Techno-Economic Comparative Analysis between Grid-Connected and Stand-Alone Integrated Energy Systems for an Educational Institute

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Techno-Economic Comparative Analysis between Grid-Connected and Stand-Alone Integrated Energy Systems for an Educational Institute

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Abstract: Promoting green energy initiatives are vital in educational institutes to encounter the energy demand and providing a sustainable life. In the most part, solar and wind energy options are chosen as renewable energy projects to meet part of electricity demand. However, because of the intermittent nature of these sources, alternative technologies should be chosen to provide effective and sustainable solutions. Various energy resources need to be combined in order to provide effective and efficient power generation. The present paper therefore focuses on the feasibility study of integrated energy systems for the energy supply of the educational institution. The work examines the techno-economic performance of various grid-connected and stand-alone integrated energy systems for an educational institute for making a decision before implementing green energy technologies. First, the energy demand is estimated for the entire campus. Further, the potential of renewable energy resources is assessed using NASA and NREL. A detailed survey was carried out to select the components required to model the various integrated energy systems. The modelling, optimization and economic study are performed using HOMER Pro software. A comparative economic analysis is made among considered integrated systems using Net Present Cost (NPC), COE and pay-back period. The study divulges that the grid-connected hybrid system is the optimal one for meeting the power demand of the institute in a reliable manner.

Keywords: Integrated energy system; Solar/ Wind energy; Diesel generators, HOMER Pro.

1. Introduction

Educational institutions are in great need to maintain or upgrade their prevailing infrastructure to suit the growing economy and demand for education. This swift in infrastructural expansion will lead to more power demand by these institutions. Most of the current infrastructural needs of institutions are exclusively dependent on conventional energy. Currently, maximum of the electricity is produced from burning fossil fuel resources like coal, oil and gas. The usage of these resources causes pollution and climate changes. It is very important to minimize the pollution and climate changes by using renewable energy resources as an alternative to fossil fuels resources. However, the country's economy depends on fossil fuels. As the energy demand is ever increasing, the only effective elucidation is to utilize the available and feasible renewable energy sources effectively. Further, the renewable energy based technologies should be adopted in all sectors before the exhaust of fossil fuel resources[1]. The renewable energy is obtained from sun, wind, bio mass, water etc. moreover renewable energy sources are pollution free, eco-friendly and accessible at free of cost.

Solar and wind resources are considered as intermittent energy sources because they are seasonal specific. For these two types of renewable energy, wind energy is the more effected source if compared to the solar energy due to its inconsistency. Similarly, the stand-alone systems containing these two unpredictable energy sources will produce varied output energy and thus cannot guarantee the continuity of power for meeting the necessary load requirement. To overcome the above mentioned problems, integrated energy systems are developed[2]. The addition of different energy resources makes the system to produce continuous output energy without any fluctuations. In general hybrid energy systems contain diesel generators, loads, renewable energy resources, energy storage, power converters, etc.[3].

The hybrid systems can be categorized as stand-alone and grid-connected. The former systems are normally used in isolated places where the extension of grid network is not feasible and locations where grid failures occurs frequently[4]. On-grid hybrid systems are directly connected to the local utility grid. On-grid hybrid systems allow us to meet our load demand by integrating the renewable energy sources and grid. In these systems, the excess power is generally sold to the grid and shortage of energy is met by purchasing from the grid[5].

Few studies carried out on techno-economic performance assessment of On-grid and Off-grid hybrid energy systems are discussed here. Muselli et al.[6] analysed the PV-Diesel generator based hybrid system and shown that the system has greater reliability in generating electrical energy. Bagen and Billinton[7] study reveal that the operating cost can be minimized by implementing solar-wind-diesel generator hybrid system. Givler and Lilienthal[8] showed that the PV/diesel system suits economically better than solar based systems. Rehman et al.[9] analysed the feasibility study of Wind-PV-Diesel hybrid energy system for a village and identified that the hybrid power systems exhibit higher reliability and lower cost of generation than the energy system based on single source of energy. Sen and Bhattacharyya[10] designed stand-alone integrated energy system for a rural village and identified that the considered configuration is more cost-effective choice than conventional grid extension. Chade et al.[11] conducted hybrid energy system analysis for Grimsey Island and showed that a wind-hydrogen hybrid system is economically optimal. Amutha et al.[12] analyzed different combinations of hybrid energy systems for electrifying a village and observed that PV-Wind-Diesel generator-Battery integrated configuration is best choice among all other hybrid system combinations. Baghdadi et al.[13] compares the performance of diesel generator systems with the hybrid PV-Diesel-Wind-Battery system for electrifying remote regions and observed that 69% of conventional fuels can be saved if hybrid PV- Diesel-Wind-Battery system is implemented. Though the above works mainly focused on economics of hybrid systems in small villages and islands, very few works are also devoted to economic analysis of hybrid energy systems for buildings. Singh and Baredar[14] performed techno-economic assessment of a solar PV, fuel cell, and biomass gassifier hybrid energy system for energy centre MANIT Bhopal and observed that this system will generate an excess electricity of 36 kWh/year with zero unmet electric load. Tomar and Tiwari[15] performed techno-economic evaluation of grid connected PV systems for households and observed that this system economically beneficial to household customers. Usman et al.[16] designed three hybrid system configurations for electrifying Faculty of Engineering and Technology department, Jamia Millia Islamia, and observed that PV-Grid hybrid system is more cost-effective with lowest cost of energy of Rs 8.84/kWh. Kumar and Bhimasingu et al.[17] designed a PV-wind-diesel generator-battery-grid connected hybrid energy system for a building in a technical university and observed that the designed system is more economical and environment friendly, which leads to 6.18% of annual cost savings.

Most of the above studies indicate that little research is being done on the assessment of the techno-economic efficiency of hybrid energy systems in technical institutions. Furthermore, these studies are limited to a small building in a specific area. However, as per the author’s knowledge, no work has been done on feasibility study of hybrid energy systems for the entire campus of the institute. In addition, meeting energy demand in an efficient and cost-saving manner depends on a variety of factors, such as location, availability of resources, load and government subsidies, technological and economic aspects of the various components of the energy system. Considering the above facts, the present work is focused on design and optimal sizing of integrated energy system for meeting the energy requirement in the entire campus of the institute considering the academic and residential areas of the institute in northern coastal district of Andhra Pradesh in India. Four different hybrid energy systems are designed and carried out simulations to meet the energy demand of the campus and comparative study is made to provide an economic feasible solution.

2. Energy assessment at location

The JNTUK-University college of Engineering Vizianagaram (UCEV) is located in the rural village of Dwarapudi in the Vizianagaram district of Andhra pradesh in India. The campus is having a primary load requirement of 1814 kWh/day with a peak value of 214.99 kW and a deferrable load of 85.50 kWh/day with a peak value of 28.50 kW. The primary load demands are the electrical load demands that the hybrid system can serve at a specific time whereas deferrable load demands are the electrical load demands that can be met any time with a specific time intervals. Water pumping is considered as a deferrable load. The primary load summary of the campus is shown in Fig. 1. It is perceived that the maximum energy requirement is in March and April between 6.00 pm to 11.00 pm. This is due to the fact that during these hours in summer all the lightening loads, electrical fans and air conditioners in residential area of the campus consumes majority of electrical energy. The deferrable load profile of the campus is shown in Fig. 2. The deferrable load of the campus is seen to be less in the month of May. This is due to the fact that during this month, summer holidays are given to students, so that the operating motor load on hostel blocks is almost negligible.

2.1 Solar energy data

The JNTUK-UCEV campus located at latitude of 18° 9.1° North and 82° 22.5° East. The annual average solar radiation at the specified location is taken from National Aeronautics and Space Administration (NASA) resource website[18]. The yearly average solar energy available at the location is 4.82 kWh/m^2/ day. The monthly average of clearness index and solar radiation is shown in Fig. 3.

2.2 Wind energy data

The annual average wind speed at the campus location is 4.64 m/s and the altitude of campus location is 129 m above from sea level[19]. The diurnal pattern strength is 0.25 and the auto correlation factor is 0.85[20].The monthly average wind

speed over a year is shown in Fig. 4. From solar and wind data, it is seen that the solar energy available is less in July and August months whereas, the wind speed is high in these two months. So high wind speed in July and August months compensates the less solar radiation effect and makes total renewable resources to be available throughout the year.

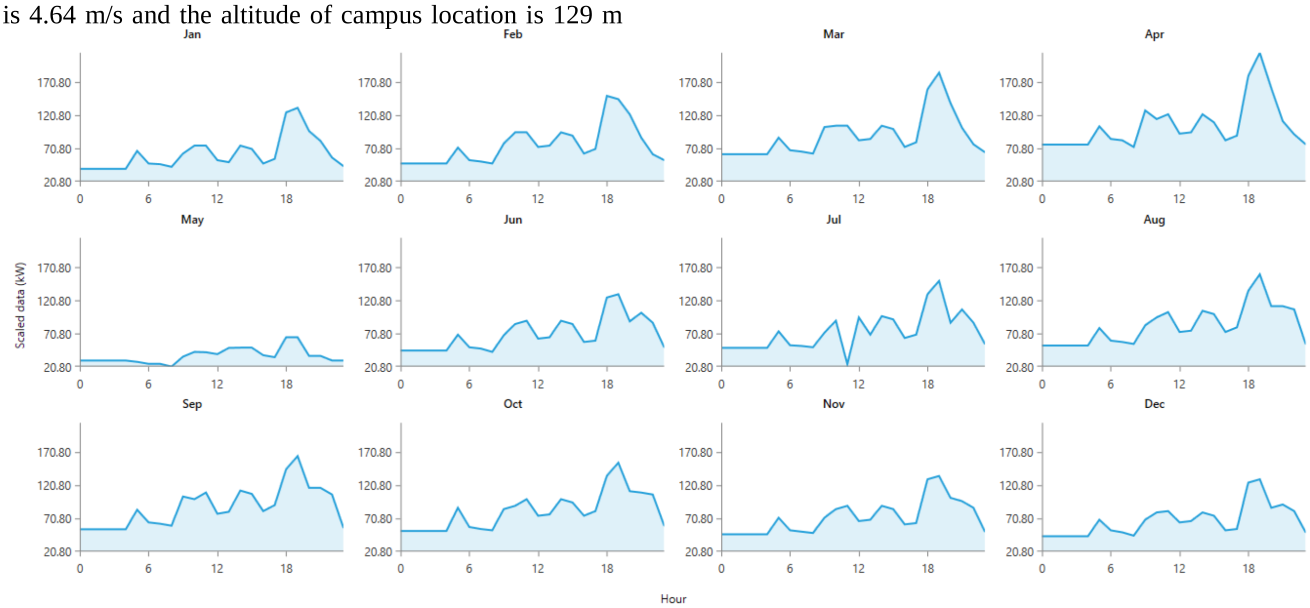

Fig. 1: Primary load profile of the campus.

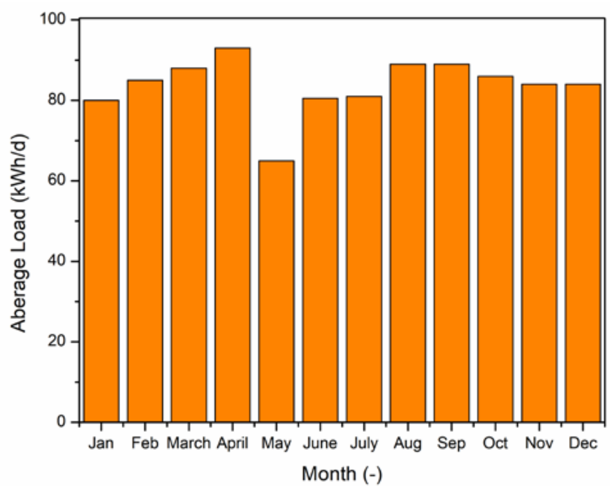

Fig. 2: Deferrable load profile of the campus.

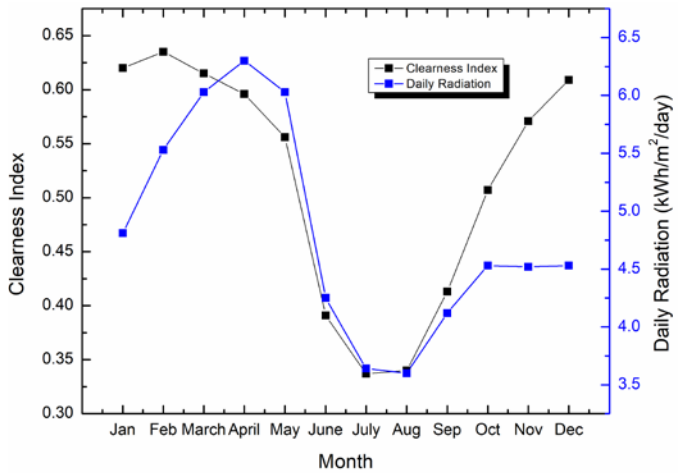

Fig. 3: Solar energy data at the campus location.

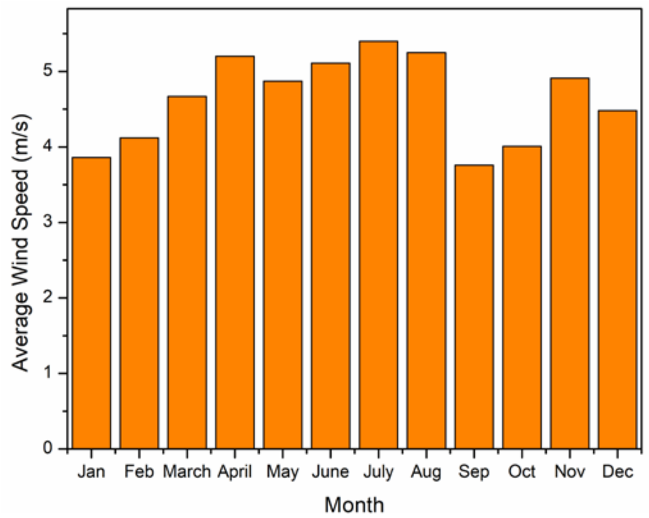

Fig. 4: Wind energy data at the campus location

3. Methodology

The present section confers the methodology and design aspects of different integrated systems for supplying the optimal power generation to the considered educational institute. For this study, the HOMER software is used to model various interconnected energy systems complemented by the HOMER pre-evaluation and post-analysis. The detailed methodology followed in the present work is shown in Fig.5.

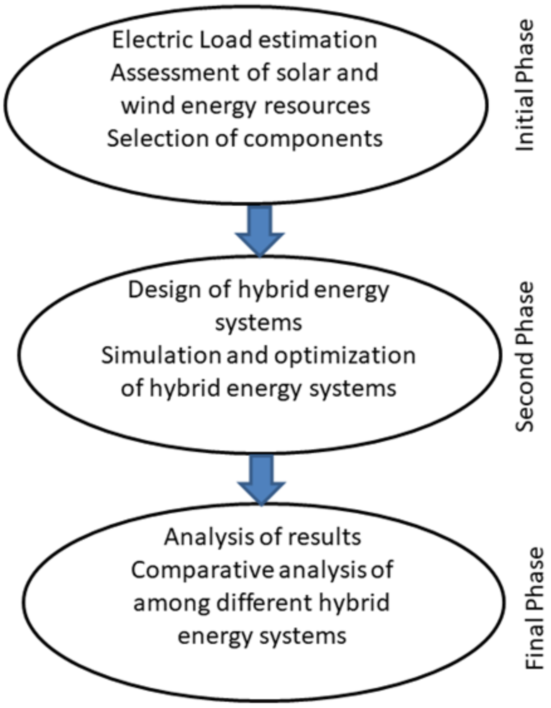

Fig.5. Methodology adopted in the present work

The work has been conducted in three stages. In the initial phase of the study, a comprehensive electrical load assessment was carried out separately for the academic and residential parts of the institute. The full load profile of the institute as a whole was evaluated with the aid of load data collected from the institute’s academic and residential campuses. Then, the availability of solar and wind energy resources at the location is measured using data from the National Aeronautics and Space Administration (NASA) information website. In addition, a detailed survey was conducted on the selection of each part of the hybrid energy system on the basis of technical and economic requirements. During the second phase of research, four different hybrid energy systems were designed to take into account load data, resources and different components using HOMER pro software. Moreover, simulations and optimization of the different hybrid energy systems are carried out. In the final step of the study, a thorough analysis of the optimal hybrid energy systems was carried out and a comparative analysis was carried out between the various hybrid energy systems to make a decision on the optimal hybrid energy system to satisfy the energy needs of the educational institution.

3.1 Economic and technical specifications

The economic and technical specifications of different components that are used in modelling of hybrid energy systems are discussed in forthcoming sub sections.

3.1.1 Solar PV system

SunPower E20-327(SPR-PV) model solar panels are considered for the study. The capital and replacement cost of 1 kW solar panel are chosen as $615 and $584 separately. The life span of solar panel is 25 years. Derating factor of PV panel is taken as 88% and the ground reflectance is considered as 20%[22]. The performance of the PV array shall be calculated as[14]

$$P_{\text{out}} = P_{\text{NPV}}(G/G_{\text{ref}})\left[1+K_{\text{T}}(T_{\text{C}}-T_{\text{ref}})\right] \tag{1}$$

3.1.2 Wind turbine

A Whisper 200 series (Wh200) model wind turbine is considered in this work. The capital, replacement, operation and maintenance (O&M) cost per kW are chosen as $1000, $923 and $9.23 individually. The life period is 20 years and a hub height of 12.5 m[23]. The Whisper wind turbine gives DC power output. The wind speed at the hub height can be calculated using logarithmic law as

$$U_{\text{hub}} = U_{\text{anem}} \frac{\ln\left(Z_{\text{hub}} / Z_{\text{o}}\right)}{\ln\left(Z_{\text{anem}} / Z_{\text{o}}\right)} \tag{2}$$

The wind speed at the hub height can be calculated using power law as

$$U_{\text{hub}} = U_{\text{anem}} \left(\frac{Z_{\text{hub}}}{Z_{\text{anem}}}\right)^{\alpha} \tag{3}$$

In order to conform to the actual conditions, the power value expected by the power curve is multiplied by the air density ratio, according to the equation.

$$P_{\text{WTG}} = \left(\frac{\rho}{\rho_0}\right) P_{\text{WTG ,STP}} \tag{4}$$

3.1.3 Converter

A Solax X3-hybrid 10 model converter is chosen for study. The per kW capital, replacement and O&M cost of converter are chosen as $277, $261 and $9.23 separately. The life of converter is 15 years with an efficiency of 97%[9].

3.1.4 Batteries

The batteries considered for this study are Exide 6LMS model. It is a 12 volts battery with a nominal capacity of 100 Ah and life time of 10 years and round trip efficiency of 80%[24]. The capital, replacement and O&M cost of battery are considered as $161.5, $131 and $4.6 respectively. The storage capacity (C_{Wh}) is calculated by the equation[14]

$$C_{\text{Wh}} = \left(\text{E}_{\text{L}} \times \text{AD}\right)\eta_{\text{inv}}\eta_{\text{b}}\text{DOD} \tag{5}$$

3.1.5 Diesel generators

There are total five generators already installed in JNTUK-UCEV campus. They are Kirloskar generator(G1)-100 kW, Ashokleyland generator (G2)-50 kW, Kirloskar generator (G3)-50 kW, Kirloskar generator (G4)-50 kW, Kirloskar generator (G5)-50 kW. The initial capital cost of all generators is taken as zero as these were already part of the institute. The replacement and O&M cost of generator G1 are chosen as $8461 and $3.8. For generator G2 the replacement and O&M cost are $6153 and $1.92. The replacement and O&M costs of generators G3, G4 and G5 are considered as $6923 and $1.92. The cost of diesel per litre is taken as $1. The output power equation of generator is given by equation[17]

$$F = F_0 Y_{\text{gen}} + F_1 P_{\text{gen}} \tag{6}$$

3.1.6 System economics and constraints

The life of the complete system is considered as 25 years. The expected Inflation rate is 2%. The Nominal discount of 6%[25] is considered. The maximum annual capacity shortage is taken as 0% and the simulation time step is taken as 60 min[26].

3.1.7 Grid input

The cost of electricity purchased by JNTUK-UCEV campus from APEPDCL is $0.145/kWh. The excess electricity generated by the Grid connected hybrid systems could be selling back to the grid with a feed in tariff of $0.08/kWh.

3.2 Modelling of different hybrid energy systems

In the present section, four different hybrid systems are modelled by considering technical and economic specifications of different components which are discussed in the last section. Two grid-connected and two stand-alone hybrid energy systems are modelled with the help of Hybrid Optimized Model for Electric Renewables (HOMER Pro) software[21] in the present study. They are

Case 1:	PV-Wind- Diesel generator hybrid system.
Case 2:	PV-Diesel generator hybrid system.
Case 3:	PV-Wind-Diesel generator-Grid connected hybrid system.
Case 4:	PV-Diesel generator-Grid connected hybrid system.

The detailed modelling of each case of the integrated energy system is discussed in forthcoming sub sections.

3.2.1 Case1

In this hybrid model, all five diesel generators in the campus are considered along with PV arrays, wind turbines and batteries. Fig. 6 depicts the hybrid model of the Case1. Solar and wind are considered as primary sources for generation of electrical energy. The PV arrays are mostly operates during day time and the wind turbines operate throughout the day. Whenever, the electric energy Requirement is not produced by the primary energy sources, the generators operate and fulfil the demand. The battery is used to store electrical energy when the supply exceeds the demand. Further, the converter is added in the design to convert DC power to AC.

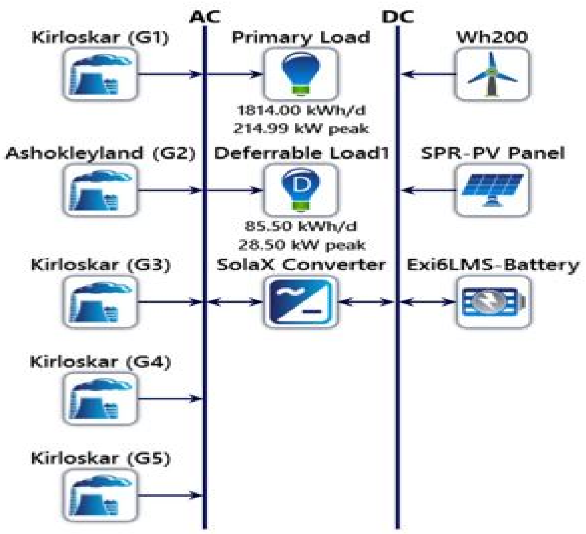

Fig. 6: PV-Wind-Diesel generators hybrid energy system.

3.2.2 Case 2

The model presented in this section is similar to the earlier model except the omission of wind turbine. The HOMER simulation model is shown in Fig. 7. All the five generators connected in this hybrid system are acts as secondary sources of electrical energy.

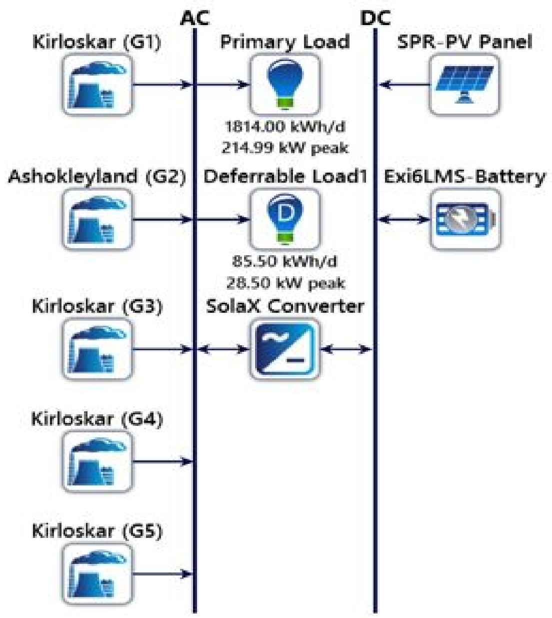

Fig. 7: PV-Diesel generators hybrid energy system.

3.2.3 Case 3

The first two cases are focused on design of stand-alone integrated systems. In the present case, the hybrid system is connected local grid as shown in Fig.8. The primary renewable energy resources such as Solar and wind are taken. The storage battery is not included in the present model as the hybrid system is coupled to the grid. The additional energy generated than demand is sold to the grid and energy could be purchased when the demand exceeds the generated power.

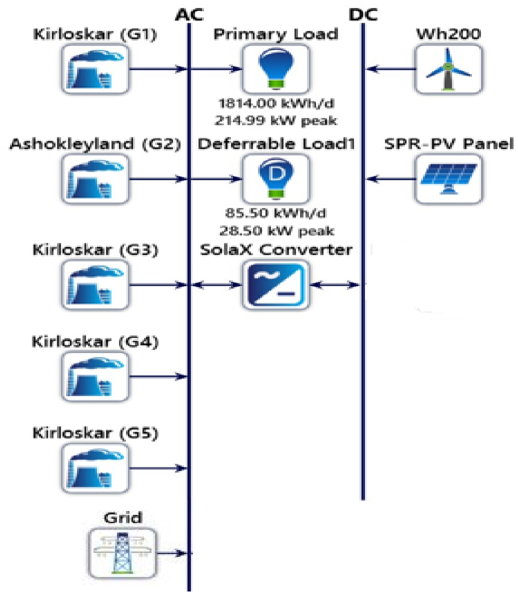

Fig.8: PV-Wind-Diesel generators- Grid connected hybrid energy system.

3.2.4 Case 4

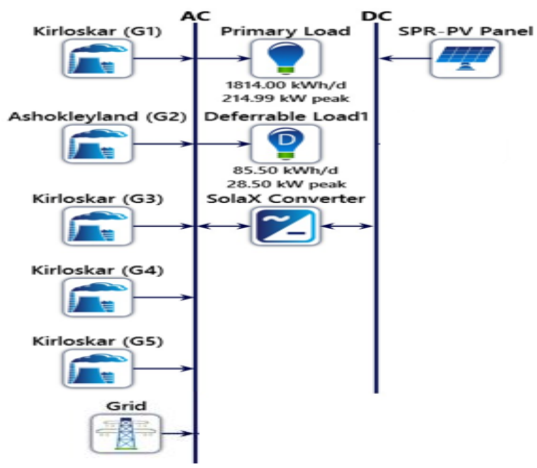

Fig. 9: PV-Diesel generators- Grid connected hybrid energy system.

In Case 4, the solar energy is only considered as primary energy resource. The HOMER simulation model of case 4 is depicted in Fig. 9. In both of these grid connected hybrid system models the diesel generators and utility grid are acts as secondary sources of electrical energy.

3.3 Economic Modelling of hybrid energy systems

Economics plays a significant role in both the simulation and optimization phase of HOMER. In the simulation phase, the device works to minimize overall net present costs. In the optimization process, the device configuration looks for the lowest overall net present expense.

The total net present cost is the life-cycle cost of the hybrid energy system. The system with the lowest net present cost is thus the best hybrid energy configuration. The following equation is used to measure the salvage value of each item at the end of the project life.[14)]

$$S = C_{rep} \frac{R_{rem}}{R_{comp}} \tag{7}$$

For each component, the capital, replacement, O&M and fuel costs shall be combined with the salvage value and any other expense to calculate the annualized cost of the component. The following equation is used to calculate the total net present cost[14)].

$$NPC = \frac{C_{ann,tot}}{CRF\left(i, R_{proj}\right)} \tag{8}$$

CRF is the capital recovery factor given by the equation[21)].

$$CRF\left(i, N\right) = \frac{i\left(1+i\right)^{N}}{\left(1+i\right)^{N} - 1} \tag{9}$$

The following equation is used to calculate the levelized cost of energy[14)]

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \tag{10}$$

4. Results & Discussion

Simulations are carried out for all the cases of integrated energy systems using HOMER pro. The optimal solution for the economic power generation for each case is identified based on net present cost. The Net Present Cost (NPC) is used to provide the Rank to various possible configurations of the system. The optimal solution will be decided based on the lowest NPC value. The optimization results and economic features of all four models are discussed in forthcoming sub sections.

4.1 Case1

The optimization results of Case1are shown in Table 1. The first row of Table 1 represents the first rank and it is considered as the optimal system design that meets the electrical energy requirement of the campus. NPC and Cost of Electricity (COE) of the optimal hybrid configuration are $1752942 and $0.161 respectively. Table 1 shows the optimal arrangement for Case1. It comprises a 500 kW PV panel, five 1 kW wind turbines, 100 kW Kirloskar generator (G1), 50 kW Ashokleyland generator (G2), 50 kW Kirloskar generator (G3), 50 kW Kirloskar generator (G4), 50 kW Kirloskar generator (G5), 1200 Exide batteries and 250 kW converter.

Table 1. Optimization results of PV-Wind-Diesel

SVR-PV (kW)	Wh20	G1 (kW)	G2 (kW)	G3 (kW)	G4 (kW)	(G5) (kW)	Exi6LMS	Solax Con (kW)	Disp	COE ($)	NPC ($)
500	5	100	500	50	50	50	1200	250	LF	0.161	1.75M
500	5	100	500	-	-	-	1200	250	LF	0.161	1.76M
500	5	100	500	50	50	-	1200	250	LF	0.161	1.76M
500	5	100	500	50	-	50	1200	250	LF	0.161	1.76M
500	5	100	500	-	50	50	1200	250	LF	0.161	1.76M

Table 2. Annual electricity production of optimal hybrid energy system components

Production	kWh/yr	%
SPR-PV Panel	727153	82.9
Kirloskar (G1)	88412	10.1
Ashokleyland (G2)	48490	5.53
Kirloskar (G3)	852	0.0972
Kirloskar (G4)	30	0.00342
Kirloskar (G5)	0	0
Wh200	12068	1.38
Total	877005	100

The amount of annual electrical energy generated by each component of optimal hybrid configuration is presented in Table 2. It indicates that the total yearly electricity produced to satisfy the required load is 877005 kWh/year. It is perceived that the 82.9% of electricity demand is met by PV panels, 1.38% electric load demand is met by Wind turbines, 10.1% of load demand is met by Kirloskar generator (G1), 5.53% electricity is supplied from Ashokleyland generator (G2) and 0.0972%, 0.00342% of load demand is met by Kirloskar generator (G3) and Kirloskar generator (G4). HOMER considers all generators in the best optimal system configuration to take their salvage values in to account. The monthly average electrical energy produced by each component of optimal hybrid energy system configuration is shown in Fig. 10.

The costs of different components of the Case1 during the life period of the complete system are shown in Table 3.

It is observed that the contribution of total cost of Batteries, PV panels and Kirloskar generator (G1) is maximum in NPC of the system. Further, the total cost of G1 (27.11% of the total system cost) is more as compared to the solar PV panels despite the lower share of its generating power than Solar PV.

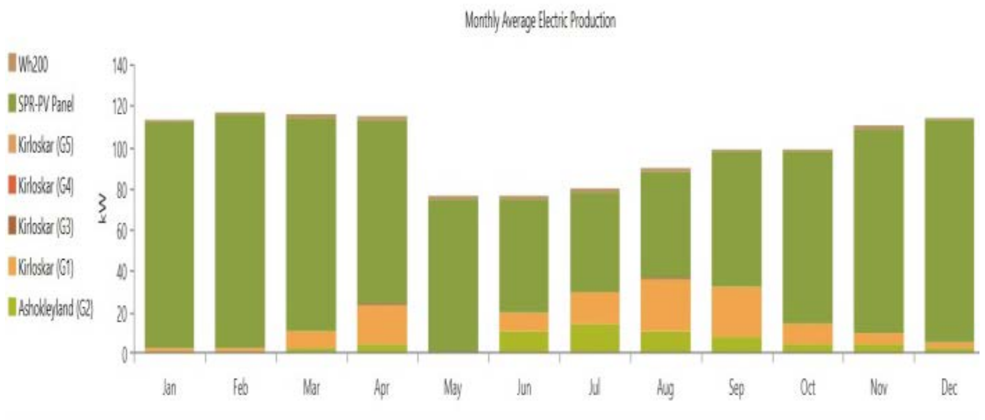

Fig. 10: Monthly average electrical energy generated by individual components of Case1.

Table 3: Cost summary of optimal hybrid energy system components

Name	**Capital ($)**	**O&M ($)**	**Replacement ($)**	**Salvage ($)**	**Fuel ($)**	**Total ($)**
Ashokleyland (G2)	0.00	37413	2421	-2280	203297	240850
Exi 6LMS Battery	193800	86953	179838	- 30046	0.00	430545
Kirloskar (G1)	0.00	79074	3532	- 2908	395647	475345
Kirloskar (G2)	0.00	1391	0.00	- 2545	5116	3963
Kirloskar (G3)	0.00	60.49	0.00	- 2642	189.97	2392
Kirloskar (G4)	0.00	0.00	0.00	- 2,580	0.00	2,580
Other	13846	145395	0.00	0.00	0.00	159241
SolaX X3-hybrid10	69250	36349	36643	- 8314	0.00	133928
SPR-PV Panel	307500	0.00	0.00	0.00	0.00	307500
Wh200	5000	726.97	2,138	- 1323	0.00	6542
System	589396	387362	224572	-52638	604250	1752942

Table 4. Optimization results of PV-Diesel generators hybrid energy system

SVR-PV (kW)	G1 (kW)	G2 (kW)	G3 (kW)	G4 (kW)	(G5) (kW)	Exi6LMS	Solax Con (kW)	Disp	COE ($)	NPC ($)
510	100	50	50	50	50	1200	250	LF	0.162	1.77M
510	100	50	50	50	50	1300	250	LF	0.162	1.77M
510	100	50	-	-	-	1200	250	LF	0.162	1.77M
510	100	50	50	50	-	1200	250	LF	0.162	1.77M
510	100	50	50	-	50	1200	250	LF	0.162	1.77M

4.2 Case 2

The optimization results of Case 2 considered for overall area are shown in Table 4.The NPC and COE of the optimal hybrid configuration are $1765177 and $0.162 respectively. From Table 4, the optimal hybrid system configuration is selected. It consists of a 510 kW PV panel, 100 kW Kirloskar generator (G1), 50 kW Ashokleyland generator (G2), 50 kW Kirloskar generator (G3), 50 kW Kirloskar generator (G4), 50 kW Kirloskar generator (G5), 1200 Exide batteries and a 250 kW converter. The amount of annual electric power produced by individual power developing devices of optimal configuration is noted in Table 5. It is seen that the total annual electricity generated to satisfy the energy requirement is 882408 kWh/year. Approximately, 84.1% of electricity demand is met by PV panels, 10.3% of load demand is met by Kirloskar generator (G1), 5.55% electricity is generated from Ashokleyland generator (G2) and 0.0964%, 0.00340% of total generated is produced by Kirloskar generator (G3) and Kirloskar generator (G4).

Table 5: Annual electricity production of optimal hybrid energy system components

Production	kWh/yr	%
SPR-PV panel	741696	84.1
Kirloskar (G1)	90862	10.3
Ashokleyland (G2)	48970	5.55
Kirloskar (G3)	851	0.0964
Kirloskar (G4)	30	0.00340
Kirloskar (G5)	0	0
Total	882408	100

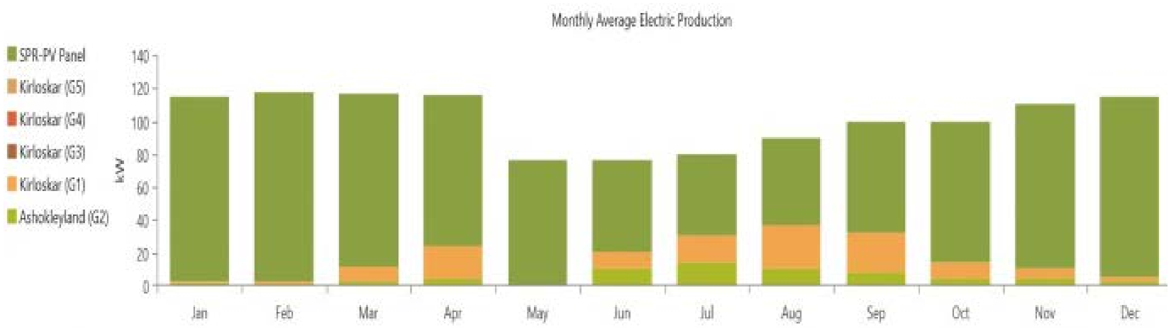

Fig. 11: Monthly average electricity production of optimal hybrid energy system components.

Table 6: Cost summary of optimal integrated energy system components

Name	Capital ($)	O&M ($)	Replacement ($)	Salvage ($)	Fuel ($)	Total ($)
Ashokleyland (G2)	0.00	37292	2413	- 2287	204605	242023
Exi 6LMS Battery	193800	86953	179838	-30046	0.00	430545
Kirloskar (G1)	0.00	80271	3578	-2854	405871	486866
Kirloskar (G3)	0.00	1361	0.00	- 2547	5082	3896
Kirloskar (G4)	0.00	60.49	0.00	-2642	189.97	- 2392
Kirloskar (G5)	0.00	0.00	0.00	- 2580	0.00	- 2580
Other	13846	145395	0.00	0.00	0.00	159241
SolaX Converter	69250	36349	36643	- 8314	0.00	133928
SPR-PV Panel	313650	0.00	0.00	0.00	0.00	313650
System	590546	387681	222473	-51271	615749	1765177

Table 7. Optimization results of PV-Wind-Diesel generators-Grid connected hybrid energy system

SVR-PV (kW)	Wh200	G1 (kW)	G2 (kW)	G3 (kW)	G4 (kW)	(G5) (kW)	Exi6LMS	Grid (kW)	Solax Con (kW)	Disp	COE ($)	NPC ($)
500	5	100	50	50	50	50	300	215	250	LF	0.0638	1.06M
500	5	100	50	50	50	50	300	215	250	LF	0.0638	1.06M
500	5	100	-	50	50	50	300	215	250	LF	0.0639	1.06M
500	5	100	-	50	50	50	300	215	250	LF	0.0639	1.06M
500	5	100	50	50	50	-	300	215	250	LF	0.0640	1.06M

The monthly average electricity generated by the individual components of optimal hybrid energy system configuration is shown in Fig. 11. The costs of different components of the Case 2 during the life period of the complete system are shown in Table 6. It is perceived from the table that the total cost of each component follow the similar trend of Case1.However, the cost of the solar and G1 is increased minimally as compared to the Case 1. Further, the solar PV and G1 contribution in generating the power is marginally improved than the Case 1.

4.3 Case 3

The optimization results of Case 3 considered for overall area are revealed in Table 7. The NPC and cost of COE of the optimal hybrid system configuration are $1056667 and $0.0638 respectively. It is seen that the optimal configuration comprises a 500 kW PV panel, five

1 kW wind turbines, 100 kW Kirloskar generator (G1), 50 kW Ashokleyland generator (G2), 50 kW Kirloskar generator (G3), 50 kW Kirloskar generator (G4), 50 kW Kirloskar generator (G5) and a grid support of 215 kW (see in Table 7) The amount of annual electrical energy generated by individual components of optimal hybrid energy system configuration is shown in Table 8. It is seen that the share of solar PV in power generation is more (64.5%). While, the grid share is 34.4%.This shows that the nearly 64.5% energy is conserved as compared to the existing scenario of purchasing the entire power from the grid. The monthly average electrical energy generated by individual power devices of optimal configuration is shown in Fig. 12. The cost summary of various components of the optimal configuration during the life period is shown in Table 9. It is perceived from the table that the contribution of total cost of Grid and PV panels is maximum in NPC of the system. The amount of $ 27669 spent to the local utility grid for purchasing electricity. The energy exchange between the hybrid energy system and the grid is presented in Table 10. It is observed that the annual net energy purchased is 30351 kWh.

Table 8. Annual electricity production of optimal hybrid energy system components

Production	kWh/yr	%
SPR-PV Panel	727153	64.5
Kirloskar (G1)	0	0
Ashokleyland (G2)	0	0
Kirloskar (G3)	0	0
Kirloskar (G4)	0	0
Kirloskar (G5)	0	0
Wh200	12068	1.07
Grid purchases	388328	34.4
Total	1127549	100

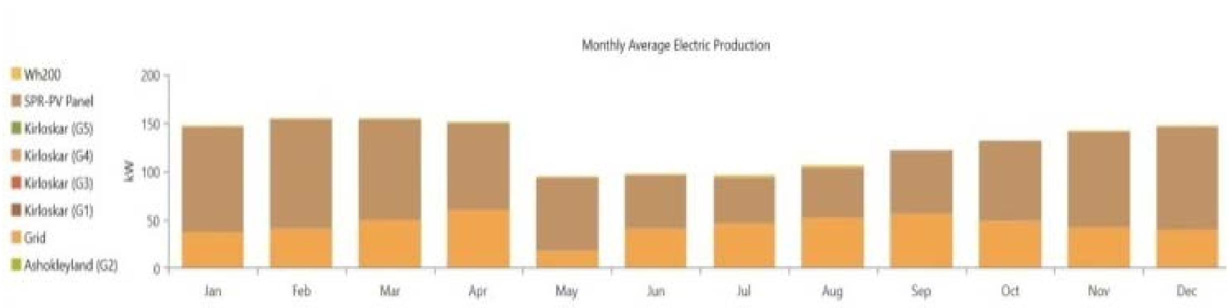

Fig. 12: Monthly average electrical energy generation of various components of optimal hybrid system.

Table 9. Cost summary of different components of optimal hybrid energy system

Name	Capital ($)	O&M ($)	Replacement ($)	Salvage ($)	Fuel ($)	Total ($)
Ashokleyland (G2)	0.00	0.00	0.00	-2293	0.00	-2293
Grid	0.00	435859	0.00	0.00	0.00	435859
Kirloskar (G1)	0.00	0.00	0.00	-3153	0.00	- 3153
Kirloskar (G3)	0.00	0.00	0.00	- 2580	0.00	- 2580
Kirloskar (G4)	0.00	0.00	0.00	- 2580	0.00	-2580
Kirloskar (G5)	0.00	0.00	0.00	-2580	0.00	- 2580
Other	13846	145395	0.00	0.00	0.00	159241
SolaX X3-hybrid10	83100	43618	43972	-9977	0.00	160713
SPR-PV Panel	307500	0.00	0.00	0.00	0.00	307500
Wh200	5000	726.97	2138	-1323	0.00	6542
System	409446	625599	46110	- 24487	0.00	1056667

Table 10. Monthly Grid Energy Exchanges

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)
January	27471	44773	-17302	132	401.48
February	27456	39471	-12014	150	823.52
March	37511	37759	-247	185	2,418
April	43644	27473	16171	215	4131
May	13781	37805	-24025	64.9	-1026
June	29497	15955	13542	157	3001
July	34015	12837	21178	150	3905
August	39348	13068	26280	160	4660
September	40211	18991	21219	193	4311
October	35981	30040	5941	155	2814
November	30282	36157	-5874	135	1498
December	29129	43648	-14519	130	731.89
Annual	388328	357977	30351	215	27669

4.4 Case 4

Table 11. Optimization results of PV-Diesel generators-Grid-connected hybrid energy system

SVR-PV (kW)	G1 (kW)	G2 (kW)	G3 (kW)	G4 (kW)	(G5) (kW)	Grid (kW)	Solax Con (kW)	Disp	COE ($)	NPC ($)
500	100	50	50	50	50	215	300	LF	0.0648	1.07M
500	100	50	50	50	50	215	300	LF	0.0648	1.07M
500	100	-	50	50	50	215	300	LF	0.0659	1.07M
500	100	-	50	50	50	215	300	LF	0.0650	1.07M
500	100	50	50	50	-	215	300	LF	0.0650	1.07M

Table 12. Annual electricity production of optimal hybrid energy system components

Production	kWh/yr	%
Sunpower E20-327	727153	64.8
Kirloskar 125KVA	0	0
Ashokleyland 63KVA	0	0
Kirloskar 63KVA	0	0
Kirloskar 63KVA(1)	0	0
Kirloskar 63KVA(2)	0	0
Grid purchases	394868	35.2
Total	1122021	100

The optimization results of Case 4 are shown in Table 11. The NPC and COE of the optimal system configuration are $1069868, and $0.0648 respectively. From Table 11, it is seen that the optimal hybrid system configuration consists of a 500 kW PV panel, 100 kW Kirloskar generator (G1), 50 kW Ashokleyland generator (G2), 50 kW Kirloskar generator (G3), 50 kW Kirloskar generator (G4), 50 kW Kirloskar generator (G5), 300 kW converter and a Grid support of 215 kW. The total annual electric power generated to meet the requirement is 1122021 kWh (see in Table 12).

It is noted that 64.8% of the electrical energy is met from Solar PV and 35.2% purchased from grid. The monthly average electrical energy generated by individual power devices of optimal configuration is shown in Fig.13. The various costs associated with hybrid system components during the project lifetime are shown in Table 13. It is seen from table that the contribution of total cost of grid and PV panels is maximum in NPC of the system.

Table 13. Cost summary of optimal hybrid energy system components

Name	Capital ($)	O&M ($)	Replacement ($)	Salvage ($)	Fuel ($)	Total ($)
Ashokleyland 63 KVA	0.00	0.00	0.00	-2293	0.00	-2293
Grid	0.00	455601	0.00	0.00	0.00	455601
Kirloskar 125KVA	0.00	0.00	0.00	-3153	0.00	- 3153
Kirloskar 63KVA	0.00	0.00	0.00	- 2580	0.00	-2580
Kirloskar 63KVA Copy	0.00	0.00	0.00	-2580	0.00	-2580
Kirloskar 63KVA (1)	0.00	0.00	0.00	-2580	0.00	- 2580
Other	13846	145395	0.00	0.00	0.00	159241

SolaX X3-hybrid10	83100	43618	43972	-9977	0.00	160713
SunPower E20-327	307500	0.00	0.00	0.00	0 .00	307500
System	404446	644614	43972	- 23164	0.00	1069868

Table 14. Monthly Grid Energy Exchanges

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge ($)
January	27782	44578	-16795	132	462.21
February	27791	39254	-11463	150	889.40
March	38055	37500	555	185	2518
April	44207	26979	17228	215	4252
May	14313	37332	-23018	65.0	-911.12
June	30216	15538	14678	158	3138
July	34913	12450	22463	150	4066
August	40156	12684	27472	188	4808
September	40602	18806	21796	193	4383
October	36386	29801	6585	155	2892
November	30806	35841	-5035	135	1600
December	29641	43404	-13763	130	825.61
Annual	394868	354166	40703	215	28923

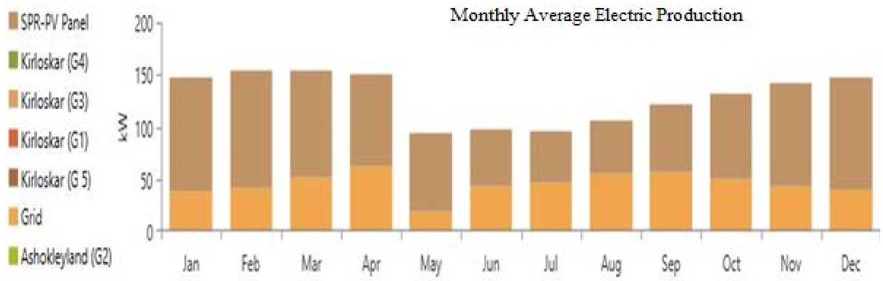

Fig. 13: Monthly average electricity production of optimal hybrid energy system components.

The total net energy procured from the grid is presented in Table 14. It is observed that annually the campus has to pay an amount of $ 28923 to the local utility grid for purchasing electricity. This is due to the fact that the net energy purchase from the grid is increases as compared to the Case 3.

4.5 Comparison between different integrated energy systems

A comparative study between four cases of hybrid energy systems are presented in the Table 15. The results such as initial capital cost, NPC, COE and payback period are compared between four cases. It is seen that the Case 3 has less COE, payback period and NPC as compared to other cases. However, the initial capital cost of the optimal configuration (Case 3) was slightly more than the Case 4 and less than the Case 1 and Case 2. In the Case 4, the omission of wind turbine leads to the minimizing the overall cost of the Case 4. Further, the overall cost of the Case 1 and Case 2 is more than the Case 3.

Table 15. Comparative study of integrated energy systems

Type of Hybrid system	Initial capital cost($)	NPC ($)	Payback period (years)	COE ($)
CASE1	589396	1752942	9	0.161
CASE2	590546	1765177	9.8	0.162
CASE3	409446	1056667	3.5	0.0638
CASE4	404446	1069868	4.4	0.0648

5. Conclusion

In this paper, two grid-connected and two stand-alone integrated energy systems are modelled for JNTUK-UCEV campus using HOMER Pro. The simulation results show that the On-grid integrated energy systems are more optimal than the stand-alone integrated energy systems. Among the two On-grid hybrid systems the PV-Wind-Diesel generators- on-grid hybrid system comprising 500 kW PV panel, five 1 kW wind turbines, 100 kW Kirloskar generator (G1), 50 kW, Ashokleyland generator (G2), 50 kW Kirloskar generator (G3), 50 kW Kirloskar generator (G4), 50 kW Kirloskar generator (G5), 300 kW converter and a grid support of 215 kW is found to be the best optimal configuration to fulfil the energy needs of the campus. This optimized hybrid energy system produces 1127549 kWh of power to meet the demand. Further, solar panels are contributing its share of 64.5% of total power generation. 1.07% of electricity demand is supplied from Whisper wind turbine and 34.4% electricity demand is supplied from grid. This optimal hybrid energy system releases CO_2 of 245423 kg/yr and SO_2 of 1,064 kg/yr in to the atmosphere. The NPC and COE of the optimal hybrid energy system are found to be $1056668 and $0.0638 respectively. These results could be useful for energy managers and decision makers to select the suitable hybrid energy system for education institutes which are having the similar load profile and geographical conditions to conserve energy and promote green energy utilization.

Nomenclature

AD	Battery's depth of discharge
COE	Cost of energy
CRF	Capacity recovery factor
DOD	Daily autonomy
NASA	National Aeronautics and Space Administration(-)
NPC	Net present cost($)
NREL	National Renewable Energy Laboratory(-)
$C_{ann,tot}$	Total annualized cost($)
C_{rep}	Replacement cost of the component($)
C_{Wh}	Storage capacity(kWh)
E_{def}	Total amounts of deferrable load(kWh/year)
$E_{grid,sales}$	Amount of energy sold to the grid per year(kWh/year)
E_L	Total energy demand(kWh/year)
E_{prim}	Total amount of primary load(kWh/year)
F	Output power of generator(kW)
F_0	Fuel curve intercept coefficient(L/hr/kW)
F_1	Fuel curve slope (L/h/kW)
G	Solar radiation (W/m)
G_{ref}	Solar radiation at reference conditions (Gref = 1000 W m^{-1})
i	Annual real interest rate (%)
K_T	Temperature coefficient of the maximum power (%/°C)
N	Number of years
P_{gen}	Electrical output of the generator (kW)
P_{NPV}	Rated power at reference conditions (kW)
P_{out}	Output power from the PV cell (kW)
P_{WTG}	Wind turbine power output (kW)
$P_{WTG,STP}$	Wind turbine power output at standard temperature and pressure (kW)
R_{comp}	Lifetime of the component (Years)
R_{proj}	Project lifetime (Years)
R_{rem}	Remaining life of the component (Years)
S	Salvage value ($)
T_c	Cell temperature (°C)
T_{ref}	Temperature at reference conditions (Tref = 25 °C)
U_{anem}	Wind speed at anemometer height (m s^{-1})
U_{hub}	Wind speed at the hub height of the wind turbine (m s^{-1})
Y_{gen}	Rated capacity of the generator
Z_{anem}	Anemometer height (m)
Z_{hub}	Hub height of the wind turbine (m)
Z_o	Surface roughness length (m)

Greek Symbols

ρ	Actual air density (kg m^{-3})
ρ_0	Air density at standard temperature and pressure (1.225 kg m^{-3})
η_b	Battery efficiency(%)
η_{inv}	Inverter efficiency(%)

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