Indonesian Journal of Electrical Engineering and Computer Science
Vol. 36, No. 1, October 2024, pp. 1~14
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v36.i1.pp1-14

Smart grid solutions for sustainable photovoltaic-electric vehicle integration in Bangladesh

Al Amin Hossain, Abdus Samad
Department of Electrical, Electronic, and Communication Engineering (EECE), Military Institute of Science and Technology (MIST), Dhaka, Bangladesh

Article Info

Article history:

Received Feb 9, 2024
Revised Apr 16, 2024
Accepted Jun 5, 2024

Keywords:

Electric vehicles
Environment sustainability
Grid tied charging station
Homer grid
Photovoltaic

ABSTRACT

Environmental concerns and the depletion of fossil fuel supplies are driving the rapid integration of photovoltaic (PV) systems into the electrical grid and electric vehicles (EVs) into the transportation sector. Issues like unpredictable power outages and shifts in demand require a cost-benefit analysis and efficient scheduling. In order to optimize PV power consumption and EV charging while taking seasonal variations into consideration, this study offers a novel solar-based grid-tied charging station with an improved scheduling technique. The existing charging station connected to the grid and solar promises not only reduced grid demand and cost savings, but also energy independence and environmental benefits. In the actual case in Rajshahi, Bangladesh, it is carried out using a Homer Grid case study. Bangladesh may promote environmental sustainability and resource conservation with this technology.

Corresponding Author:

Al Amin Hossain
Department of Electrical, Electronic, and Communication Engineering (EECE)
Military Institute of Science and Technology (MIST)
Mirpur Cantonment, Dhaka, Bangladesh
Email: alamin.hossain@reverie-bd.com

1. INTRODUCTION

As per recent scenario, Bangladesh's renewable sector has only 4.59% of total share (29.3 megawatts (MW)), mainly derived from gas, coal, and heavy fuel oil (HFO) [1]. However, the Bangladeshi government's vision 2021 aims to produce 10% (2,000 MW) of the country's total power by 2021 and 20% by 2030 from renewable sources [2]. Thus, solar power is key to Bangladesh's renewable energy goals [3] and its application in electric vehicle charging stations is indispensable. As of December 2020 [4], there were just 14 home charging stations with capacity of 278 kW for electric vehicles (EVs) in our nation. Furthermore, these stations need solar energy and take longer to charge, hence they are not suitable for high-load commercial applications. However, depending on the location of this case study here, the combination of solar energy with another energy source or grid backup can guarantee reliable and quick charging for commercial applications. By 2030, the government wants to see at least 15% of all registered vehicles be EVs [5]. About 560 MW of the 20,430 MW of power produced each year come from renewable sources, which offers a viable solution to the demand-supply imbalance [6]. EVs must be considered when designing and managing electric power systems. The clever integration and design of EV systems can have numerous technical and financial benefits, including a more reliable energy infrastructure, improved voltage stability, reduced power losses, less carbon emissions, and lower electricity generation costs. Bangladesh had 0.62 tons of CO_2 emissions per capita in 2021. With an average yearly growth rate of 5.32%, Bangladesh's CO_2 emissions per capita increased from 0.05 tons in 1972 to 0.62 tons in 2021 [7]. In addition, the combination of renewable energy sources with EV charging has become a prominent trend in modern power systems and environmental cleansing. Modern technology has led to the replacement of traditional grid systems with integrated ones that can handle renewable energy sources and EVs. Unplanned EV integration can result in a number of potential problems for distribution systems, including increased peak demand, voltage instability, poor power quality, overloading transformers, excessive power, and energy losses [8]. The researchers' strategic analysis, which is depicted in Figure 1 [9], summarizes Bangladesh's EV adoption.

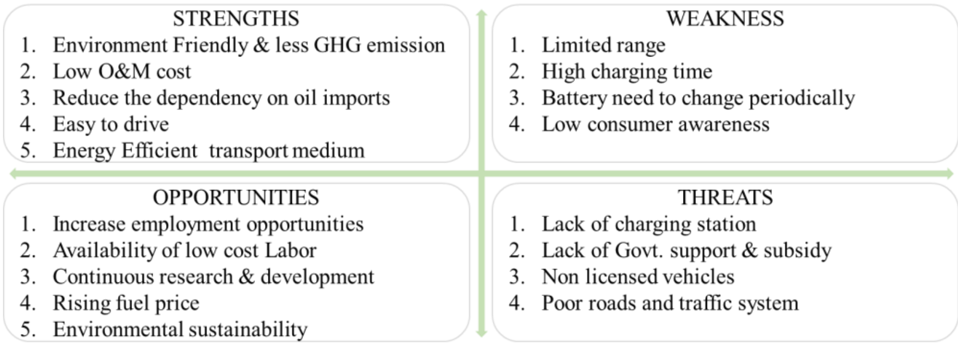

Figure 1. SWOT for EV in Bangladesh [9]

The solar charging station architecture presented by a study uses a combination of unidirectional PWM approach for Chittagong region, Bangladesh, which is based on the grid to vehicle (G2V) strategy in the smart grid, and a charge controller based on the battery charging strategy [10]. A work investigated a solar-powered EV charging station idea along the Dhaka-Chattogram national route, building on a study by Mridul *et al.* [11], but the concept was beset by two serious flaws that would have made it unfeasible in seasons of low sunlight: it relied too heavily on an outdated and ineffective charger controller, and it lacked a hybrid power-generating mechanism. Building on the idea of RES-based charging stations [12], a study looked into how grid connectivity, battery storage, and the use of solar and wind energy sources may be combined to provide sustainable EV charging. This strategy provided a viable way to support energy independence and grid resilience while encouraging ecologically friendly charging infrastructures. This study emphasized the significance of comprehensive site assessment in such projects, taking inspiration from the EVCS concept for Chittagong's CGP International Airport reported [13], which blended wind power with existing PV and grid connections. The airport project's planned area lacks adequate analysis, which emphasizes the necessity of thorough feasibility studies to guarantee the best possible design. This research extended the conversation by pointing out shortcomings in the method's meteorological data accuracy and computational precision, which is consistent with a work on optimizing grid connection and PV/wind power for EV charging stations using homer grid [14]. The reliability and efficacy of these optimization tactics could be increased by addressing these constraints through improved modeling and data collecting methodologies. This study improved on the Bayesian model for EV charging station site selection that was introduced [15] by exploring its potential for successfully navigating the uncertainties and complexities involved in the deployment of large-scale charging networks. Making use of the Bayesian framework's advantages in managing data scarcity and modeling interdependencies could yield insightful information about where to locate charging stations and how best to allocate resources. Building on the research presented [16], the study showed how to successfully design a hybrid charging station that uses a single voltage source converter (VSC) and is powered by diesel engines and PV batteries. The control system's extraordinary adaptability was demonstrated by this creative design, which allowed it to operate in dispersed generation, grid-connected, and islanded modes with ease.

This project extended the capabilities of the three-phase hybrid boost converter for PV charging stations by simulating and assessing its performance in five major domains: reactive power monitoring, DC voltage control, maximum power point tracking, and overall energy management [17]. This thorough investigation provided insightful information for maximizing these converter systems' dependability and efficiency. Building on the design ideas presented [18], the study investigated the architecture of a scalable and effective charging station. With fifteen bidirectional grid-connected converters, fifteen EV charging ports, two renewable energy sources, one maximum power point tracking (MPPT) controller, and fifteen bidirectional energy sources combined, this design encourages sustainable charging infrastructure without sacrificing functionality or adaptability. Building on the two-stage power allocation and EV management method established [19], this research further explored the optimization dynamics within grid-tied PV-battery charging stations. By emphasizing the intricate interactions between solar, battery backup, and grid supply along with integrated charging power dispatch, this methodology created the way for improved operational efficiency and energy management. Inspired by the mathematical model for assessing PV potential in urban-scale energy systems that was published [20], the study broadened its focus to include the intricate interactions between power flows between producers, charging stations, and the networks that are current. This all-encompassing method offered insightful information about optimizing the cooperative advantages of incorporating PV systems into extensive metropolitan energy networks. However, daviation can be arised on distribution transformer due to large EV penetration and the controlled charging can solve the issue along with no extra upgradation [21], [22]. Research has been done on how to optimize electric vehicle charging and power grid management for a more efficient system [23]. Based on demand and supply management of electricity, impacts on vehicle to grid (V2G) along with (G2V also studied [24], [25].

This research proposes a charging station design for EVs that prioritizes green energy sources along with existing grid. Several potential optimization options for the proposed charging station have been identified through this research. While consideration was initially given to including wind energy as a renewable source, the chosen project location is not conducive to effectively harnessing wind power. However, the possibility of integrating a generator as an additional power source has been explored. The generator would serve as a useful backup in cases where wind power is unavailable or insufficient to maintain a charging service, although the primary goal is to preserve natural resources and cultivate a greener environment. Additionally, the inclusion of battery storage has been considered, despite it being currently cost-prohibitive for construction within Bangladesh. This option provides a reliable means of storing energy, especially during emergencies or crises. Furthermore, the use of mobile application-based sensors to monitor the grid and solar systems has been explored, offering better optimization and control. While the implementation of this technology may pose challenges within Bangladesh's construction landscape, it holds the potential for enhanced efficiency and grid management. If a future solution to the current challenges is found, consideration will be given to increasing the project's work and striving for optimal performance during implementation, with a focus on cost efficiency.

In order to develop an ideal schedule and perform a techno-economic evaluation of EVs using the Homer Grid software, this study involves the integration of charging stations with both the grid and solar energy sources. In this paper, a case study of a charging station on Rajshahi's main road is presented. The key contributions and innovations of this study are outlined as follows: analyzing Rajshahi's atmosphere for precise charging station design, examining system costs and power with different grid and solar setups using Homer Grid, identifying the most efficient system setup, considering technical and economic factors, planning EV charging schedules for efficient energy use, exploring how solar energy reduces the environmental impact of gas emissions.

2. METHOD AND CALCULATIONS

This section explains how the model has been designed, the methods are used, and the specific approach took in this study. Here, the details about the model's structure and the followed steps are found. Subsequently, the decisions taken for the data analysis are also explained.

2.1. Methods for the suggested system

The project has been conducted using Homer Grid, a software tool designed for comparing electric vehicle charging station installation possibilities. This software organizes and filters optimal output data according to specified criteria and user requirements, enabling the construction of the required model, as illustrated in Figure 2. The three primary composnents of the proposed plan-site loads, grid availability, and solar power coupling are shown in Figure 3. First, the best location for integrating solar energy is selected. Second, studies of the weather patterns and solar potential of the target area have been carried out. The grid budget and scheduling costs for the location are also examined. The fourth phase is analyzing the distribution of EV loads. The system is designed to meet demand for EVs once the load is anticipated and regular daily sessions are planned. The optimal solar system configuration is determined by estimates of the load. Finally, the EVs timing has been designed to optimize the power output of the solar system.

2.2. Analyzing resources and environmental issues

In Figure 4, an envision is being executed in the project in Bangladesh's Rajshahi district, where net metering is feasible. Rajshahi's coordinates are 24°22′26″ N, 88°36′04″ E. The findings demonstrate the region's viability for building a solar system.

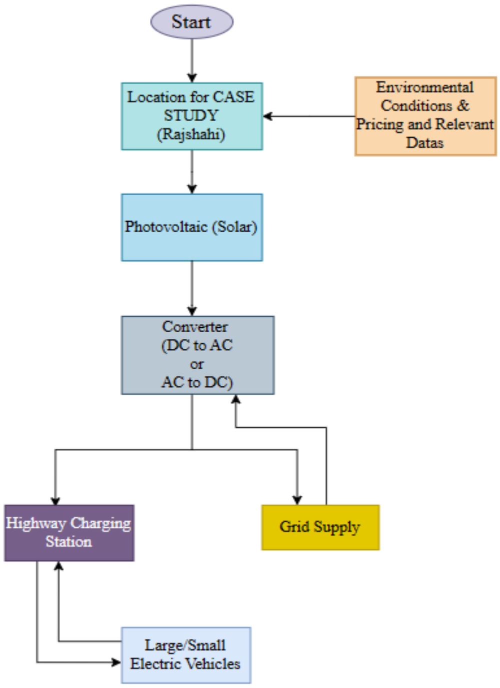

Figure 2. Proposed system flow chart

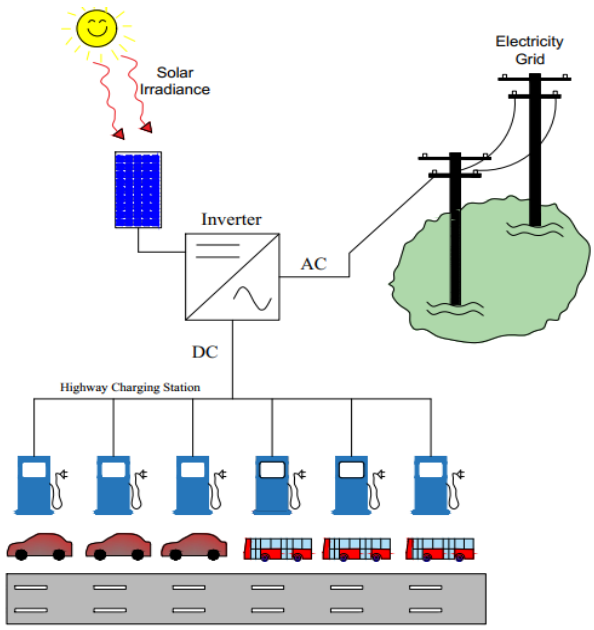

Figure 3. The prototype

Figure 4. Bangladeshi map with Rajshahi region indicated

Figure 5 depicts the solar suitability of the area, with a yearly median radiation of 4.88 kWh/m^2 per day. Maximum solar radiation occurs in April, while September sees the lowest. The clearness index, peaking in February and dipping in July at 0.544, is displayed for each month. Figure 6 illustrates the impact of seasonal temperature variations on PV system production in Rajshahi, with an average annual temperature of 26.32 degrees Celsius. The lowest temperature is 17.66 degrees in January, and the highest is 32.52 degrees in May. Figure 7 focuses on rainfall considerations, showing rainy days and average monthly rainfall. July has the most rainy days (20), while November and December have the fewest. In Figure 8, daily sunshine hours are crucial for PV system planning. November boasts the highest average of 8 hours of sunshine per day, while July has the least sun visibility.

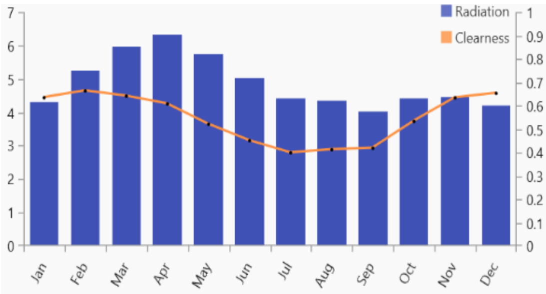

Figure 5. Solar radiation graph

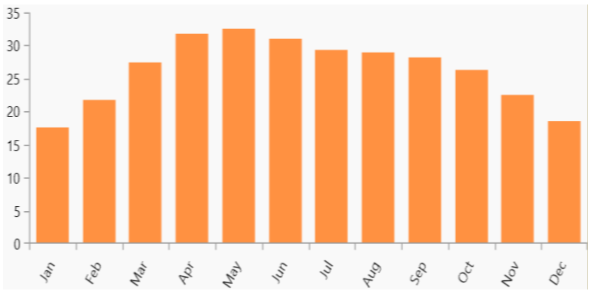

Figure 6. Temperature graph

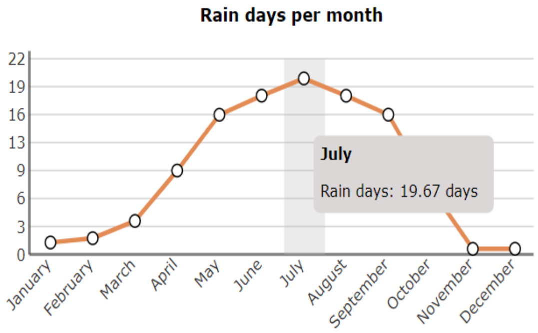

Figure 7. Graph of rainy days

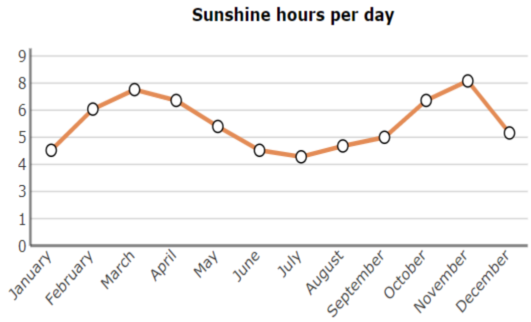

Figure 8. Graph of sunshine hours

2.3. Used mathematical formulas

– Per unit cost of energy: the cost involved in creating or consuming a certain amount of energy is expressed as the per unit cost of energy, or PUCOE.

$$\text{PUCOE} = \frac{\text{TOTAL}_{\text{COST, YR}}}{\text{LOAD}_{\text{AC}} + \text{LOAD}_{\text{DC}}} \quad (1)$$

– Electric load estimation: the quantity of energy needed to meet particular needs in a predetermined amount of time is referred to as energy demand.

$$\text{E}_{\text{Demand}}(\text{KWh}) = \text{L}_{\text{Demand}}(\text{KW}) * \text{Time(h)} \quad (2)$$

$$\text{Energy}_{\text{Total Demand}}(\text{KWh}) = \sum_{i=1} n * \text{Energy}_{\text{Demand}}(\text{KWh}) \quad (3)$$

– Capital recovery factor: a financial statistic known as the Capital Recovery Factor is used to determine, under the assumption of a fixed interest rate, the annual payment required to recover the initial capital investment over a given length of time.

$$\text{C}_{\text{re.fac}}(i, n) = \frac{i\,(1+i)^n}{(1+i)^n - 1} \quad (4)$$

Here, i = annual interest rate, n = the total number of years for a project.

– Grid supplied power: a power grid is a network of interconnected devices used to produce, transmit, and distribute electrical power. It is also referred to as an electrical grid or an energy grid.

$$\text{P}_{\text{grid}} = \begin{cases} 0; & P \leq E_{PV} \\ P - E_{PV}; & P > E_{PV} \end{cases} \quad (5)$$

Here, P_{grid} = power supplied by the grid, E_{PV} = power generated by the PV source.

– Net present cost: a monetary metric called net present cost (NPC) is used to assess an investments or project’s long-term economic viability. It is the total of all project-related expenses and benefits, discounted for the time value of money.

$$C_{year} = C_{re,fac}\ (i, R_{project\_life}\ ) \times C_{NPC,Total} \quad (6)$$

– Solar modules: the NPC is the overall cost incurred during the course of a project. This covers all project-related expenses, such as the initial capital outlay, power sellback, and income generation.

$$P_{PV} = P_{NPV} \times \frac{G}{G_{ref}} \times [1 + K_t \times \left([T_{amb} + \frac{NOCT - 20}{800}] \times G - T_{ref}\right) \quad (7)$$

Here, P_{PV} = power generated by PV sources, T_{ref} = reference time for PV generation, T_{amb} = ambient temperature.

– Solar converters: solar converters are mostly used to convert solar panel DC into AC power and grid-generated AC power into DC power.

$$\eta_{\ cnv} = \frac{Power_{output}}{Power_{input}} \quad (8)$$

Here, $\eta_{\ cnv}$ = the converter's power output to input ratio.

2.4. Load estimation of EVs

The charging station can accommodate 200 EVs which includes 125 small, 75 large vehicles, with load ratings of 140 kW and 60 kW. It has six charging outlets that produce a total of 120 kW. Daily demand averages 200 charging sessions. Peak consumption occurs between 5:00 and 9:00 p.m., with the lowest load falling between 2:00 and 5:00 a.m. The station successfully controls demand, ensuring that the 200 charging sessions per day are properly scheduled, shown in Figures 9 and 10.

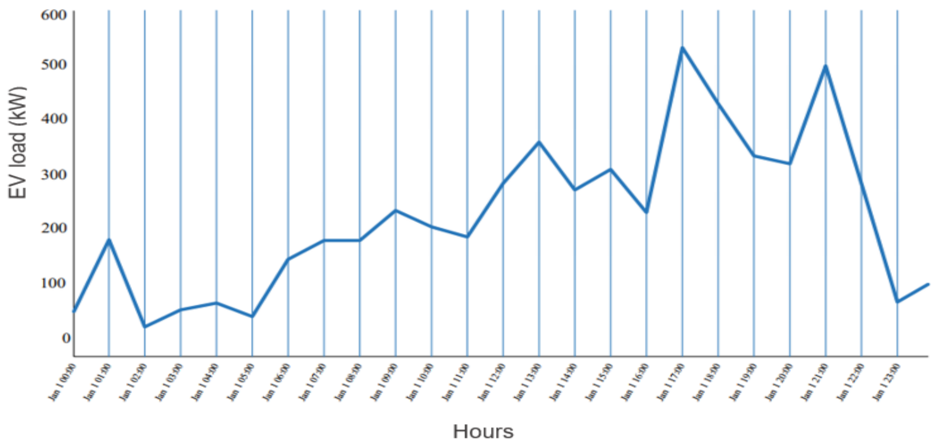

Figure 9. January's daily average load spectrum of EVs

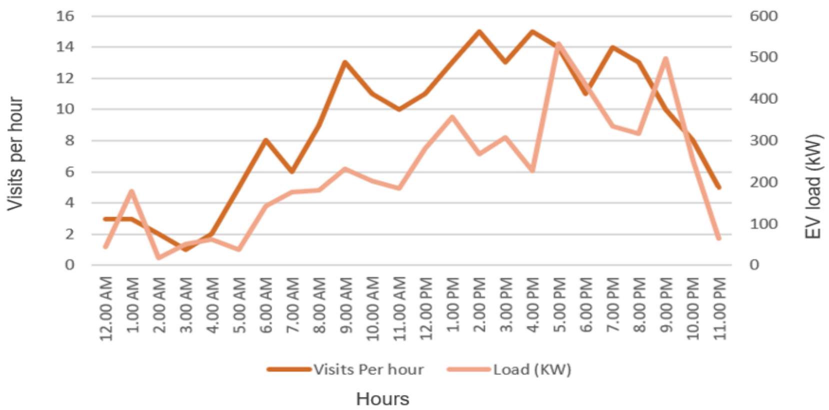

Figure 10. Daily average load spectrum and visits per hour of EVs

2.5. Proposed system overview

The Homer Grid program used to construct the Rajshahi grid-tied charging station, featuring a solar of 1,000 kW coupled with an 700 kW converter. The ideal converter selection determines by criteria such as energy cost, NPC, and energy conversion efficiency. The charging station, with six 120 kW slots, provides grid connectivity and dependability during periods of low solar power. The grid tariff comprises a 0.081 kWh energy price and a 0.688 kW demand charge, with a set monthly fee. The PV system's cost-effective power generation at $0.0572 per kWh and a specific yield of 1,584 kWh/kW improves the total system efficiency.

3. RESULTS AND DISCUSSION

In this instance, the optimal results of the suggested system are studied. It has looked at the generation and usage of power, financial sustainability, and general efficacy of the strategy. The data and observations gathered during the study served as the foundation for this thorough analysis.

3.1. Overview of power generation and utilization

The PV system contributes 40.5% which is 997,940 kWh/year of the total energy production, while the grid provides 59.5% which is 1,468,733 kWh/year. Table 1 summarizes the yearly power production. Table 2 details the yearly energy consumption, with 5.12% of the energy generated returned to the grid. The proposed system may act as a backup during blackouts. Table 3 provides information on monthly energy purchases, sales, and related costs, with a focus on utility bill comparison.

The electricity from the solar system is less expensive per kWh ($0.0572) than it is from the grid ($0.081/kWh). This system generates 2,734 kWh per day on average, with an efficiency ratio of 18.1%. Between 10:00 a.m. and 5:00 p.m., the solar system reaches its maximum output. The research highlights Rajshahi's aptitude for solar energy production.

The converter in the system runs for 4,373 hours each year at a capacity factor of 22.2%, producing an average output of 108 kW. It converts 992,018 kWh of input energy into 942,417 kWh of production and 46,601 kWh of energy loss every year. Figure 11 depicts converter manufacture. Figure 12 depicts a grid-connected charging station that sells 123,338 kWh (5.12% of total usage) back to the grid yearly. EVs consume 2,287,812 kWh, constituting 94.9% of energy use. The grid-connected system uses the total generated energy of 2,446,672 kWh each year.

Table 1. Grid and solar power generation throughout a year

Production	kWh/year	%
Canadian solar max power CS6X-325P	997,940	40.5
Grid purchase	1,468,733	59.5
Total	2,466,672	100

Table 2. Yearly energy use for proposed system

Consumption	kWh/year	%
AC primary load	0	0
Grid sale	123,338	5.12
EV charger served	2,287,812	94.9
Total	2,411,150	100

Table 3. Analysis of monthly utility expenses

Month	Imported energy	Energy traded	Net energy purchased	Peak load	Energy charge	Demand charge	Demand response	Fixed charge	Minimum charge	Taxes ($)	Total
January	122,007	15,178	106,829	616	9,062.93	416.70	0	20.40	0	0	9,500.03
February	104,659	14,679	89,980	618	7,684.69	424.95	0	20.40	0	0	8,130.04
March	113,965	15,939	98,026	625	8,370.47	429.66	0	20.40	0	0	8,820.53
April	113,238	12,198	101,040	610	8,513.57	411.77	0	20.40	0	0	8,945.74
May	121,400	10,188	111,211	614	9,283.21	422.09	0	20.40	0	0	9,725.70
June	129,652	4,732	124,920	617	10,246.31	404.89	0	20.40	0	0	10,671.59
July	138,763	4,605	134,158	630	10,991.13	414.06	0	20.40	0	0	11,425.59
August	142,253	5,427	136,825	617	11,299.38	413.26	0	20.40	0	0	11,663.04
September	143,050	6,134	136,916	597	11,255.85	404.15	0	20.40	0	0	11,680.40
October	140,732	8,085	132,647	602	10,962.69	414.41	0	20.40	0	0	11,397.49
November	118,915	14,269	104,645	622	8,861.55	415.09	0	20.40	0	0	9,297.04
December	116,422	15,788	100,634	591	8,577.66	390.21	0	20.40	0	0	8,988.27
Annual	1,505,055 (kWh)	127,223 (kWh)	1,377,832 (kWh)	630 (kW)	115,039.40 ($)	4,961.23 ($)	0	244.80 ($)	0	0	120,245.46 ($)

Figure 13 depicts the annual production summary for PV and utilities. In comparison to the EV, the utility system, illustrated in sky blue, supplies the majority of electricity. Notably, March has the highest PV output, whilst July has the lowest. In a country where ensuring uninterrupted power supply is a primary concern, the proposed system's design appears to be a solution, annually supporting the current power system and balancing grid demand by 997,940 kWh. This analysis indicates the feasibility of using solar energy to generate electricity in the Rajshahi region, and it invites investors to implement the proposed system to meet EV energy demands and balance grid loads.

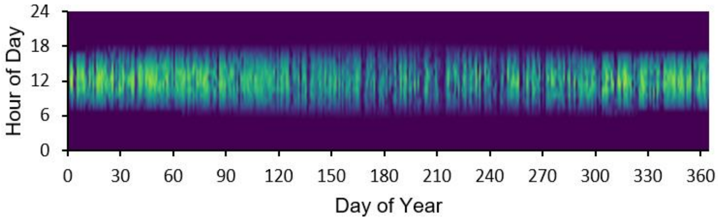

Figure 11. Yearly solar generation

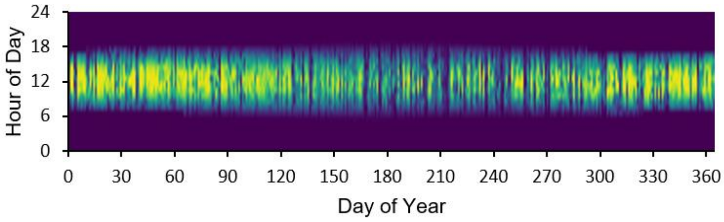

Figure 12. Power conversion in the solar converter

Figure 13 depicts the annual production summary for PV and utilities. In comparison to the EV, the utility system, illustrated in sky blue, supplies the majority of electricity. Notably, March has the highest PV output, whilst July has the lowest. In a country where ensuring uninterrupted power supply is a primary concern, the proposed system's design appears to be a solution, annually supporting the current power system and balancing grid demand by 997,940 kWh. This analysis indicates the feasibility of using solar energy to generate electricity in the Rajshahi region, and it invites investors to implement the proposed system to meet EV energy demands and balance grid loads.

The Figure 14 shows how much electricity is generated by the grid and solar panels each year. In June, August, and September, irradiance is lower. PV production takes place between 5:00 a.m. and 6:00 p.m., also it is supplemented by the grid outside of those hours. Peak PV output occurs between February and December due to increasing radiation, as demonstrated in Figure 14(a) to 14(d) along with Figure 14(j).

The solar system provides the majority of all electricity throughout these times of year, with significantly decreased grid demand at night. The electric vehicle project prioritizes solar energy usage. As indicated in Figure 14(e) to 14(i), power generation hours are reduced during rainy months such as June, July, and August, resulting in lower PV power production. However, renewable generation increased in October, November and December, as presented in Figure 14(j) to 14(l). As a result of the findings, the Rajshahi region may be considered environmentally conscious as a significant portion of electricity is produced by the solar system.

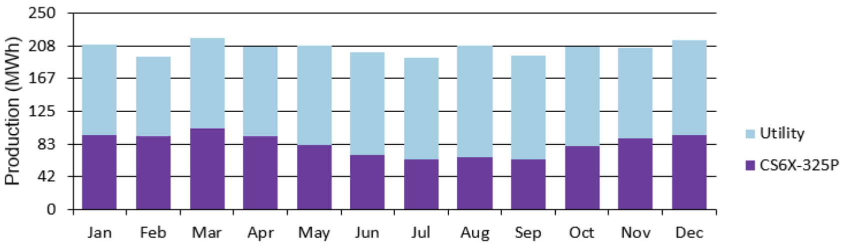

Figure 13. Allocation of production between utility and solar

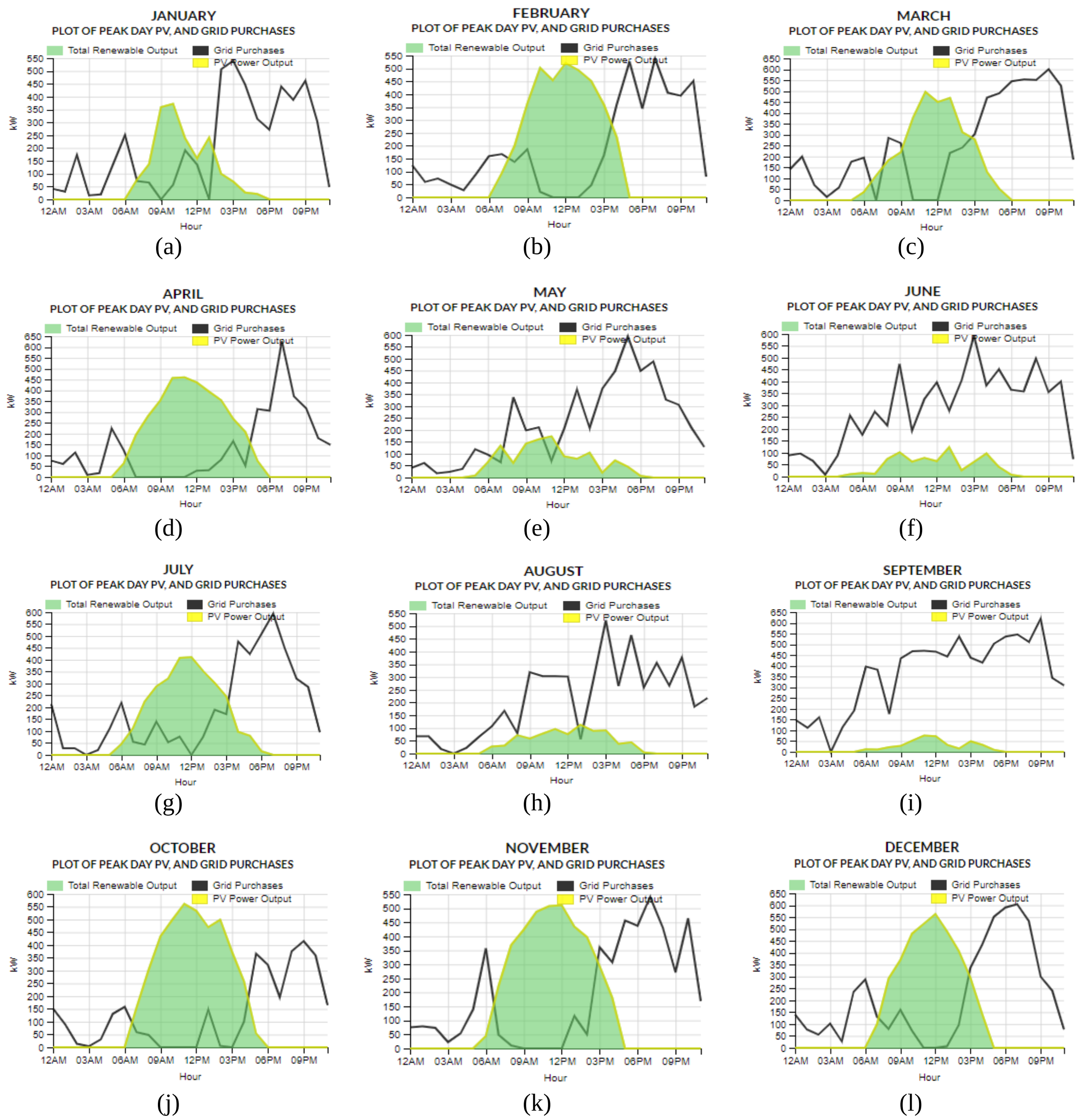

Figure 14. Daily representation of energy production by grid and PV for: a) January, b) February, c) March, d) April, e) May, f) June, g) July, h) August, i) September, j) October, k) November, and l) December

3.2. System cost evaluation

The cost evaluation of the framework indicates a capital expense of $42,586, with $26,756 in beginning capital. The replacement cost is $1,388, the annual operating cost is $14,841, and the salvage share is $400. The system's costs are compiled in Table 4, while its expenses are reported in Table 5. Given the projected SGTCS's significance and investor appeal, careful evaluation of installation and associated costs is critical. Along with technical and environmental benefits, the cost study finds the proposed solution fair, potentially lowering the PUCOE to 0.081 $/kWh from the grid's 0.688 $/kWh. This cost-effective strategy generates money for investors and has the potential to benefit the area economy.

Table 4. Proposed system's cost evaluation

Elements	Revenue	Substitute	O&M	Fuel	Salvage	Total
Canadian solar max power CS6X-325P	25,071.31	0	32,410.98	0	-400	57,081.89
Highway charger	0	0	-137,268.73	0	0	-137,268.73
Simple tariff	0	0	117,520.65	0	0	117,520.65
System converter	1,685.47	1,388.24	2,178.89	0	0	5,252.60
Total	26,756.78	1,388.24	14,841.78	0	-400	42,586.40

PUCOE, basic capital expenses, and NPC for the 30-year project period are included in the yearly expense evaluation of the framework that is covered in this section. The system's net present value remains fixed at $550,536. The solar power system construction cost $324,109, while the project's operation and maintenance costs came to $418,993 in total. This is the expense estimate for the suggested system design, as shown in the table. The salvage value is $-55,176. The grid's operating cost is $1,519,250, with no upfront costs. The converter, initially priced at $21,788, requires replacement after 5-years for a total of $17,946. The system's overall capital expenses are $345,898.

Table 5. Evaluation of the proposed system's yearly expenses

Elements	Revenue	Substitude	O&M	Fuel	Salvage	Total
Canadian solar max power CS6X-325P	324,109.80	0	418,993.48	0	-5,176.20	737,927.08
Highway charger	0	0	-1,774,543.84	0	0	-1,774,543.84
Simple tariff	0	0	1,519,250.08	0	0	1,519,250.08
System converter	21,788.91	17,946.47	28,167.64	0	0	67,903.02
Total	345,898.71	17,946.47	191,867.36	0	-5,176.20	550,536.35

Table 6 shows the essential parameters for the charging scheduling approach, which takes into account both small and large EVs, with session durations of 10-15 minutes for small EVs and 25-30 minutes for large EVs. EVs use 2,287,812 kWh of energy yearly, with a maximum output of 662.2 kW. 198 daily charging sessions are supported by six chargers, each of which has an overall capacity of 120 kW. The optimum EV scheduling strategy reduces lost sessions to around 1.1 per day, ensuring that charging resources are used to their full potential.

Figure 15 illustrates the highway charger's charging power on weekdays and weekends, revealing a modest overnight EV load with an increase during 6:00 a.m. to 10 p.m. The graph shows 24-hour average load demand. Figure 16 depicts the monthly electrical output from the highway charging station, which peaks at 200 MWh in August, drops to 174 MWh in February, and remains below 188 MWh in September and November. In April and June, the station generates more than 188 MWh. These numbers demonstrate how the highway charging station's monthly electricity output changes over the course of the year.

Table 6. EVs arranging parameters

	Sessions per year	Annual energy served (kWh)	Power each session (kWh)	Daily sessions	Peak power (Kw)	Daily missed sessions (avg)	Usage variable (%)
Highway charger	72,585	2,287,812	31.5	198.9	662.2	1.1	48.4

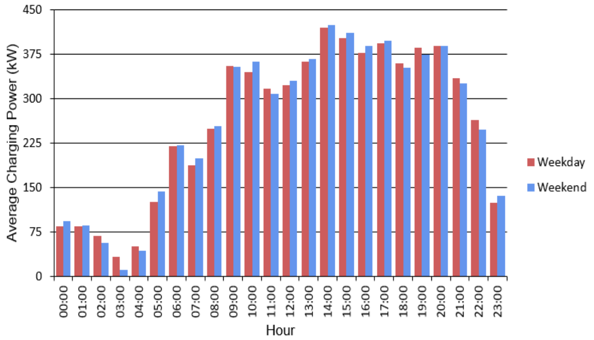

Figure 15. Estimated average charging load spectrum

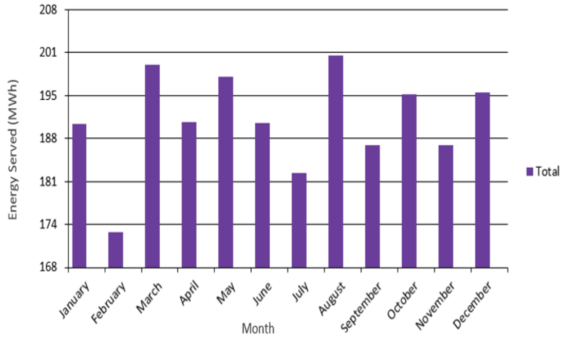

Figure 16. Charger's monthly energy provision

The majority of EVs are powered during 9:00 a.m. and 10:00 p.m., based on the results. This indicates that the peak hours of installed solar power generation are when the greatest number of EVs will be charged. As a result, the proposed system is optimized to make the most of the solar system's charging capacity. Even though particular months have been selected, the configuration of electric cars is regularly observed over several days of each month, employing a distinct plan for every day to guarantee that the maximum number of sessions occurs on median. We conduct various research to determine the ideal times of the month to charge EVs by highlighting the significance of our findings.

The average load for the EV charging station in relation to grid scheduling is shown in Figure 17. 214 sessions had been conducted as of January 1st, according to the graph in Figure 17(a), with grid supply being used for the majority of those sessions. This is due to less sun irradiation in January, which resulted in less solar generation. The total grid and solar power supply had concluded 205 charging events once the month ended. Solar energy primarily powered the majority from 8:00 a.m. to 11:00 a.m. and 5:00 p.m. to 7:00 p.m. on January 1st. Conversely, the majority were solar-powered from 12 p.m. to 4 p.m. on January 30th as demonstrated in Figure 17(b).

Furthermore, the majority of April sessions were powered by solar panels, according to the graph in Figure 17(c). On the initial day of the month, 218 sessions generated 6,866 kWh of energy, and by the end of the month, 193 sessions were completed. The increase in solar generation during April resulted from heightened sun irradiation and a decrease in grid supply. On April 1st, the grid supplied most of the electricity from 7:00 a.m. to 5:00 p.m., followed by a shift to solar power from 7:00 p.m. to 8:00 p.m. In contrast, the majority relied on solar power from 8:00 a.m. to 4:00 p.m. on April 30th before transitioning to grid electricity at 7:00 p.m., according to the graph in Figure 17(d).

Moreover, due to the low available irradiance in July, the grid system consistently maintained its maximum power output throughout the month. It is evident that 213 sessions were completed at the start of July, as indicated in Figure 17(e), consuming 7,091 kWh of energy, and by the month's conclusion, 231 sessions were accomplished. Notably, both the initial and final charging times fall within the range of 77 to 78. On July 1st, the primary electricity supply occurs between 05:00 and 09:00 pm, whereas the grid dominates the power supply on July 30th throughout the day, reaching its peak at 07:00 pm., as demonstrated in Figure 17(f).

Subsequently, the solar system and grid facilitated 259 sessions that were finalized in early July, consuming 7,938 kWh of electricity. There were 239 completed charging events by the last day of the month. As indicated in Figure 17(g), it is evident that the initial energy supply on October 1st was 6,938 kWh, decreasing to 7,179 kWh on October 30th. When the month came to its end, according to the graph in Figure 17(h), the grid predominantly supplies power throughout the day, peaking at 9:00 p.m., even though the majority is provided between 5:00 and 9:00 p.m. on the first day of October. The designed system ensures the dependability of EVs, with the solar system contributing a substantial proportion of the electricity. In July, solar systems yield the minimal electricity output due to reduced sun irradiation. Despite the SGTCS generating less solar electricity during the winter in our region, we can still draw the maximum power from the grid.

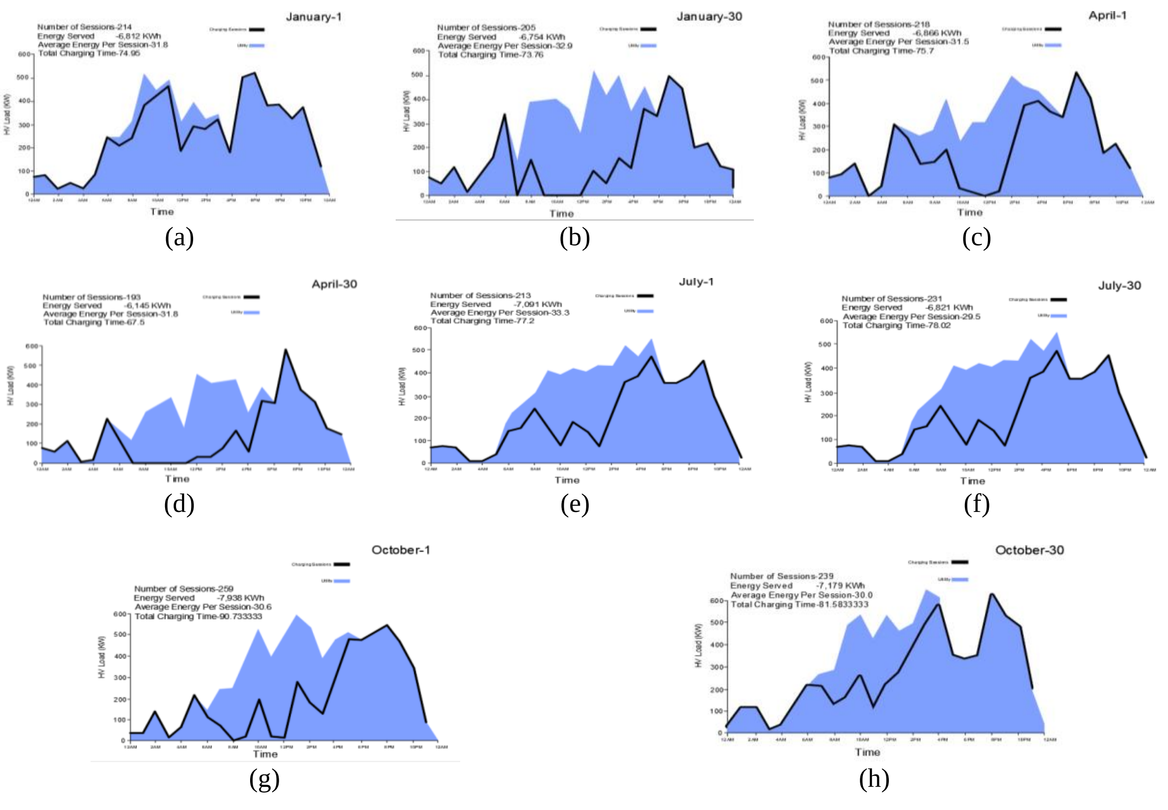

Figure 17. Average scheduling of electric vehicle for: (a) January 1st, (b) January 30th, (c) April 1st, (d) April 30th, (e) July 1st, (f) July 30th, (g) October 1st, and (h) October 30th

Furthermore, the median load pattern for the full year is displayed in Figure 18. The data indicates that the peak demand for EVs was 662 kW on March 16 and grew to 651 kW supply on June 18. Subsequently, the load was reduced to 2.50 kW on May 16th, the lowest figure that could be achieved, and it stayed reduced to 58 kW on July 3rd. The price schedule subtracts, on average, 198 sessions every day from the 200 scheduled sessions. Furthermore, when the system had excess power or the grid had excess electricity, it reached its maximum sessions. Additionally, EVs are setup such that most charging events occur during the day, when the solar is more powerful.

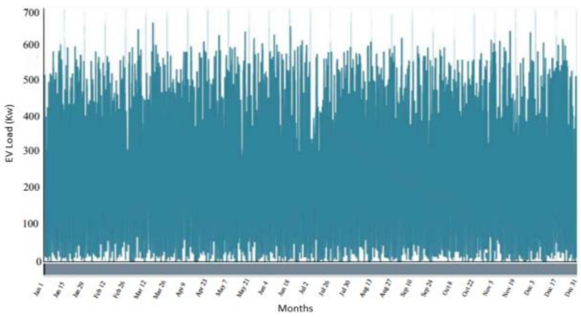

Figure 18. Electric vehicle charging analysis from January to December

3.3. Emission of carbon

The proposed system demonstrates a decrease in carbon emissions from 1,311,698 kg/year in the base scenario to 842,048 kg/year. Figure 19 indicates that implementing the suggested solar-powered charging station connected with it reduces carbon emissions by 469,650 kg per year. Monthly emissions peak at 90 metric tons in August before falling to the lowest of 64 tons in February.

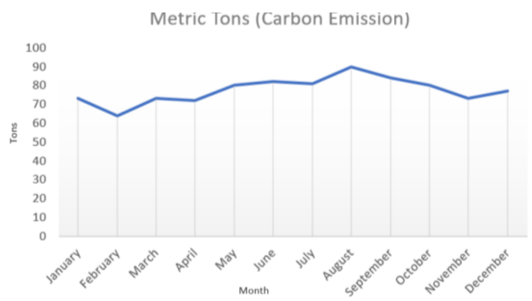

Figure 19. Emissions of carbon throughout the entire year

3.4. Major findings and contradiction

Table 7 compares the projected charged station connected to solar and grid systems to the baseline scenario without solar. The proposed system costs $0.0746/kWh, which is less than the base case of $0.833. The proposed system has an NPC of $550,536, which is less than the $690,393 base case. The system's renewable percentage is 39.10%, indicating that renewable energy accounts for a bigger share of the load. Compared to the base example, the SGTCS reduces demand by 997,940 kWh per year. Its carbon footprint is significantly lower by 842,048 kg/year than the grid's carbon of 1,311,698 kg/year.

Table 7. An analogy between the suggested system and the base case

Category	Base system	Proposed system
COE ($/kWh)	0.0833/kWh	0.0746/kWh
NPC	$690,393	$550,536
Renewable fraction	0%	39.10%
Grid load reduction	0 kWh/year	997,940 kWh/year
Carbon emission	1,311,698 kg/year	842,048 kg/year

4. CONCLUSION

The revolutionary potential of solar power PV is further enhanced by the growing demand for EVs in today's technologically advanced world, which offers more comfort, convenience, and financial advantages. This innovative idea not only illustrates the useful merging of solar power with electric cars, but it also provides an affordable pathway towards a more sustainable future. With a projected cost of $0.06/kWh compared to $0.081/kWh for the grid, the solar coupled with grid highway charging station is predicted to significantly reduce per-unit energy costs. By contributing 42.4% (834,388 kWh) of the total energy and drawing only 57.6% from the grid, the PV system lowers annual grid use by 834,388 kWh.

This study is considering necessary measures to lessen the dependency on fossil fuels and boost the effectiveness of our renewable energy initiative. Integrating energy storage devices is a crucial choice as they may store extra electricity from solar panels and offer a consistent power supply even on cloudy days. This improves project stability in addition to meeting financial and environmental goals. In addition, it will be created a smartphone app and solar monitoring system that will offer real-time data for ongoing performance monitoring and well-informed decisions regarding the growth of PV capacity. Grid integration will be simplified by the software, which will offer the best energy supply and demand balance for dependable service during periods of high demand or bad weather. Since this study is based on a real-time case, the purpose of it is multifaceted and revolves around advancing the integration of solar power, particularly PV systems, with EVs to promote sustainability and address the challenges associated with fossil fuel dependency. There is ongoing research and development being done on the usage of EVs in smart grids. In the near future, EVs are anticipated to become more prevalent as a new vehicle technology in the real-world applications of smart grid integrations because to the decreased cost of storage units. Because of the increases in battery capacity and lifespan, the integration of EVs into the smart grid is receiving a lot of attention. On the Bangladeshi perspective, the following sections will be the main emphasis of research studies on this vehicle-grid integration in this context: Advanced charging systems, energy management for a more effective use of renewable energy sources, using EVs as auxiliary services for the grid's dependable and secure operation, and energy trading for vehicles are the first four.

REFERENCES

[1] F. A. Akash, S. M. Shovon, W. Rahman, M. A. Rahman, P. Chakraborty, and M. U. Monir, "Greening the grid: a comprehensive review of renewable energy in Bangladesh," *Heliyon*, vol. 10, no. 5, p. e27477, Mar. 2024, doi: 10.1016/j.heliyon.2024.e27477.

[2] F. A. Begum, "Rooftop solar power-a sustainable option for Bangladesh," *The Financial Express*, no. August, pp. 1–4, 2019.

[3] B. Imam, "Why is solar power development so slow in Bangladesh? | The daily star," *The Daily Star*, 2018.

[4] S. Islam, "Bangladesh plans to attract EV manufacturers," *Pv Magazine International*, 2020.

[5] LightCastle Analytics Wing, "Current shape of electric and hybrid vehicle ecosystem in Bangladesh," *Light Castle Partners*, 2021. https://www.lightcastlebd.com/insights/2021/06/the-current-shape-of-ev-and-hybrid-vehicle-ecosystem-in-bangladesh/ (accessed Dec. 30, 2022).

[6] M. H. Masud, M. Nuruzzaman, R. Ahamed, A. A. Ananno, and A. N. M. A. Tomal, "Renewable energy in Bangladesh: current situation and future prospect," *International Journal of Sustainable Energy*, vol. 39, no. 2, pp. 132–175, Feb. 2020, doi: 10.1080/14786451.2019.1659270.

[7] "Barbados - CO2 emissions per capita," 2020. https://knoema.com/atlas/Barbados/CO2-emissions-per-capita (accessed Sep. 16, 2022).

[8] H. Shareef, M. M. Islam, and A. Mohamed, "A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles," *Renewable and Sustainable Energy Reviews*, vol. 64, pp. 403–420, Oct. 2016, doi: 10.1016/j.rser.2016.06.033.

[9] M. R. Ahmed and A. K. Karmaker, "Challenges for electric vehicle adoption in Bangladesh," in *2nd International Conference on Electrical, Computer and Communication Engineering, ECCE 2019*, Feb. 2019, pp. 1–6, doi: 10.1109/ECACE.2019.8679288.

[10] M. M. Islam, N. K. Das, S. Ghosh, and M. Dey, "Design and implementation of cost effective smart solar charge station," in *2014 9th International Forum on Strategic Technology, IFOST 2014*, Oct. 2014, pp. 339–342, doi: 10.1109/IFOST.2014.6991135.

[11] M. K. Mridul, A. Al Mahbub, M. T. Alam, and M. Ali, "Designing solar charging station for electric car at dhaka-chattogram national highway in Bangladesh," in *2020 IEEE Region 10 Symposium, TENSYMP 2020*, 2020, pp. 66–69, doi: 10.1109/TENSYMP50017.2020.9230763.

[12] M. M. Rashid, M. N. I. Maruf, and T. Akhtar, "An RES-based grid connected electric vehicle charging station for Bangladesh," in *1st International Conference on Robotics, Electrical and Signal Processing Techniques, ICREST 2019*, Jan. 2019, pp. 205–210, doi: 10.1109/ICREST.2019.8644130.

[13] S. Hasan, M. Zeyad, S. M. M. Ahmed, D. M. Mahmud, M. S. T. Anubhove, and E. Hossain, "Techno-economic feasibility analysis of an electric vehicle charging station for an International Airport in Chattogram, Bangladesh," *Energy Conversion and Management*, vol. 293, p. 117501, Oct. 2023, doi: 10.1016/j.enconman.2023.117501.

[14] A. Ghatak, R. B. Alfred, and R. R. Singh, "Optimization for electric vehicle charging station using homer grid," in *2021 Innovations in Power and Advanced Computing Technologies (i-PACT)*, Nov. 2021, pp. 1–7, doi: 10.1109/i-PACT52855.2021.9696626.

[15] S. Hosseini and M. Sarder, "Development of a Bayesian network model for optimal site selection of electric vehicle charging station," *International Journal of Electrical Power & Energy Systems*, vol. 105, pp. 110–122, Feb. 2019, doi: 10.1016/j.ijepes.2018.08.011.

[16] B. Singh, A. Verma, A. Chandra, and K. Al Haddad, "Implementation of solar PV- battery and diesel generator based electric vehicle charging station," *IEEE Transactions on Industry Applications*, vol. 56, no. 4, pp. 1–1, 2020, doi: 10.1109/TIA.2020.2989680.

[17] A. Tazay and Z. Miao, "Control of a three-phase hybrid converter for a PV charging station," *IEEE Transactions on Energy Conversion*, vol. 33, no. 3, pp. 1002–1014, Sep. 2018, doi: 10.1109/TEC.2018.2812181.
[18] H. Fathabadi, "Novel wind powered electric vehicle charging station with vehicle-to-grid (V2G) connection capability," *Energy Conversion and Management*, vol. 136, pp. 229–239, Mar. 2017, doi: 10.1016/j.enconman.2016.12.045.
[19] D. Yan, H. Yin, T. Li, and C. Ma, "A two-stage scheme for both power allocation and EV charging coordination in a grid-tied PV–battery charging station," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 10, pp. 6994–7004, Oct. 2021, doi: 10.1109/TII.2021.3054417.
[20] M. Brenna, A. Dolara, F. Foiadelli, S. Leva, and M. Longo, "Urban scale photovoltaic charging stations for electric vehicles," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 4, pp. 1234–1241, Oct. 2014, doi: 10.1109/TSTE.2014.2341954.
[21] M. Kumar, S. Vyas, and A. Datta, "A review on integration of electric vehicles into a smart power grid and vehicle-to-grid impacts," in *2019 8th International Conference on Power Systems (ICPS)*, Dec. 2019, pp. 1–5, doi: 10.1109/ICPS48983.2019.9067330.
[22] R. Moghe, F. Kreikebaum, J. E. Hernandez, R. P. Kandula, and D. Divan, "Mitigating distribution transformer lifetime degradation caused by grid-enabled vehicle (GEV) charging," in *2011 IEEE Energy Conversion Congress and Exposition*, Sep. 2011, pp. 835–842, doi: 10.1109/ECCE.2011.6063857.
[23] M. Li, Y. Wang, P. Peng, and Z. Chen, "Toward efficient smart management: a review of modeling and optimization approaches in electric vehicle-transportation network-grid integration," *Green Energy and Intelligent Transportation*, p. 100181, Feb. 2024, doi: 10.1016/j.geits.2024.100181.
[24] D. Jóźwiak, J. Pillai, P. Pavani, B. Bak-Jensen, and J Jantzen, "Optimal charging and discharging strategies for electric cars in PV-BESS-based marina energy systems." *Electronics*, vol. 12, p. 1033,2023, doi: 10.3390/electronics12041033.
[25] V. K. Manickam and K. Dhayalini, "Hybrid optimized control of bidirectional off-board electric vehicle battery charger integrated with vehicle-to-grid," *Journal of Energy Storage*, vol. 86, p. 111008, May 2024, doi: 10.1016/j.est.2024.111008.

BIOGRAPHIES OF AUTHORS

Al Amin Hossain holds a B.Sc. degree in Electrical and Electronics Engineering from the American International University Bangladesh and is on the verge of completing his M.Sc. in Electrical Electronics and Communication Engineering (EECE) at the Military Institute of Science and Technology. Recognized for his academic achievements, he received the outstanding project and thesis award (2nd position) at AIUB in 2013-14. His research interest lies in the intersection of machine learning, electricity market forecasting, and power systems control, with a specific focus on short-term electricity price forecasting and the implementation of fuzzy unified power flow controllers. Currently a key member of reverie power and automation engineering limited, he leads the engineering and design team and holds a prominent position in the R&D team. His professional expertise extends to the design and solution of MV/LV electrical substations, MV/LV type tested switchgear panels, GIS and AIS switchgear panels, data center electrical systems, power quality management, busbar trucking systems, lightning protection systems, photovoltaic systems, testing and commissioning of substations, project management, and schematic design using ePlan and other related software, as well as power system analysis utilizing ETAP. He is Certified in AutoCAD electrical, ETAP, ABB (TTA panel), ONAY lightning protection system, and CCDCFP by SAPCO in Bangladesh's industrial sector. He can be contacted at email: hossain.amin899@gmail.com.

Professor Abdus Samad a distinguished academic and professional in Electrical, Electronic, and Communication Engineering (EECE), currently serves as a Professor at the Military Institute of Science and Technology. Born on August 3rd, 1951, in Bangladesh, he achieved academic excellence with a First-Class result in his 1973 Bachelor's degree from Rajshahi University. His Masters is from Roorkee University (now IIT) and Ph.D. from the Indian Institute of Technology (IIT) in 1987 showcased his expertise in power system and communication system reliability engineering. With a career spanning over 42 years, Professor Samad has held key academic and administrative roles, including Vice-Chancellor of Prime University, Dhaka. His research interests span power system engineering, reliability analysis, electronics, communication systems, graph theory, and image processing. Beyond academia, he has contributed significantly to the industrial sector, holding roles such as Director of BIT, Khulna. Awards, recognitions, and cultural exchange scholarships underscore his commitment to excellence, innovation, and leadership, leaving an enduring impact on the electrical engineering landscape in Bangladesh. He can be contacted at email: prof.m.a.samad01@gmail.com.