# Feasibility analysis and modeling of a solar hybrid system for residential electric vehicle charging

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**Article Info**

***Article history:***

Received Aug 17, 2023
Revised Oct 22, 2023
Accepted Nov 29, 2023

***Keywords:***

Energy demand management
MiPower
Optimal design electric vehicle charger
Roof top solar plant
Shadow mapping
Solar Pro

**ABSTRACT**

The process of transforming sunshine energy into electrical power is known as solar power generation. Photovoltaic (PV) technology has recently proved its cost-effectiveness and low environmental impact in generating power. The key goals of this study are to develop a solar PV system for charging electric vehicles (EVs) while utilizing the residential apartment's current domestic power supply. This study focuses on modeling grid-interactive solar PV systems for charging EVs inside a 40-unit residential apartment complex. The Solar Pro tool is used to do the techno-economic analysis of the modeled PV system. The research investigates the installation of a rooftop solar plant devoted to delivering electricity to EV charging devices on a real-time five-story residential building. The performance of the PV plant is tested under a variety of scenarios, including EV loading, shadow mapping, and local meteorological conditions. The PV plant's size is optimized at 150 kW, taking into consideration economic aspects as well as the actual proportions of the structure. In addition, the MiPower tool is used to do a load flow study of the modeled system, which includes both the grid and the PV system. This research evaluates line losses, line loading, and voltage levels at each bus at maximum loading circumstances.



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## 1. INTRODUCTION

Charging of electric vehicles (EVs) using grid supply dominated by conventional energy sources is high and the purpose of rolling out the electric vehicle is completely defeated since conventional internal combustion (IC) engine-based vehicle during running condition emits carbon-rich gases in the atmosphere and it is powered by crude oil. To create an emission-free environment, technocrats brought vehicles that are powered by electrical energy which will not emit any carbon particles in the atmosphere and will not harm any living organism on the earth. Charging EVs is a challenging one since there is not enough charging station infrastructure available in the country. Due to a shortage of charging infrastructure, charging of EVs is done mostly through conventional fossil fuel-based energy sources which is again polluting the environment. Automobile companies in India started working on manufacturing the EV and research activities about EV sub-components were going in a rapid phase in the country. Even people started thinking about EVs due to zero emissions in the atmosphere and low running costs [1]. The EV charging infrastructure in India and it is a vision towards achieving 100% electric vehicle by 2030 was discussed in the paper. The Government measures in encouraging the establishment of EV chargers by private firms and incentives were elaborated by Kore and Koul [2]. The EV charging infrastructure feasible in the Indian market in terms of power quality, technologies on power electronics converters used in the EV chargers, and energy management of EV chargers were discussed in the study [3]. Challenges in the adoption of EVs in the Indian market and factors that affect the usage of EVs by people were discussed in detail. Majorly lack of infrastructure for charging the EVs and the high cost of subsystems used in electric vehicles is high was highlighted by Nair *et al.* [4]. Energy from the wind plant is used to charge the EV and the author proposed the model based on game theory for charging the EV at minimum cost based on available energy in the place i.e. either fossil energy or wind energy [5]. The financial feasibility of charging the EV in the working places under parking slots of the office is analyzed in terms of financial. The separate tariff structure for charging the EV in the working place prevailing in Greece country was analyzed by comparing the internal rate of return (IRR) and payback period for the capital investment made on installing the EV charger [6]. A literature review about the establishment of EV chargers and factors that influence the optimal placement of EV chargers was discussed by Khan *et al.* [7].

Charging of plug-in hybrid electrical vehicle (PHEV) in the existing power distribution network and problems associated with charging the EV in the power system was briefed by the author. The possibility of charging the EV with renewable sources that are integrated with the existing grid supply was discussed in the paper. The author listed the problems of discharging the energy stored in the battery by the plug-in hybrid electric vehicle to the grid as well as charging EVs by the stochastic nature of renewable energy [8]. The author proposed a model for charging the EV connected to a microgrid system which has a hybrid power source consisting of conventional fossil-based energy as well as renewable sources. The model proposed by the author takes care of charging the EV at a lesser cost of energy as well as ensuring the energy for charging the EV is taken mostly from renewable energy [9]. Energy storage sizing was optimized concerning the cost and to get reliable power without compromising the quality of the power supply [10].

The design of a grid-interactive PV system of capacity 2 kW was done using PVsyst. Performance and analysis of the 2 kW system were done using simulation software and detailed energy loss in the system was evaluated using the PVsyst. The performance ratio of the designed on-grid system was calculated using the software [11]. The energy storage element is becoming a vital part of renewable energy, especially in the case of PV systems, due to the intermittency output of the PV plant, the load connected to the PV system would be greatly affected to mitigate this energy storage element plays a vital role in supplying the required amount of energy to the load when PV output is less. Techno-economic analysis of PV with energy storage element for analyzed for the system feeding the small enterprise and the sizing of PV and energy storage was done based on energy demand [12]. Integrating the renewable system especially energy output from wind and solar will reduce the carbon footprint to the larger extent. The carbon dioxide emission into the atmosphere would be greatly reduced if the energy demand is fulfilled with larger portions of renewable energy [13]. The building energy consumption can be optimized to less usage of grid supply by integrating the power output from the PV system. The PV system integration in the building makes it easy to harvest the energy from the PV panels [14].

The 100 kWp PV system was designed and analyzed in terms of performance ratio is done using the PVsyst simulation tool. The PV module considered in this study is polycrystalline cells and the performance of the PV system is done using the PVsyst software [15]. EV charging in the workplace using the renewable sources consisting of solar and bio mass resources was modeled and techno-economic analysis of the system was carried out using the Homer Pro tool.

The performance analysis of the system concerning technical aspects which includes the optimization of each renewable source in the hybrid configuration was simulated and the financial analysis of the system which includes the cost of energy, net present cost and payback period of the system is studied using the Homer pro tool [16]. A hybrid energy system was designed for the educational institute to meet the energy demand of the institute using renewable sources PV and wind. The renewable sources modeling was done using the Homer Pro tool and a complete techno-economic analysis of the system was carried out using the Homer Pro [17]. Figure 1 describes the concept of solar-based EV charging, EVs will be charged from solar energy during the daytime and when there is a deficit of energy generation from the solar, the vehicle will be charged from the grid supply. Most of the research papers were not focused on using the on-grid PV system for charging the EV, they were focused mostly on a standalone system. Research articles in the past focused on the design and development of standalone PV systems for charging the EV as well as focused on optimum generation of energy from PV. Most of the researchers focused on using renewable sources to meet the energy demand of the residential building but did not address charging the EV in the existing grid supply of the building. They have not explored utilizing the existing grid infrastructure along with a grid-interactive PV system for charging the EV.

In this work, the modeling of PV sources and techno-economic feasibility study for charging the EV using PV sources is done using the Solar Pro tool. Even a feasibility study on the performance of the system with and without shadow mapping was carried out and it is one of the uniqueness of this work. In this research work, the inverter output from the PV plant is fed to the EV charger distribution feeder to supply the power to the EV and it is not connected to the domestic load distribution feeder of the apartment. In this study, we took dimension of the apartment which is located in Chennai, Tamil Nadu, India where we are planning to explore the installation of the rooftop PV plant for generating power to meet the energy demand of the EV. Dimension of the apartment/building under study was taken and the same was drafted in computer aided design (CAD) software and the CAD file was imported into Solar Pro software for further analysis. The simulation software optimizes the size of the PV plant based on the dimension of the building as well as weather data about the site location and forecasts the energy output from the PV plant which is installed on the rooftop of the building, which is used for charging the EV. This paper describes the modeling of a PV plant and the numerical simulation of a PV system for producing electricity and energy solutions for residential apartments to charge their EV from the PV plant. Through numerical simulation using the Solar Pro tool, the optimum size of the grid-connected PV system and the feasible sites are analyzed for the PV-grid-connected power plant of the apartment.

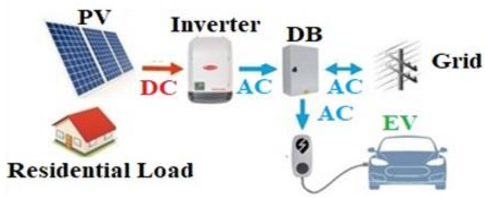


Figure 1. On grid system for EV charging

The research work in this paper is presented in such a way that, section 2 presents the system modeling. Research method in section 3 presents the system assessment which outlines the EV charger capacity, the energy demand of flats in the residential apartments and EV capacity, section 4 presents the technical analysis of the system, section 5 presents the results and discussion and section 6 presents the conclusion. This study identifies specific research gaps and addresses them through its unique and innovative contributions. i) Suitability investigation of a rooftop PV system, as well as the feasibility of charging electric cars within the residential complex using a hybrid power solution that combines PV panels with the existing grid supply; ii) Designing the PV configuration to adequately fulfill the energy requirements of both the EV charger and the residential consumers within the building or apartment; iii) Developing an optimal design for the utilization of the building's rooftop space to maximize energy harvesting from the PV plant, with a specific emphasis on charging electric vehicles (EVs); iv) Analyzing the performance of rooftop plants under various conditions, encompassing both complete and partial shadow mapping; and v) Developing the feasible techno-economic analysis report of the building, which includes a rooftop PV plant with a grid-interactive inverter, utilizing the Solar Pro tool.

## 2. MATHEMATICAL MODELLING

The Solar Pro software [18] uses following the mathematical equations to find the output from renewable energy resources. The PV array temperature modeling has been expressed (without wind velocity) as in (1).

$$P_T = A_1 x T_{air} + I_1 x G + C_1 \quad (1)$$

where, $P_T$ is PV temperature, $T_{air}$ is outside air temperature, $G[kW/m2]$ is irradiance, $A_1$ is air temperature regression coefficient initial value = 1, $I_1$ is irradiance regression coefficient initial value = 45, $C_1$ is constant initial value = 0 (This generally represents the influence of wind, so its value is normally ≦ 0). The wind impact module temperature is calculated as (2).

$$P_T = G_A . e^{(a + b.W_P)} + T_{air} \quad (2)$$

where $P_T$ is PV temperature, $T_{air}$ is outside air temperature, $G[W/m2]$ is irradiance, $Wp[m/s]$ is wind speed. The overall PV equivalent circuit and its I-V characteristics has expressed by (3) and (4).

$$I = I_{Ph} - I_0 \mid e^{C(V + IR_S)} - 1 \mid - \left(\frac{V + IR_S}{R_P}\right) \quad (3)$$

$$C = \frac{q}{D_P . K . T_M} \quad (4)$$

$I_{ph}$ is photovoltaic current, $I_o$ is diode saturation current, $R_s$ is inner series resistance R, $R_p$ is inner parallel resistance, $q$ is elementary charge, $k$ is Boltzmann constant, $T_M$ is module temperature, $D_P$ is diode factor (number of cells in-series diode efficiency index). The effects of shadow density and its influence on the performance in terms of direct irradiance received has been observed and expressed by (5).

$$I = \frac{100 - SHADOW\ DENSITY\ (\%)}{100} \quad (5)$$

where, $I$ is the directirradiance of the PV module.

## 3. RESEARCH METHOD

The methodology of this work adopted in this study is given in Figure 2 which includes the assessment of building dimensions and drafting the building dimension into CAD software. Modelling the PV sources is done as per the dimension of the rooftop of the building using Solar pro tool. The energy output from the PV sources under the theoretical condition as well as under actual operating shadow condition of the PV plant is estimated through Solar Pro tool. Techno-economic feasibility study of the complete system consist of PV source and grid supply is performed through optimization tool.

In this study, EV charger load and building consumer load are given as input to the Solar Pro tool. The solar pro tool estimates the annual energy output from the PV plant modeled on the rooftop of the building as well as performs feasibility analysis and outputs the payback period. The shadow analysis helps to find out the actual energy output from the PV plant that can be given as input to the EV charger unit and how much additional energy is required to charge the EV. In this work, real-time variables about solar modules and inverter are considered and the same is given as input to the Solar Pro tool. The direct current (DC) cable loss and alternating current (AC) cable loss in this study are considered as 3% and 1% respectively. The load flow analysis of the hybrid power system consisting of PV and grid is carried out in the MiPower tool. The electrical sizing of the PV plant taken from the Solar Pro tool is given as input to the MiPower tool. The voltage at each bus, power loss in the system and line loading of the cables interconnecting each bus during the maximum loading condition are evaluated using the MiPower tool.

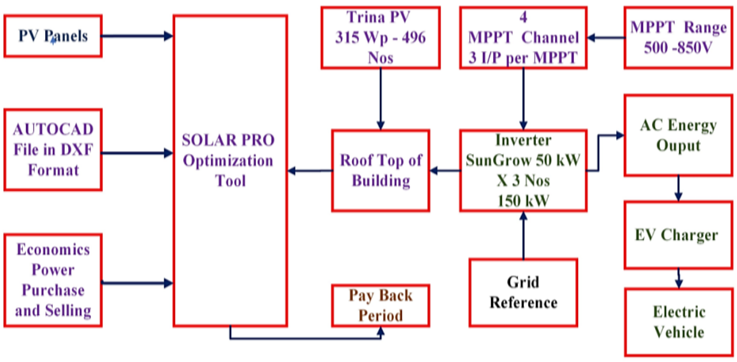


Figure 2. Methodology of the proposed design

### 3.1. Design assessment of the system

The assessment of the system includes the assessment of the load (EV charging load and domestic load), assessment of the building and assessment of renewable sources (PV). This stage has three important phases, such as load demand assessment, resource availability assessment and technical elements cost analysis. From this post-simulation assessment, the design constraints and user-defined constraints were considered. It will help improve the performance accuracy of the proposed hybrid renewable energy (HRE) system.

#### 3.1.1. Assessments of electrical load demand

The energy demand considered in this work includes the energy demand of residential consumers of the building as well as the EV charging load. The total residential consumers in the residential apartment is

40 Nos i.e. 40 flats/houses, the total population of the electric vehicle (EV) considered in this study is 80 Nos (2 wheeler is 40 no's and 4 wheeler is 40 no's). The apartment that is considered for this study is a five-story building, and on each floor, there are 8 flats so a total of 40 flats are there in this building. The sanctioned load of each flat is 5 kW and the total sanctioned load of the entire building (apartment) is 200 kW. The energy demand of the entire building is measured and validated using a power analyzer [19]. The average energy measured by the power analyzer of the entire residential building per day under study is 2,900 kWh and peak demand is 160 kW. The peak load is observed in the building during evening hours from 6 pm to 8 pm. Minimum power drawn from the mains is observed in the afternoon from 2 pm to 4 pm and it is about 80 kW. The assessment of the system includes the assessment of the load (EV charging load and domestic load), assessment of the building and assessment of renewable sources (PV). This stage has three important phases, such as load demand assessment, resource availability assessment and technical elements cost analysis. From this post-simulation assessment, the design constraints and user-defined constraints were considered. It will help improve the performance accuracy of the proposed HRE system.

Figure 3 depicts the energy demand of the customer consisting of 40 nos. Variation of the energy demand of the building for 24 hours a day is shown in Figure 3. The energy consumed by the domestic load in the building was measured using a power analyzer in the daytime from 6 am to 6 pm as well as in night time from 6 pm to 6 am. Energy demand measured per house during the daytime is 36 kWh and at night time it is about 36.5 kWh. The total energy demand measured per house during the complete day is 72.5 kWh. The total energy demand recorded during the daytime is 1,440 kWh and the peak power is 150 kW, whereas at night time total energy demand recorded is 1,460 kWh and the peak power is 160 kW. The peak power drawn during the daytime is 150 kW and it is observed 2 times in day time i.e. from 6 am to 8 am and 12 pm to 2 pm. The peak power drawn during the night time is 160 kW and it is observed one time in night time i.e. from 6 pm to 8 pm.

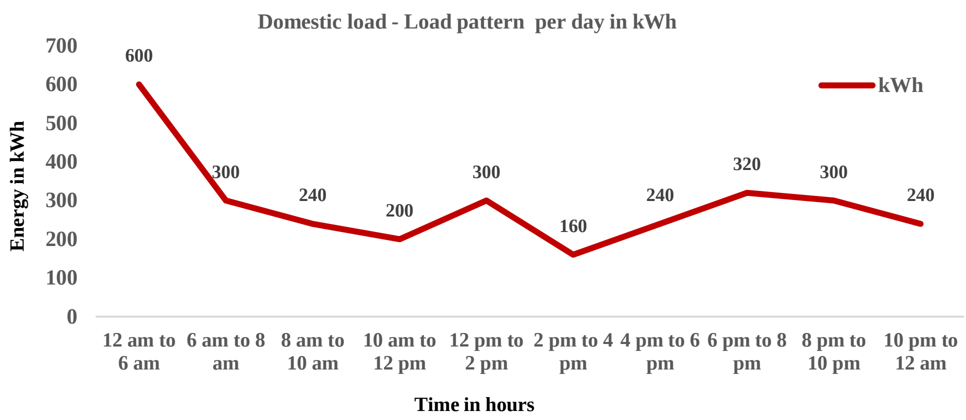


Figure 3. Energy demand of the building per day

### 3.1.2. Assessments of EV load demand

The electrical vehicle (EV) of two-wheelers and four-wheelers is considered for the study. In this residential building, we considered 40 no's of two-wheeler and 48 no's four-wheeler. The energy required for charging the two-wheeler is 3 kWh whereas the energy required for charging the four-wheeler is 21.5 kWh. The time required for charging the two-wheeler is 3.5 hrs, whereas for a wheeler it is about 1 hour. Table 1 depicts the energy demand for the electric vehicles of two-wheelers and four-wheelers. In this study, the time of 12 hours is considered from 6 am to 6 pm, and night time is considered from 6 pm to 6 am. In the daytime, we can charge the 3.5 no's of two-wheeler EVs and 24 no's of four-wheeler EVs (four-wheeler fast chargers would have two guns so simultaneously two vehicles can be charged at a time). The energy required for charging the 20 no's of a two-wheeler EV is 60 kWh and the energy required for charging the 24 no's of four wheeler EV is 516 kWh and the same is shown in Figure 4. Total energy required for charging the two-wheeler EV and four wheelers in a day time is 576 kWh.

Table 2 shows the power capacity considered in this study for EV charger of two wheeler and four-wheelers [20], [21]. The total power demand required for EV chargers (both two & four-wheelers) is 39 kW. Figure 5. Shows the power requirement of EV which includes two-wheeler and four-wheeler. The total power capacity of the EV charger considered in this study is 39 kW.

Table 1. Energy consumption of EV

| S. No | Type of EV | Charging time for EV Hrs | Energy (Kwh) | Total kWh |
|---|---|---|---|---|
| 1 | 2Wheeler | 3.5 | 3 | 60 |
| 2 | 4Wheeler | 1 | 21.5 | 516 |
| | | | | 576 |

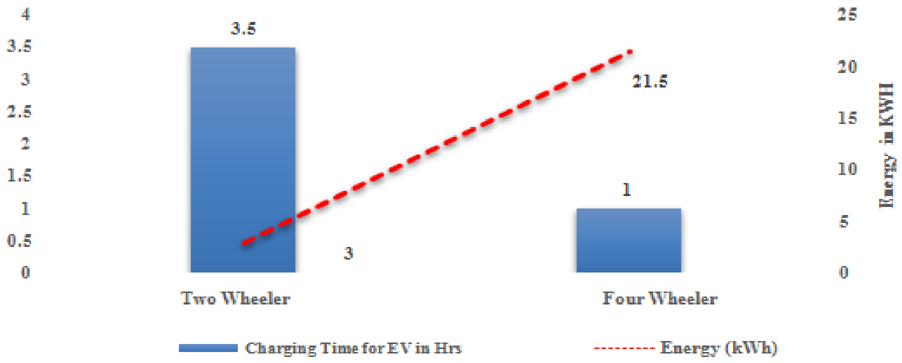


Figure 4. Energy requirement of EV

Table 2. Total power capacity of EV charger

| S. No | Type of EV | No of vehicles | Charging time (6 am to 6 pm) hrs | No of charger | Power capacity for charger (kW) | Total capacity |
|---|---|---|---|---|---|---|
| 1 | 2Wheeler | 20 | 12 | 6 | 1.5 | 9 |
| 2 | 4Wheeler | 24 | 12 | 2 Gun | 15 | 30 |
| Total No of EV's | | 44 | | Total Power Capacity | | 39 |

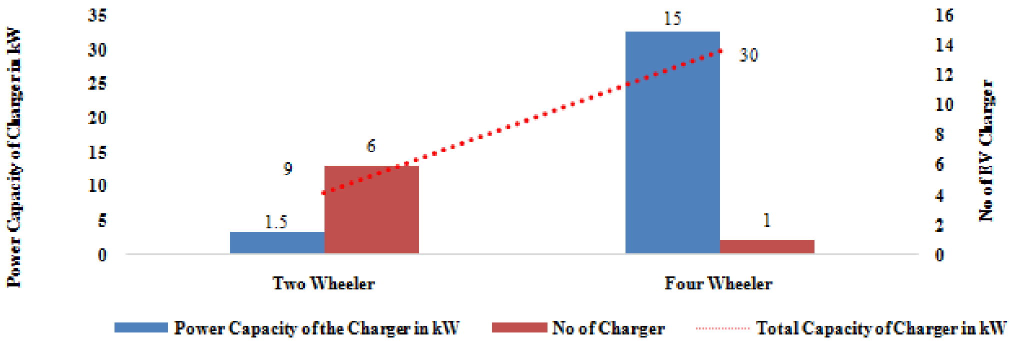


Figure 5. EV charger – power capacity

### 3.2. Energy harvesting technology assessment

The assessment of the system includes calculating the rooftop area of the building which is under study, assessment of the solar insolation of the site, and assessment of the capacity of PV modules and inverters. The apartment taken for the study has the dimension of 63 m (L) × 23.7 m (W) this building is five storied and has a total number of flats is 40 flats, on each floor there is 8 flats. The rooftop of this building is used to generate the PV output through the PV modules. The PV output from this rooftop of the building is exclusively used for charging the EV through a grid-connected inverter. The rooftop of the building under study is rectangular and PV sizing of the building is optimized using the Solar Pro tool.

#### 3.2.1. PV module and solar resource

The building under study is located in Chennai which corresponds to latitude and longitude of 13.0827, 80.2707. As per data taken from national aeronautics and space administration (NASA) for solar insolation, the average available solar radiation is 5.18 kWh/m3/day. As per meteorological data received for the project under study, it has been a clear sky for almost 275 days and it is an encouraging factor to generate the power output from the PV plant. The PV module [22] considered for this study is 315 Wp from Trina make, the dimension of the panel is the length as 0.992 m, width as 1.65 m and the area of the module is 1.64 m$^2$. The electrical specification of the solar module which is taken for the study, voltage and current corresponds to the maximum power point is 33.30 V and 9.46 Amps.

### 3.2.2. On and OFF grid environment assessment

In this research grid tie inverter to make the sun grow is considered of capacity of 50 kW. The total no of inverters considered in these 3 no's and the total capacity of the Inverter is 150 kW. The maximum power point tracking (MPPT) range for the inverter taken for this study ranges from 500 to 850 V and the operating efficiency of the inverter is 98%. The Power supply to the apartment is taken from local distribution company (DISCOM), which supplies the power to the building at the voltage rating of 11 kV. The contract demand of the building is 300 kW and the connected load of the building under study is 200 kW. The grid supply from DISCOM is fed to the power distribution point of the building through a step-down transformer at the voltage level of 415 V. From the main distribution center power is distributed to each flat (consumer) through the necessary switch gear and protection equipment. In this study power generated from the PV plant is fed to the main distribution point where the local DISCOM supply is fed to the building. In this study, we considered a grid-tied inverter so there is exchange of power takes place between the grid and the load. The export of the power PV plant to the grid takes place when there is surplus power available in the system and as well as import of power from the grid to the load takes place when there is deficit power demand at the load end. The energy tariff considered for this study is given in Table 3.

Table 3. Energy tariff in Rs

| S. No | Power import tariff in Rs | Power export tariff in Rs |
|---|---|---|
| 1 | 3 | 4 |
| 2 | 4 | 5 |

## 4. OPTIMAL TECHNO-ECONOMIC ANALYSIS: CASE STUDY

The Solar Pro tool is used in this work to optimize the design size of the PV plant based on the roof plan input given to it. Based on the roof plan given to the input of the tool, PV modules are optimized. The design process in the Solar Pro tool includes a selection of the metrological databases, selection of site, selection of PV module type and manufacture, selection of inverter, number of arrays, no of modules in the array, I-V characteristics study of the system, shadow mapping analysis of the system, power study and economic analysis which includes the cost setting (input) and load setting (input). Based on the input given to the tool, Solar Pro outputs the expected power output from the PV plant in kWh for the whole year from January to December, the payback period of the project in the months/year, bill reduction in rupees and annual saving in rupees.

The roof plan input of the building drawn in the AutoCAD tool in DXF format is exported to the Solar Pro software. Figure 6 shows the Roof top of the building with PV modules of the building which are imported from AUTOCAD software and drawn in the Solar Pro tool. Using the auto array installation, complete the roof space filled with PV modules. The outer dimension of the building is 63 m (L) × 23 m (W).

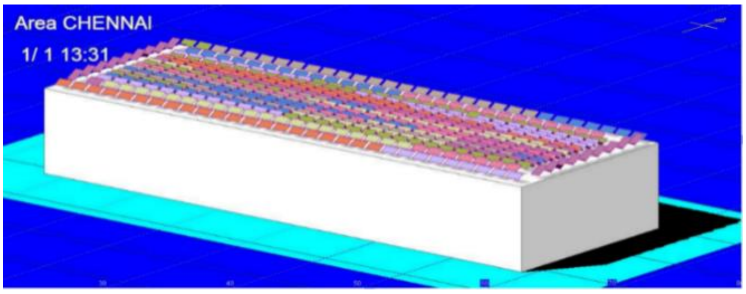


Figure 6. Roof top of the building with PV modules

### 4.1. Proposed PV structure to the building

The PV module electrical connection is done based on the MPPT range of the inverter selected for the project. In this study the number of arrays was configured as 8 no's and the number of modules connected in series is 21 no’s (maximum). The total number of modules installed on the roof top of the building is 496 no’s, the total DC capacity of PV modules installed is 156 kWp and the number of inverters considered in this study is 3 no each of 50 kW.

### 4.2. I-V Characteristics of the solar plant

The I-V curve of the complete PV system was simulated in two ways, in method -1 PV complete system I-V curve was done using standard test condition (STC) and in method -2, the I-V curve was done using the actual weather condition corresponding to site location. Under STC conditions the value of the Vpm is 699.09 V, whereas the Ipm is 74.35 Amps, and the power output is 51.977 kW from each inverter. The variation of I-V concerning the actual weather conditions about site location is simulated and estimated as 0.859 kW/m$^2$. Under actual weather conditions, the value of the Vpm is 693.87 V, whereas the Ipm is 64.44 amps, and the power output is 44.716 kW from each inverter. Table 4 shows the variation of the power output from the PV system under ideal and actual conditions.

Table 4. I-V curve under ideal condition and actual condition

| S. No | Ideal condition | Actual condition |
|---|---|---|
| 1 | Vpm: 699.09 V Ipm: 74.35 amps | Vpm :693.87 V Ipm: 64.44 amps |
| 2 | Irradiance: 1 kW/m$^2$ | Irradiance: 0.89 kW/m$^2$ |
| 3 | Pmax: 51.977 kW | Pmax: 44.716 kW |

## 5. RESULTS AND DISCUSSION

PV modelling for building roof top [23] was done and design was carried out using Solar Pro tool. The Solar Pro tool gives the complete first-hand information for the selection of the inverter and balance of system (BOS). The I-V curve of the PV plant under ideal condition (without shadow) was evaluated as 44.716 kW as against the design value of 50 kW. The estimated total power output from the PV plant per year is 229303.05 kWh and specific AC energy is 1467.63 kWh/kWp.

### 5.1. Energy economics analysis without shadow

The economic study of the PV plant was done based on the energy tariff, load energy and cost (O&M cost, Equipment cost and operation cost). The energy required for EV charging and consumer domestic load is given input to the software and the same was given in Table 5. Bill reduction by charging the EV during the day-time alone per annum is Rs 825491. The payback [24] period for the PV plant is estimated as 8 years and 6 months. At the new energy tariff, bill reduction, selling price and the buying price of the energy are calculated. It was found that bill reduction was increased to 27% (Rs 1054794), the selling price was increased to 25% (Rs 687909) and the buying price was increased to 33% (Rs 4709350). The payback period for the PV plant is estimated as 6 years and 5 months.

Table 5. EV and residential load

| Energy Unit | Day Time kWh | Night Time kWh | Total Energy kWh | Electricity Price Rupees |
|---|---|---|---|---|
| Total | 735840.0 | 533220 | 1269060.00 | 3807180 |

### 5.2. Performance of the PV plant with shadow

The Performance of the PV plant under shadow mapping is discussed below. The electrical parameters of each inverter are calculated based on actual condition considering the shadow mapping and it was 15.88, 11.97, and 10.58 kW. The total power output from the PV plant per year is 186236.43 kWh and specific AC energy is 1191.99 kWh/kWp. The Bill reduction per annum is Rs 670451.

### 5.3. Comparative analysis

The performance of EV charging [25] through PV sources is compared and analyzed considering the shadowing effect as well as without the shadowing effect. It is seen that the output of the PV plant is high and it gives an AC output of 229303.05 kWh when there is no shadowing effect and the output of the PV plant under shadowing effect is less and its AC output is 186236.43 kWh. Detailed technical and economic comparison of PV plants with shadow and without shadow is carried out and parameters are presented in Table 6.

Table 6. EV and residential load

| Shadowing (Yes/No) | Total Irr. kWh/m$^2$ | PV energy kWh | AC energy kWh | Specific AC energy (kWh/kWp) | Bill reduction (Rs) | Selling price (Rs) | Buying price (Rs) | PayBack |
|---|---|---|---|---|---|---|---|---|
| No shadow | 1952.21 | 236346.17 | 229303.05 | 1467.63 | 825491 | 550327 | 3532010 | 8.5 Years |
| With shadow | 1952.21 | 191956.74 | 186236.43 | 1191.99 | 670451 | 446967 | 3583689 | 10.91 Years |

Figure 7 depicts the technical performance of the PV plant concerning the shadowing effect and without the shadowing effect. PV energy is 236346.17 kWh under no shadowing effect and it is 191956.74 kWh under shadowing effect. Economic analysis of the PV plant concerning shadowing and without shadowing was done considering the energy tariff of Rs 3 (energy purchase price from the grid) and Rs 4 (energy selling price to the grid). Bill reduction and selling price under no shadowing effect are high as compared to the shadowing effect, the buying price of energy to meet the energy demand of the load under no shadowing is less and is about Rs 35,32,010 whereas in the Shadowing effect, it is high and is about Rs 35,83,689. The payback period is less and it is 8.5 years under no shadowing effect, whereas it is 10.91 years in shadowing effect. Figure 8 depicts the economic performance of the PV plant.

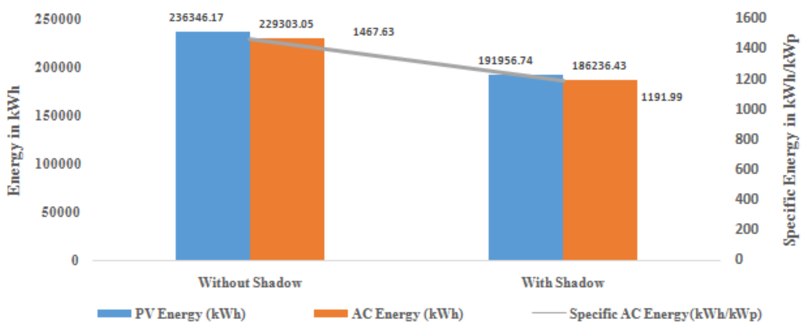


Figure 7. Technical performance of PV plant

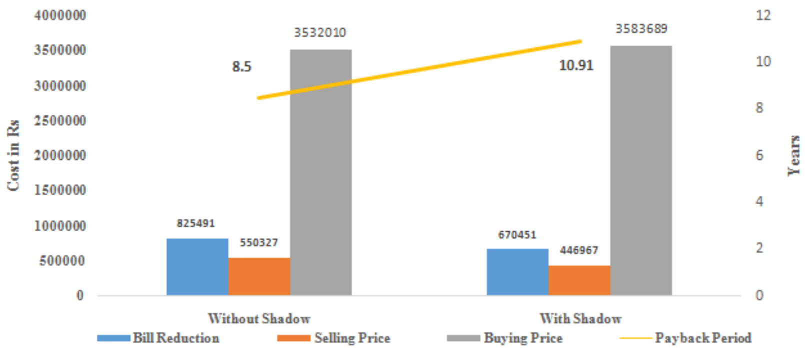


Figure 8. Economic analysis of PV plant

## 5.4. Load flow study

The load flow study of the modeled system consists of PV and existing the grid supply is studied using the MiPower tool at the maximum load condition. In the load flow study, the system under study was configured as three bus, two power distribution cables connecting the bus, two loads (EV and residential consumer) were connected in the individual buses, grid source and PV was connected at the respective buses as shown in Figure 9. The load flow analysis results were given in Table 7. The total power demand of the system (EV load and residential load) is shared by the grid and PV sources in the proportion of 48% and 52% respectively. The percentage of real power loss in the complete system is only 0.053%. The domination of PV sources in sharing the energy to the load is more as compared to the grid. It is evident from the results that at maximum loading conditions voltage at each distribution node is maintained at 415 V due to this reliability of the system is ensured.

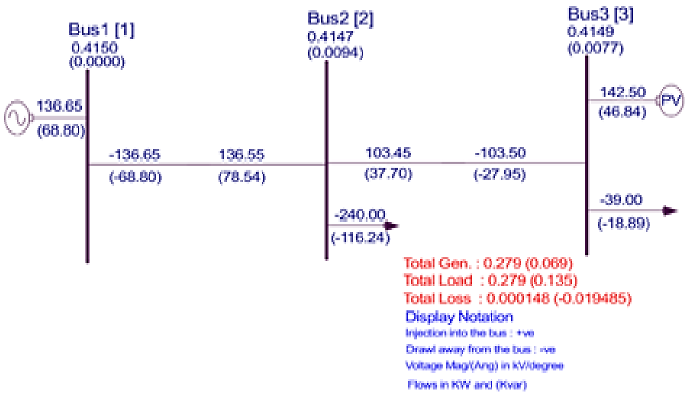


Figure 9. Load flow study of complete system

Table 7. Summary of load flow results

| S. No | Parameters | Value |
|---|---|---|
| 1 | Real power drawn from the grid in MW | 0.137 |
| 2 | Reactive power from the grid in MVAr | 0.069 |
| 3 | Grid power factor | 0.89 |
| 4 | Real power drawn from the PV in MW | 0.142 |
| 5 | Reactive power from the PV in MVAr | 0.047 |
| 6 | Total real power load in MW | 0.279 |
| 7 | Total reactive power load in MVAr | 0.135 |
| 8 | Total real power loss in MW | 0.000148 |
| 9 | Percentage of real power loss | 0.053 |
| 10 | Total reactive power loss in MVAr | -0.019485 |

### 5.5. Environmental analysis

The environmental performance of the PV plant about EV charging was computed and analyzed. It is seen from the computational results that both crude oils, as well as $CO_2$ reduction, were noticed high in the without shadowing effect condition as compared to the shadowing effect. The amount of $CO_2$ and crude oil reduction without the shadowing effect is 117,403 kg and 58,931 liters respectively, whereas with the shadowing effect amount of $CO_2$ and crude oil reduction is 95,353 kg and 47,863 liters respectively.

The amount of $CO_2$ and crude oil reduction without the shadowing effect is 1,17,403 kg and 58,931 liters respectively, whereas with the shadowing effect amount of $CO_2$ and crude oil reduction is 95,353 kg and 47,863 liters respectively. Computation of $CO_2$ and crude oil reduction is calculated as per the conversion factor defined in the article [26] and the same was presented in Table 8. Figure 10 depicts the environmental performance of the PV plant under shadowing and without shadowing effect.

Table 8. Environmental parameters

| Shadowing (Yes/No) | Crude oil reduction (L) | $CO_2$ reduction (Kg) |
|---|---|---|
| No Shadow | 58,931 | 117,403 |
| With Shadow | 47,863 | 95,353 |

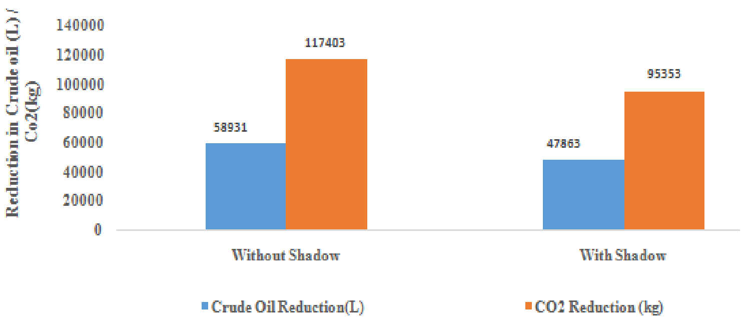


Figure 10. Environmental performance of PV plant

## 6. CONCLUSION

This case study evaluated the possibility of charging 80 electric cars, 40 two-wheelers and 40 four-wheelers, here research concentrated on the daytime load, which included both EV charging and domestic consumption, whereas the nocturnal load included just residential household usage. Using the Solar Pro program, we performed a techno-economic feasibility analysis. Based on the actual dimensions of the building chosen for the research, the best size for the photovoltaic (PV) plant was determined to be 156 kWp in DC capacity, and the inverter was developed with a 150 kW rating, consisting of three 50 kW inverters. According to the Economic feasibility assessment created by the tool, EV charging throughout the day leads in a bill decrease of Rs 8.25 lakhs under ideal circumstances with no shading. The system has an 8-year and 4-month payback period, assuming an energy rate of Rs 3 for energy purchase and Rs 4 for energy export to the grid. When the PV panels are shaded, the yearly cost is reduced to Rs 6.70 lakhs, and the payback term is extended to 10 years and 4 months. The results of the load flow analysis, as acquired using the MiPower tool, show that the system is stable and reliable. The overall power loss at maximum loading circumstances was just 0.148kW when both electric vehicle (EV) load and residential load were connected to the existing power distribution feeder. Electricity generated from PV sources covered almost 100% of the EV load, and any surplus electricity from such sources was also given to the residential load.

## ACKNOWLEDGEMENT

The authors are highly thankful to All India Council for Technical Education, New Delhi, India under Research Promotion Scheme, File No. 8-119/FDC/RPS (POLICY-1)/ 2019-20 for their financial grant towards this project.

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