

Energy Management and Techno-Economic analysis of Solar, Wind, and Grid-connected EV Charging station: A Case Study in India

¹Sohankumar Prajapati, ²Sanjay R Vyas

¹Research Scholar, Kadi Sarva Vishwavidyalaya, Gandhinagar, Gujarat, India

²Professor, L.D.R.P Institute of Technology and Research, Gandhinagr, Gujarat, India

Abstract

Globally, electric mobility is growing in popularity. The charging station appears to be an integral part of the overall strategy. A solar photovoltaic (PV) and wind energy system as local energy sources to deliver power for an electric vehicle charging station becomes crucial to generating profit and environmental benefits compared to a local grid-powered charging station. An economic and technical evaluation of a charging station that draws power from multiple sources will be carried out to assess the economic factors for charging station operators. This investigation makes reference to the city of Santalpur in the Indian state of Gujarat. The various types of power flow are developed based on the production of power in real time. The system is designed to charge 60 electric vehicles at various times throughout the day. In MATLAB, the proposed system is evaluated. The proposed method is contrasted with an electric vehicle (EV) charging station that uses only grid electricity. The results demonstrate that the proposed method yields a 21% increase in daily profit. In addition, there has been a 44% reduction in grid stress. The proposed system has a payback period of three and a half years and reduces annual carbon emissions by eighty-two tonnes.

Introduction: The transition to electric mobility is one potential global strategy for lowering greenhouse gas emissions in the transportation sector. The worldwide EV3030 movement, which has set the target of having at least 30% of all newly sold cars be electric by 2030, is supported by just a select few nations, including India.



Fig. 1. View of proposed system

Objectives: To reduce grid burdern. Increase profit for charging station owner. Reduce carbon emission.

Methods: As per renewable energy assessment, the four modes of energy flow are designed.

To verify that the PV-wind hybrid system meets the load power requirement, the PPV and PW must be calculated. The goal function is developed by taking dependability into account.

The difference between produced and demanded power is computed as follows:

$$\Delta P(t) = P_{pv}(t) + P_w(t) - P_{EVL}(t) - P_{LL}(t) \quad (4)$$

In the event that generation from these sources is insufficient to meet load demand, electricity is drawn from the grid at a cost of $P_g(t)$. In addition, the excess electricity from the sources after fulfilling the load demand is sold to the grid at $P_g(t)$. On the grid side, it is considered that there are no constraints on selling and buying electricity. The instances are generated as follows with respect to $\Delta P(t)$.

Results:

Table 1. Outcome Analysis

Parameter	Unit	GP-EVCS	Proposed SWGP-EVCS		
		Grid	Solar	Wind	Grid
EVs charge in a day	Number	60	60		
EV Charging Rate	INR/unit	19	19		
Grid Electricity Tariff	INR/unit	8.00	0	0	8.00
Amount of Energy Consume by EVs and	KWh/day	1186.6	227.5	268.2	691.0
Energy Purchase Cost from Grid	INR	9493.2	0.0	0.0	5528.0
Total amount of energy sold to the Grid	KWh/day	--	31.6		
Revenue generate from Renewable Energy	INR	--	71.2		
Amount of Energy sale for EVs charging	KWh/day	1014.4	1014.4		
Revenue generate from EVs Charging	INR	19274.5	19274.5		
Net Profits from EV Charging	INR	9781	13746.5		
Energy Profit	%	50.7	71.3		
Percentage of More Energy Profit	%		21		
Grid Stress Reduction	%		44		
Payback period	Years	2.3	3.5		
CO ₂ emissions reduction (individual)	Tons/Year		64.1	17.9	
Total Carbon dioxide emissions reduce	Tons/Year		82.0		

Conclusions: In the context of the Indian power market, this paper examines energy management and techno-economic analysis in relation to the cost-effective strategy of solar, wind, and grid-powered EV charging stations (SWGP-EVCS). The proposed approach is contrasted with a baseline EV charging station that only uses grid electricity (GP-EVCS). The dynamic demand from EVs and the real-time forecasted energy from renewable sources have been taken into consideration while creating the four modes of energy flow. As per the techno-economic analysis, the proposed SWGP-EVCS base system has the following key findings against GP-EVCS:

- Has a 21% increase in profit on an exercised day.
- There has been a 44% reduction in grid stress.
- It reduces carbon emissions by 82 tones in a year.

However, GP-EVCS has a payback period of 2.3 years, whereas a SWGP-EVCS has a 3.5 year payback due to the higher initial investment.

The proposed system can be applied to large scale EV charging networks.

Keywords: EVCS Energy management, RES Based EVCS, PV, Wind tided EVCS, Techno-Eco analysis of EVCS

1. Introduction

In this paper, a grid-connected system, solar PV, and wind energy are used to deliver energy for an EV charging station (EVCS). Fig. 1 depicts the perspective of the proposed EV charging infrastructure.

Nishanth et al. [1] investigated the performance of the charging station that charges 17 EVs per day with the goal of site selection and technical and economic analyses. The results reveal a lower net present cost of \$303 291.26 and an energy cost of \$0.072/kWh with a 50% decrease in emissions. In Kabir et al. [2], the authors made use of a centralised system that was built on integer linear programming (ILP) in order to determine the appropriate cost for EV charging. The purpose of this research was accomplished when it was discovered that a speedier charging process could be carried out at the lowest possible cost. Wu et al. [3], presented two different algorithms that were used to evaluate the requirements for electric vehicle (EV) charging as well as the savings in annual expenditures that may be realised by enterprises and office complexes. The results demonstrated that the methods are both effective from a computational standpoint and functional in real time. What's more noteworthy is that they were able to save 7.2% on average, which brought the total savings to 6.9%. Gong et al. [4] studied a method for charging electric cars that would not only reduce the amount of energy used but also save drivers money. The optimal findings showed that there was potential for a 7.6% reduction in charging expenditures during the winter and a 10.3% reduction during the summer. In Zhou et al. [5], an optimization model was made to solve the problem of how big EV charging stations should be by combining RES, ESS, and different types of chargers. The proposed model was made to cut down on investment costs and make EV charging stations more profitable. According to Singh et al. [6], ABC and PSO optimization algorithms were performed to obtain least leveled cost of electricity (LCOE) and minimize the loss of power supply probability (LPSP). According to the work that was done by Yaqin et al. [7], an optimization model was designed to assist with the charging of electric cars. This model was developed so that it could adapt to new requirements while keeping

the cost of electricity to a minimum. An energy management system (EMS) was developed by Sayed et al. [8] and carried out in Egypt to govern the flow of electricity from renewable energy sources (RES) to electric vehicles (EVs). The authors, Rahman et al. [9], attempted to reduce carbon emissions by deploying solar PV, wind, and fuel cell energy sources in HOMER software and system analysis based on Monte Carlo simulations. A strategy for the management of energy was presented by Akil et al. [10] in order to facilitate the charging of electric vehicles in industrial zones in Turkey with the aim of charging EVs at the lowest possible cost. Their findings suggest that the requirements for recharging electric vehicles might be satisfied in a variety of time frames. Gunkel et al. [11] investigated the influence that the Balmorel model would have on the integration of RES with EVCS. Optimum demand response and coordination of electric vehicle (EV) aggregators presented by Harsh et al. [12], Liu et al. [13], a system for conserving energy in electric vehicles, was developed after taking into account various driving circumstances. By taking a look at electric vehicle management, the authors of Casella et al. [14] produced a review for the convergence of the transportation and smart grid industries. Zhao et al. [15] focused on a method to reschedule the power system that took into account electric vehicles as well as renewable sources of electricity. However, not only did Ouramdane et al. [16] take into consideration EVs and renewable energy sources, but they also included energy storage. Its primary focus was on home energy management rather than that of businesses. The aim of optimising charging station revenues by limiting grid power purchases and selling power to the grid during periods of great solar availability was realised through the design of the charging algorithm by Prajapati et al. [17]. The microgrid imbalance, variable EV demand, and the cost of electricity were all factors that inspired the Zandrazavi et al. [18] study's authors to create a stochastic multi-objective optimization model. Epsilon-constraint techniques and fuzzy logic were used to solve the issue. Optimize energy management and reduce energy-related costs using the GFO-VITG method, as described in Rajesh et al. [19]. Amir et al. [20] came up with the

Q-learning method to lower the costs of running microgrids with renewable energy sources and charging stations for electric vehicles on a large scale. In Goli et al. [21], a DC link voltage sensing-based control approach was developed for energy flow modes in PV, ESU, and grid-based EV charging. This was done to lower the cost of running the system. The droop regulation technique was used by Raj et al. [22] to reduce grid stress caused by fast charging in PV, BESS, and grid-connected systems. The charging and discharging power from the ESS, as well as the electricity drawn from the grid, are optimised in PV Integrated EV Charging Stations by Chaudhari et al. [23] in accordance with price band allocation. A stochastic model was developed by Himabindu et al. [24] for the optimal power sharing in PV-Wind-ESU and grid-powered EV charging stations for the EV traffic profile, arrivals, and resource use pattern. The PV-ESU connected electric car charging cost can be reduced using the time-of-use adjustment strategy.

The system consists of solar PV panels installed on the charging station's roof and a ground-mounted wind turbine set at a height of 10 meters. The charging station is also connected to the grid supply.

2. Objectives

The system consists of solar PV panels installed on the charging station's roof and a ground-mounted wind turbine set at a height of 10 meters. The charging station is also connected to the grid supply.

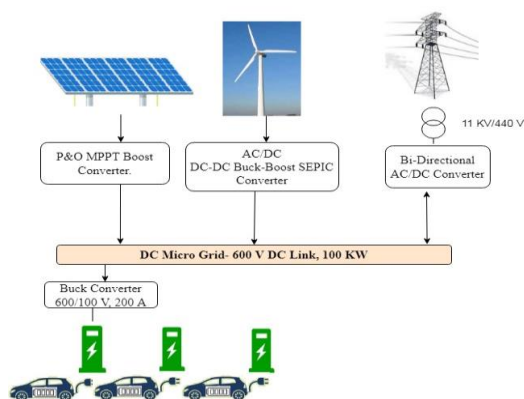


Fig. 2. Schematic diagram of proposed system

Methods

2.1. Photovoltaic (PV) System

The polycrystalline type PV panels are placed on the roof of the charging station at a fixed tilt angle. The charging station is designed for three chargers of 15 KW, 20 KW, and 50 KW capacities. The size of the solar PV plant is 50 KW on the basis of roof area available and the energy needed at the charging station. The Santalpur city of Patan district in Gujarat state of India, having latitude 23.75 and longitude 71.15, was selected for the charging station's technical and economic analysis. For the real-time power forecast, the weather data was taken from [25], Based on the temperature and amount of sunlight at the site, Eq. (1) is used to find out the PV power [26],

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_T}{G_{T_STC}} \right) [1 + \alpha_p (T_c - T_{c_STC})] \quad (1)$$

Where;

Y_{pv} = PV array sizing in kW

f_{pv} = the PV derating factor in %

Estimated system loss 14.08 % including soiling loss 2 %, Shading loss 3 %, Module mismatch loss 2%, Wiring loss 2%, Joints 0.5 %, weak radiation 1.5 %, Name plate rating 1% and availability 3 %.

G_T = Irradiance in kW/m²

G_{T_STC} = Irradiance of 1000 W/m² at standard test conditions

α_p = the temperature coefficient of power [%/°C]

T_c = the PV cell temperature in the current time step [°C]

T_{c_STC} = the temperature of a PV cell under standard test conditions [25°C].

In Table 2, the parameters of the PV system are shown.

Table 2. Parameters of Solar PV System

Para	P _p	Mod	Arr	Module	W	N	N
Unit	K	%	deg	--	W	-	-
Value	50	15.5	23	Polycry	30	1	9

2.2 Wind Turbine

The onshore ground mounted wind turbine of 50 KW capacities selected for the deliver energy to charging station. The day of 15th April 2022 hourly wind speed data availed from [27].

The power output from wind turbine on the basis of wind speed calculated by Eq. (2) [28];

$$P_w = \begin{cases} 0 & v \leq v_c \text{ or } v \geq v_o \\ P_r * \frac{v^k - v_c^k}{v_r^k - v_c^k} & v_c \leq v \leq v_r \\ P_r & v_r \leq v \leq v_o \end{cases} \quad --(2)$$

Where P_r is rated power; v_c is the cut-in wind speed; v_r is the rated wind speed; and is the v_o cut-off wind speed.

Table 3. Parameters of PMSG Wind turbine

Parameter	P_r	v_c	v_r	v_o	H_h	N_g	N_b
Unit	KW	m/s	m/s	m/s	m	%	%
Value	50	2	11	25	10	8	8

2.3 Grid

The grid power is taken from an 11/440 V pole mounted transformer and supplied back when surplus power occurs. The grid supply comes from 11 KV feeders from the 66 KV substations. According to the GERC tariff order 2022-23 [29], the energy tariff from the grid is considered INR 4.0 as an energy charge for HT Connection for electrical vehicle charging stations. The gross purchase cost of grid energy per KWh is taken at RS. 8.0, including fix charge, energy charge, fuel charge, and electricity duty. On the other hand, the surplus renewable energy rate for sale to the grid is estimated to be Rs. 2.25 [30].

2.4. Estimation of EV Charging Station Load

The following models of Indian EV cars and their battery capacities are considered [31].

Table 4. Electric vehicle models and battery capacity.

Sr. No.	EV Model	Battery Size (kWh)
1	Mahindra eVerito	21.2
2	Tata Tigor	26
3	Tata Xpres-T	21.5
4	TATA NEXON	40.5
5	Hundai Kona	39.2
6	MG ZS	45
7	Mahindra eSupro	25

The station's lightning load and other auxiliary load are assumed while the EV load is estimated as per Eq. (3).

$$P_{EV_{Load}} = (SOC_{Req} - SOC_{Ini}) \times EV_i - BC \quad --(3)$$

Table 5. Electric Vehicles Load Estimation

Hour	No. Of EVs Plugged	EV Model	EV Battery Capacity (KWh)
1	1	Hundai Kona	39.2
2	0		0
3	0		0
4	3	TATA NEXON	40.5
		Hundai Kona	39.2
		Mahindra	21.2

Initial SOC (%)	Required SOC (%)	Real Time Max EV Load (KW)
15	85	27.4
0	0	0.0
0	0	0.0
0	85	34.4
10	85	29.4
15	80	13.8
		77.6

The EV load for the 24 hour period is estimated as per the above calculation.

Table 6. EVs' Load for the 24 hour time period

Hour	No. of EV Plugged	EV Load (KW)
1	1	27.4
2	0	0.0
3	0	0.0
4	3	77.6
5	3	44.9
6	3	55.0
7	3	44.2
8	3	62.1
9	3	41.3
10	3	47.0
11	2	33.5
12	2	38.2
13	3	40.4
14	3	37.2
15	3	48.3
16	3	39.4
17	2	39.4

18	3	59.8
19	3	63.2
20	3	35.9
21	3	55.2
22	3	42.7
23	2	30.9
24	3	50.9
Total	60	1014.4

2.5 EV Charging Rate

The charging rate of electrical vehicle is availed INR 19.00/KWh from TATA power charging tariff in Gujarat [32].

3. ENERGY MANAGEMENT OPERATIONAL STRATEGY

As per renewable energy assessment, the four modes of energy flow are designed.

To verify that the PV-wind hybrid system meets the load power requirement, the PPV and PW must be calculated. The goal function is developed by taking dependability into account.

The difference between produced and demanded power is computed as follows:

$$\Delta P(t) = P_{PV}(t) + P_W(t) - P_{EVL}(t) - P_{LL}(t) \quad (4)$$

In the event that generation from these sources is insufficient to meet load demand, electricity is drawn from the grid at a cost of $P_g(t)$. In addition, the excess electricity from the sources after fulfilling the load demand is sold to the grid at $P_g(t)$. On the grid side, it is considered that there are no constraints on selling and buying electricity. The instances are generated as follows with respect to $\Delta P(t)$.

3.1 Energy Flow Operational Modes

Mode-1

$P_W + P_G$ to EVs & Station local load

If $\Delta P(t) < 0$, during night time, power generation from PV is zero and wind power is not enough to drive the station's total load. The deficit power for the load is available from the grid as follows:

$$P_{g_{imp}}(t) = (P_{EVL}(t) + P_{LL} - P_W(t)) / \eta_{rec} \quad (5)$$

Mode-2

P_W to Grid & Station local load

When no vehicle is charging at the charging station at 2:00 am, the EV load is zero and wind power is enough to drive the station's local load. The surplus wind power is exported to the grid for the revenue generation.

$$P_{g_{exp}}(t) = (P_W(t) - P_{LL}(t)) / \eta_{inv} \quad (6)$$

Mode-3

$P_{PV} + P_W + P_G$ to EVs & Station local load

If $\Delta P(t) < 0$, The electricity provided by the rooftop solar PV and wind turbines is insufficient to drive the required power for EVs and the local electric load. As a result, the needed electricity is obtained from the grid as follows:

$$P_{g_{imp}}(t) = (P_{EVL}(t) - P_W(t) - P_{PV}(t)) / \eta_{rec} + P_{LL} \quad (7)$$

In this scenario, the load from electric cars (EVs) is higher than the available power from solar and wind, which leads to power shortages while attempting to charge EVs from the grid. This could also happen if there were a big jump in the number of EVs at the charging station.

Mode-4

$P_{PV} + P_W$ to Grid, EVs & Station local load

If $\Delta P(t) > 0$, the total amount of power produced by PV panels and wind turbines is enough to charge EVs and meet local load needs. Also, the excess power $P_{g_{exp}}(t)$ is sold to the grid, which is calculated as follows:

$$P_{g_{exp}}(t) = (P_{PV}(t) + P_W(t) - P_{EVL}(t)) \eta_{inv} - P_{LL}(t) \quad (8)$$

3. Results

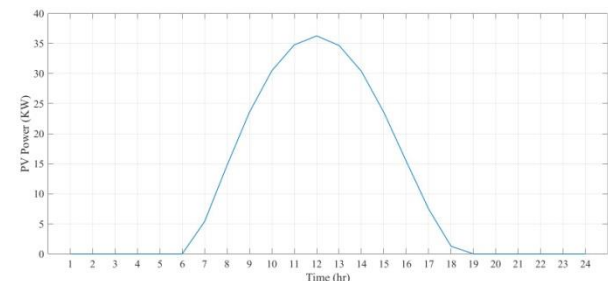


Fig. 3. PV Power Generation.

The highest PV power production at a site is found at 36.25 KW at 12:00 noon, while total production of solar PV power throughout the day is 257.8 KWh. The average sunshine hours of the available location is 5.2 hours, as estimated.

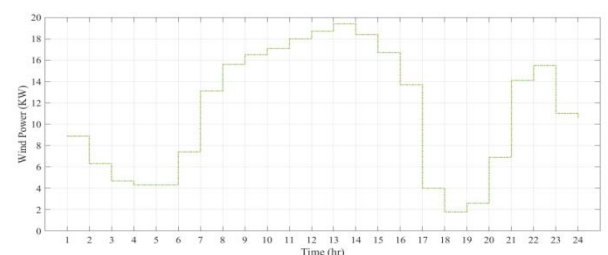


Fig. 4. Wind Power Generation.

Fig. 4 shows the amount of power generated by a wind turbine with an installed capacity of 50 KW is at its highest point of 19.4 KW at the time of 13:00 hours, and it is at its lowest point of 1.8 KW at the time of 18:00 hrs. Throughout the course of the day, a daily average wind power measurement of 10.78 kilowatts (KW) was obtained. The total wind power in a day is observed at 269.5 KW.

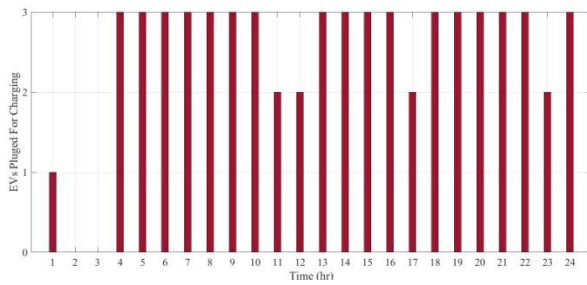


Fig. 5. Numbers of EVs plugged.

Fig. 5 depicts the total number of electric cars that are currently being charged at an EVCS. During the day, there are a total of sixty electric vehicles (EVs) charged.

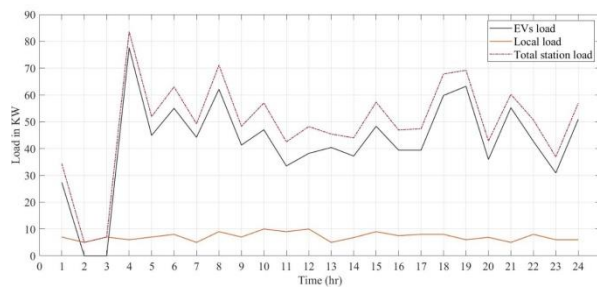


Fig. 6. Total load at the charging station

In Fig. 6, the overall electric load at the charging station is shown. This is the sum of the local load at the charging station as well as the load from electric vehicles charging.

The total load at EVCS is lowest when there are no electric cars arriving for charging. Hence, the EVCS load in that event is only 5KW due to local load. When there is a local load and the maximum number of electric cars is linked into the system in further time, the load is at its greatest, which is an instant of 83.6 kW. Over the course of the twenty-four hours, the overall total EV load was 1014.4 KW, while the local load was 172.2 KW. As a result, there is a total electric load of 1186.6 kW at the charging station.

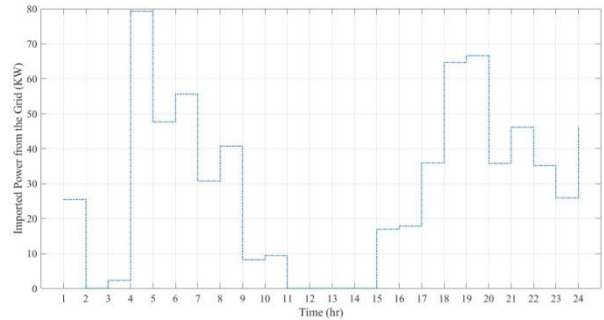


Fig. 7. Power imported from grid

When the EV load is higher than RES, the power is imported from the grid to meet the charging requirements of EVs. Throughout the day, 691 KW of power were brought in from the grid.

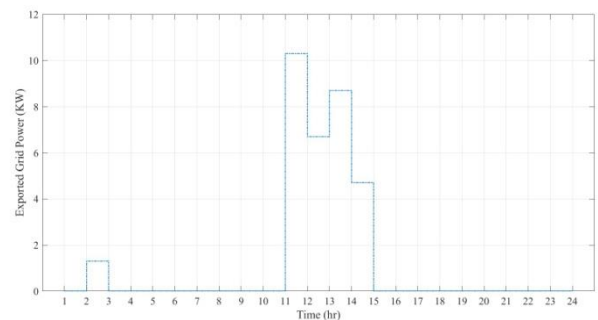


Fig. 8. Power Exported to grid

In the event that demand for electricity from EVs is lower than the quantity of energy being produced by RES sources, the surplus energy from RES is delivered back into the grid. This happens during the period of time starting at midnight and going until five in the afternoon, inclusive. In addition, solar and wind power were used to generate energy that was sold to the grid between the hours of 2:00 to 3:00 am and 11:00 am to 15:00 pm. Throughout the day, a total of 31.6 KWh of electricity exported. The highest unit, 10.3 KWh, was exported between 11 and 12 p.m.

As shown in Fig. 8, whenever the demand for electricity from EVs is greater than the amount of energy that is being created by RES sources, the surplus energy is imported from the grid. This occurs anytime the demand for electricity from EVs is higher than the amount of energy that is generated.

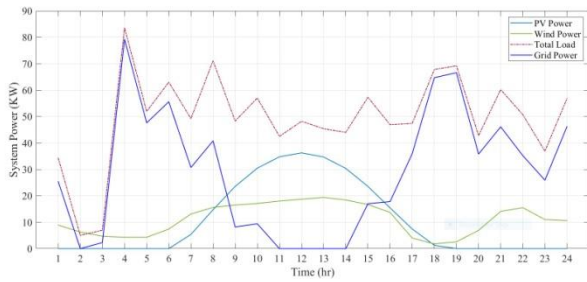


Fig. 9. System Power

The charging station's total load is fulfilled by solar, wind, and grid energy.

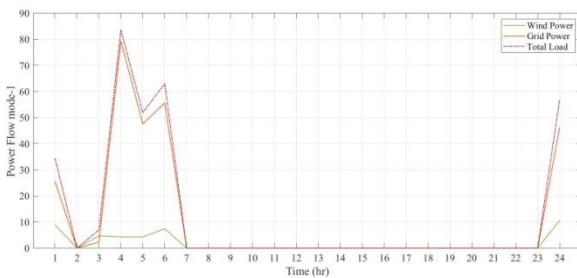


Fig. 10. Energy Flow Mode-1

Fig. 10 depicts a potential scenario for the transfer of energy in mode 1.

Mode: 1 PW+PG to EVs & Station local load

During this mode, the charging station has an average load demand of 296.9 KW, while the renewable energy source only provides an average of 40.1 KW of power. The 256.8 kilowatts of power that had to be brought in from the grid in order to compensate for the shortfall in load demand

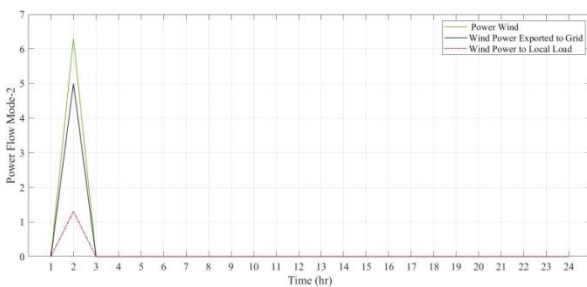


Fig. 11. Energy Flow Mode-2

Mode:2 PW to Grid & Station local load

When operating in this mode, the power produced by the wind turbine is 6.9 KW while the demand at the charging station is 5 KW. Therefore, the extra electricity of 1.9 kilowatts was transmitted to the grid, and 5.0 kilowatts were given to charge the electric vehicles.

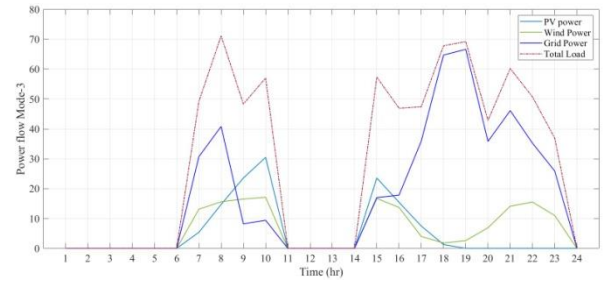


Fig. 12. Energy Flow Mode-3

Mode:3 PPV+PW+PG to EVs & Station local load

In Fig. 12, mode-3, The amount of power generated by solar PV is 121.78 kW, the amount of power generated by wind is 148.7 kW, and the amount of load demand is 704.7 kW; thus, 434.2 kW of shortfall electricity is withdrawn from the grid to fulfill load demand.

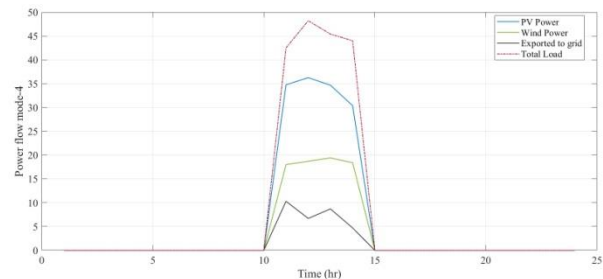


Fig. 13. Energy Flow Mode-4

Mode-4: PPV+PW to Grid, EVs & Station local load

The charging station load in mode 4 is 180.1 KW, which is more than sufficient to meet the real-time load demand. In mode 4, the PV power is 136 KW while the wind power is 74.4 KW. The extra 30,3 KW was sent back into the grid, which made money for the owner of the charging station.

4. Discussion

In Table 7. Type of charger and its capacity is considered as per EVCS revise guideline from ministry of power, government of India [33].

Table 7. Charging station Cost Analysis

Particulars	Rating	Cost in INR (incl. 18% GST)	Ref.
CCS-2 Charger	50 KW (2 Gun)	1200000/-	[34]
Bharat DC – 001 Charger	20 KW (1 Gun)	250000/-	[35]

Bharat DC – 001 Charger	20 KW (1 Gun)	250000/-	
Electricity connection, transformers,	11/440 V	700000/-	[36]
Civil Works	Room	300000/-	
Maintenance and Technical team		300000/-	
Management Software		400000/-	
Land Lease (INR 50,000 per month)		600000/-	
Initial Investment(INR)		4000000	
Solar PV plant (Rs.38236 Rs./KW)	50 KW	1911800	[37]
Wind Turbine	50 KW	2700000	[38]
Initial Investment (INR)		8611800	
Net Annual cash flow (INR)	GP-EVCS	SWGP-EVCS	
	1760633	2474361	

5.1 Payback Period Calculation

$$\text{Payback Period} = \frac{\text{Initial investment}}{\text{Cash flow per year}} \quad \text{--(9)}$$

Payback Period for GP- EVCS :

Initial investment = 40,000,00.00 (As per Table 7.)

Cash flow/Y = Net profit/day \times 30 \times 6 (Avg. Months) renewable power production and Electricl vehicles load.

Net profit/day =

$$\begin{aligned} \text{Revenue from EVs Charging} - \text{Energy Purchase Cost} \\ = 19274.5 - 9493.2 = 9781.3 \approx 9781.00 \end{aligned}$$

$$\therefore \text{Cash flow per year} = 9781 \times 30 \times 6 = \text{Rs.}17,60,633.00$$

$$\therefore \text{Payback Period For GP-EVCS} = \frac{\text{Rs.}40,000,00}{\text{Rs.}17,60,633}$$

$$= 2.27 \approx 2.3 \text{ Years}$$

Payback Period for SWGP - EVCS :

Initial investment = 86,118,00.00 (As per Table 7.)

Cash flow/y = Net profit/day \times 30 \times 6 (Avg. Months)

Net profit/day =

$$\begin{aligned} \text{Revenue from EVs Charging} - \text{Energy Cost} \\ = 19274.5 - 5528 = 13746.5 \end{aligned}$$

$$\therefore \text{Cash flow per year} = 13746.5 \times 30 \times 6$$

$$= \text{Rs.}2474361.00$$

\therefore Payback Period For SWGP-EVCS

$$= \frac{\text{Rs.}86,11,800}{\text{Rs.}24,74,361} = 3.48 \approx 3.5 \text{ Years}$$

5.2 Profit Calculation

Profit of GP-EVCS :

$$\begin{aligned} \frac{\text{Net Profit from EVs charging}}{\text{Revenue generate from EV charging}} \times 100 \\ = \frac{9781}{19274.5} \times 100 = 50.7 \% \end{aligned}$$

Profit of SWGP-EVCS:

$$\begin{aligned} \frac{\text{Net Profit from EVs charging}}{\text{Revenue generate from EV charging}} \times 100 \\ = \frac{13746.5}{19274.5} \times 100 = 71.3 \% \end{aligned}$$

5.3 CO2 Emission Reduction Calculation

CO2 Emission Reduction from Solar PV

From [39], a factor of 0.932 kg is multiplied by one KWh of electricity from a solar PV rooftop power plant in India to get the amount of carbon dioxide reduction in tones per year.

The data of yearly solar potential of a site, obtained from NREL [40].

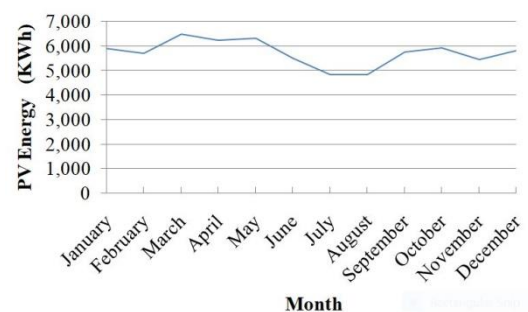


Fig. 21. Month Wise PV Power Production

The aforementioned energy generation takes into account the 23.3 percent of total system loss. In other words, the performance ratio of the PV plant is taken to be 76.7%.

CO₂ Emission Reduction From Solar PV Plant

CO₂ Emission reduction / annum

$$= 0.932 \text{ kg} \times \text{Annual KWh} \quad (10)$$

∴ CO₂ Emission reduction / annum

$$= 0.932 / 1000 \times 68795$$

CO₂ Emission reduction / annum = 64.1 Tons

CO₂ Emission Reduction from Wind PV Plant

Wind speed data from a location in Santalpur, Gujarat, was gathered from NASA [41] to compute the annual energy output from a 50 KW wind generator, and the project site's geographical coordinates are 23.75° N and 71.15° E.

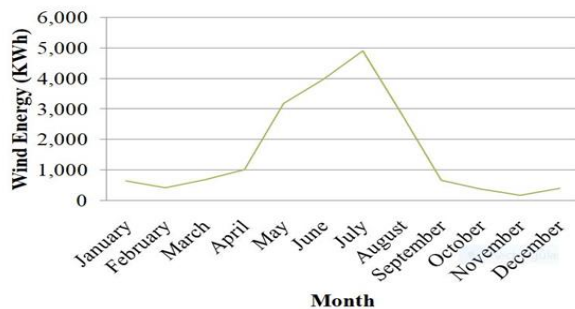


Fig. 22. Month Wise wind Power Production

CO₂ Emission reduction / annum

$$= 0.932 \text{ kg} \times \text{Annual KWh} \quad (11)$$

∴ CO₂ Emission reduction / annum

$$= 0.932 / 1000 \times 19200$$

CO₂ Emission reduction / annum = 17.9 Tons

Total Carbon emission reduction from Solar and Wind Plant = 64.5 + 17.9 = 82 Tons/annum. Outcome Analysis presented in Table 1.

NOMENCLATURE:

EVCS	Electrical vehicle charging
GPEVCS	Grid Powered EV Charging
SWGPs	Solar, Wind and Grid
EV	Electrical Vehicle
P _{EVL}	Electrical Vehicle Load
P _{LL}	Local Load at charging
P _{PV}	PV Power
P _w	Wind power
P _G	Grid Power
P _{g_{imp}}	Power imported from the grid
P _{g_{exp}}	Power exported to the grid
RES	Renewable Energy Sources
NREL	National Renewable Energy Laboratory
NASA	National Aeronautics and Space
KWp	Kilowatt Peak
η _{inv}	Inversion Efficiency
η _{rec}	Rectification Efficiency

PMSG	Permanente Magnet synchronous
Hh	Hub height
Ng	Generator efficiency
N _b	Gearbox efficiency
GECR	Gujarat State Electricity Regulation
INR	Indian Rupees
MMPT	Maximum Power Point tracking
SEPIC	Single ended Primary Inductor Converter
PV	Photo voltaic
CCS-2	Combine charging system Type-2
CO ₂	Carbon dioxide
K _g	Kilogram

References

- [1] Nishanthi, Jayasankar, Sathiasamuel Charles Raja, Thangavel Praveen, Joseph Jeslin Drusila Nesamalar, and Paramasivam Venkatesh. "Techno-Economic Analysis of a Hybrid Solar Wind Electric Vehicle Charging Station in Highway Roads." International Journal of Energy Research 46, no. 6 (2022): 7883–7903. (<https://doi.org/10.1002/er.7688>).
- [2] Kabir, Mohammad Ekramul, Chadi Assi, Mosaddek Hossain Tushar, and Jun Yan. "Optimal Scheduling of EV Charging at a Solar Power-Based Charging Station." IEEE Systems Journal 14, no. 3 (2020): 4221–31. (<https://doi.org/10.1109/jsyst.2020.2968270>).
- [3] Wu, Di, Haibo Zeng, Chao Lu, and Benoit Boulet. "Two-Stage Energy Management for Office Buildings with Workplace EV Charging and Renewable Energy." IEEE Transactions on Transportation Electrification 3, no. 1 (2017): 225–37. (<https://doi.org/10.1109/tte.2017.2659626>).
- [4] Gong, Lili, Wu Cao, Kangli Liu, Yue Yu, and Jianfeng Zhao. "Demand Responsive Charging Strategy of Electric Vehicles to Mitigate the Volatility of Renewable Energy Sources." Renewable Energy 156 (2020): 665–76. (<https://doi.org/10.1016/j.renene.2020.04.061>).
- [5] Zhou, Kaile, Dingding Hu, and Shanlin Yang. "Optimal Sizing of EV Charging Stations Considering Charging Scheduling and Renewable Energy." SSRN Electronic Journal,

- (2022).
(<https://doi.org/10.2139/ssrn.4143346>).
- [6] Singh, Shakti, Prachi Chauhan, and Nirbhaw Jap Singh. "Feasibility of Grid-Connected Solar-Wind Hybrid System with Electric Vehicle Charging Station." *Journal of Modern Power Systems and Clean Energy* 9, no. 2 (2021): 295–306. (<https://doi.org/10.35833/mpce.2019.000081>).
- [7] Zhou, Yaqin, Rajnish Kumar, and Shaojie Tang. "Incentive-Based Distributed Scheduling of Electric Vehicle Charging under Uncertainty." *IEEE Transactions on Power Systems* 34, no. 1 (2019): 3–11. (<https://doi.org/10.1109/tpwrs.2018.2868501>).
- [8] Sayed, Khairy, Ahmed G. Abo-Khalil, and Ali S. Alghamdi. "Optimum Resilient Operation and Control DC Microgrid Based Electric Vehicles Charging Station Powered by Renewable Energy Sources." *Energies* 12, no. 22 (2019): 4240. (<https://doi.org/10.3390/en12224240>).
- [9] Rahman, Mohammad Mominur, Ghazi A. Ghazi, Essam A. Al-Ammar, and Wonsuk Ko. "Techno-Economic Analysis of Hybrid PV/Wind/Fuel-Cell System for EVCS." 2021 International Conference on Electrical, Communication, and Computer Engineering (2021). (<https://doi.org/10.1109/icecce52056.2021.9514084>).
- [10] AKIL, Murat, Emrah DOKUR, and Ramazan BAYINDIR. "Energy Management for EV Charging Based on Solar Energy in an Industrial Microgrid." 9th International Conference on Renewable Energy Research and Applicatio, (2020). (<https://doi.org/10.1109/icrera49962.2020.9242663>).
- [11] Gunkel, Philipp Andreas, Felipe Junqueira Faust, Klaus Skytte, and Claire Bergaentzle. "The Impact of EV Charging Schemes on the Nordic Energy System." 2019 16th International Conference on the European Energy Market (EEM), (2019). (<https://doi.org/10.1109/eem.2019.8916569>).
- [12] Harsh, Pratik, and Debapriya Das. "Optimal Coordination Strategy of Demand Response and Electric Vehicle Aggregators for the Energy Management of Reconfigured Grid-Connected Microgrid." *Renewable and Sustainable Energy Reviews* 160 (2022): 112251. (<https://doi.org/10.1016/j.rser.2022.112251>).
- [13] Liu, Chunna, and Yan Liu. "Energy Management Strategy for Plug-in Hybrid Electric Vehicles Based on Driving Condition Recognition: A Review." *Electronics* 11, no. 3 (2022): 342. (<https://doi.org/10.3390/electronics11030342>).
- [14] Casella, Virginia, Daniel Fernandez Valderrama, Giulio Ferro, Riccardo Minciardi, Massimo Paolucci, Luca Parodi, and Michela Robba. "Towards the Integration of Sustainable Transportation and Smart Grids: A Review on Electric Vehicles' Management." *Energies* 15, no. 11 (2022): 4020. (<https://doi.org/10.3390/en15114020>).
- [15] Zhao, Shihao, Kang Li, Zhile Yang, Xinzhi Xu, and Ning Zhang. "A New Power System Active Rescheduling Method Considering the Dispatchable Plug-in Electric Vehicles and Intermittent Renewable Energies." *Applied Energy* 314 (2022): 118715. (<https://doi.org/10.1016/j.apenergy.2022.118715>).
- [16] Ouramdane, Oussama, Elhoussin Elbouchikhi, Yassine Amirat, Franck Le Gall, and Ehsan Sedgh Gooya. "Home Energy Management Considering Renewable Resources, Energy Storage, and an Electric Vehicle as a Backup." *Energies* 15, no. 8 (2022): 2830. (<https://doi.org/10.3390/en15082830>).
- [17] Prajapati, Sandhya, and Eugene Fernandez. "Solar PV Parking Lots to Maximize Charge Operator Profit for EV Charging with Minimum Grid Power Purchase." *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, (2020), 1–11. (<https://doi.org/10.1080/15567036.2020.1851325>).
- [18] Zandrazavi, Seyed Farhad, Cindy Paola Guzman, Alejandra Tabares Pozos, Jairo Quiros-Tortos, and John Fredy Franco. "Stochastic Multi-Objective Optimal Energy Management of Grid-Connected Unbalanced

- Microgrids with Renewable Energy Generation and Plug-in Electric Vehicles.” *Energy* 241 (2022): 122884. (<https://doi.org/10.1016/j.energy.2021.122884>).
- [19] Rajesh, P., Francis H Shajin, Balapanur Mouli Chandra, and Bapayya Naidu Kommula. “Diminishing Energy Consumption Cost and Optimal Energy Management of Photovoltaic Aided Electric Vehicle (PV-EV) by GFO-VITG Approach.” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, (2021), 1–19. (<https://doi.org/10.1080/15567036.2021.1986606>).
- [20] Amir, Vahid, Shahram Jadid, and Mehdi Ehsan. “Operation of Networked Multi-Carrier Microgrid Considering Demand Response.” *COMPEL - The international journal for computation and mathematics in electrical and electronic engineering* 38, no. 2 (2019): 724–44. (<https://doi.org/10.1108/compel-07-2018-0276>).
- [21] Goli, P., and W. Shireen. “PV Powered Smart Charging Station for Phevs.” *Renewable Energy* 66 (2014): 280–87. (<https://doi.org/10.1016/j.renene.2013.11.066>).
- [22] Raj Kunwar, Dol, Bijay Sharma, Sunil Paudel, Tanka Nath Ojha, and Menaka Karki. “Relieving Grid by Adding PV and Bess for Economical Charging of EV in the Charging Station.” *American Journal of Computer Science and Technology* 3, no. 1 (2020): 7. (<https://doi.org/10.11648/j.ajcst.20200301.12>).
- [23] Chaudhari, Kalpesh, Abhisek Ukil, K Nandha Kumar, Ujjal Manandhar, and Sathish Kumar Kollimalla. “Hybrid Optimization for Economic Deployment of ESS in PV-Integrated EV Charging Stations.” *IEEE Transactions on Industrial Informatics* 14, no. 1 (2018): 106–16. (<https://doi.org/10.1109/tii.2017.2713481>).
- [24] N., Himabindu, Santoshkumar Hampannavar, Deepa B., and Swapna M. “Analysis of Microgrid Integrated Photovoltaic (PV) Powered Electric Vehicle Charging Stations (EVCS) under Different Solar Irradiation Conditions in India: A Way towards Sustainable Development and Growth.” *Energy Reports* 7 (2021): 8534–47. (<https://doi.org/10.1016/j.egy.2021.10.103>).
- [25] “PVWatts - NREL.” PVWatts Calculator. Accessed October 1, (2022). (<https://pvwatts.nrel.gov/pvwatts.php>).
- [26] Idoko, Linus, Olimpo Anaya-Lara, and Alasdair McDonald. “Enhancing PV Modules Efficiency and Power Output Using Multi-Concept Cooling Technique.” *Energy Reports* 4 (2018): 357–69. (<https://doi.org/10.1016/j.egy.2018.05.004>).
- [27] “NASA Power.” NASA. NASA. Accessed October 1, (2022). (<https://power.larc.nasa.gov/data-access-viewer/>).
- [28] Filom, Siyavash, Soheil Radfar, Roozbeh Panahi, Erfan Amini, and Mehdi Neshat. “Exploring Wind Energy Potential as a Driver of Sustainable Development in the Southern Coasts of Iran: The Importance of Wind Speed Statistical Distribution Model.” *Sustainability* 13, no. 14 (2021): 7702. (<https://doi.org/10.3390/su13147702>).
- [29] “Tariff Orders.” Gujarat Electricity Regulatory Commission. Accessed October 19, 2022. (<https://gercin.org/order-category/tariff-orders/>).
- [30] “Guvnl.” Accessed October 1, (2022). (<https://suryagujarat.guvnl.in/Gujarat-Solar-Power-Policy-2021.pdf>).
- [31] Choose my electric vehicle. Government of India, Niti Ayog. Accessed October 1, (2022). (<https://e-amrit.niti.gov.in/choose-my-electric-vehicle>).
- [32] “Tata Power EZ Charge – Apps on Google Play.” Tata Power EZ Charge. Tata Power. Accessed October 1, (2022). (https://play.google.com/store/apps/details?id=com.tatapower.evapp&hl=en_IN&gl=US).
- [33] Government of India, Ministry of power. “Light EV DC Charge Point - Powermin.gov.in.” Accessed October 1, (2022). (https://powermin.gov.in/sites/default/files/webform/notices/Final_Consolidated_EVCI_Guidelines_January_2022_with_ANNEXURES.pdf).
- [34] “CCS Type EV Charger.” indiamart.com. Accessed October 19, (2022).

- (<https://www.indiamart.com/proddetail/ccs-type-ev-charger-21886550248.html>).
- [35] "Bharat DC 001 15kw EV Charger." indiamart.com. Accessed October 1, (2022). (<https://www.indiamart.com/proddetail/bharat-dc-001-15kw-ev-charger-23465437333.html>).
- [36] Kandagal, Sandesh. "Charging Stations in India- Cost, Companies & Franchise - E-Vehicleinfo." E, January 15, (2022). (<https://e-vehicleinfo.com/charging-stations-in-india-cost-companies-franchise/>).
- [37] National Portal for Rooftop Solar - Ministry of New and Renewable Energy. Accessed October 1, (2022). (https://solarrooftop.gov.in/rooftop_calculator).
- [38] "Horizontal Axis Wind Turbine." indiamart.com. Accessed October 1, (2022). (<https://www.indiamart.com/proddetail/horizontal-axis-wind-turbine-16459124697.html>).
- [39] Kale, Dhanaji, and Prasad Kokil. "A Study of the Performance and Carbon Credit Analysis of a 6 KWP Rooftop Solar Photovoltaic Power Plant at Sanjay Group Aurangabad, India." OMICS International. OMICS International, April 23, (2019). <https://www.omicsonline.org/open-access/a-study-of-the-performance-and-carbon-credit-analysis-of-a-6-kwp-rooftop-solar-photovoltaic-power-plant-at-sanjay-group-aurangabad-108540.html>.
- [40] NREL. n.d. Review of SOLAR RESOURCE DATA. Accessed October 6, (2022). (<https://pvwatts.nrel.gov/pvwatts.php>).
- [41] NASA. 2018. "ArcGIS Web Application." Nasa.gov. (2018). (<https://power.larc.nasa.gov/data-access-viewer/>).