{Bat} \times \eta_{Bat} \times DOD} \quad (2)$$

$$N_{Series} = \frac{V_{Bus}}{V_{Bat}} \quad (3)$$

$$N_{Parallel} = \frac{E_{Bat}}{V_{Bat,rated}} \quad (4)$$

The charging station's battery banks, state of charge (SoC) and depth of discharge (DoD) can be evaluated using Equations (5), (6), and (7) [10,11].

$$C_{Bat}(t) = C_{Bat}(t-1)(1-\sigma) + \left[P_{PV}(t) - \frac{P_{load}(t)}{\eta_{con}}\right]\eta_B \quad (5)$$

While charging:

$$P_{PV}(t) = \frac{P_{load}(t)}{\eta_{inv}} > 0 \; with \; C_{Bat}(t)(t-1) < C_{BatMax} \quad (6)$$

While discharging:

$$P_{PV}(t) = \frac{P_{load}(t)}{\eta_{inv}} < 0 \; with \; C_{Bat}(t)(t-1) > C_{BatMax} \quad (7)$$

3 Results and Discussion

A hypothetical electric vehicle load is considered in this study. Using the above-discussed methodology in Section 2, a simulation is carried out in the hybrid optimization tool. While modeling, the data related to solar power panels, batteries are considered based on the real-time markets. The technical details, such as the electric vehicle charging time, are considered based on the literature. In addition, the time at which the user decides on charging the vehicle is assumed. The results analysis includes the investigation of the electric vehicle load patterns, solar power generation potential, the battery charging, and discharging parameters variation over time.

In Figure 2, the daily load profile of the electric vehicle is shown. As per this, it is understood that electric vehicles are charged during 6-9 AM in the morning hours. Between 19 to 22 PM hours in the evening. The load patterns would vary slightly depending upon the season; hence, we estimated the possible variation in the load as per the seasonal change and this is shown in Figure 3.

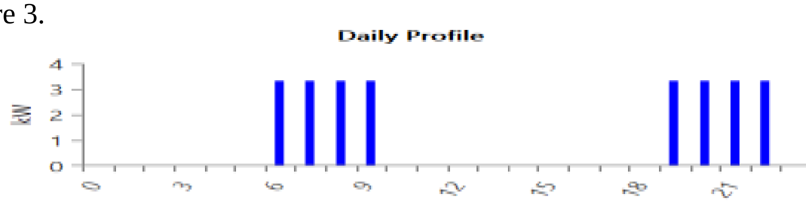

Figure 2 Daily Load Profile of the Electric Vehicle

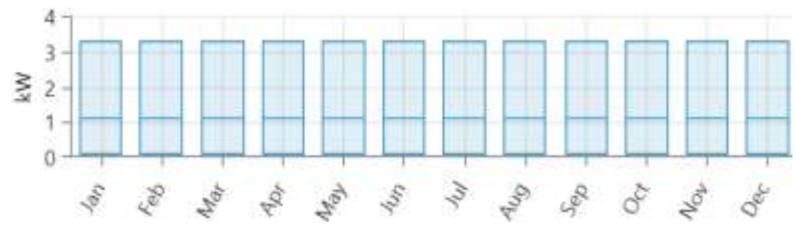

Figure 3 Load Profile of the Electric Vehicle on a Seasonal Basis

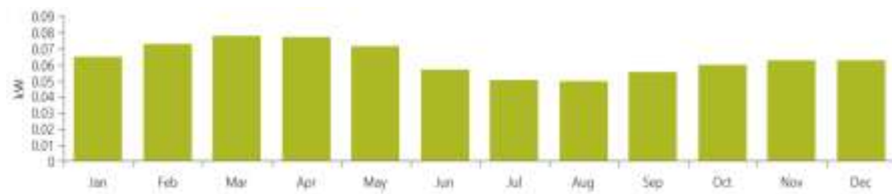

Figure 4 Power Output From the Off-Grid Solar Power Plant

In Figure 4, the solar power outputs are shown. From Figure 4, it is understood that the solar plant operates efficiently with an average power of at least 0.06 kW. The maximum generation potential is observed to be in the month of March and April, whereas the list is seen in August.

The generated output from the solar plant is given to the charging station equipment, where the battery banks are charged continuously. To understand the charging patterns, the state of the charge parameter is investigated here. In Figure 5, the SOC of the charging station is shown. Most of the time, it is charged to 100%. In a few months, i.e., in June, July, August, and September, the SOC is dropped. The minimum SOC is observed in August

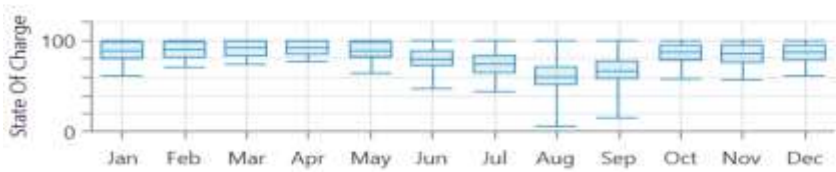

Figure 5 The State of the Charge of the Energy Storage Bank in the Charging Station

The overall performance characteristics of the proposed off-grid solar-powered electric vehicle charging station are shown in Figure 6. From the characteristics, it is clear that the charging station has sufficient energy to meet the load requirement most of the time. This can be validated as it in line with the SOC. In addition, solar power availability is only up to 6 PM. The discharge power condition is maintained steady between 19:00 to 22:00, and this is the time where electric vehicles are connected as per the given load profile. For the remaining time, the system is kept charging, and where the energy content is kept constant. If we closely observe the characteristics, a slight drop in the energy content is observed when the electric vehicles are charging.

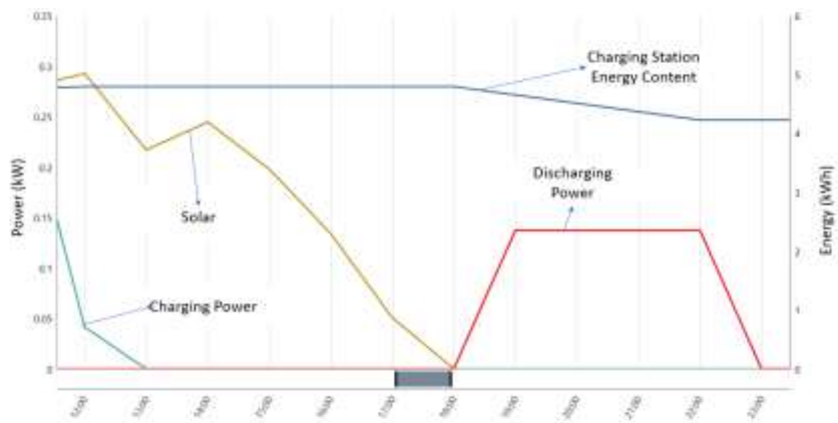

Figure 6 Performance Characteristics of the Solar-Powered Electric Vehicle Charging Station

4 Conclusions

In this study, off-grid solar photovoltaic system is designed for serving the electric vehicle load. The system modeled here is specific to the electric vehicle infrastructure i.e., the charging station. The analysis suggested that the solar-powered electric vehcle charging station is technically feasible enough to meet the load requirements. At the same, solar panels are quite efficient in maintaining energy content.

References

[1].Kumar, N. M., Reddy, G. R., & Miriyam, A. “Potential emission reductions from India’s transport sector: a view from the green transportation projects under CDM”, Energy Procedia, vol. 147,pp. 438-444, 2018.

[2].Boschmann, E. E., & Kwan, M. P. “Toward socially sustainable urban transportation: Progress and potentials”, International journal of sustainable transportation, vol.2, no. 3, pp.138-157, 2008.

[3].de Lucena, S. E., & Soylu, S. “A Survey on Electric and Hybrid Electric Vehicle Technology Electric Vehicles”, The Benefits and Barriers, InTech, 2011.

[4].Sivadanam, N., Nagu, B., & Sydulu, M. "Performance Optimization of an Interconnected Power System in the Presence of Plug-in Hybrid Electric Vehicles", Journal of Green Engineering, vol.10, no. 9, pp.4910-4925, 2020.

[5].Sivadanam, N., Nagu, B., & Sydulu, M. "Inertial Response and Frequency Control in Electric Vehicles Integrated Renewable and Non-renewable Power System", Journal of Green Engineering, vol.10, no. 11, 2020.

[6].Karmaker, A.K., Hossain, M.A., Manoj Kumar, N. Jagadeesan, V. Jayakumar, A. Ray, B. "Analysis of Using Biogas Resources for Electric Vehicle Charging in Bangladesh: A Techno-Economic-Environmental Perspective", Sustainability, vol.12, 2020.

[7].Kumar. N.M., Chopra. S.S., Malvoni M., Elavarasan, R.M., Das, N. "Solar Cell Technology Selection for a PV Leaf Based on Energy and Sustainability Indicators—A Case of a Multilayered Solar Photovoltaic Tree", Energies, vol.13, no.23, 2020.

[8].Deb, S., Tammi, K., Kalita, K., & Mahanta, P. "Charging station placement for electric vehicles: a case study of Guwahati city, India", IEEE Access, vol.7, pp.100270-100282, 2019.

[9].Manoj Kumar, N. Ghosh, A. Chopra, S.S. "Power Resilience Enhancement of a Residential Electricity User Using Photovoltaics and a Battery Energy Storage System under Uncertainty Conditions", Energies, vol.13, no.16, 2020.

[10].Ambati, S.R., and Rao, S.S., "A Review of Microgrid Modelling, Design, and Control Simulations", Journal of Green Engineering, vol.10, no. 10, pp.9021-9041, 2020.

[11].Kumar, N.M. Chand, A.A. Malvoni, M. Prasad, K.A. Mamun, K.A. Islam, F. Chopra, S.S. "Distributed Energy Resources and the Application of AI, IoT, and Blockchain in Smart Grids", Energies, vol.13, pp.2-42, 2020.

Biographies

Appalanaidu Chowdary received his B.Tech and M.Tech graduate and currently he is a Ph,D Scholar in the Department of Electrical, Electronics and Communication Engineering, Gandhi Institute of Technology and Management (Deemed to be University), Visakhapatnam. His research area of interests includes electric vehicles, renewable systems for EVs, control algorithm power management.

Sura Srinivasa Rao, received his B.Tech, M.Tech, and PhD degrees in Electrical and Electronics Engineering. Presently, he is works as an Assistant Professor in Department of Electrical, Electronics and Communication Engineering, Gandhi Institute of Technology and Management (Deemed to be University), Visakhapatnam. His research area of interests includes power Quality Improvements and smart grids.