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Analysis of Grid Connected Solar PV-Wind based Hybrid System Including EV Charging Infrastructure for Rural Area of West Bengal

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Abstract: In modern age, the over usage of automobiles using oil based fuel, has resulted in the excessive transportation-related emission as well as caused fuel prices to rise unconditionally around the world. In this situation, the usage of electric vehicles has opened a new and alternative pathway to tackle this global problem, and provide necessary energy conservation along with emission reduction. The target is to determine an optimized hybrid renewable system with the least possible values for the individual component Levelized and Net present costs of energy. Here the work presents an analysis on the establishment of a hybrid power system to run a general village located in Digha ($21^0 37.6' N, 87^0 30.4' E$) West Bengal, India. The next goal of reported work is to implement stand-alone renewable system with EV load and optimize the cost of the energy produced, operation and maintenance; consequently, curbing the use of conventional DG sets. The PV solar arrays are utilised as the main sources of the energy used, while the battery storage system is used otherwise. The wind and solar data have been referenced from NASA's meteorological department. The location in Digha consumes 1650 kWh/day with 385.51 kW peak power and a deferrable load of 24.86 kWh/day with 4.62 kW peak load demand. An innovative methodology has been designed to facilitate the determination of electric loads for the isolated location.

Keywords: Solar PV & Wind System, Hybrid Renewable Energy Systems, EV Charging Infrastructure, Emissions, Cost of Energy.

1. INTRODUCTION

In modern times, the majority of the world's electricity supply is obtained from fossil fuels like crude oil, coal and natural gas. However, conventional sources of energy have faced various challenges such as a resource crisis and environmental issues due to internal combustion engines (ICE) in vehicles. The battery electric vehicle (BEV) is currently considered a promising alternative. A study on the cost of developing electric vehicle (EV) stations, including operation, maintenance, equipment and installation is presented in [1]. The EV charging station optimal location and size for different systems are planned using various fitness functions in [2], [3]. Controlled management of energy is used to show the EVs discharging and charging with vehicle-to-grid (V2G) operation [4], supported by an energy mismatch approach between renewable sources and loads. An optimum allocation of fast-charging infrastructure for EVs is determined based on grid constraints, operator constraints, and available traffic [5]. In [6], a discharging and charging approach is presented to minimize energy consumption demand from the main grid by finding the population of available EVs. A microgrid system based on renewables and battery is presented in [7], utilizing different meta-heuristic techniques. An intensive load demand for rural regions in Chipendeke, Zimbabwe is projected using HOMER, including socio-economic growth, in [8]. In day-ahead market scenario, an optimised generation scheduling is carried out for the HRES planning incorporating BESS utilizing multi-objective cost function [9]. The hybrid system configuration is designed optimally, implementing GWO and GA algorithms to optimize the plant's global performance and profit [10]. A study is presented on the hybrid systems technological and economic benefits comprising solar-wind-DG, to provide electricity to off-grid rural areas in Peru. The study uses HOMER to determine the optimal system configuration and compare different configurations based on renewable percentage economic indices and emissions in [11]. Electric vehicles have several advantages, including high efficiency, energy savings, zero tailpipe emissions, and low noise, which make them a desirable option [12]. However, connecting EVs to the power grid presents obstacles such as placement, network loading, and power quality, particularly in terms of reactive power support, auxiliary services, and load balances [13], [14].

With the growth of urban and industrial lifestyles, reliable electricity availability is crucial for rural areas to improve living conditions, health, education, and the economy. Unfortunately, electricity is still inaccessible to more than 250 million Indian homes, with most of them located in villages [15]. Approximately 77 million households in India still rely on kerosene for lighting, and around 44% of rural Indian households have no access to grid electricity [16]. It is time to rely less on conventional sources and use renewable resources like solar and wind energy to provide a standard electricity supply to remote regions. The excess energy from nature can be utilized to generate electricity, even without an electricity grid, providing the necessary energy required by the population [17], [18]. A hybrid system is the culmination of several renewable energy generating systems with backup DG and can efficiently model grid energy ranging from 1 kW to 100s of kW. Using a large fraction of renewable energy curbs the operational costs of the system while also providing an alternate option of DG availability [19]. HOMER is applied to evaluate the optimum size and efficient operational strategy for a hybrid renewable energy system (HRES), using three primary responsibilities like simulating, optimizing, and evaluating accuracy [19]–[21]. The HRES analysis with a PV array, wind turbine system, battery storage systems and power converter, that can also accommodate electrical vehicle loads reported in [22]. The proposed optimum system has a 500 kW PV array, a total capital cost of ₹22.5M, and no replacement cost since the project lifespan is also the PV array lifespan [23]–[25]. The round-trip battery efficiency may be simply determined when the battery state of charge is positive for charging mode and negative for discharging mode [26], [27]. The power converter facilitates optimal energy flows between different DC and AC components of the system [28]. Both primary and deferrable loads are taken into consideration, with the residential house load characteristics, individual appliance loads, and hours operated considered for both residential and commercial loads [29], [30]. Wind data and solar radiation are sourced from NASA's meteorological department [31]. The development of regional EV battery charging stations is influenced by factors such as demand, feasibility of the resource, traffic flow, and distance between the main roads and the charging station location, while factors such as traffic, geographic location, environmental protection, surrounding road network, and regional station distribution capacity affect feasibility [32]. The HRES to decrease NPC (Net Present Cost) and COE (Cost of Energy) is proposed in [33], [34], HOMER is used to simulate various system sizes, operational strategies, and component combinations here to find the best solution.

Based on the review analysis, it is evident that the adoption of EVs is increasing globally, and the lack of infrastructure for effective charging is a major problem in urban and rural areas. The solar and wind energy are freely available in plenty worldwide, so making their utilization for EV charging infrastructure development is more beneficial. Therefore, this study focuses on the techno-economic analysis of a case study involving the development of an EV charging infrastructure located in a rural area of West Bengal, considering wind and solar energy systems.

Figure 1. Geographical location of study area Digha, WB

2. CASE STUDY LOCATION

The proposed hybrid renewable energy system for Digha, West Bengal, situated about 183 km from Kolkata in the eastern part of India, includes a wind turbine, PV system with a power converter, battery units, and DG. The battery units act as a backup resource and storage system. Fig. 1 represents the geographical location of Digha, West Bengal. The wind and solar data for the location are obtained from the online information of the NASA Meteorological branch and National Renewable Energy Lab (NREL). To obtain the day-to-day load profile for different cases, the region has been surveyed, as electricity does not reach these villages. HOMER is used to simulate, optimize and evaluate the most desirable sizing and strategy for reliable operation of hybrid renewable energy system.

3. SYSTEM MODELING AND CONFIGURATION

The hybrid renewable energy system comprises with PV array, wind turbine system, battery storage, DG, power converter, and electrical loads. Based on the type of bus bars, hybrid electricity generation systems can be classified into three categories, namely, pure AC busbar systems, pure DC busbar systems, and hybrid AC-DC busbar systems. Here, AC DC bus bar configuration is taken into consideration because to its benefits in comparison to different configurations. The hybrid renewable strength gadget consists of PV machine, WT system, battery gadgets, diesel generator, strength converter and electric hundreds. In the proposed methodology, renewable energy resources and the DG themselves provide a large part of the load-demand that gives superior avgerage system-efficiency. The DG and the convertor can function both in standalone mode and in parallel. In case of a smaller load, either the DG or the battery units can be used. For an instance, the DG could be switched off between 10.00 AM to 3.00 PM as the PV provides the greater fraction of the power. However, both must be operated in combination during peak load demand. In this case, the initial capacity of Diesel Generator and the inverter may be lower, while the controller efficiently operates without stopping, generating the required power demand.

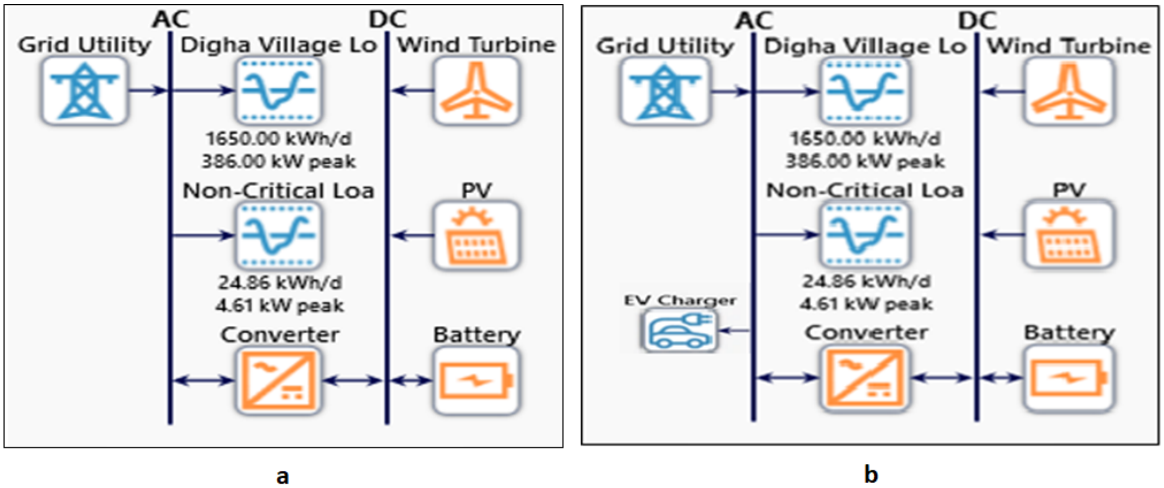

Figure 2. Proposed hybrid system for study location (a) without EV (b) With EV

Proposed hybrid system model for study location including different components is illustrated by Fig. 2. Modelling of the various functional components and parameters are briefly discussed below:

A. Solar PV

The performance characteristics and PV array design to size and evaluate the optimum characteristics of the system based on input parameters. The PV array output can be obtained as:

$$P_{array} = P_{out}k_d\left(\frac{\bar{E}_{solar}}{\bar{E}_{solar,STC}}\right)[1 + \alpha_t\left(T_{cell} - T_{cell,STC}\right)] \quad (1)$$

Where, P_out is PV array output power in KW, k_d is derating factor in %, E solar is the solar incident radiation at a particular time in kW/m^2, $E_(solar, STC)$ is solar incident radiation in standard test conditions ($1kW/m^2$), α_t is temperature coefficient in $\%/°C$, T_cell is temperature of cell at a particular instant in $°C$, and lastly $T_(cell, STC)$ is standard test conditions cell temperature (25 $°C$).

B. Battery

The battery state-of-change modelling can be written as follows:

$$B^t_{state} = B^{t-1}_{state} \pm \left(\frac{P^t_B \times \eta_B}{P_{base}}\right) \quad (2)$$

Here, we take positive value while charging mode and negative value while discharging mode. The battery SOC for t and t-1 instances are taken as B^t_{state} and B^{t-1}_{state}. Here, the P^t_B is the power of the battery during charging or discharging, η_B is the round-trip battery efficiency, and P_{base} is the base power of the battery in kWh.

C. Converter

A Converter (AC to DC) or Inverter (DC to AC) is needed by the system if both AC and DC components are present according to the required frequency. The efficiency of the convertor is given by:

$$\eta_{conv} = \frac{E}{E + E_o + cE^2} \quad (3)$$

Here, E, E_0 and c are the variable for convertor operation.

D. Load Profile

For the proposed hybrid scheme, the load characteristics has been included for a survey result of a village having similar social and economic conditions as of Digha, West Bengal. The per-hour and per day load has been recorded and calculated using EXCEL software. In this scheme, we consider two variations of load-

1) The main electrical load rated 1650kWh/day where the peak load is 385.51 kW, and
2) The deferrable load of 24.86 kWh/day where the peak load is 4.62 kW.

The primary load with day-to-day electrical appliances' power consumption and deferrable load consists water pump load to be used in irrigation purposes. The electrical load which needs a particular amt. of power in a given time range is defined as a deferrable load, however exact timing being significant. It can wait until power is available. Deferrable loads are generally related to storing needs, such as water-pumps for irrigation.

In the discussed Digha village, we have considered both residential and public and commercial loads. The load profile for study location i.e. Digha village for critical and non-critical load are represented from Fig. 3 to Fig.6. The impact assessment of total load takes into account with various factors such as the total number and types

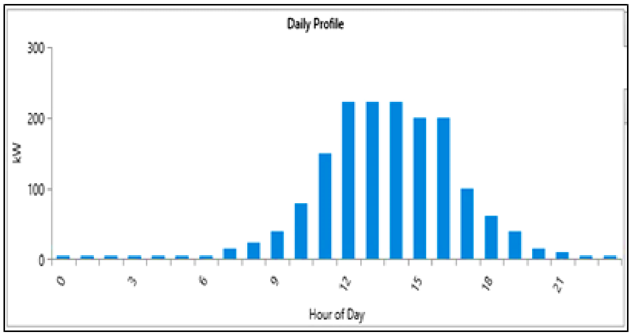

Figure 3. Daily Load Profile for Digha village

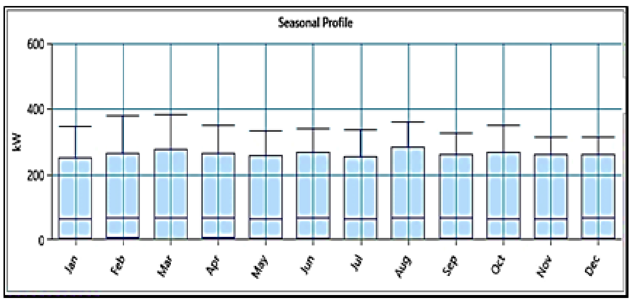

Figure 4. Monthly Load Profile

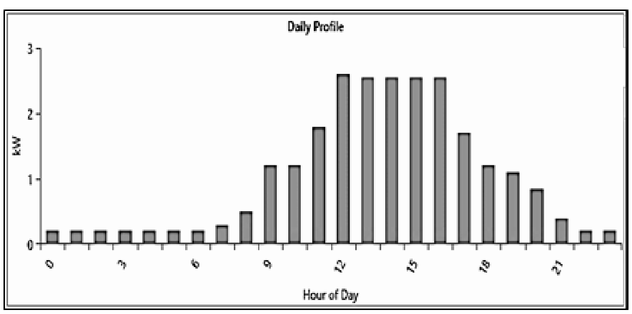

Figure 5. Daily Profile for Non-Critical Load

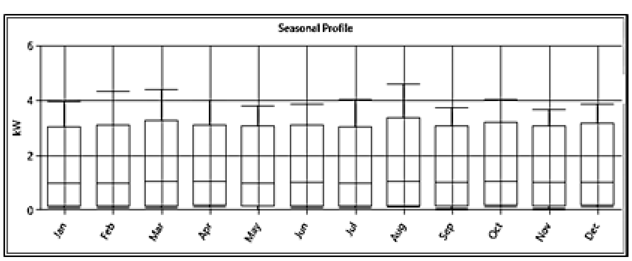

Figure 6. Monthly Profile for Non-Critical Load

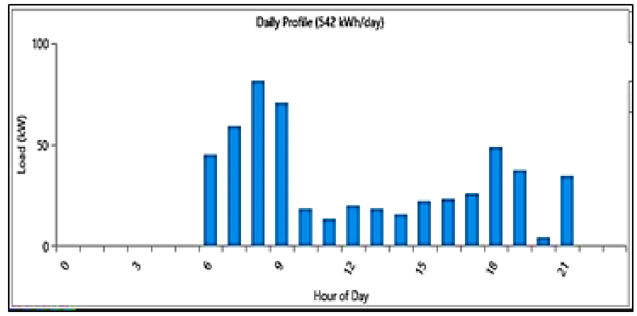

Figure 7. Daily Load Profile for EV Charging Station (542 kWh/day)

of appliances, hours of operation, rating of appliances, total residential houses and individual watt hour consumption. The estimation shows that the loads for different class houses are 646 kWh/day (high class), 595 kWh/day (middle class), and 94.5 (low class) kWh/day. The public and commercial loads include schools, health centres, street lights, mills, water pumps etc. The total loads for schools, health centres and other commercial segments are calculated as 48.75 kWh/day, 73.1 kWh/day and 189.58 kWh/day respectively. For the isolated village the gross electrical load per day is 1646.93 kWh. The yearly peak-load occurs during July calculated to be 385.51 kW. The avgerage non critical load for the Digha village is 10 hrs/day multiplied by 2.486 kW, which computes to a total of 24.86 kWh/day. The peak non-critical load is 4.62 kW. To account for the uncertain aspects of the load output, random variation of 10% and time step increment of 20% has been utilised. In the village location, minimal load variation is observed along the year; contrary to urban areas where due to large number of different electrical appliances there is a considerable amount of variation in the load.

E. EV Charging Station

The Load Profile for the EV Charging Station are illustrated in Fig.7 and Fig.8; which basically depends on the following factors:

1) EV Population Proportion with access to the Charging Station
2) Maximum power needed for charging the EV
3) Avg. duration of charge needed for the EV

4. OPERATION AND METHODOLOGY

The operational methodology of the planned hybrid renewable system aims to determine the optimized solution of all components for the proposed hybrid system. The photo voltaic array and wind-turbines will supply energy to charge the battery-storage if surplus energy remains after fulfilling the load-demand. The converter will converts DC power to AC as the PV-array output is in DC. If the battery is used if the photovoltaic arrays and the WT are not sufficient for the load. The control-methodology directs the power flow from DG to user and pump-loads, charge-discharge of Battery, in a predefined time range, to achieve

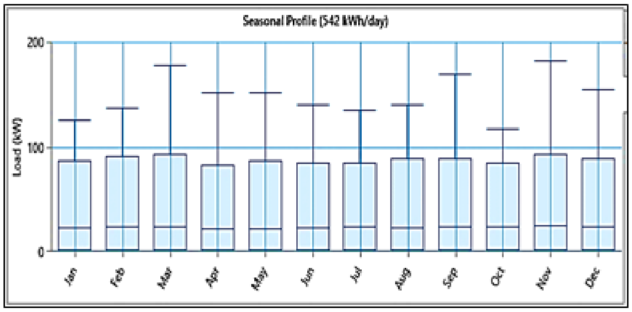

Figure 8. Monthly Load Profile for EV Charging Station (542kWh/day)

optimized performances of system regarding expenses of operation. The 2 types of dispatch-methodology in HOMER are cycling charge and load-charging depending on several key-points such as generator and components size, fuel expenses, the generator's operation and maintenance cost and the amount of system renewable energy. In this method, when generator is utilised it provides power just to fulfil the load-demand with less capacity, under cyclic charge and when the generator is used at maximum capacity with excess power, it is utilised for loads as well as changing the Battery storage.

A. *Operation and Maintenance cost*

The operating and maintaining expenses of a component is defined as the Operation and Maintenance (O& M) cost given by the total of individual O&M costs of all the components. We input the O&M cost values of the generators per hour, however for all other components of the system values are given per year. In case of the generators, HOMER evaluated the yearly O&M costs as the product of the previous value and annual-operating hours. The O&M cost for the grid is the cost of buying grid energy per year minus the earned revenue of sold energy to grid.

B. *Net Present cost*

The present expenses of component installation and operation during project-lifetime minus project-lifetime revenue earned is defines as the NPC (life-cycle or Net present cost) for the system components. HOMER evaluates the NPC for all system components together.

C. *Levelized Cost of Energy*

Levelized cost of energy (COE) is stated as the avg. cost of useful electrical power generated by the system per kWh. For evaluating LCOE, HOMER divides the yearly expense of electric power generation (i.e. the total yearly expense minus the expense of thermal load served) by the total serving electrical load, as per the equation as follows:

$$LCOE = \frac{P_{yearly} - P_{boiler} W_{thermal}}{W_{total}} \qquad (4)$$

Here, P_{yearly} is the total yearly prices of the system, $p_{(}boiler)$ is the margin-cost of the boiler, $W_{thermal}$ is the sum of served thermal loads, and lastly W_{total} is the sum of all served electric loads. In the cases of solar or wind system, $W_{thermal}$ is taken as 0 as there is no thermal load. The flow chart for modelling of hybrid renewable system with and without EV is given in Fig.10.

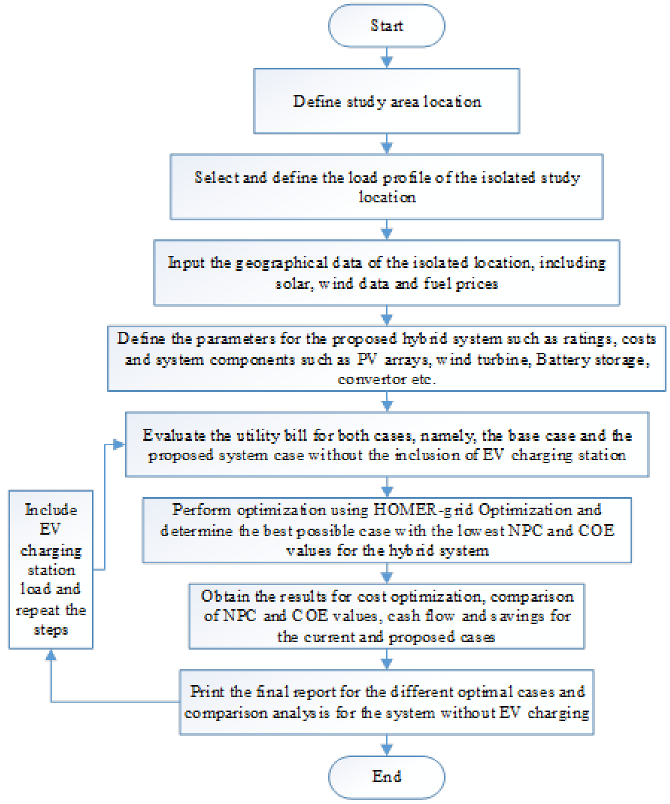

Figure 9. Flow chart for modelling of Hybrid renewable system with and without-EV

5. RESULTS AND DISCUSSION

Two different cases are analyzed and discussed for the Digha village in West Bengal. The designed hybrid system has 1650 kWh/day as primary load, with a peak load of 385.51 kW and 24.86 kWh/day as the non-critical load with peak load 4.62 kW. We take into consideration the renewable energy system with and with the addition of an external EV charging station load. The system includes Diesel Generator (DG) integrated to grid utility, along with the various system components such as the Wind Turbine, Solar PV arrays, Battery Storage systems and the converter. The main objective of the paper is to devise an optimized feasible system with the lowest achievable Net Present Cost (NPC) and the Levelized Cost of Energy (COE). HOMER has been utilized to generate the optimum economical architecture for developed hybrid renewable energy system, by simulating system model for varying sizes, strategy of operation and different combination of the system components. In HOMER implementation and calculations the 4 different combination of system components are considered

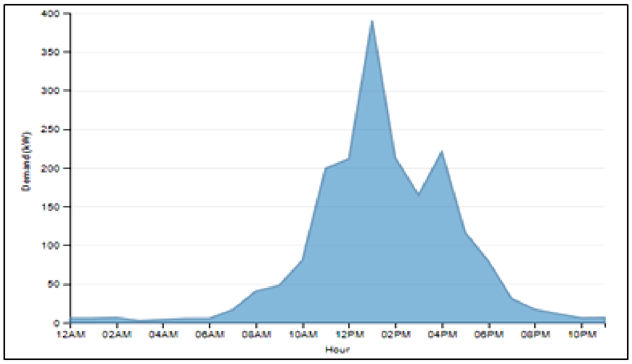

Figure 10. Load Profile of a Day with Largest Demand Occurrence without-EV (30 March)

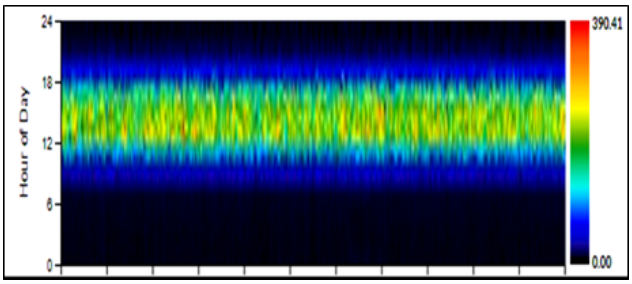

Figure 11. Heat Map with daily energy consumption patterns

namely: Grid & PV; Grid, PV & Wind Turbine; Grid, PV & battery; and Grid, PV, wind turbine & Battery. These particular combinations are influenced by the optimizing methodology used and the variables of sensitivity. For both the later discussed cases by including and excluding EV charging station loads, the first combination is found to be optimal with the reduced NPC and COE data. The reported work have used the HOMER software to generate the optimized calculation and determine the best suited size of each system component, and their respective NPC values. Therefore, it is seen that with several different combinations of the cost data possible with varying sizes of the PV arrays, no, of WT, Generator sizes, Battery Storage Units and rating of the DC-AC converters.

A. Without EV Load

Without the inclusion of an external EV charging station, the daily average electric energy usage is around 2281.9 kWh. The average monthly usage of electricity is 69.4 MWh, which equates to 832.6 MWh yearly. The annual peak electric demand occurs on March 30th evaluating to 390.41 kW as shown in Fig.10. Also, the daily energy consumption pattern, details of utility bills are demonstrated in from Fig. 11 to Fig. 13 for without EV case.

The main goal of the proposed hybrid renewable system is to reduce the NPC and COE under without-EV load by installing the solar PV system with grid utility based on optimum system design solution. The proposed system installation i.e solar system with grid utility is saving

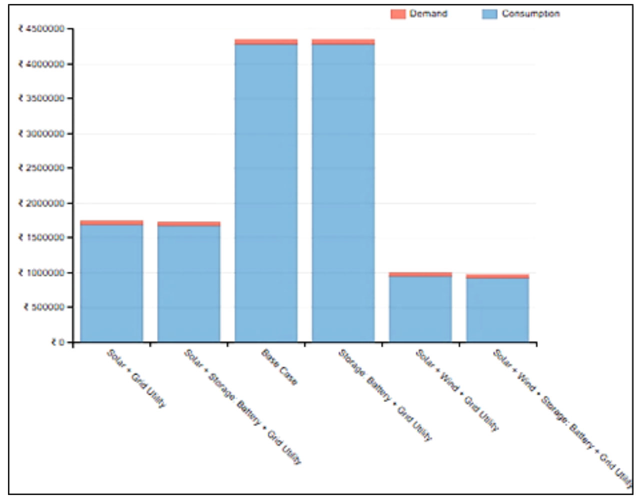

Figure 12. The Utility Bills Detail without-EV for different system

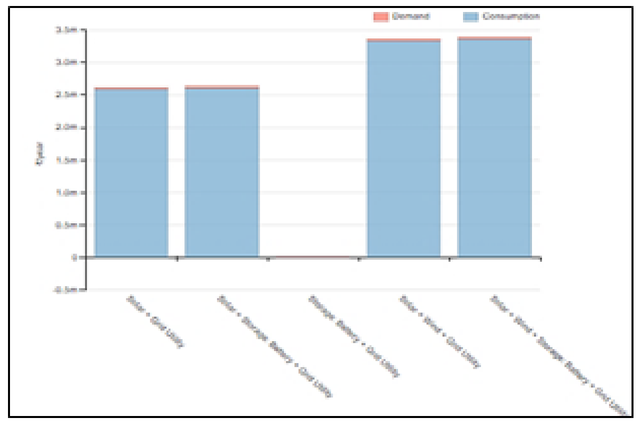

Figure 13. Annual utility bill savings estimated without-EV for different system

₹2607724 annually. Capital cost of the system is estimated to ₹22516810, while the savings throughout the system 25-year lifespan are expected to be Rupee 6,51,93,100. Internal Rate of Return (IRR) is determined to be 8.46% and payback period to be 9.8 years, respectively. It is advised to install 500 kW generic flat plate type PV arrays with a cost of ₹37.5 per watt. A cost estimate for the installation is ₹1,85,00,000, with an estimated yearly expense of ₹2,50,000. Figs. 14 and 15 show, respectively, the cash flow during the course of the project and the utility bill reductions. Fig. 16 displays the plot for without-EV load circumstances for various renewable resources and total load demand. The Table I,Table II and Table III provides the information of yearly electric energy costs and annual bill savings for the presented and proposed systems considering without EV.

B. With EV Charging Load

The average electric energy consumption with the addition of an external EV Charging station is about 2699.0 kWh per day.It is estimated that 985.1 MWh of electricity

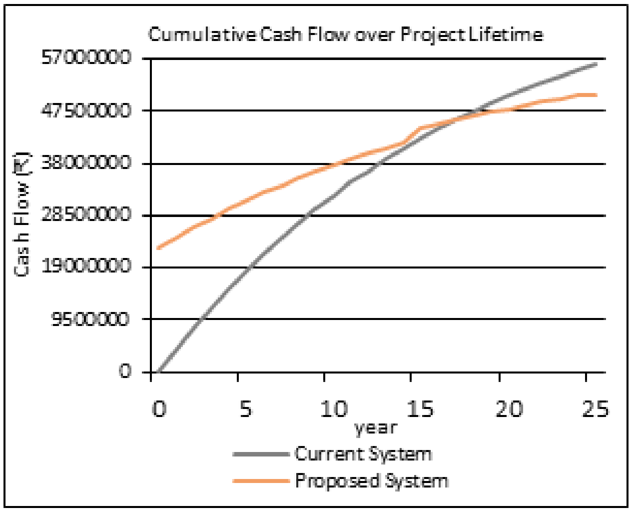

Figure 14. Total cash flow generated during project-lifetime without-EV

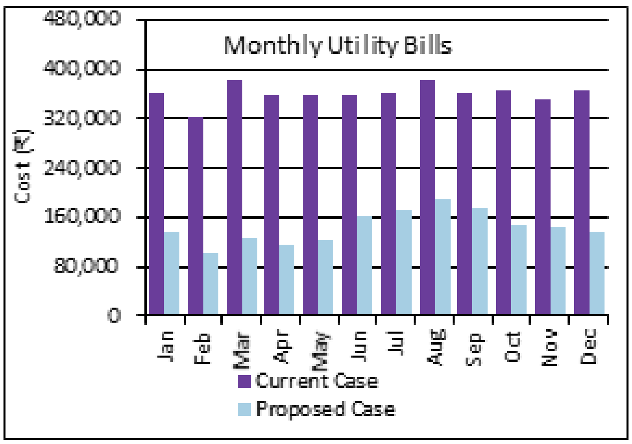

Figure 15. Monthly Utility Bill savings without-EV

are consumed on average per year, or 82.1 MWh every month. The annual peak electric demand occurs on 14th September evaluating to 450.06 kW as shown in Fig.17. The Fig.18 to Fig.20 illustrates the detail about the energy consumptions and the utility bills for different system configurations.

The grid utility with simply Solar PV array is the best system design in the second scenario. The technique is expected to save ₹32,02,109 annually. The expected savings during the project's 25-year lifespan are ₹8,00,52,725 whereas the system capital cost is around ₹2,30,75,660. The payback period and Internal Rate of Return (IRR) are computed as 8 years and 11.18 percent correspondingly. It is advised to install generic 500 kW flat plate type PV arrays with a cost of ₹37.00 per watt. The estimated installation cost is ₹1,85,00,000, with an estimated yearly expense of ₹2,50,000. Figs. 21 and 22 show separately the cash flow during the project's lifetime and the monthly power bill reductions with EV loads.

TABLE I. THE CURRENT SYSTEM BILL SUMMARY ANNUALLY WITH GRID AND WITHOUT-EV

Months	Purchased Energy (kWh)	Sold Energy (kWh)	Purchased Energy Total (kWh)	Load (Peak) (kW)	Charges for Energy	Charges for Demand	Fix Charges	Total
January	50,756	0	50,756	353	₹3,55,295	₹5,296	₹15.00	₹3,60,606
February	45,328	0	45,328	385	₹3,17,297	₹5,768	₹15.00	₹3,23,080
March	54,137	0	54,137	390	₹3,78,957	₹5,856	₹15.00	₹3,84,828
April	50,610	0	50,610	354	₹3,54,268	₹5,308	₹15.00	₹3,59,591
May	50,626	0	50,626	338	₹3,54,383	₹5,068	₹15.00	₹3,59,466
June	50,736	0	50,736	344	₹3,55,149	₹5,162	₹15.00	₹3,60,326
July	51,090	0	51,090	343	₹3,57,632	₹5,147	₹15.00	₹3,62,794
August	54,071	0	54,071	367	₹3,78,497	₹5,504	₹15.00	₹3,84,016
September	51,061	0	51,061	333	₹3,57,426	₹4,994	₹15.00	₹3,62,435
October	51,716	0	51,716	357	₹3,62,009	₹5,350	₹15.00	₹3,67,374
November	49,599	0	49,599	319	₹3,47,191	₹4,790	₹15.00	₹3,51,996
December	51,595	0	51,595	318	₹3,61,163	₹4,772	₹15.00	₹3,65,950
Annual	6,11,324	0	6,11,324	390	₹4.28M	₹63,015	₹180.00	₹4.34M

TABLE II. THE PROPOSED SYSTEM BILL SUMMARY ANNUALLY WITH GRID, SOLAR PV AND WITHOUT-EV

Months	Purchased Energy (kWh)	Sold Energy (kWh)	Purchased Energy Total (kWh)	Load (Peak) (kW)	Charges for Energy	Charges for Demand	Fix Charges	Total
January	19,243	20,754	-1,511	353	₹1,34,700	₹3,743	₹15.00	₹1,38,457
February	13,902	19,069	-5,167	385	₹97,314	₹3,369	₹15.00	₹1,00,698
March	17,675	21,405	-3,730	390	₹1,23,726	₹3,462	₹15.00	₹1,27,203
April	16,038	22,452	-6,415	354	₹1,12,266	₹4,069	₹15.00	₹1,16,349
May	17,185	23,027	-5,842	338	₹1,20,297	₹3,407	₹15.00	₹1,23,719
June	22,415	14,712	7,703	344	₹1,56,906	₹4,284	₹15.00	₹1,61,205
July	24,108	13,131	10,977	343	₹1,68,759	₹3,748	₹15.00	₹1,72,521
August	26,466	12,945	13,520	367	₹1,85,260	₹5,119	₹15.00	₹1,90,394
September	24,421	14,971	9,450	333	₹1,70,945	₹4,302	₹15.00	₹1,75,262
October	20,749	19,547	1,202	357	₹1,45,245	₹3,502	₹15.00	₹1,48,762
November	19,896	19,055	841	319	₹1,39,273	₹3,792	₹15.00	₹1,43,080
December	19,033	20,163	-1,129	318	₹1,33,232	₹3,839	₹15.00	₹1,37,087
Annual	2,41,132	2,21,231	19,901	390	₹1.69M	₹46,635	₹180.00	₹1.73M

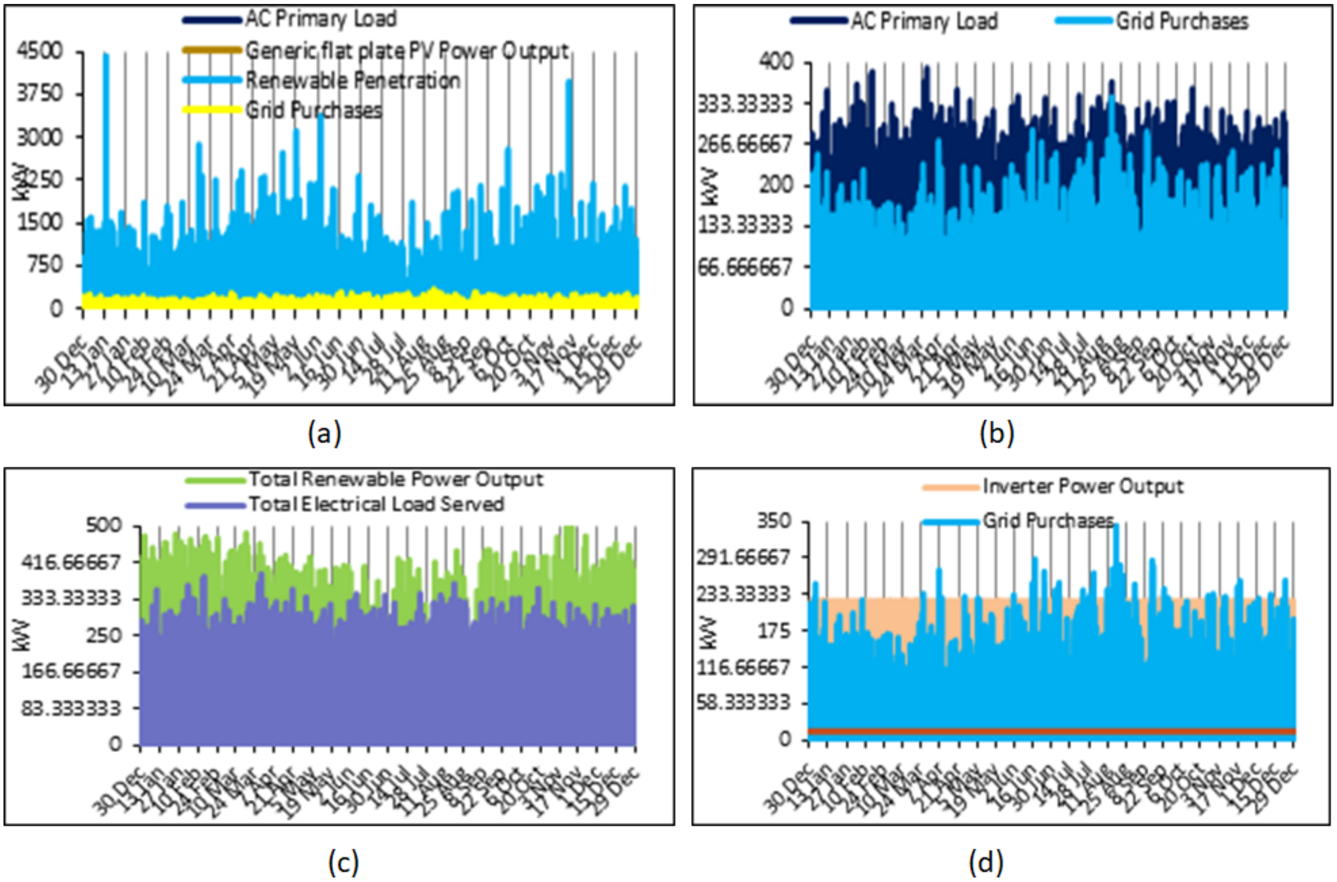

Figure 16. Plots for without-EV charging situations including different types of renewable energy and load: (a) Renewable penetration, PV power output and load served, (b) Total grid purchases and AC primary load, (c) Total load served and renewable power. (d) The total demand rate and output of the inverter.

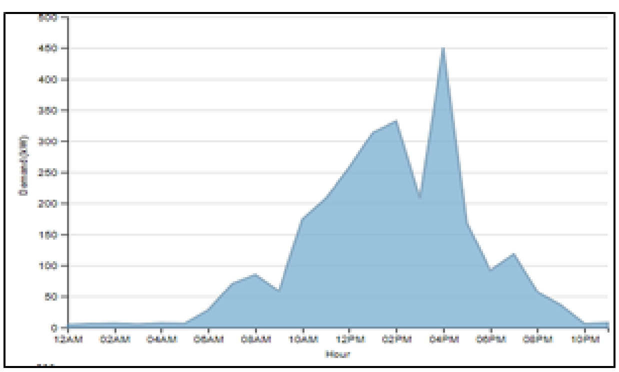

Figure 17. Load Profile of a Day with Largest Demand Occurrence with-EV (14 September)

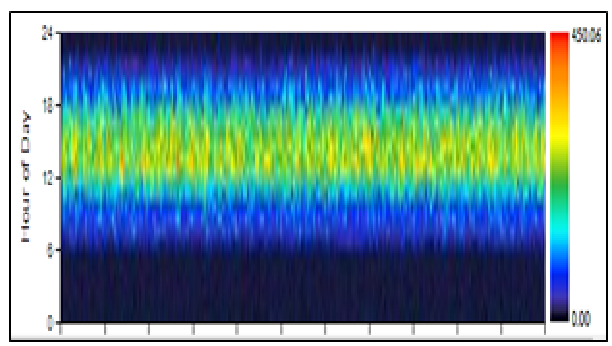

Figure 18. Heat Map with daily energy consumption patterns with-EV

As shown in Table IV, this EV depot uses 1,97,668 kWh of energy annually, with a peak demand of 182 kW. Four chargers, each with a maximum power output of 150.0 kW, are used to supply the 20.2 charging sessions per day. The electric vehicles served by this depot have the following charging characteristics as given in Table V. Also, the details about the monthly utility bills and the bill saving for proposed and current systems with-EV are tabulated in Table VI Table VII and Table VIII. The weekly EV load served and the Plots for without-EV charging situations including different types of renewable energy and load are shown in Fig.23 and Fig.24 respectively.

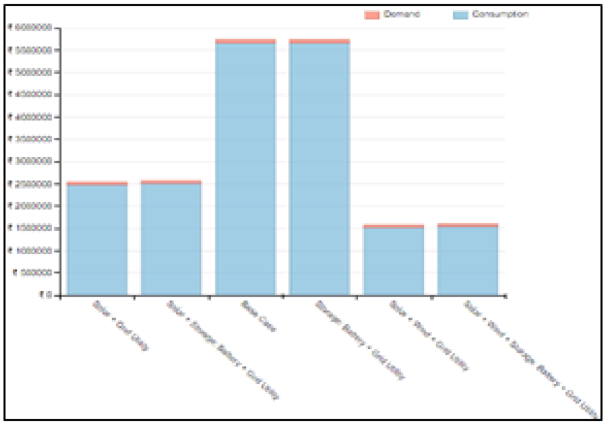

Figure 19. The Utility Bills Detail with-EV for different system

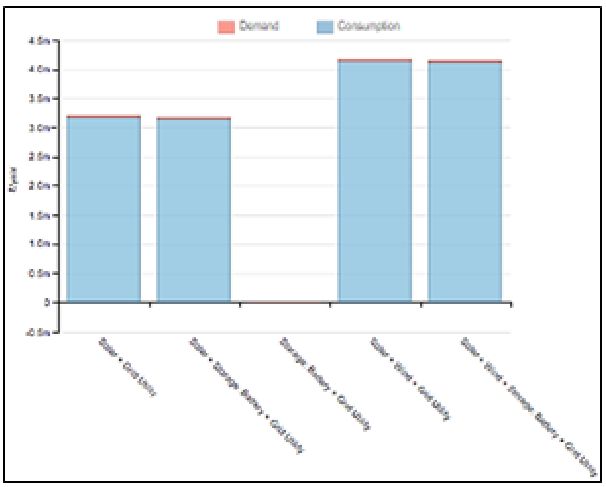

Figure 20. Annual utility bill savings estimated with-EV for different system

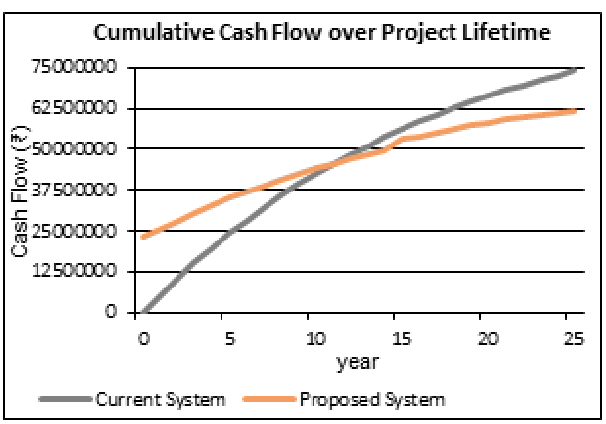

Figure 21. Total cash flow generated during project-lifetime with-EV

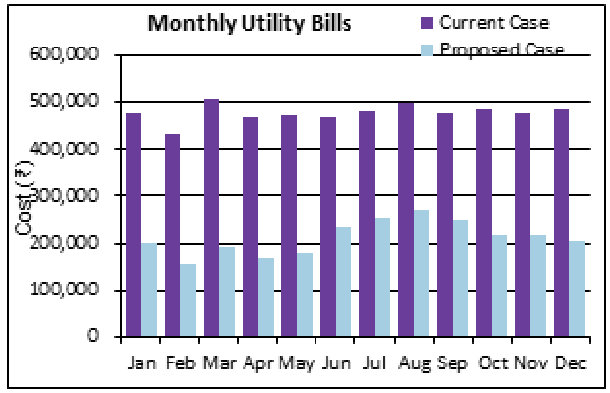

Figure 22. Monthly Utility Bill savings

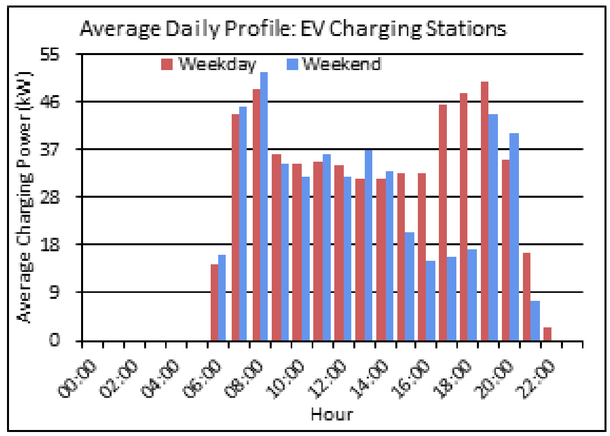

Figure 23. Weekly EV load served

TABLE III. THE PROPOSED AND CURRENT (BASE) SYSTEMS UTILITY BILLS AND SAVINGS FOR WITHOUT-EV

Systems Considered	Charges for Energy Consumption	Charges for Energy Demand	Fixed Rate	Total
Current (Base) System	₹4.28M	₹63,015	₹180.00	₹4.34M
Proposed System	₹1.69M	₹46,635	₹180.00	₹1.73M
Annual Savings	₹2.59M	₹16,380	₹0.00	₹2.61M

C. *Comparative Result Analysis*

In addition to an external Electric Vehicle Charging station, comparative changes are observed in the yearly expenses for the proposed hybrid renewable energy system. The main concern being the Levelized Cost of Energy (COE) and Net Present Cost (NPC); therefore, the simulation is performed for both the cases i.e., with and without the inclusion of the EV load on the system to asses the EV load impact. The detailed comparison for net-energy purchased, peak load and total charges for proposed systems on monthly basis with and without-EV is given in

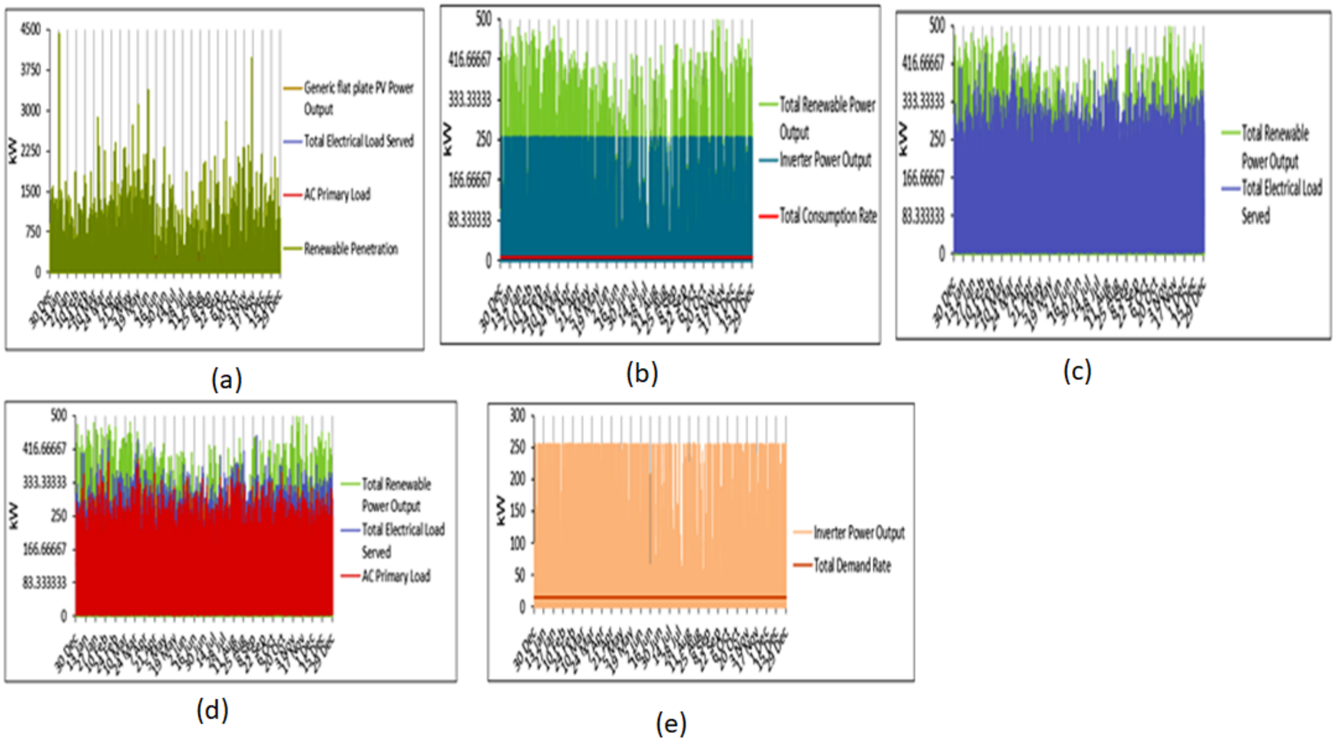

Figure 24. Plots for without-EV charging situations including different types of renewable energy and load: (a) Generation time series graph (b) Renewable and consumption rate output (c) Total load served and renewable power output (d) Total renewable with respect to AC load (e) Inverter output and total demand rate output

TABLE IV. DETAILED EV CHARGING LOAD

Energy Supplied Annually	198 MWh
Total Load (Peak)	182 kW
Per Session Energy	26.8 kWh
Sessions/Day for Charging	20.2
Sessions/Year for Charging	7,375
Sessions/Day Missed (Average)	0
Utilization-Factor	7.01 %

TABLE V. CHARGING CHARACTERISTICS OF EVs SERVED

Name	EVs population percentage (%)	Per EV maximum charging power (kW)	Average Duration for Charging (min)
EVs Large	30	150	20
EVs Small	70	50	20

Table IX. Similarly, the Table X shows the comparison of annual different energy charges without EV and with EV respectively. Also, the comparison of cost details for the different system configuration and proposed system with EV and without EV charging station are represented in Table XI and Table XII.

TABLE VI. UTILITY MONTHLY BILLS SUMMARY WITH-EV FOR BASE/CURRENT SYSTEM

Months	Purchased Energy (kWh)	Sold Energy (kWh)	Purchased Energy Total (kWh)	Load (Peak) (kW)	Charges for Energy	Charges for Demand	Fix Charges	Total
January	67,250	0	67,250	406	₹4,70,749	₹6,091	₹15.00	₹4,76,855
January	67,250	0	67,250	406	₹4,70,749	₹6,091	₹15.00	₹4,76,855
January	67,250	0	67,250	406	₹4,70,749	₹6,091	₹15.00	₹4,76,855
January	67,250	0	67,250	406	₹4,70,749	₹6,091	₹15.00	₹4,76,855
February	60,952	0	60,952	438	₹4,26,666	₹6,568	₹15.00	₹4,33,249
March	71,495	0	71,495	440	₹5,00,465	₹6,606	₹15.00	₹5,07,086
April	66,073	0	66,073	415	₹4,62,511	₹6,221	₹15.00	₹4,68,747
May	66,489	0	66,489	366	₹4,65,426	₹5,490	₹15.00	₹4,70,932
June	66,395	0	66,395	377	₹4,64,763	₹5,655	₹15.00	₹4,70,433
July	67,997	0	67,997	396	₹4,75,979	₹5,947	₹15.00	₹4,81,941
August	70,451	0	70,451	410	₹4,93,157	₹6,157	₹15.00	₹4,99,329
September	67,360	0	67,360	450	₹4,71,520	₹6,751	₹15.00	₹4,78,286
October	68,689	0	68,689	395	₹4,80,823	₹5,921	₹15.00	₹4,86,759
November	67,188	0	67,188	378	₹4,70,315	₹5,677	₹15.00	₹4,76,008
December	68,653	0	68,653	375	₹4,80,572	₹5,629	₹15.00	₹4,86,216
Annual	8,08,992	0	8,08,992	450	₹5.66M	₹72,714	₹180.00	₹5.74M

TABLE VII. MONTHLY UTILITY BILLS SUMMARY WITH-EV FOR PROPOSED SYSTEM

Months	Purchased Energy (kWh)	Sold Energy (kWh)	Purchased Energy Total (kWh)	Load (Peak) (kW)	Charges for Energy	Charges for Demand	Fix Charges	Total
January	27,787	16,957	10,830	406	₹1,94,508	₹4,197	₹15.00	₹1,98,720
February	21,606	14,983	6,623	438	₹1,51,244	₹3,519	₹15.00	₹1,54,778
March	26,592	17,827	8,765	440	₹1,86,145	₹3,938	₹15.00	₹1,90,097
April	23,412	18,797	4,614	415	₹1,63,881	₹4,206	₹15.00	₹1,68,102
May	24,954	18,646	6,309	366	₹1,74,681	₹4,422	₹15.00	₹1,79,117
June	32,501	10,992	21,509	377	₹2,27,506	₹4,613	₹15.00	₹2,32,134
July	35,677	9,609	26,068	396	₹2,49,739	₹4,938	₹15.00	₹2,54,692
August	37,763	9,742	28,021	410	₹2,64,339	₹5,269	₹15.00	₹2,69,623
September	34,609	11,270	23,339	450	₹2,42,262	₹5,811	₹15.00	₹2,48,088
October	30,549	15,561	14,989	395	₹2,13,846	₹4,628	₹15.00	₹2,18,488
November	30,120	15,241	14,879	378	₹2,10,841	₹4,783	₹15.00	₹2,15,639
December	28,505	16,504	12,001	375	₹1,99,535	₹4,702	₹15.00	₹2,04,252
Annual	3,54,075	1,76,130	1,77,946	450	₹2.48M	₹55,025	₹180.00	₹2.53M

TABLE VIII. THE PROPOSED AND CURRENT/BASE SYSTEMS UTILITY BILLS AND SAVINGS FOR WITH-EV

Cases	Consumption Charge	Demand Charge	Fixed Rate	Total
Base Case	₹5.66M	₹72,714	₹180.00	₹5.74M
Proposed Case	₹2.48M	₹55,025	₹180.00	₹2.53M
Annual Savings	₹3.18M	₹17,689	₹0.00	₹3.20M

When the base case has been defined in both the cases, we obtain four ideal cases having a better (lower) Cost of Energy than the base values. The cases with the best (lowest) value of the COE are also seen to have the lowest Net Present Cost for the system also. The total Net Present Cost (NPC) of the proposed system is the present price of all the system components accumulated over the lifetime operation, minus the present costs of the revenue earned during this lifetime operation. The NPC generally includes the initial installation costs, replacement costs, Operation and Maintenance Costs, fuel costs, any incurred penalty, and expense for grid-usage. In the second case, when the EV charging load has been added to the system, there is a considerable rise in the Net Present Cost (NPC) of the system. Without the EV, the best case has a NPC of ₹50.4M with a COE of ₹4.68 per kWh. However, with the EV charging added the best case now has a ₹61.6M with a COE of ₹4.84 per kWh.

In the first case, the utility bill savings is about ₹2.61M, while the total bill savings is ₹33.7M. The demand charges and the energy charges savings are ₹16,380 ₹/yr. and ₹2.59M/yr. respectively. However, on the addition of the EV charging station the utility bill savings rises to about ₹3.20M/yr., and the total bill savings to ₹41.4M. The demand charge savings and the energy charge savings are ₹17,689/yr. and ₹3.18M/yr. respectively. With regard to carbon dioxide emissions, without and with the addition of EV charging station, the system has a monthly carbon dioxide emission estimated to be about 152 metric tonnes/year and 224 metric tonnes/year respectively.

TABLE IX. COMPARISON OF NET PURCHASE, PEAK LOAD AND TOTAL CHARGES FOR PROPOSED SYSTEMS WITH AND WITHOUT-EV LOADS

Months	Total Energy Purchase (kWh)		Total Peak Load (kW)		Total Charges	
	Without EV	With EV	Without EV	With EV	Without EV	With EV
January	-1,511	10,830	353	406	₹1,38,457	₹1,98,720
February	-5,167	6,623	385	438	₹1,00,698	₹1,54,778
March	-3,730	8,765	390	440	₹1,27,203	₹1,90,097
April	-6,415	4,614	354	415	₹1,16,349	₹1,68,102
May	-5,842	6,309	338	366	₹1,23,719	₹1,79,117
June	7,703	21,509	344	377	₹1,61,205	₹2,32,134
July	10,977	26,068	343	396	₹1,72,521	₹2,54,692
August	13,520	28,021	367	410	₹1,90,394	₹2,69,623
September	9,450	23,339	333	450	₹1,75,262	₹2,48,088
October	1,202	14,989	357	395	₹1,48,762	₹2,18,488
November	841	14,879	319	378	₹1,43,080	₹2,15,639
December	-1,129	12,001	318	375	₹1,37,087	₹2,04,252

TABLE X. COMPARISON OF ANNUAL CHARGES FOR PROPOSED SYSTEMS WITH AND WITHOUT-EV

Purchased Energy (kWh)	Sold Energy (kWh)	Total Purchased Energy (kWh)	Charges for Energy	Charges for Demand	Total Charges
Without-EV					
2,41,132	2,21,231	19,901	₹1.69M	₹46,635	₹1.73M
With-EV					
3,54,075	1,76,130	1,77,946	₹2.48M	₹55,025	₹2.53M

TABLE XI. COST DETAILS OF THE SYSTEM WITHOUT EV CHARGING

System cases without EV	NPC (₹)	COE (₹)	Operating cost (₹/yr)	Initial capital (₹)
Grid + PV	₹50.4M	₹4.68	₹2.16M	₹22.5M
Grid + PV + Battery	₹51.0M	₹4.73	₹2.17M	₹22.9M
Grid + PV + Wind	₹91.7M	₹6.93	₹2.23M	₹62.8M
Grid + PV + Battery + Wind	₹92.6M	₹6.99	₹2.28M	₹63.2M
Base Case (Grid)	₹56.1M	₹7.10	₹4.34M	₹0.00

TABLE XII. COST DETAILS OF THE SYSTEM WITH EV CHARGING INCLUDED

System cases with EV	NPC (₹)	COE (₹)	Operating cost (₹/yr)	Initial capital (₹)
Grid + PV	₹61.6M	₹4.84	₹2.98M	₹23.1M
Grid + PV + Battery	₹62.2M	₹4.96	₹3.03M	₹23.1M
Grid + PV + Wind	₹100.0M	₹6.70	₹2.83M	₹63.4M
Grid + PV + Battery + Wind	₹101M	₹6.91	₹2.91M	₹63.4M
Base Case (Grid)	₹74.2M	₹7.09	₹5.74M	₹0.00

6. CONCLUSION

A variety of system elements, including the wind turbine, a PV system with a power converter, battery packs, and DG, are included in the proposed hybrid renewable energy system architecture. As a storage system and backup resource, the battery is offered. The two scenarios that make up the optimisation study are those with and without the addition of an EV Charging Station on the load side. Here, we compare the evaluated best case for the created system with the base case that we are considering. In the first scenario, the system's base case NPC is ₹56.1 million without the EVCS and also includes yearly energy charges ₹4.34 million and yearly demand charges ₹63015. The suggested hybrid renewable system estimates the lower NPC ₹50.4 million, including yearly energy prices and yearly demand charges of ₹1.69 million and ₹46635 respectively. In the second scenario, which includes the EV Charging Station as a load, the system's NPC is ₹74.2 million, considering yearly energy charges of ₹5.74 million and yearly demand charges of ₹72714. Similar to the last instance, the planned power system's decreased NPC value is ₹61.6 million, which includes yearly energy charges and yearly demand charges of ₹2.98 million and ₹55025, respectively. As a result, it is clear that the optimal scenario has a substantially lower NPC and energy cost base value than the base values for the two situations discussed above about EV Charging Station loads. When EVCS is included, the LCOE falls from ₹7.10/kWh to ₹4.68/kWh in the first scenario and from ₹7.09/kWh to ₹4.84/kWh in the second scenario. In a similar way, the total annual utility bill, pollution emissions, demand, and energy costs are all much lower in comparison to the base statistics for both of the situations described.

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