

CASE STUDY

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Optimal configuration analysis for a campus microgrid—a case study

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Abstract

The foremost issues of 21st century are challenging demand of electrical energy and to control the emission of Green House Gases (GHG) emissions. Renewable energy resources based sustainable microgrid emerges as one of the best feasible solution for future energy demand while considering zero carbon emission, fossil fuel independency, and enhanced reliability. In this paper, optimization and implementation of institutional based sustainable microgrid are discussed based on cost analysis, carbon emission, and availability of energy resources. Various microgrid topologies are considered for addressing the most ideal solution. The metrological data such as irradiance is acquired from solar satellite data of NASA (National Aero Space Agency) while the data for wind speed is taken from synergy enviro engineer's site. HOMER[®] simulation tool is used for modelling and optimization purpose.

Keywords: Microgrids, Distributed generation, Renewable energy resources, Battery bank, Diesel generator, Solar photovoltaic system, Wind turbine system

1 Introduction

Worldwide, the demand of energy is increasing day by day, if the conventional methods of bulk power generation are not changed then this will lead to major environmental concern because of high carbon emissions which ultimately affect the human health and ecological system badly. To avoid hazardous effect of global warming and due to environmental concerns, government and key stakeholders are now switching the way of power generation from conventional sources to sustainable and renewable energy resources [1].

People in developed countries, have access to reliable and high quality power supply but in developing countries like India, people from most of the states are facing various issues related to poor quality of power supply like frequent power outages, inadequate grid capacity and huge power losses from transmission and distribution network. These problems are very common almost in all rural areas of India [2]. All these issues can be sorted by transforming to microgrids which will not only provide more efficient and reliable power but also provide opportunity to the people of developing countries to live a better life, free from hazardous and polluting emissions.

Future power supply will be less dependent on conventional method of power generation because fossil fuels are limited for energy production and public awareness for environment protection are also increases globally. So, there is a need of power generation from environmental friendly techniques. These technologies include power generation from photovoltaic, wind, geothermal, biomass etc. also known as renewable sources of power generation and power generation from non-conventional technologies such as microturbines and fuel cells. These types of power generation sources generally come in distributed generation system and may operate in standalone and grid connected mode depending on the requirement of the system. For example, in remote areas and in faulty conditions these power sources mostly operate in standalone mode otherwise in grid connected mode [3]. Several desirable factors like easy siting, less environmental impact, enhanced system efficiency, security and reliability improvement, power quality enhancement and congestion management in transmission and distribution network due to peak shaving reduction can be achieved by employing these technologies [4]. Major concern associated with the use of renewable energy resources is their intermittent nature depending on weather conditions due to which the integration and operation of a microgrid becomes a challengeable task. This issue can be

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sort out using microturbines, diesel generators, small gas turbines and with the help of high density energy storage devices [5]. However, the use of energy storage devices may not be economical and their use mainly depends on location and other system configurations.

Microgrid can be defined as a part of distribution network including one or more distributed energy sources and having the capability to operate either in grid connected or standalone mode deployed in a limited geographical area [6]. There are various available favourable sites for the implementation of microgrids like remote areas, rural areas etc. where plenty of renewable energy resources are available for clean and green power generation. In such locations, microgrids can be operated in an islanding mode to achieve reliable and stable power supply by combining loads with the distributed energy resources available on the respected site. Based on market segments, microgrids can be categorized into five types: i) remote “off-grid” Microgrids ii) Campus/Institutional microgrids iii) Military base microgrids iv) Community/Utility microgrids and v) Commercial and Industrial microgrids [7]. Other way to categorize microgrid is based on the output voltage supplied to the load, and according to it microgrids can be classified into two types i) AC microgrid and ii) DC microgrid. There are many factors which makes microgrids very important, some of them are as follows: During the conditions of blackout, natural disaster etc. microgrids can maintain the normal power supply in the system, cost of Transmission and Distribution (T&D) losses will be saved with the help of microgrid, Demand of electricity is increasing day by day which ultimately require expenditure in T&D expansion, microgrids can defer these expenditures, microgrids generally uses renewable energy sources for power generation and these sources are environmental friendly having almost zero emission, quality and reliability of power supply is also enhanced with the help of microgrid in remote locations by means of renewable energy sources

Table 1 Approximate Daily Electric Load Consumption of Hostel

Load	Rating (W)	Usage (hrs/day)	Quantity
Fan ^a	80	14	180
Tube Light	40	7	405
Geysers ^a	3000	4	12
Heater ^a	1000	4	70
Water Cooler ^a	1700	24	13
Cooler ^a	200	13	120
Halogen	1000, 500	10	4, 3
Laptop	70	6	300
Exhaust Fan	160	18	18
Phone charger	3	2	401

^a indicates seasonal load

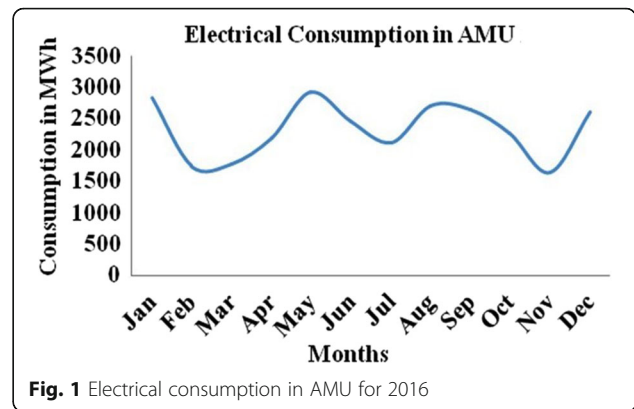


Fig. 1 Electrical consumption in AMU for 2016

and combined heat and power (CHP) generation, cost of energy can be greatly reduced and so on [8].

In this paper, various topologies of microgrid are analysed to find out the best possible configuration in terms of achieving various desirable objectives like better economical configuration as well as reduction in global warming, CO₂ footprints and other environmental problems.

The paper is structured into seven sections; first section gives the introduction of the research work, while section 2 discusses the objectives of the research work, and section 3 gives the detailed description of considered test system along with its load profile. Section 4 discusses the cost analysis for a typical microgrid while section 5 elaborates the system components, resources and modelling in detail. Section 6 gives the discussion on the results obtained through simulation considering six different cases and section 7 concludes the findings of the paper.

2 Objectives of this study

The objectives of this study for which the whole analysis is done are:

- To reduce the dependency on fossil fuels and conventional method of power generation.
- To make a zero-carbon nature through maximum utilization of renewable energy resources with the help of microgrid.

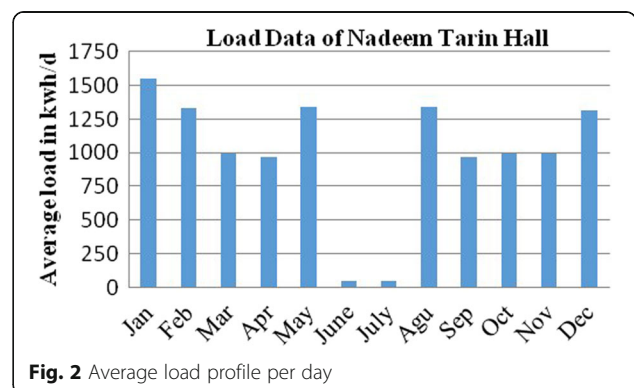


Fig. 2 Average load profile per day

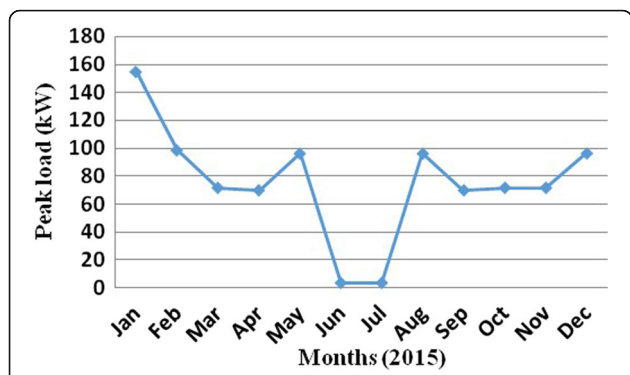


Fig. 3 Monthly peak load variation profile

- Help government of India and other major stake holder in realizing faster adoption of microgrids for ecological and environmental benefits.
- To reduce the purchases of energy from the grid.
- To provide a reliable, sustainable, economical, innovative, and optimize power system in the form of microgrid for commercial and residential purposes.

3 Case description

The demand of energy is rising from various sectors of society such as industries, resident as well as educational Institutes. On national as well as international scale, there are vast list of universities with growing number of departments, canteens and hostels. They added up a mass amount of energy demand on utilities, which can be made independent over the conventional sources by deploying microgrid system using renewable and non-conventional sources of energy. The educational institutes have a

responsibility to become a role model for the nation to save energy and promote optimization. They should also develop and promote indigenous technology. They support many faculties and training facilities which can be a good platform to raise the awareness and promote energy saving [9]. For the case study Aligarh Muslim University (AMU) is taken, which is situated in western Uttar Pradesh, India. The study of electricity consumption trend in AMU provides vital information that can be used to analyse, design and implement a suitable solution for the deployment of microgrid that can cut down the electricity usage from conventional grid and GHG emissions, thus save environment.

3.1 Electricity Consumption

AMU which is run by central government has a student strength of approx. 39000 [10]. Total installed capacity is 13.63 MVA as shown in Table 1 [11], it has 12 faculties which includes more than 110 departments and centers. Their consumption is approx. 65% while 16 halls of residence consume 25% of total consumption [12], annual electricity consumption for 2016 is shown in Fig. 1.

Uttar Pradesh Power Corporation Limited (UPPCL) sanctioned a load of 6.1 MVA to the campus of this university. But due to increase in load demand, university consumption overshoot the limit of 7.952 MVA in Nov 2014 followed by 7.880 MVA in August 2015 [11].

3.2 Load Profile

Several initiatives have taken by vice chancellor for green and clean campus. In this regard microgrids are investigated for residential halls. Nadeem Tarin hostel is one of them which is taken for case study, it includes 146

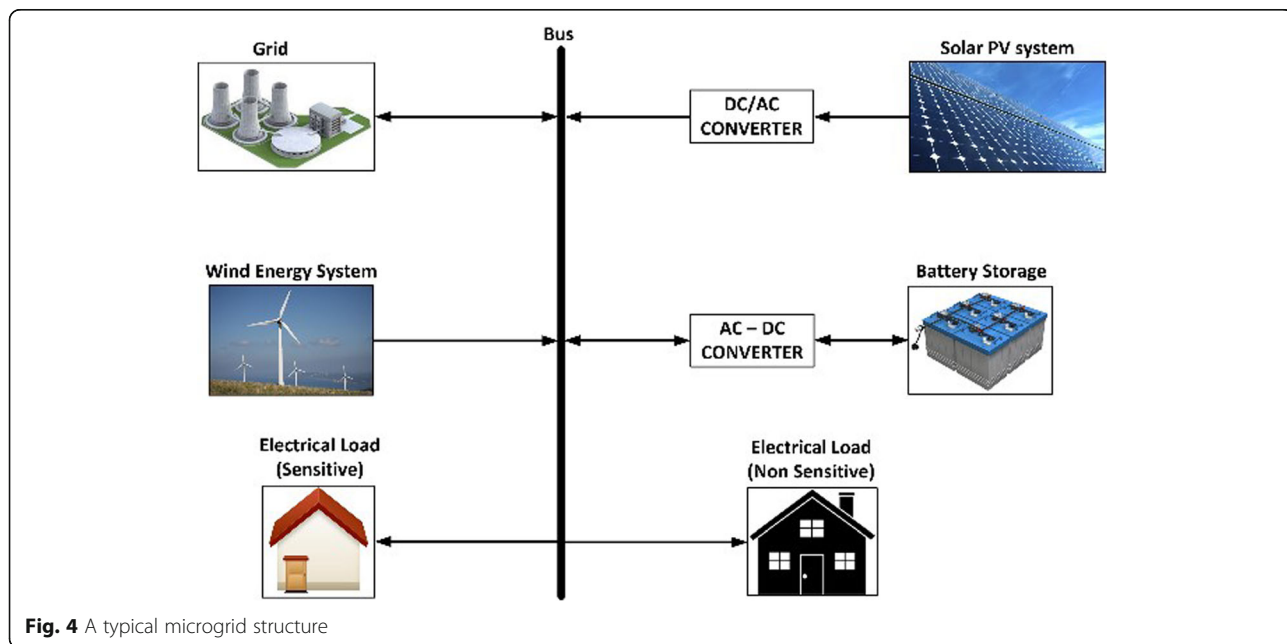


Fig. 4 A typical microgrid structure

rooms as non-sensitive load while dining hall, reading room, Common room and provost office can be considered under the category of sensitive load.

The details of different types of load commonly used in this hostel are listed in Table 1.

The daily average hostel load is 992.43kWh with a random variation of 10% while the peak load is 171.78 kW with a random variation of approx. 8%. Average load profile is shown in Fig. 2 and monthly peak load variation is shown in Fig. 3. There is a huge variation in load profile because a minimum load of approx. 0.54 kW is recorded during the vacation period whereas in peak winter and summer days, load rapidly increases up to 171.78 kW.

4 Cost analysis for a typical microgrid

This section provides the mathematical cost function formulation for a microgrid. The evaluation of microgrid operation can be carried through its cost and emission analysis. Since, a typical microgrid consists of mainly two types of generators viz. dispatchable and non-dispatchable generators, an electric power flow on a typical microgrid can be represented as shown in Fig. 4.

It is to be noted that fixed cost for various Distributed Energy Resources (DERs) incurred due to primary equipment cost and installation does not depend upon power dispatch and can be treated as a constant. Also for DERs which requires a converter for AC/DC conversion the cost of converters is included in the fixed costs. The main aim of the cost function formulation is to consider the cost of dispatchable units, such as diesel generator, cost of non dispatchable units, e.g. PV, wind, battery storage and cost of power purchased or sold to grid. The operational cost of the microgrid is the sum of all cost incurred in the system [13]. Also, hourly emission from each DER unit is considered to optimize the carbon footprints and levels of pollution from the operating microgrid.

4.1 Cost of diesel generator

Considering the operation time slot for the diesel generator to be 't' (in hours), cost of fuel to be C_f (in INR), C_{md} as the maintenance cost of the diesel genset, then the total cost of operation for generator (denoted by C_{dg}) is

$$C_{dg} = P_{dg}/E_{ff} * C_f * t + C_{md} * P_{dg} + F_{dg} \quad (1)$$

Where, P_{dg} is the power generated by diesel generator in kW, E_{ff} is the efficiency of diesel genset and F_{dg} is the fixed cost of diesel generator comprising of equipment and installation cost.

4.2 Cost of PV generator

The PV generator does not incur any running cost/fuel cost since the solar radiation is present throughout the day without any expenditure. However, a maintenance cost for the PV panel, depending upon its power production as well as the fixed cost is considered as the operational cost for the PV generator (denoted by C_{pv}).

$$C_{pv} = P_{pv} * C_{mpv} + F_{pv} \quad (2)$$

Where, P_{pv} is the power generated by the PV generator in kW, C_{mpv} is the maintenance cost of PV panel and F_{pv} is the fixed cost.

Table 2 List of some important parameters

Component	Specification	
PV	Material	Polycrystalline Silicon
	Size	1480*670*35 mm
	Max Power	150watt
	Max Power Current	8.29A
	Max Power Voltage	18.1 V
	Derating Factor	80%
Wind Turbine (WT)	Turbine type	Upwind
	Rotor diameter	21.5 m
	Hub heights available	37 m, 31 m, 25 m, 21 m
	Rated power	100 kW
	Rated rotor speed	60 rpm
	Rated output voltage	400 VAC, 50 Hz
	Working wind speed	3–25 m/s
Diesel Generator	Power Capacity (kW/kVA)	100/125
	Rated Voltage	415/240
	Rated Speed	1500 rpm
	Rated Power	100 kW
Battery	Type	1kWh Lead Acid
	Nominal Voltage	12.0 V
	Maximum Capacity	83.4 Ah
	Round Trip Efficiency	80%
	Float Life	10 years
	Maximum charge Rate	1 A/Ah
	Maximum charge Current	16.7 A
Converter	Maximum Discharge Current	24.3 A
	Initial State of Charge	98%
	Minimum state of Charge	30%
	Range	100kWp
	Voltage range	310 V-450 V
	THD	<0.8%
	Max Efficiency	97.2%
Ambient Temperature	-25 to 550 C without de-rating	

Table 3 Monthly average solar global horizontal irradiance data

Month	Clearness Index	Daily Radiation (kWh/m ² /day)
January	0.36	3.62
February	0.457	4.75
March	0.562	5.9
April	0.665	6.77
May	0.729	7.03
June	0.703	6.54
July	0.597	5.64
August	0.554	5.5
September	0.51	5.27
October	0.517	5.35
November	0.427	4.31
December	0.354	3.51

4.3 Cost of Wind generator

The wind generator operational cost consists mainly of fixed installation cost, equipment cost and the cost of maintenance incurred for power produced from the wind generator (denoted by C_w).

$$C_w = P_w * C_{mw} + N_w \tag{3}$$

Where P_w is the power generated by the PV generator in kW, C_{mw} is the maintenance cost for the wind generator and N_w is combined equipment and installation cost.

4.4 Cost of Battery Storage

The battery storage (BS) is an important part of the microgrid since it stores surplus energy and supplies deficit energy and maintains stability in microgrid operation. The cost of battery storage can be represented as (denoted by C_{bs}).

$$C_{bs} = P_{bs} * C_{mbs} + C_b \tag{4}$$

Where P_{bs} is the power charged into the battery system and C_{mbs} is the maintenance cost for the battery and C_b is the cost of the battery. It is to be noted when the BS supplies deficit energy to the microgrid then P_{bs} is negative denoting revenue for the battery owner.

4.5 Cost of grid supply

A grid is assumed to be an infinite bus which can supply or consume any amount of power. While the microgrid is in grid connected mode, the power supplied from the grid to the microgrid is charged as,

$$C_{grid} = P_{grid} * \alpha \tag{5}$$

Where α is cost of electric unit supplied from the grid in INR/kWh.

Also, the cost of power sold to the grid is

$$C_{mgrid} = P_{grid} * \beta \tag{6}$$

In case when the excess energy is sold to the grid, the factor β is the selling rate of power in INR/kWh and P_{grid} is negative in order to balance the cost equation and generate revenue for the microgrid. In a typical microgrid scenario, $\beta > \alpha$, however the tariff structure varies from location to location.

5 System Components, Resources and Modeling

U.S. National Renewable Energy Laboratory (NREL) developed HOMER[®] optimization tool for better designing and planning of microgrids which are mainly fuelled by renewable energy resources. After considering various design topologies and uncertain parameters like future fuel prices, wind speed, load growth etc., HOMER[®] finds out the best optimal results. HOMER[®] supports the integration of renewable energy resources with the utility grid and works effectively in the stand alone as well as grid connected mode of operation of microgrids [14]. Using HOMER[®] optimization tool, one can check and analyse large number of optimal combinations of various types of i) power sources: wind turbine, solar photovoltaic (PV), microturbine, fuel cell, biomass, utility grid, diesel generator etc. ii) energy storage technologies: battery bank, flow batteries, hydrogen, fly wheels etc. and iii) loads: daily profile with seasonal variation, deferrable, thermal etc.

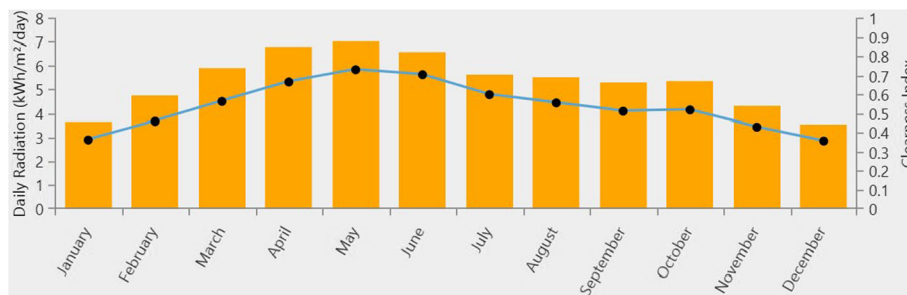


Fig. 5 Variation in monthly average solar global horizontal irradiance data

Table 4 Monthly average wind speed data

Month	Average (m/s)
January	2.884
February	3.09
March	3.76
April	3.863
May	4.996
June	5.047
July	4.275
August	3.296
September	3.966
October	2.987
November	2.266
December	2.627

In HOMER[®] optimization tool, the total Net Present Cost (NPC) is taken as an economically preferable quantity that is used in an optimization process. This NPC includes all the system costs like grid cost, operation cost, replacement cost, maintenance cost, capital cost, fuel consumption cost and other types of miscellaneous cost. Based on the inputs provided by modeler like resource availability, technological options, equipment costs etc., HOMER[®] simulates different system configurations and as per NPC it displays all the possible techno-economic feasible configurations. The simulation results of HOMER[®] comes in the form of tables and graphs which ultimately helps modeler in comparing too many feasible configurations simultaneously and ranking them as per techno-economic basis.

Simulation, Optimization and Sensitivity Analysis are the three most important tasks performed by HOMER[®]. These three parameters evaluate techno-economic feasibility of various available technological options after accounting all possible variations in electric load, energy resource availability, technology cost, etc. i) Simulation: For an entire year and in time steps from 1 min to 1 h, HOMER[®] simulates the operation of a hybrid microgrid. In this area, HOMER[®]

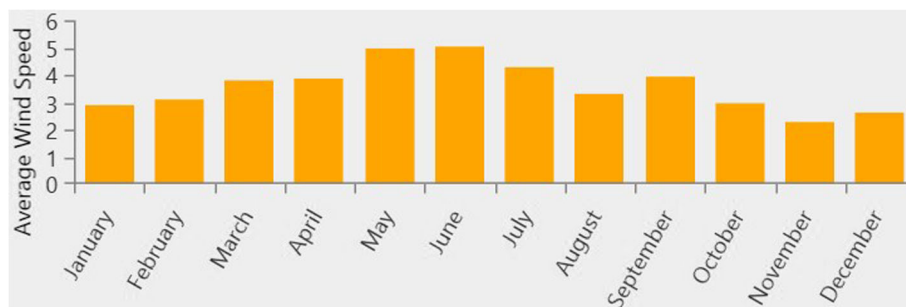
determines the technical feasibility and lifecycle cost of a hybrid microgrid. The optimization and sensitivity analysis tasks of HOMER[®] mainly depends on the capability of simulation task. ii) Optimization: In a single run, HOMER[®] inspects all the possibilities and as per optimization variable of choice, it sorts the system accordingly. In this area, based on search space defined by modeler, minimum total net present cost, constraints, etc., HOMER[®] displays all the feasible results and system configurations. iii) Sensitivity Analysis: In a single run HOMER[®] compares and checks thousands of possibilities. In this area, HOMER[®] checks the importance of all parameters variations and aspects with time by running and comparing the results of thousands of simulations. HOMER[®] finds out the optimal results based on different sizes and quantities of the equipment's along with constraints as defined by user. If the modeler is not confirmed about the best value of any particular variable, then with the help of sensitivity analysis modeler can enter different possible values of that variable and sensitivity analysis shows how the simulation results depends on these values.

System components like solar photovoltaic panels, wind turbines, diesel generator, converter and battery bank are taken for the modelling of different types of topologies considered in this paper. Important parameters related to these components are listed in Table 2.

In this paper, energy demand of the hostel is addresses with the help of different topologies. The daily average load of 992.43 kWh/d with peak load of 171.78 kW is considered for modelling in HOMER[®]. The details of different system components used in this paper are as follows.

5.1 Solar photovoltaic system

PV panel size, solar radiation and PV cell temperature are some factors which can affect the generation of electrical power supply from solar energy. Lifetime of 25 years are assumed for PV panel and the size of PV

**Fig. 6** Variation in monthly average wind speed data

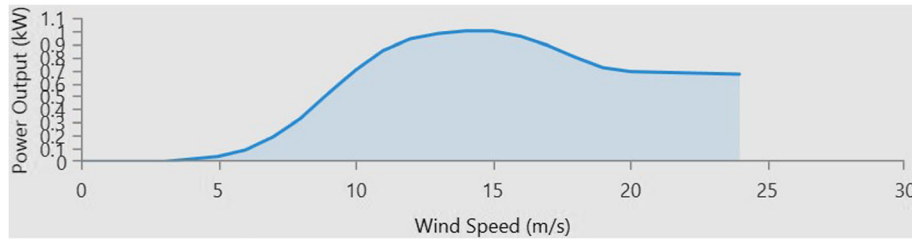


Fig. 7 Wind turbine power curve

panel is varied from 140, 145, 150, 155, 160 kW to evaluate better results.

The equation for calculating the output power of PV panels used in HOMER[®] is as follows [15]:

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \tag{7}$$

Where,

- f_{PV} : Derating factor of PV
- Y_{PV} : PV array rated capacity (kW)
- I_T : Global solar radiation incident on the surface of PV array (kW/m²)
- I_S : Standard amount of radiation used to rate the capacity of PV array (1 kW/m²)

Latitude and Longitude coordinates of Aligarh are 27.8800° N and 78.0800° E respectively. Annual Average Solar Global Horizontal Irradiance Data for the proposed site is 5.35 kWh/m²/day. With reference to the above mentioned coordinates the solar radiation data taken from [16] for HOMER[®] is as shown in Table 3 and Fig. 5.

5.2 Wind Turbine System

Wind speed and tower height are the main factors which can affect the electrical power supply from wind energy. Lifetime of 20 years are assumed for wind turbine and the size is varied from 90, 95, 100, 105, 110 kW to evaluate better results.

The equation for calculating the output power of wind turbine is as follow [17]:

$$P_{wt}(t) = \begin{cases} 0, v(t) < v_{ci} \\ av(t^3) - bP_r, v_{ci} < v(t) < v_r \\ P_r, v_r < v(t) < v_{co} \\ 0, v(t) > v_{co} \end{cases} \tag{8}$$

Where,

- P_r : Mean rated power
- v_{ci} : Cut-in wind speed

- v_{co} : Cut-out wind speed
- v_r : Rated wind speed

Annual average wind speed at the proposed site is 4.50 m/s. The data showing the variation in wind speed is as shown in Table 4 and Fig. 6 [18].

Figure 7 represents the variation in wind turbine power production at different wind speeds.

5.3 Diesel Generator System

Since, renewable energy resources are intermittent in nature, so there are chances of complete and partial outages of these resources due to which diesel generator is required as a backup source for meeting the electrical demand of primary load.

Minimum load ratio and lifetime hours of diesel generator are taken as 25% of 15000 respectively for modelling.

Equation for calculating the generator’s fixed cost of energy used in HOMER[®] is as follow [15]:

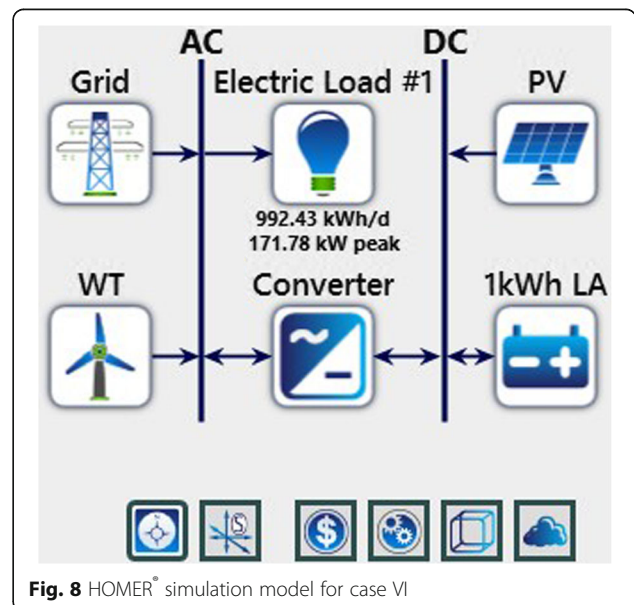


Fig. 8 HOMER[®] simulation model for case VI

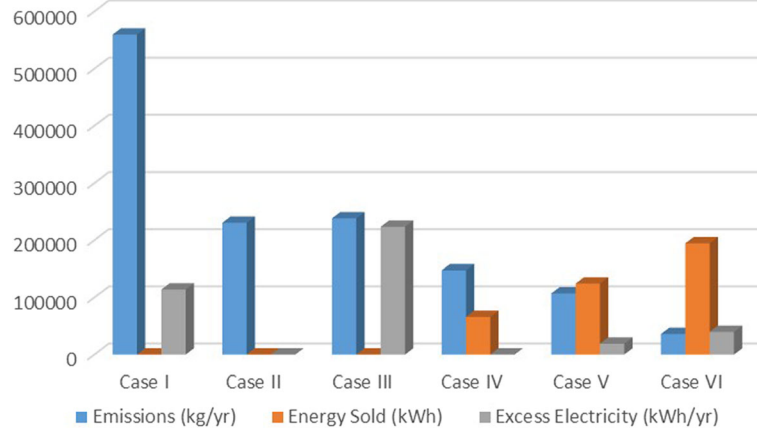


Fig. 9 Variation in emissions, energy sold and excess electricity in all the cases

$$C_{gen, fixed} = C_{om, gen} + \frac{C_{rep, gen}}{R_{gen}} + F_o Y_{gen} C_{fuel, eff} \quad (9)$$

Where,

- $C_{om, gen}$: Operation and maintenance cost (INR/hour)
- $C_{rep, gen}$: Replacement cost (INR)
- R_{gen} : Generator lifetime (hours)
- F_o : Fuel curve intercept coefficient (fuel/hour/kW)
- Y_{gen} : Generator capacity (kW)
- $C_{fuel, eff}$: Effective price of fuel (INR/quality of fuel). It includes the cost penalties associated with the emission of pollutants from the generator.

5.4 Battery Bank System

Battery bank size, battery charge and discharge rate are the main influencing factors associated with the power output of the battery bank system. Batteries are essential in hybrid power system to store surplus electrical energy generated through renewable energy resources during low demand periods and to release deficit energy during shortage and high demand periods respectively. Lifetime throughput of

800 kWh are assumed for battery bank and the size is varied from 240, 245, 250, 255 kWh to evaluate better results.

Equation for calculating the state of charge (SOC) is as follow [15]:

$$SOC(t) = (1-Q)SOC(t-1) + P_{cd}\Delta(t)e_{cd}/E \quad (10)$$

Equation for calculating the life of battery bank (in years) is as follow [13]:

$$R_{batt} = \min\left(\frac{N_{batt} Q_{lifetime}}{Q_{thrpt}}, R_{batt, f}\right) \quad (11)$$

Equation for calculating the wear cost of battery is as follow [15]:

$$C_{bw} = \frac{C_{rep, batt}}{N_{batt} Q_{lifetime} \sqrt{\eta_{rt}}} \quad (12)$$

Where,

- $SOC(t)$ and $SOC(t-1)$: State of charge at time (t) and (t-1)
- Q: hourly discharging rate
- E: Total energy

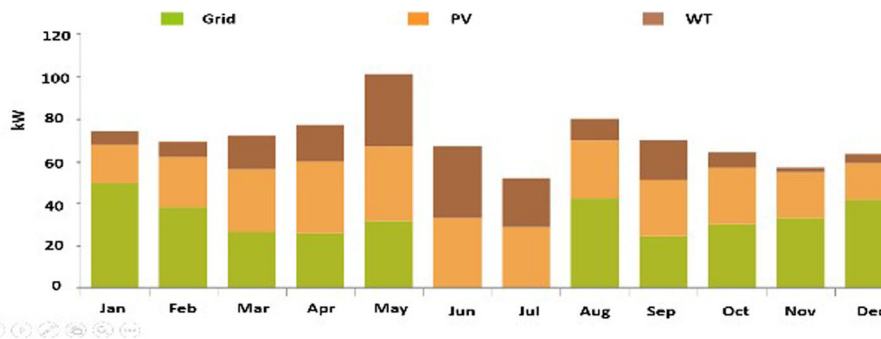


Fig. 10 Monthly average electricity production (Case VI)

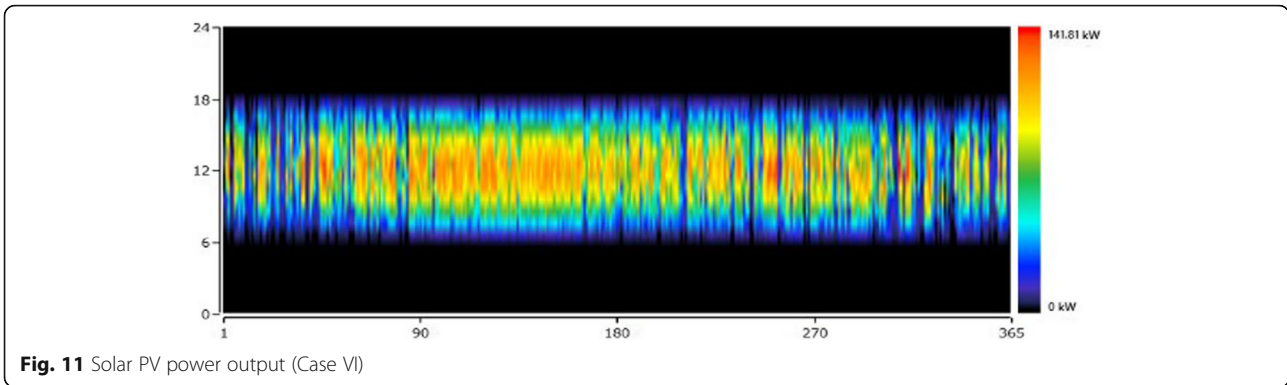


Fig. 11 Solar PV power output (Case VI)

e_{cd} : Efficiency of charge and discharge
 N_{batt} : Number of batteries in a battery bank
 $Q_{lifetime}$: Lifetime throughput of a single battery
 Q_{thrp} : Total amount of energy that cycles through the battery bank in 1 year (annual throughput)
 $R_{batt,f}$: Maximum life regardless of throughput (float life of the battery)
 $C_{rep,batt}$: Replacement cost of the battery bank
 η_{rt} : Round-trip efficiency

R_{proj} : Project Lifetime
 $CRF(i, R_{proj})$: Capital Recovery Factor

6 Discussion and Evaluation

HOMER[®] microgrid analysis tool is used for the simulation of various microgrid topologies to find out the optimal and economical solution among various microgrid topologies considered in this paper. HOMER[®] simulates various system configurations according to specified technical constraints and gives result based on Net Present Cost (NPC) of the system. HOMER[®] calculates NPC using equation:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{Proj})} \tag{13}$$

Where,

$C_{ann,tot}$: Total annualised cost
i: discount rate

In university premises, electric power supply is available almost all the time and the problem of power outage only occurs in case of severe fault conditions which happens very rarely. The average feed in tariff or grid sell back price of 7 INR/unit is assumed for analysis generated through solar PV and wind turbine system [19, 20].

Analysis of various microgrid topologies based on the considered load profile are as follow:

6.1 Case I: Diesel Generator (168 kW)

In this case, it is assumed that there is no power supply form conventional grid as well as from renewable energy resources. Diesel generator is only the single power source for meeting the whole load demand. This is the worst case in terms of cost of electricity (COE), Net Present Cost (NPC), Operating Cost (OC) and CO₂ emissions having high values of INR 35.48 INR 166 M, INR 12.5 M and 544705 kg/year. respectively. So, supplying power to meet demand only from diesel generator is not a desirable case in terms of economical and environmental aspect.

6.2 Case II: Utility Grid

In this case, it is assumed that all the load demand is supplied by utility Grid. Here, it is assumed that there is

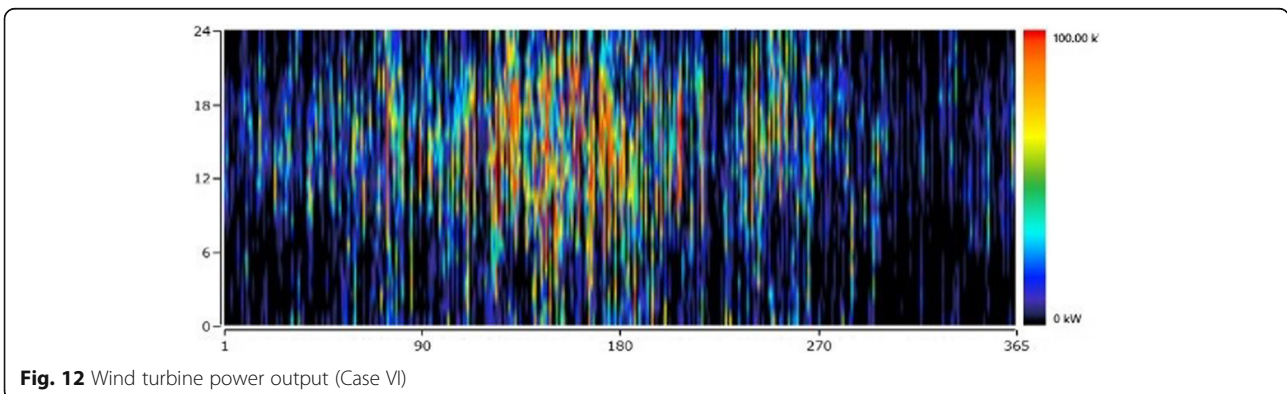
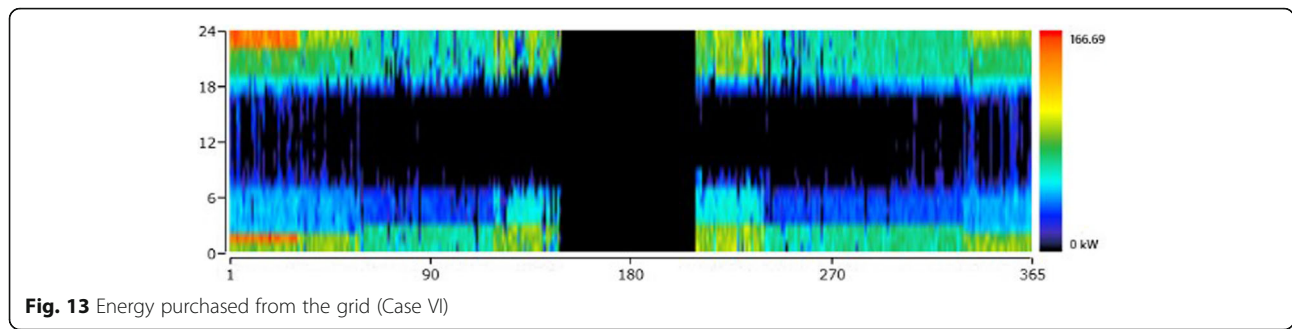


Fig. 12 Wind turbine power output (Case VI)



no single outage and Grid is available to supply power all over the time. The COE, NPC, OC and CO₂ emissions obtained in this case are INR 6.0, INR 28.1 M, INR 2.17 M and 228933 kg/year. respectively.

6.3 Case III: Diesel Generator (110 kW), PV (150 kW), wind turbine (100 kW) and Battery bank (250 kWh)

In this case, it is assumed that there is no Grid supply and load demand is fulfilled by the combination of diesel generator and renewable energy sources i.e. through solar PV and wind turbine system. The COE, NPC, OC and CO₂ emissions obtained in this case are INR 18.65, INR 87.3 M, 5.36 M and 231948 kg/year. respectively.

6.4 Case IV: Grid and Wind Turbine (100 kW)

In this case, only Grid and wind turbine system are responsible for meeting load demand. The COE, NPC, OC and CO₂ emissions obtained in this case are INR 4.64, INR 25.7 M, 1.52 M and 146436 kg/year respectively.

6.5 Case V: Grid, PV (150 kW) and Battery bank (250 kWh)

In this case, only Grid and solar PV system are responsible for meeting load demand. The COE, NPC, OC and CO₂ emissions obtained in this case are INR 2.95, INR 18.6 M, 0.896998 M and 106497 kg/year. respectively. If a battery bank of 250 kWh is added in this case to store excess electricity and for supplying power to load in emergency conditions then the value of COE, NPC, OC and CO₂ emissions will change and increases to INR 3.83, INR 23.2 M, INR 1.11 M and 118289 kg/year. respectively.

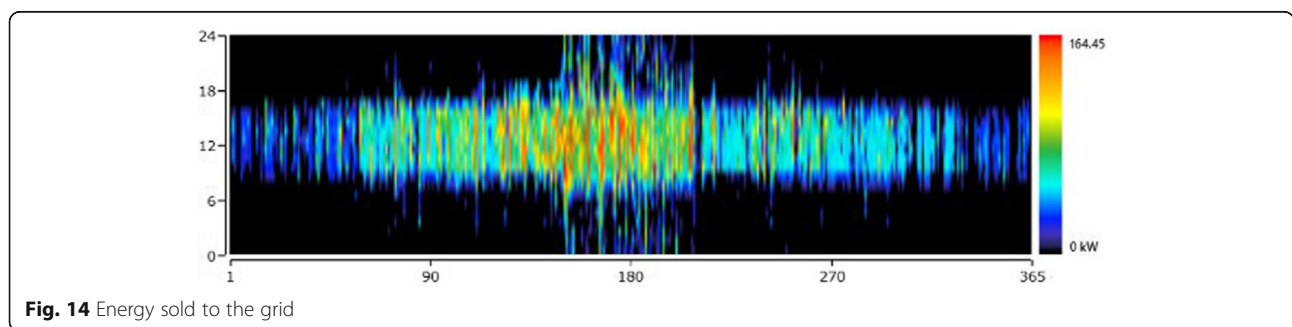
6.6 Case VI: Grid, PV (150 kW), Wind Turbine (100 kW) and Battery bank (250 kWh)

Figure 8 shows a schematic diagram of various components connected in a HOMER[®] simulation analysis tool. In this case the combination of Grid, Solar PV and wind turbine system is considered for supplying power to the expected load. The COE, NPC, OC and CO₂ emissions obtained in this case are INR 2.41, INR 17.3 M, 0.353125 M and 35792 kg/year. respectively. If a battery bank of 250 kWh is added in this case then the values of COE, NPC, OC and CO₂ emissions will change to INR 2.85, INR 20.5 M, INR 0.441733 M and 35792 kg/year. respectively.

Figure 9 shows a comparative study by considering the impact of i) emissions like carbon dioxide, carbon mono-oxide, unburned hydrocarbons, particulate matters, sulphur dioxide and nitrogen oxides, ii) energy sold to grid and iii) excess electricity generated in all the six different cases.

From the analysis of various cases as discussed above, it is clear that a combination of grid, solar PV and wind turbine system seems to be the most desirable one in term of economical as well as environmental aspect, because all the values obtained here are the most favourable as compared to other cases.

Figure 10 shows a monthly average electricity production profile. Load demand is low in the months of June and July because these months come under the period of summer vacations and due to low load demand in these months only the generation from PV and wind turbine system is enough for meeting the load demand.



Figures 11 and 12 shows a power output from PV and wind turbine system respectively. Figures 13 and 14 shows an energy purchased and sold from and to the Grid respectively.

7 Conclusion

Demand of electricity is increasing day by day and fossil fuels are limited for power generation, so there is a need to adopt non-conventional and environmental friendly methods of power generation to meet the country's requirements. In view of this Government of India also initiated several subsidy schemes and missions like Jawaharlal Nehru National Solar Mission etc. for setting up power generation project using renewable energy resources. Deployment of microgrids is one of the best available technology for achieving this goal. Educational institutes have a responsibility to become a role model for the nation to save energy and promote optimization. These institutes support many students, research scholars, faculties and training facilities which can be a good platform to raise the awareness and promote energy saving. In view of this, different microgrid topologies are considered and analyzed in this paper. For different locations and system constraints, these microgrid topologies may differ. Many software's are available to analyze technical and economical feasibilities. HOMER optimization tool is used in this paper to check all the possible combinations and configurations. Based on large number of simulation results obtained from HOMER, a combination of grid, solar PV and wind turbine system is found to be the most optimal case for the specified load. In this case, the value of COE, NPC, OC and CO₂ are found to be less with respect to the other considered topologies.

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Availability of data and materials

All data is given in the paper or properly cited wherever necessary.

Authors' contributions

FI carried out all the simulation work along with drafting of the manuscript under the guidance of ASS. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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