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OPTIMIZED GRID CONNECTED MODEL FOR POWER GENERATION FOR A UNIVERSITY CAMPUS

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ABSTRACT: Pakistan has faced the most serious power shortage since the last decade, forcing utility operators to suffer periodic power outages. The preeminent cause of this "load shedding" is the production of energy from fossil fuels, the price for which is continuously growing. In this regard, the use of Diesel Generators (DG) has always been a preferred alternative because they are immediately available even at the higher Cost of Energy (COE). Due to Green House Gas (GHG) emissions, backup power generation based on DG has an adverse impact on the environment. So, it is the need of the hour to design a system that can generate electrical power by using more renewable energy and less DG and fossil fuels. Renewable energy has the ability to cope with energy crises, and it is now being implemented worldwide. This study addresses the energy crisis of grid-connected site of National Fertilizer Institute, Institute of Engineering and Fertilizer Research (NFC IE&FR), Faisalabad. The research is conducted by using available solar and biomass resources in addition to DG. For simulation purposes, the potential demand is validated, and available resources are identified. The system with multiple combinations of Renewable Energy Technologies (RETs) is anticipated to simulate with a Hybrid Optimization Model for Electric Renewables (HOMER). Optimization and size considering technical and economic factors, which include Net Present Cost (NPC) and COE and power generation rooftop PV are tackled using HOMER. Four cases are taken into account to investigate the most efficient and optimum microgrid option. Among all these four cases, a hybrid system based on PV, bio-generator, diesel generator, grid, battery and the converter, which is basically case-III of this study comes out to be the most feasible and cost-effective solution for TNPC & COE with reduced emissions and saving of the fuel. And more importantly, the use of the residuals of biomass energy left after the production of electrical power can be effectively used as agricultural fertilizer.

Keywords: Institutional Microgrid, HOMER, Environmental Emissions, Fossil Fuels.

INTRODUCTION

Though Pakistan has the potential to produce excess electricity, the lack of planning and inadequate power plants installed has resulted in the low production of electricity. This shortage caused load shedding of many hours across the nation. As the country is progressing, its electricity demand is growing at an annual rate of 8% (Qasim and Kotani, 2014). This demand will increase further to 54 GW by the end of 2020, and in 2030, it will be 113 GW (Shakeel *et al.*, 2016).

The weakness of the energy sector of Pakistan was revealed when the heatwave hit in June 2015 and about 2,000 occupants in the south of Pakistan passed away in a week time. Prolonged load shedding and energy shortfall are responsible for Rs. 14 billion cost to Pakistan economy last year. Around 140 million people in Pakistan suffer from severe load shedding of more than 12 hours daily and they are unable to access electricity produced by the utility grid. Pakistan uses imported oil and diesel to produce electric power which is one of the main reasons behind the lack of production and expensive electricity. Plus, it has a bad impact on the environment. Previous studies (Pakistan Economic Survey, 2015-16) show that Pakistan produces 64% of electricity from fossil fuels. Therefore, this classification of fossil fuels indicates that the energy security of Pakistan is severely damaged. Due to this low production, the average shortage in supply was around 5,000 MW, which further increased to 7,000 MW during peak hours (Nehrir *et al.*, 2011). Pakistan is one of those countries that have sufficient amount of renewable energy sources (RESs) like solar, geothermal, wind, biogas, canal fall /micro hydel, bio-diesel, biomass, energies of the tidal/ocean and so forth. A renewable energy system-based hybrid sources have attracted great consideration as they are a reliable and clean source of energy (Sheikh, 2010). The demand for electricity in the university campus can be fulfilled using renewable energy resources. Microgrid consuming renewable resources is one of the suitable alternatives that could solve discussed issues. This alternative will not only decrease the COE but also improve reliability in the supply of power system and improve environmental emissions.

The study in this paper is based on HOMER and it contributes using eight novel aspects.

- First, the main objectives include component's optimal sizing, optimization of cost, and system feasibility.
- Most of the research is conducted about energy sources of Pakistan, but no one focuses on how to utilize it.
- The study of this paper is conducted using fixed angle PV panels.
- The main goal of this paper is to provide a reliable supply of power.
- The scope of study further expands by emphasizing on the productive use of electrical power on the university campus.
- Microgrid integration with bioenergy is not really focused by researchers before. But in this paper, the author has focused on this area.
- In this paper, HOMER is used to load the basic profile of the university and its hostel.

In this research, an efficient and improved strategy is introduced for a hybrid microgrid system. This strategy improves operation time and also saves battery life.

Reference (Sheikh, 2009) presented a study of conventional and renewable energy resources in Pakistan. The study includes a computable condition for supply, manipulation, and generation of available sources. In the study, authors point out that renewable energy resources have a fractional part in the conventional energy sector of Pakistan due to lack of research and poor planning in the renewable sector. They also discuss the bright prospect of renewable energy resources available in Pakistan and suggest that proper planning and study can resolve the serious energy crisis. References (Asif, 2009; Chaudhry *et al*. 2009; Abbas *et al*., 2017; Abbas *et al*., 2017) highlighted the preferable locations for hydropower generation, solar radiation map, and biomass potential in Pakistan. Reference (Amer and Daim, 2011) discussed the RESs of Pakistan, i.e. solar PV, wind, biogas, hydropower, biomass, fuel cell technology and their current position and future scenarios. The challenges and key factors for the feasible evolution of RESs available in Pakistan are also mentioned. Further, reference (Kamel *et al*., 2015) pointed out the important technological points that cause a shortage of electricity RETs assortment in Pakistan. The authors pointed out the existing problems and discussed the ways to introduce future investment in national grids. The electricity pricing system and sector-wise consumption in Pakistan are well-highlighted. In references (Tasdighi *et al*., 2013; Bidram and Davoudi, 2012; Iyer *et al*., 2010; Ustun *et al*., 2012; Piagi and Lasseter, 2001), the performance of microgrid was analyzed from various parameters like power scheduling, improvement in power quality, electric power management, protection and control. However, references (Starfelt and Yan, 2008; Momeneh *et al*., 2016; Sinha and Chandel, 2014) ensured power quality and reliability with limited efforts to implement the technology to commercial and industrial scale. Reference (Waqar *et al.*, 2015) confirms that HOMER is the simplest and effective tool for evaluating RETs. Reference (Nasir and Khan, 2016) proposed a hybrid microgrid comprising diesel generator, hydro-electric generator, PV panels, batteries and biomass. The system contains the best size generator set with the lowest cost. Reference (Givler and Lilienthal, 2005) proposed a smart hybrid grid and minimized the conversion stages, by allocating AC and DC load to the same grid through smart power electronics controller, to reduce the conversion losses. But this study only focuses on the solar energy.

Several scholars have modeled and analyzed hybrid microgrid using HOMER in multiple perspectives. Reference (Hafez and Bhattacharya, 2012) gave detailed research conducted in Sri Lanka, directed by Givler. The diesel/solar PV hybrid system is recognized as an economical solution compared to the independent solar PV domestic system. However, this research highlights the basic electrical demands and inability to cope with the effective use of electrical energy. In Zhang *et al*., (2016), the optimum strategy and design of RETs based hybrid microgrid scheme for 'an imaginary rural society' were explored. Although the research includes wind power, solar photovoltaic power, diesel power generation and power resources for power generation and also considers electricity demand for more than a day, the hypothetical nature of these suppositions makes the operation of many off-grid areas simple. Reference (Abbas, 2015) conducted a relative study on HOMER to estimate the optimum size of grid-connected hybrid solar PV and biomass energy systems. In reference (Singh and Kaushik, 2016), a two-tier plan for planning island microgrids with regard to Compressed Air Energy Storage (CAES) was discussed. This research proposes a two-layer plan to find the optimal size of CAES and DG. Reference (Cotto and Lee, 2017) carried out research on the modular design of microgrids for photovoltaic system medical services. Reference (Ferroukhi, 2014) proposed a cost-effective design, i.e. hybrid energy system (PV, diesel, and wind) for remote sites off the grid, Rakhi Gaj located in Pakistan. The research addresses the power needs of home applications and pumping equipment.

The proposed research study offers the best combination of conventional and naturally available renewable resources at a suitable site to fulfill the desired energy demand in a viable and reliable manner and to find out whether such type of hybrid system is an economical solution for Pakistan or not. In order to achieve the objective, a load of a university campus in Faisalabad city is chosen. We validate the potential demand and identify resources that are available. Then we model the multiple combinations of RETs system and used HOMER software for this application.

The paper has sections as follows: Section II gives the review of the literature; Section III discusses the input date of the system and briefly explains the resource assessment of the system under consideration; Section IV shows simulation results under different cases; Section V gives the conclusion of the research in this paper.

MATERIALS AND METHODS

At the start of this work, air temperature, radiation of solar, availability of bioenergy and load profile are evaluated. Then all this real-time data is fed into HOMER.

Load: The university campus, NFC IE&FR is considered as load profile located at latitudes 31° 59' 0" N and longitudes 73° 59' 0" E in Faisalabad. The university's total load is divided into two profiles: one is the load of the university, and the other one includes the load of the hostel. The load changes in only two-time steps and is almost constant. The hourly load profile of the whole day for the university and the hostel is shown in Figure 1 and Figure 2 respectively. Other load features are given in Table 1.

Solar PV: Solar energy technology is the most important renewable energy source (RES). According to Prediction of Worldwide Energy Resources, (2017) the prices of solar photovoltaic (PV) modules have recently dropped by 80% and are expected to continue to fall. Pakistan is located in a sun-drenched belt, an average of the global insolation of solar is 5.00-7.00 kWh/m^2/day occurs in Pakistan, in which the persistence factor is over 85% in about 95% of the area (Renewable Energy Report, 2009). NASA Surface Meteorology and Solar Energy Website is a source of solar resource which is used for the current study of the selected site. More precisely, the average solar radiation is 5.188 kWh/m^2/day, and the average clarity index is 0.604 per year. Throughout the year, there is the availability of solar radiation. So, the amount of output power PV can be achieved (see Figure 3). National Electric Power Regulatory Authority (NEPRA) estimated that in Pakistan the approximate project cost of a solar plant (> 1.00 MW ≤ 20.00 MW) is $1562770. This covers the inverter, dealer mark-ups, photovoltaic panels, land price shipping, shade, array structure, tariffs, overall installation, engineering management and fencing cost (Shamshad, 1998). Fixed PV panels are considered in the study, i.e. non-tracking. The impact on cost and technical performance of the PV panel is also considered.

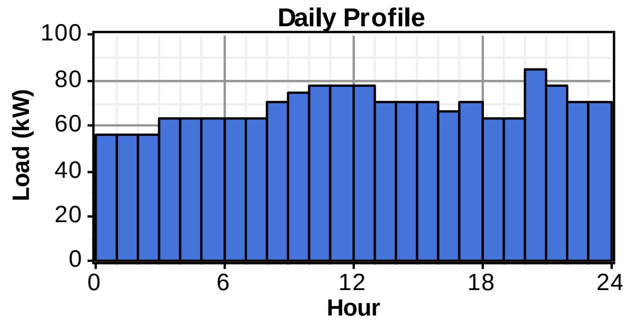


Fig. 1: Hourly load profile (university load)

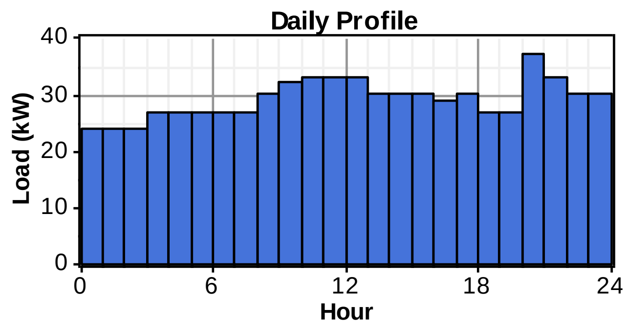


Fig. 2: Hourly load profile (hostel load)

Table 1. Characteristics of load.

Load Type		Main	Hostel
Average (kWh/day)		1618	695
Peak (kW)		152	66
Load Factor (%)		0.438	0.438
Random	Day-day	15	15
Variability (%)	Time-time	20	20

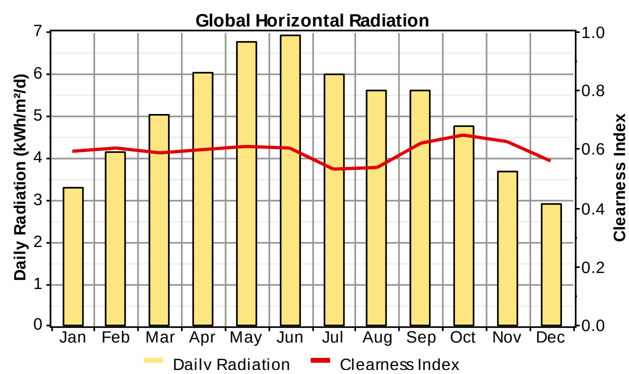


Fig. 3. Solar radiation profile on a monthly basis (at the selected site)

To cater to different effects of dust particles and temperature on PV panels, a de-rating factor of 80% is used. HOMER generates synthesized values using the Graham algorithm. This synthesis results in a large sequence of data that has hour-to-hour and day-to-day variability.

Bio-Fuels: Commonly-used biofuels are biogas, biodiesel, and bioethanol. In this study, the main benefit of using biogas is that it can reduce toxic waste in our environment. This type of power supply can ensure the decentralization of energy sources (Waqar *et al.*, 2015). The biodegradation of organic materials is used to produce biogas when oxygen is absent. Oxidization/combustion of gases such as CO, CH_4, and H_2 can be carried out easily. Biogas raw materials include animal waste, plants, agricultural, municipal and sewage and so on. According to (Sheikh, 2010; Givler and Lilienthal, 2005; Ferroukhi, 2014) country's potential to generate power is 14.25 million cubic meters per day.

Faisalabad has a number of poultry and dairy farms; the animal waste of these farms can be utilized to produce biogas. This method is efficient because it has low heating value, high efficiency, better control, and cleaner combustion. In this research, animals' dung was used. In Figure 4, potentially available biomass has been depicted.

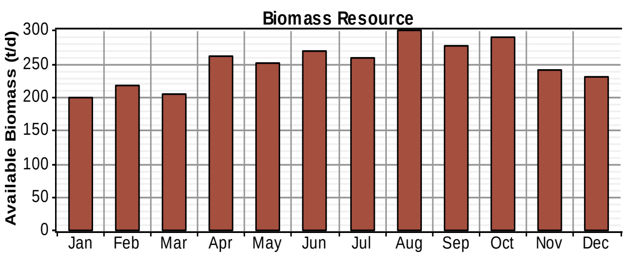


Fig. 4: Biomass profile for all the months of the year

Biogas has the following characteristics:

- Specific gravity = 0.94;
- Density = 1.22 kg/Nm^3;
- DG size = 50 m^3;
- To generate the "1kWh" electricity, the total amount of gas required is "0.6 m^3";
- Calorific value = 4500 kcal/m^3;
- Efficiency = 80%;
- Gasification ratio = 0.7 kg/kg;
- LHV of the biomass = 5.5 MJ/kg;
- Content of carbon = 5%;

The calorific value in biogas is less than that of fossil fuels, so the percentage of fossil fuels is replaced by biogas. The ratio of replacement is 8:1. During the experiment, it is assumed that the ratio remains constant regardless of the fuel mixing or power output.

It is considered that biodiesel and biogas both are primarily extracted from vegetable oils and animal wastes. The main advantage of this fuel is that it has 4% carbon with no sulfur whereas in diesel it is only 0.33% sulfur and 88% carbon.

Batteries: In the case of solar-based power systems, an important factor is the distribution of power at night. In this situation, proposed batteries keep the voltage constant during peak hours and also provide efficient cost. They also provide power in reserve as well that can be used during shortfall, which usually happens at night hours. In this study, the battery used for experiment is Surrette 4KS25P, which is a lead-acid deep cycle battery. The rated capacity for this battery is 1900 Ah (7.6 kWh) and a 4 V battery. Plus, lifetime of the battery is 10,569 kWh.

The battery is referred to as in maximum capacity charged state when it is fully charged. But it is impossible to use this amount of energy at such a rate of discharge current; due to this reason the size of the battery is not considered in terms of its maximum capacity. By deep cycling, the battery cannot be discharged because it can damage or decrease the life of the battery.

Through HOMER, the maximum capacity is calculated which is utilized in its kinetic energy model. Furthermore, the DC bus voltage per string is defined accordingly. A 48 V DC bus is constructed by utilizing 12 batteries per string. The discharging and charging cycle of the batteries can be modeled using HOMER.

RESULTS AND DISCUSSION

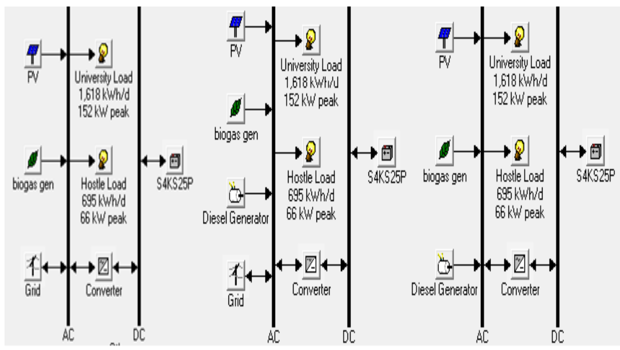
The life-cycle cost of a microgrid and its technical feasibility per hour annually are computed using HOMER. Moreover, the microgrid setup and operational strategy of the energy supply segments are analyzed to determine the functionality of these segments function in a given setup over some stretch of time. Operational activity of microgrid is modeled and simulated in HOMER for long time duration. In HOMER, sensitivity analysis and optimization is dependent on this simulation ability (Lambert *et al.*, 2006).

Four scenarios are taken into account to investigate the most efficient and optimum microgrid option, as given in Table 2. Figure 5 shows the energy option combination of RETs for the planning of microgrid, adopted in case II, case III and case IV. Case-I is the present case (DG-Grid). Case-II includes PV panels with a fixed angle with a slope of 31.633º W to S, converters, bio-generators, grid, and batteries. The same grouping is taken in case-III as in case-II, but DG is also attached. Case IV includes PV, BG, DG, batteries, and converter, which is the same as case III with excluded grid.

Table 3 gives the capital cost, input size, and operational and maintenance (O&M) costs. The optimal sizing of the system is listed in Table 4, and the graphical representation of this optimal sizing is given in Figure 6.

Table 2. Details of all the four cases.

Details	Cases
Grid, DG (Existing Case)	I
PV, BG, Grid, Battery, Converter	II
PV, BG, DG, Grid, Battery, Converter	III
PV, BG, DG, Battery, Converter	IV



(a) (b) (c)

Fig. 5. Energy option combination of RERs for microgrid planning

Table 3. Capital cost, input size plus operational O&M costs.

Sources	Sizes	Capital Cost	O&M Cost
DG	1-500	150 $/ kW	0.005$/hr./kW
PV	1-600	750 $/ kW	0$/yr./kW
BG	0-150	1000$/ kW	0.020$/hr./kW
Battery	0-10	150$/battery	10$/yr./battery
Converter	0-1000	300$/kW	0

Table 4. Optimized plan of microgrid for all cases.

Sources	I	II	III	IV
DG (kW)	100	0	100	100
Grid (kW)	100	41	41	0
PV (kW)	0	500	500	500
Battery (No)	0	120	0	120
BG (kW)	0	150	100	100
Converter (kW)	0	100	0	100

Economics Analysis: Net Present Cost (NPC) and Levelized Cost of Energy (LCOE) are the economic factors that can rank the configuration of the power system. LCOE is utilized by HOMER such that the per kWh average cost generated by the system of the useful energy is shown in (1)

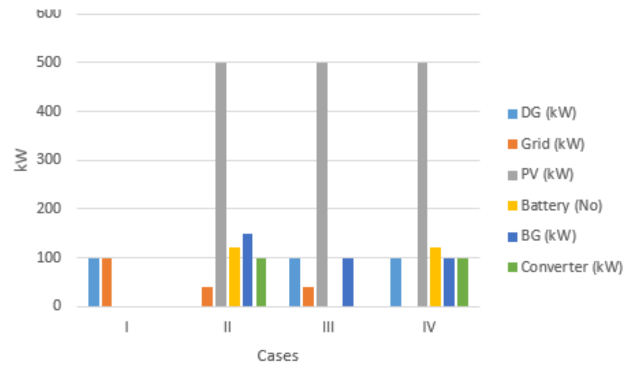


Fig. 6. Optimized plan of microgrid

$$LCOE = \frac{C_{ann,tot}}{E_{primary,AC}} \quad (1)$$

where

$C_{ann,\ tot}$: System net annualized cost [$/yr]

$E_{prim,AC}$: AC primary load served [kWh/yr]

The per annum cost of the system is equal to the annual operating cost plus its capital cost and the cost of replacement over the life of the project. In HOMER, the economic main output is represented by the Total NPC (TNPC). Mathematically, the TNPC is expressed by

$$TNPC = \frac{C_{ann,tot}}{CRF(i,N)}, \text{with } CRF = \frac{i(1+i)^N}{i(1+i)^N - 1} \quad (2)$$

where CRF (*i*, *N*) denotes the capital recovery factor; *i* is interest rate; *N* represents the project's lifetime [year(s)].

The considered economics inputs in this research are the following:

- ✓ Yearly rate of interest = 6%
- ✓ Project's lifetime = 25 years
- ✓ Fixed capital cost of the system = 0$
- ✓ Fixed O&M cost of the system= 0$
- ✓ The penalty of capacity shortage = 0$/kWh

In HOMER, through economic inputs, we can calculate the NPC of the system. Figure 7 represents the comparison between TNPC, COE and O&M cost of all the cases. Correspondingly, numerical cost values are summarized in Table 5.

As can be observed from Figure 7 that Case-III has the lowest TNPC as well as lowest COE and O&M cost (see also Table 5). Moreover, case-III has fewer emissions as compared to the case I and IV but has higher emissions in comparison to case-II (see Table 5). So, it can be concluded that case-III is the best feasible scenario with respect to economics, and case-II with respect to environmental emissions. So, we can say that case-III is the best applicable state in terms of economics. Figure 8 shows the percentage contribution from all the sources, also the percentage excess electricity, and percentage renewable fraction for all cases.

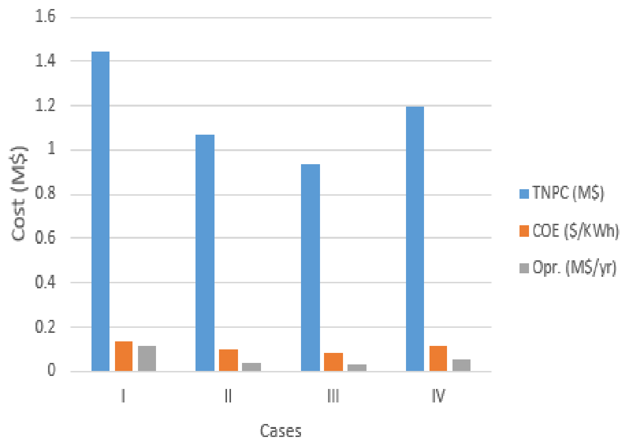


Fig. 7. Cost comparison

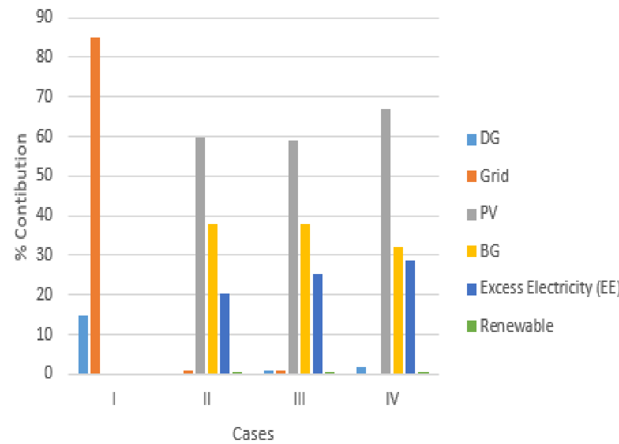


Fig. 8. Percentage contribution of different sources

Table 5. Cost comparison for all cases.

Cost	TNPC (M$)	COE ($/kWh)	Opr. (M$/yr.)
I	1.444	0.134	0.111
II	1.072	0.099	0.039
III	0.935	0.087	0.034
IV	1.201	0.111	0.051

Although the research includes solar photovoltaic power, diesel power generation and power resources for power generation and also considers electricity demand for more than a day, the hypothetical nature of these suppositions makes the operation of many off-grid areas simple. Table 7 shows that the integration of more RETs and intelligent use of surplus electricity makes our proposed system more promising and efficient. Case studies evaluated in this paper are feasible and cost-effective with regard to the existing scenario.

Table 6. Comparison of emissions for all cases.

kg/yr.	CO_2	CO	SO_2	NO
I	841,591	1,677	2,294	4,547
II	581,335	402	416	11,133
III	616,503	1,322	50	13,309
IV	808,065	1,549	472	14,363

Table 7. Contribution of different sources in percentage.

Sources	I	II	III	IV
DG	15	0	1	2
Grid	85	2	2	0
PV	0	60	59	66
BG	0	38	38	32
Electricity Generated through Sources	100	100	100	100
Excess Electricity (EE)	0	20.4	25.2	28.9
Renewable	0	0.605	0.590	0.665

Savings and "CO_2" Reduction: The annual average loading is found to be 844,246 kWh. Taking current rate COE (0.21$/kWh) into account, the consumers are viable for 177,291$ per annum for the consumption of energy. Our proposed system with a COE of 0.087 $/kWh can save up to 44.5% cost per annum and can also pay the capital cost. Carbon dioxide emission is decreased up to 27 %, as presented in Table 6.

Sensitivity Analysis: One of the many advantages of HOMER is that if the individual is unsure about the optimal value of any particular variable, then different generated random values can be used to observe the system behavior. In the microgrid system, important variables are temporary. Table 8 shows the parametric values of diesel price, biomass, and solar insolation. In Table 8, bold values are base values and sensitivity values are represented by italic values. Optimal sizing after sensitivity analysis is shown in Table 9 and Figure 9 whereas Table 10 and Figure 10 shows a comparison of the cost after sensitivity analysis.

Table 8. Sensitive values of different parameters.

Parameter	Sensitivity Values
Scaled average biomass generation per year (ton/d)	**250**, *150*
Scaled average solar irradiation per year (kWh/m^2/d)	**5.061**, *6.0*
Price of diesel ($/L)	**0.6**, *0.7*

Table 9. Optimized size after sensitivity analysis.

Sources	I	II	III	IV
DG (kW)	100	0	100	100
Grid (kW)	100	41	41	0
PV (kW)	0	500	500	500
Battery (No)	0	0	0	120
BG (kW)	0	150	100	100
Converter (kW)	0	0	0	100

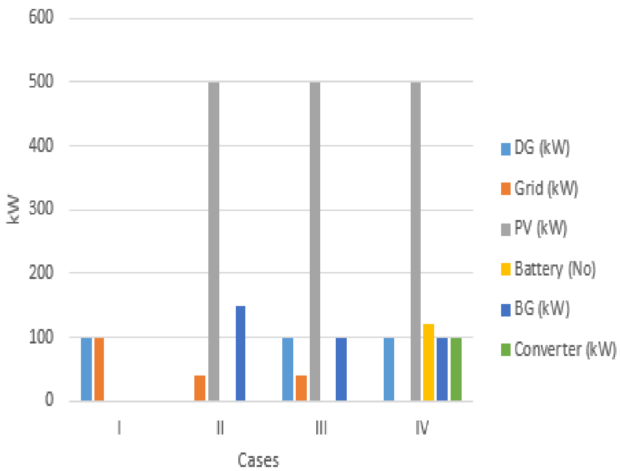


Fig. 9. Optimal sizing after sensitivity analysis

Table 10. Cost comparison after performing sensitivity analysis

Cost	TNPC (M$)	COE ($/kWh)	Opr. (M$/yr.)
I	1.523	0.141	0.118
II	1.006	0.093	0.037
III	0.916	0.085	0.033
IV	1.173	0.109	0.049

System Control and Constraints: In HOMER, according to the desired specifications, the user can control and set parameters. In our proposed system, by constraints specified by a user, a system can generate at least up to 60% of the energy consumed. But this value can be varied depending on the selection of the user and has a significant effect on the TNPC.

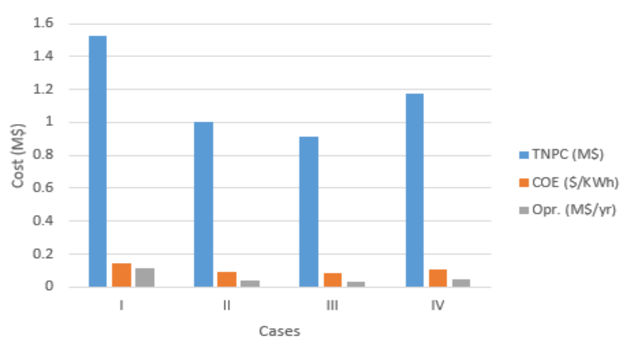


Fig. 10. Cost comparison after sensitivity analysis.

During the simulation process, another constraint is a maximum annual shortage. This value is set to zero as the institutions, commercial industries and agencies do not compromise on reliability, disruption of energy and quality. In this research, it is assumed that the system is provided with a peak or maximum load, it may happen only for a small interval of time. Control parameters and constraints used in this work are as follows:

- ✓ Operating output of PV = 30%
- ✓ Time-stepped simulation = 1 hour
- ✓ Charge's setpoint state = 80%
- ✓ Allow system with generator less than peak load.

Dispatch Strategy: A dispatch strategy is planned carefully, which contains a set of principles and instructions. These instructions and principles govern the operation of the generators plus device storage. In this study, HOMER can model load following and cyclic charging (2 working states of the generator).

HOMER modeling is the best choice when we consider factors such as the size of the battery, the price of fuel, generator size, operational cost, and the cost of maintenance, plus the quantity of natural energy in the system and the nature of renewable resources.

In the method of cyclic charging, during the process HOMER schedules a controllable supply of power for each hour of the day. It selects the best combination of available power supplies based on the demand fulfillment and strategy of load following. This increases the output of generators with the best possible combination.

Battery State of Charge (SOC): The state of charge (SOC) of the battery is equal to its depth of discharging (DOD), and there is an inverse state between them which is 100% = empty; 0% = full. SOC is discussed in order to study the state of battery current, whereas DOD is the term to study the life of battery after its repeated use. Figure 11 shows the battery SOC per day of the whole year.

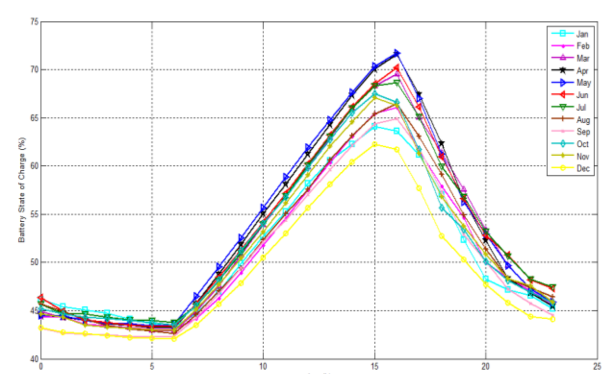


Fig. 11. Battery SOC of 24 hours over the year.

Kalman filtering and integration of current are indirect methods that can measure SOC. In HOMER, when battery SOC is below a certain point and is not charged in a previous hour, then HOMER will not allow discharging of the battery during the current hour. So, the generator may be required to supply both load and charge battery requirements at the same time. The battery is charged when it reaches the SOC set point. The battery bank timing is reduced when the battery is at low SOC. SOC also tends to push fewer discharge cycles during the whole year and hence causes fewer starts of generators. The set-point of SOC is fixed at 80%. The SOC target is around 50%, which, at rated power, sets fifteen minutes of charging and discharging. This setting is also compatible with spare generators. The strategy of operation demands BESS should charge when production of renewable energy exceeds load demand.

Conclusion: This research article explores the method for optimization of university load, with good planning in HOMER. In this method, the improved topology of hybrid energy systems has been presented. It focusses on various cases that tend to improve operational and optimization strategies. When discussing different cases, optimal size determination method is applied to find the best-optimized configuration. After experimentation, a hybrid system based on PV, bio-generator, diesel generator, grid, battery and the converter (case-III) is the most feasible and cost-effective solution for COE. The operation strategy applied in this paper not only improves the topology of the system but also makes this system more efficient. This proposed solution should be applied in the university as a model example, as it can be used as a beneficial solution to solve the energy crisis in Pakistan. This solution is not only environment-friendly but also reduces the cost and the burden from the national grid. The electricity produced through this method is cheaper and reliable. The finding in this paper is useful for the Government of Pakistan to make a decision and makes effective policy, not for the public sector but the private sector as well.

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