Pollution, 6(2): 325-336, Spring 2020
DOI: 10.22059/poll.2020.293034.719
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Study on an Existing PV/Wind Hybrid System Using Biomass Gasifier for Energy Generation

Malik, P.[1*], Awasthi, M.[1] and Sinha, S[2].

1. Centre for Energy and Environmental Engineering, National Institute of Technology, Hamirpur, Himachal Pradesh, India- 177005

2. Centre for Energy & Environment, Malaviya National Institute of Technology, Jaipur, Rajasthan, India-302017

Received: 01.12.2019 Accepted: 16.02.2020

ABSTRACT*:* Untapped pine needles with high potential for energy generation in the hilly area are not only a waste of resource but also increase the chance of environmental hazards as forest fires and GHG emission. This study is conducted to propose a new hybrid system (PV/Wind/Biomass) using abundant pine needle resource as a replacement of existing roof-mounted PV/wind hybrid system and analyse the feasibility using Hybrid Optimization of Multiple Energy Resources (HOMER). Biomass gasifier is integrated to meet the increased load demand of 29.5 kW from 4.3 kW at the Centre for Energy and Environment Engineering building in NIT-Hamirpur. Both cases (with and without storage) has been considered in this research study. New optimized configuration is found to be a $1kW_p$ PV array, one wind turbine of capacity 5kW, gasifier with a 17 kW capacity, 10 numbers of 12v batteries connected in series and 10 kW converter. The comparative analysis of off-grid hybrid systems shows that the system with the storage unit was more economical with 0.222 $/kWh as the cost of energy generation compared to the system without storage unit. The proposed hybrid system is found more reliable, economical and environment friendly and save about 27815 kg of CO_2 per year when only diesel is used to meet the same energy demand. Therefore, biomass gasifier in decentralized small-scale power plants can be a better replacement for diesel generators.

Keywords: PV system, Biomass energy, HOMER, Wind energy, Hybrid energy system

NOMENCLATURE

Symbol	Representation	Symbol	Representation
TNPC	Total net present cost	SOC	State of charge
LCOE	Levelized cost of energy	GHG	Green-house gasses
PV	Photovoltaic system	SOC	State of charge
BG	Biomass gasifier system	CRF	Capital recovery factor
WT	Wind turbine system		
DG	Diesel generator		

[*] Corresponding Author, Email: prashantmalik04@yahoo.in

INTRODUCTION

Conventional resources are currently being used to meet the increasing demand for energy due to industrialisation, population growth, improvements in technology and changing lifestyles (Das et al., 2017; Rohani & Nour, 2014). A shift to clean, cost-effective and reliable renewable resources for energy generation is needed (Bala & Siddique, 2009; Kanase-Patil et al., 2011; Qoaider & Steinbrecht, 2010). Cost-effectiveness of the renewable system is aided by the technological advancements and changes in the policies in recent times since the cost of energy generation from renewable resources has gone down considerably at the global level.

Most of the studies in the past two decades have been conducted on PV and/or the wind hybrid systems with fossil fuel. Few studies also focused on biomass-based hybrid systems in low windy areas (Afzal et al., 2010; Bernal-Agustín & Dufo-Lopez, 2009; Chauhan et al., 2019; Elhadidy & Shaahid, 2000; Salehin et al., 2016). Optimization model has been developed by Kanase-Patil et al., (2011) to optimized MHP-biomass-biogas-wind-solar based integrated system for a cluster of villages in the hilly state of Uttrakhand, India. The study found the optimum size of various renewable energy power systems based on the cost of energy and reliability index. Neto et al., (2010) suggested a PV/Biogas hybrid energy system using goat manure as biomass to meet the electrical demand of rural areas for a rural electric application using as a feedstock for the digester. Other researchers also discussed the feasibility analysis and assessment of renewable energy-based power systems for rural areas electrification around the globe (Balamurugan et al., 2009; Goel & Sharma, 2017; Mandelli et al., 2016; Rahman et al., 2016). In the present study NIT-Hamirpur located in Himachal Pradesh was selected as a study location. An abundant amount of unutilized pine needles as a biomass feedstock in the gasifier for power generation seems to be a better resource due to circumvention of pine needles forest fires in Himachal Pradesh (Bisht et al., 2014; Bharti & Awasthi, 2013; Chandran et al., 2011). Gasifier based system can be a replacement of the diesel engine as a backup unit in hybrid systems with the environmental-friendly solution (Garrido et al., 2016; Parihar et al., 2019; Tiwari et al., 2019). The purpose of this study was to utilize the wasted pine needles as resource and maximize the generation of existing PV/wind hybrid energy system using biomass gasifier to meet the entire load demand of the building of CEEE (Centre for Energy and Environment Engineering) in NIT Hamirpur and hence power enhancement using a renewable and economical system was attempted to fulfil the required load. The simulation of the existing system with and without battery has been conducted to find out the most optimum solution to the problem.

This study will not only provide valuable inputs for stand-alone renewable energy-based decentralized systems but also help in formulating guidelines for the promotion of green energy-based energy systems in the region and it can play a major role in control of pollution and forest fires.

Materials and methods

The existing 6 kW PV/Wind hybrid system was installed at the roof top of Centre for energy and environment engineering building in NIT Hamirpur which consists of 1 kW_p PV system, 5 kW_p wind turbine, 5 KVA, 120 V Su-kam make inverter with a battery bank of 150 Ah capacity in which 10 numbers of 12V batteries connected in series (Sinha & Chandel, 2015). Figure 1 shows the schematic diagram and actual setup of existing hybrid system.

The existing PV/wind hybrid system was not capable to meet the entire load demand of CEEE building because it was designed initially to fulfil the partial load demand (4.3kW). There was a need to add another renewable resource-based power generating systems according to the availability of land area and renewable resources. The schematic diagram of the proposed hybrid system with suggested modification is shown in figure 2. The technical specifications and cost details of major parts of the proposed hybrid system are shown in table 1. The solar resource at the selected site was very good (5.5 $kWh/m^2/day$) but PV array setup was needed a larger installation area and CEEE rooftop has a limited area for installation. The power generation from existing wind turbine system was minimum (0.122 kW) because the wind speed was very low (2.32 m/s) at this location (Sinha & Chandel, 2016). Diesel generator may be added but it is not a suitable option economically and environmentally because diesel generator has a major contribution in GHG emission. So there was a need of another renewable resource integration with the existing system. Biomass gasifier needs a small installation area and hence seems to be the best solution to meet the load demand of the entire building. Biomass was abundantly available in the form of pine needles, which was more than sufficient as per gasifier needs. Figure 3 shows the flow chart to find out optimized system configuration at the study location. The proposed stand-alone system was simulated with and without storage unit for economic and power generation analysis.

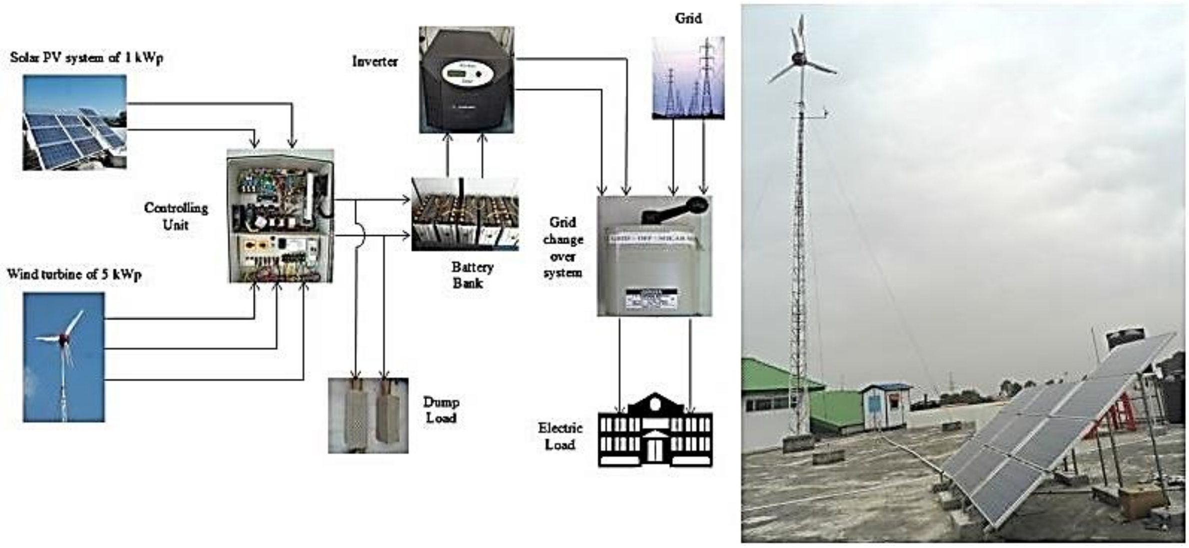

Fig. 1. Schematic and actual solar/wind hybrid system setup at rooftop of CEEE, NIT Hamirpur.

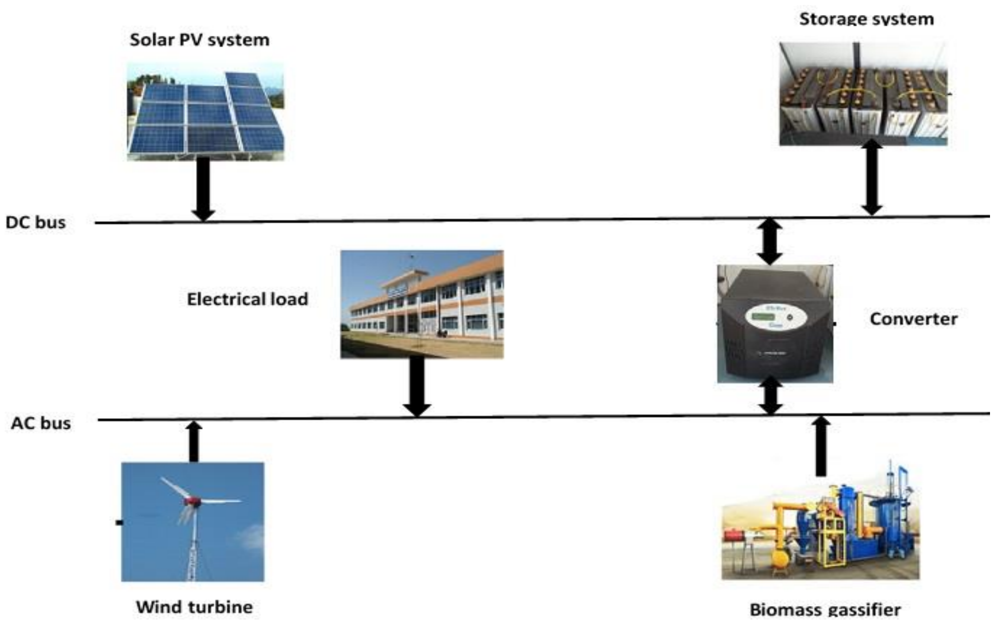

Fig. 2. The schematic diagram of proposed hybrid energy system.

Table 1. Technical specifications and cost details of proposed hybrid system.

Parameters	Value	Parameters	Values
PV system		Wind system	
Capacity range (kWp)	1-30	Rated capacity (kW)	5
Efficiency at standard test condition (%)	13	Rotor diameter (m)	4.26
Slope or tilt angle (degree)	31	Number of blades	3
Capital cost ($)	741	Cut-in wind speed (m/s)	2.5
Replacement cost ($)	741	Cut-out wind speed (m/s)	25
Operating and maintenance cost ($/yr)	25	Rated wind speed (m/s)	11
Lifetime (yr.)	25	Replacement cost ($)	8413
		Operating and maintenance cost ($/yr)	144
Biomass gasifier		Capital cost ($)	8413
Rated capacity range (kW)	1-17	Lifetime (yr)	15
Minimum load ratio (%)	30		
Capital cost ($)	1162	Converter	
Replacement cost ($)	872	Rated capacity range (kW)	1-10
Operating and maintenance cost ($/yr)	0.010	Efficiency (%)	95
Lifetime (Hrs.)	15000	Capital cost ($)	116
		Replacement cost ($)	116
Battery storage		Operating and maintenance cost ($/yr)	3
Nominal voltage (V)	12	Lifetime (yr.)	10
Nominal capacity (Ah)	150		
Minimum state of charge (%)	40	Other economic inputs	
Batteries per string (No)	10	Annual real interest rate (%)	5.95
Total DC voltage (V)	120	System fixed capital cost ($)	2331.2
Capital cost ($)	273	System fixed O&M cost ($/yr)	116.56
Replacement cost ($)	211	Project lifetime (yr)	25
Operating and maintenance cost ($/yr)	5.96		

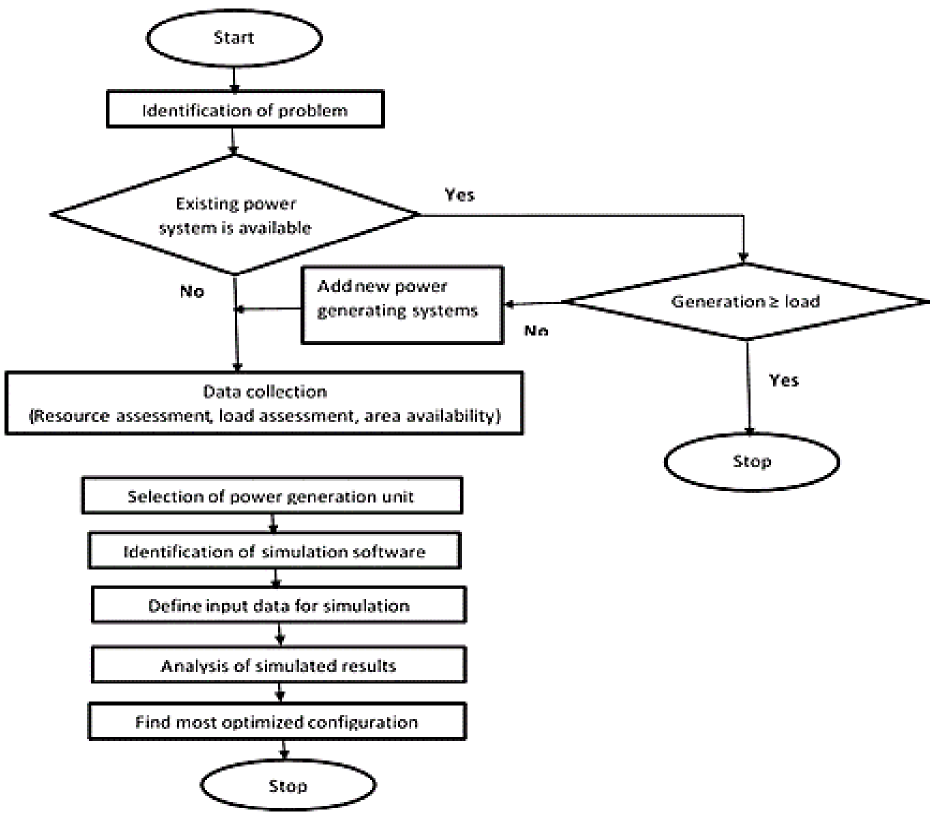

Fig. 3. Flow chart of methodology used in hybrid system designing

In the present study Hybrid Optimization of Multiple Energy Resources (HOMER) developed by National Renewable Energy Laboratory (NREL) was used to find out the most feasible configuration as per partial electrical load demand of the building. (Sinha & Chandel, 2014) reviewed several software tools used for the optimization of hybrid systems and concluded that HOMER is one of the most efficient software to simulate an on-grid and off-grid renewable hybrid system design for a wide range of applications. HOMER simulates different renewable and non-renewable energy systems and most optimized solution was provided to the end-user based on the net present cost (Ahmad et al., 2018; Aziz et al., 2019; Chauhan & Saini, 2016; Das et al., 2017; Mishra et al., 2016; Nag & Sarkar, 2018; Ramchandran et al., 2016; Sarker, 2016; Shahzad et al., 2017; Singh & Baredar, 2016). The information on available resources, costing details of systems, constraints, and control methods were used as an input in system analysis. The decision input variables in this study were:

1) Gasifier size 2) PV array sizing 3) Number of wind turbines 4) Inverter size 5) Size of the battery bank

The PV modules output power is calculated in HOMER by using the equation (1):

$$P_{pv} = Y_{pv} D_{pv} \left(\frac{G_T}{G_n} \right) \left[1 + \alpha_p \left(T - T_{ref} \right) \right] \quad (1)$$

where, P_{pv} is the power generation from PV array (kW), Y_{pv} represents the rated capacity of PV array at standard test conditions (kW), D_{pv} symbolizes the PV de-rating factor (%), G_T is incident solar radiation in the current time step (kW/m^2), G_n is the incident radiation at standard test conditions (kW/m^2), α_p denotes the temperature coefficient of power (%/^{0}C), T is the PV cell temperature in the current time step (^{0}C), T_{ref} is PV cell temperature under standard test condition. Wind turbine output power calculation is done by equation (2) and (3) at given hub height

$$\frac{V}{V_r} = \left(\frac{H}{H_r} \right)^{\alpha} \quad (1)$$

$$P_{WTG} = \left(\frac{\rho}{\rho_0} \right) * P_{WTG,STP} \quad (2)$$

Where,

V = the wind speed at the hub height of the wind turbine [m/s]

V_r= the wind speed at anemometer height [m/s]

H = the hub height of the wind turbine [m]

H_r= the anemometer height [m]

α = the power law exponent

P_{WTG} = the wind turbine power output [kW]

$P_{WTG,STP}$ = the wind turbine power output at standard temperature and pressure [kW]

ρ = the actual air density [kg/m3]

ρ_0 = the air density at standard temperature and pressure (1.225 kg/m3)

The biomass gasifier size depends on some important factors such as biomass quantity (T) at the location, calorific value of biomass (CV_{BM}), hours of operation per day (H_{BM}) and overall biomass gasifier system efficiency (η_{BMGS}). Gasifier hourly energy output is calculated by using equation (4).

$$E_{BMGS}(t) = \frac{T(kg/y) \times CV_{BM} \times \eta_{BMGS} \times \Delta t}{365 \times 860 \times H_{BM}} \quad (4)$$

where E_{BMGS} is the energy generation in kWh and Δt is the time step (1h).

The total net present cost (C_{NPC}) and cost of energy (COE) is calculated using equation (5) and (6)

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, N)} \quad (5)$$

where, $C_{ann,tot}$ is the total annualized cost ($/yr) and CRF denotes the capital recovery factor with interest rate (i) and project lifetime (N).

$$COE = \frac{C_{ann,tot}}{E_{prim,AC}} \tag{6}$$

where $E_{prim,AC}$ is the AC primary load served (kWh/yr)

The weather monitoring station was installed at CEEE (Lat. 31.590 N, Long. 76.520 E; altitude 875 m) with existing PV/wind hybrid system to collect the resource data. The system was equipped with a data acquisition system, which stores data at an interval of 1 second. In this study year, 2018 data measured at 10 m height with 1-minute interval was used for the system analysis. The graphical representation of the annual mean of solar radiation with the clearness index is shown in figure 4. The monthly average daily global solar radiation at study location ranges from 2.53 kWh/m2/day to 5.5 kWh/m^2/day. The maximum solar radiation mainly occurs in the month of May and minimum in January. The monthly average wind speed ranges from 1.8 m/s to 2.32 m/s with the highest wind speed occurring in the month of May and minimum in July. The graphical representation of the annual mean of wind speed is shown in figure 3.

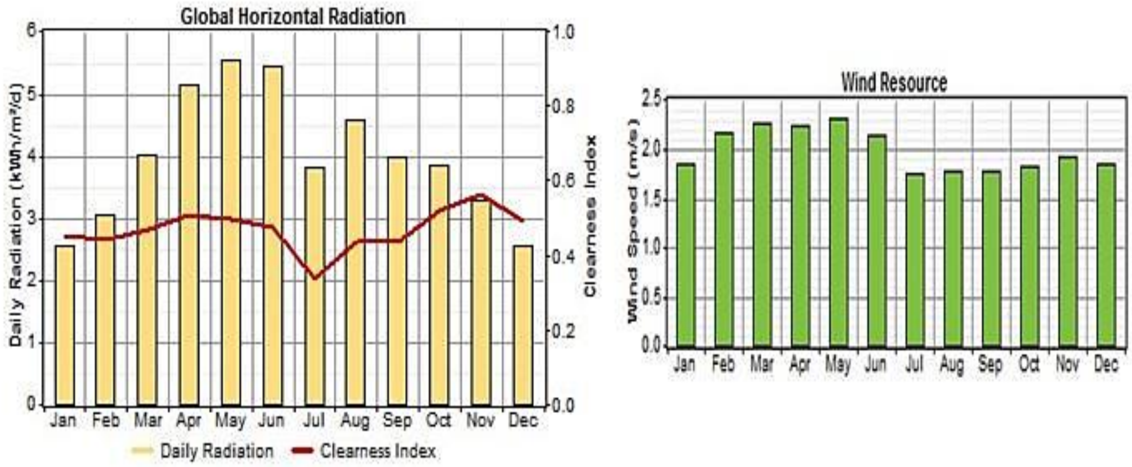

Fig. 4. Monthly average global solar radiation and wind speed at CEEE, Hamirpur (H.P)

The total pine forest covers around 58-hectare land inside the campus and 1-hectare pine forest typically gives 11.9-ton pine needles per year (Bisht &Thakur, 2016). The total pine availability in the study location is around 690 ton/year.

System sizing strongly depends on the electrical load demand of the study area. So load demand was one of the most important parameters in optimized system designing. The hourly consumption data of CEEE building for weekdays of a year was used in this study because the institute remains working for 5 days a week. Most of the energy requirement for a typical weekday was almost from 9 am to 6 pm. The load demand was low in the month of June-July due to summer vacations. The average daily load demand, average energy demand, peak load demand and a load factor of the building was 3.65 kW, 87.6 kW h/d, 29.2 kW and 0.125 respectively. Fig. 5 shows the monthly load consumption pattern.

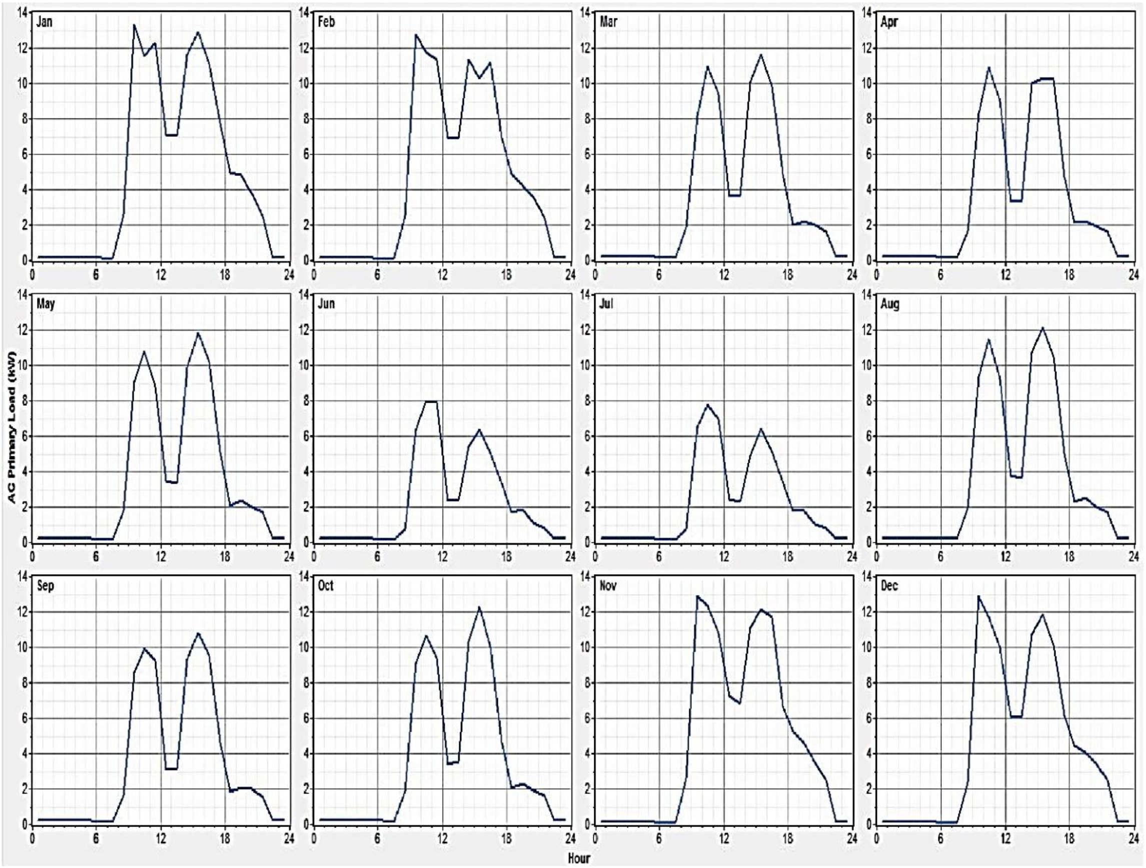

Fig. 5. Month wise daily electric load profile of CEEE building, Hamirpur, India

RESULT AND DISCUSSION

This study is mainly focused on power enhancement to meet the load demand of entire CEEE building and reliability improvement of existing PV/wind hybrid by integrating an environment friendly, technically possible and economical renewable energy generation unit. A detailed assessment of land and resources availability with various configuration simulation in HOMER has been done and finally biomass gasifier is selected for integration with existing system. The analysis shows that the hybrid energy system with 1kW$_p$ PV array, one wind turbine of 5kW, gasifier of 17 kW capacity, 10 numbers of 12 V batteries connected in series, a 10 kW converter was the most optimized solution. The annual electricity production from the optimized hybrid system shows that the biomass gasifier contribution in electricity generation was highest followed by PV and wind. (Sinha & Chandel, 2017) suggested that micro-wind turbines with a lower cut in speeds will perform better at this location. Figure 6 shows monthly average energy production of the gasifier, PV and wind systems with a storage unit for the study area. Gasifier has maximum percentage share (57%) in total electricity generation by the proposed hybrid power system as shown in Figure 7. Gasifier monthly average electricity generation was maximum (4.8 kW) in the month of January and minimum (2.22 kW) in June as per the electricity requirement.

PV array monthly average profile of electricity generation shows that maximum electricity generation was achieved in the month of May and minimum in July. Wind turbine monthly average electricity output is shown in figure 6 and indicates that the maximum generation occurs in the month of May and minimum in December. The daily average electricity generation from renewable resources shows that biomass gasifier daily average energy production is maximum followed by PV and wind, which varied from 3.14 units/kW/day to 6.76 units/kW/day. Figure 8 shows the normalized daily unit generation by different energy resources.

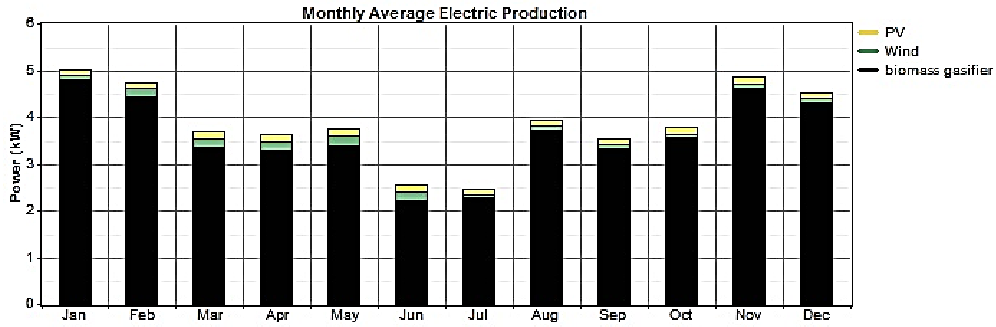

Fig. 6. Monthly average electricity generation from PV/Biomass/Wind/Battery hybrid system

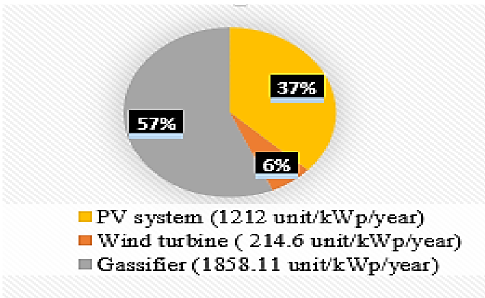

Fig. 7. Yearly power generation of integrated systems with storage unit

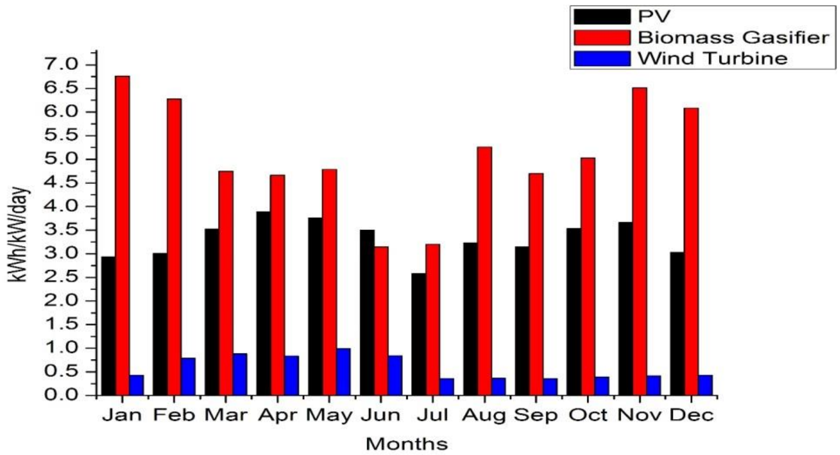

Fig. 8. Normalized daily energy production for PV, BM and Wind.

Overall analysis results of the proposed hybrid energy system with storage and without storage is shown in table 2 and conclude that hybrid system with storage was much better in comparison of the hybrid system without a storage unit. 33873 units per year at 0% capacity shortage through 100% renewable fraction was achieved by the optimized hybrid system (with storage) as total energy generation.

Frequency histogram for SOC of battery

bank for hybrid system is shown in fig. 9 and analysis has been found that annually state of charge frequency is around 5-7%, when battery SOC goes below 80% because battery is mainly used when demand is higher than total energy generation from all renewable resources.

Economic analysis of proposed hybrid system for 25 years also has been done and found that biomass gasifier has highest capital cost $19754 and replacement cost $22277. Nominal cash flow for 25 years is shown in Figure 10.

Table 2. Comparison of proposed hybrid systems with and without storage unit.

Parameters	System type	
	Hybrid system with storage	Hybrid system without storage
PV system (kW_p)	1	1
Wind turbine system (kW_p)	5	5
Gasifier system (kW)	17	26
Battery (no.)	20	0
Initial capital cost ($)	37859	41813
Operating cost ($/year)	4158	11079
Total NPC ($)	91268	184114
COE ($/unit)	0.222	0.448
Biomass required (ton)	16	27
Gasifier operation (hours)	2356	6186
Total generation (kWh/year)	33873	54411

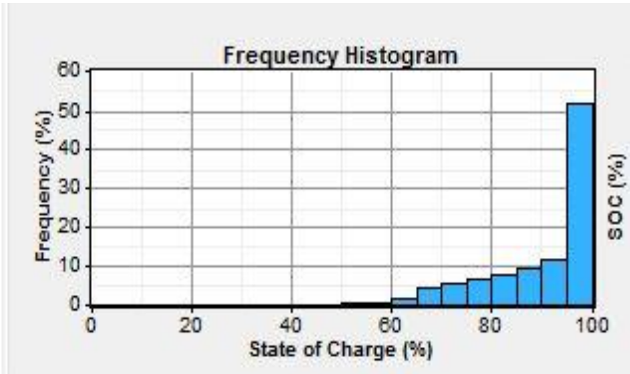

Fig. 9. Frequency histogram for SOC of battery bank

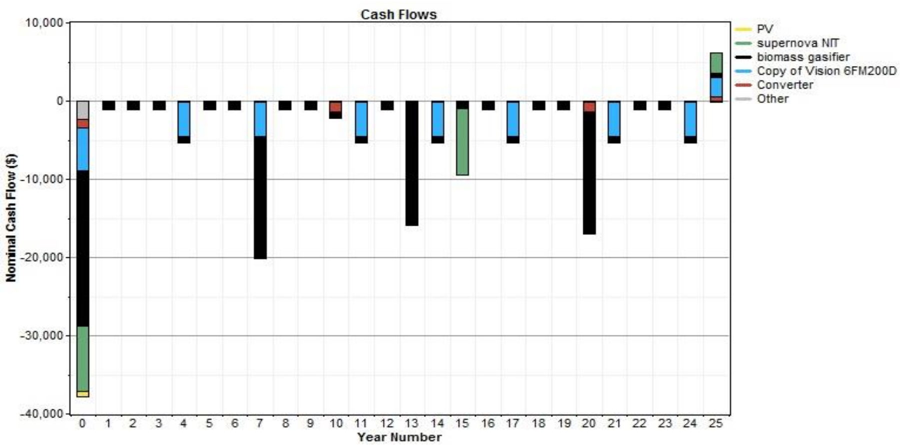

Fig. 10. Cash flow details of the proposed PV/Wind/BM/Battery hybrid energy system.

CONCLUSION

This study focused on enhancing an existing PV/wind hybrid energy system in power generation using a biomass gasifier unit to meet the building's increased load demand. Solar resource assessment for study location shows good power generation possibilities through the use of PV panels, but PV array expansion was not possible due to the limited deployment area. Also expansion of wind generation is also not feasible due to low windy nature of the location. The study location has a good biomass resource so biomass gasifier integration with existing system is a suitable option economically, environmentally and socially for institute as well as local community. The proposed system will diminished the overall diesel requirement of backup unit in campus and decline CO_2 emission.

- The optimized configuration of a proposed hybrid system with gasifier for energy demand of 88kWh/day for study location consists of a 1kWp PV array, 5kW wind turbine, 17kW biomass gasifier, 10 numbers of batteries and a 10 kW converter.
- The comparative study for with and without storage unit shows that the proposed hybrid system with a storage unit was much better and economical in comparison to the system without storage at this location.
- The proposed hybrid system with storage unit was generating the total power around 33,873 kWh/year at cost of energy 0.222$/unit.
- The cost of generating electricity was also lowest because local biomass was used in the gasifier as a fuel, also it is advantageous for its intermittent usage and storage capacity.
- Different areas in Indian context can be surveyed like unutilized pine needles in the present case and states like Punjab, Haryana, Uttar Pradesh, Kerala for rice husk, wheat straw, coconut shell, bagasse etc.

Moreover the proposed hybrid system may be used in remote areas where grid expansion is not possible. The stand-alone biomass-based hybrid power generation systems will increase the satisfaction level of costumers with its higher reliability and environment-friendly nature.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Afzal, A., Mohibullah, M. and Kumar Sharma, V. (2010). Optimal hybrid renewable energy systems for energy security: a comparative study. International Journal of Sustainable Energy., 29(1); 48-58.

Ahmad, J., Imran, M., Khalid, A., Iqbal, W., Ashraf, S. R., Adnan, M., Ali, S. F. and Khokhar, K. S. (2018). Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar. Energy., 148; 208-234.

Aziz, A. S., Tajuddin, M. F. N., Adzman, M. R., Azmi, A. and Ramli, M. A. (2019). Optimization and sensitivity analysis of standalone hybrid energy systems for rural electrification: A case study of Iraq. Renewable energy., 138; 775-792.

Bala, B. K. and Siddique, S. A. (2009). Optimal design of a PV-diesel hybrid system for electrification of an isolated island-Sandwip in Bangladesh using genetic algorithm. Energy for sustainable Development., 13(3); 137-142.

Balamurugan, P., Ashok, S. and Jose, T. L. (2009). Optimal operation of biomass/wind/PV hybrid energy system for rural areas. International Journal of Green Energy., 6(1); 104-116.

Bernal-Agustin, J. L. and Dufo-Lopez, R. (2009). Simulation and optimization of stand-alone hybrid renewable energy systems. Renewable and Sustainable Energy Reviews., 13(8); 2111-2118.

Bharti, V. and Awasthi, M. (2013). Pine needle charcoal briquettes: Rural technology option in pine forest Region. International Journal of Power System Operation and Energy Management., 2(1,2); 50-54.

Bisht, A. S., Singh, S. and Kumar, M. (2014). Pine needles a source of energy for Himalayan Region. International Journal of Scientific & Technology Research., 3(12); 161-164.

Bisht, A. S. and Thakur, N. S. (2016). Pine needle biomass a potential energy source for himalayan region. In 2016 7th India International Conference on Power Electronics (IICPE); 1-4.

Chandran, M., Sinha, A. R. and Rawat, R. B. S. (2011). Replacing controlled burning practice by Alternate methods of reducing fuel load in the Himalayan Long leaf Pine (Pinus roxburghii Sarg.) forests. In 5th International Wildland fire conference, Sun city, South Africa; 9-13.

Chauhan, A. and Saini, R. P. (2016). Techno-economic feasibility study on Integrated Renewable Energy System for an isolated community of India. Renewable and Sustainable Energy Reviews., 59; 388-405.

Chauhan, A., Khan, M. T., Srivastava, A. and Saini, R. P. (2019). Performance Optimization of a Grid-Connected PV/Biomass-Based Hybrid Energy System Using BBO Algorithm. In Applications of Computing, Automation and Wireless Systems in Electrical Engineering, Springer, Singapore; 133-144.

Das, B. K., Al-Abdeli, Y. M. and Kothapalli, G. (2017). Optimisation of stand-alone hybrid energy systems supplemented by combustion-based prime movers. Applied energy., 196; 18-33.

Das, B. K., Hoque, N., Mandal, S., Pal, T. K. and Raihan, M. A. (2017). A techno-economic feasibility of a stand-alone hybrid power generation for remote area application in Bangladesh. Energy., 134; 775-788.

Elhadidy, M. A. and Shaahid, S. M. (2000). Parametric study of hybrid (wind+ solar+ diesel) power generating systems. Renewable energy., 21(2); 129-139.

Garrido, H., Vendeirinho, V. and Brito, M. C. (2016). Feasibility of KUDURA hybrid generation system in Mozambique: Sensitivity study of the small-scale PV-biomass and PV-diesel power generation hybrid system. Renewable Energy., 92; 47-57.

Goel, S. and Sharma, R. (2017). Performance evaluation of stand-alone, grid connected and hybrid renewable energy systems for rural application: A comparative review. Renewable and Sustainable Energy Reviews., 78; 1378-1389.

Kanase-Patil, A. B., Saini, R. P. and Sharma, M. P. (2011). Sizing of integrated renewable energy system based on load profiles and reliability index for the state of Uttarakhand in India. Renewable Energy., 36(11); 2809-2821.

Mandelli, S., Barbieri, J., Mereu, R. and Colombo, E. (2016). Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. Renewable and Sustainable Energy Reviews., 58; 1621-1646.

Mishra, S., Panigrahi, C. K. and Kothari, D. P. (2016). Design and simulation of a solar–wind–biogas hybrid system architecture using HOMER in India. International Journal of Ambient Energy., 37(2); 184-191.

Nag, A. K. and Sarkar, S. (2018). Modeling of hybrid energy system for futuristic energy demand of an Indian rural area and their optimal and sensitivity analysis. Renewable Energy., 118; 477-488.

Neto, M. B., Carvalho, P. C. M., Carioca, J. O. B. and Canafístula, F. J. F. (2010). Biogas/photovoltaic hybrid power system for decentralized energy supply of rural areas. Energy Policy., 38(8); 4497-4506.

Parihar, A. K. S., Sethi, V. and Banerjee, R. (2019). Sizing of biomass based distributed hybrid power generation systems in India. Renewable Energy., 134; 1400-1422.

Qoaider, L. and Steinbrecht, D. (2010). Photovoltaic systems: a cost competitive option to supply energy to off-grid agricultural communities in arid regions. Applied Energy., 87(2); 427-435.

Rahman, M. M., Khan, M. M. U. H., Ullah, M. A., Zhang, X. and Kumar, A. (2016). A hybrid renewable energy system for a North American off-grid community. Energy., 97; 151-160.

Ramchandran, N., Pai, R. and Parihar, A. K. S. (2016). Feasibility assessment of Anchor-Business-Community model for off-grid rural electrification in India. Renewable Energy., 97; 197-209.

Rohani, G. and Nour, M. (2014). Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates. Energy., 64; 828-841.

Salehin, S., Ferdaous, M. T., Chowdhury, R. M., Shithi, S. S., Rofi, M. B. and Mohammed, M. A. (2016). Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis. Energy., 112; 729-741.

Sarker, S. (2016). Feasibility analysis of a renewable hybrid energy system with producer gas generator fulfilling remote household electricity demand in Southern Norway. Renewable Energy., 87; 772-781.

Shahzad, M. K., Zahid, A., Rashid, T., Rehan, M. A., Ali, M. and Ahmad, M. (2017). Techno-economic feasibility analysis of a solar-biomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software. Renewable energy., 106; 264-273.

Singh, A. and Baredar, P. (2016). Techno-economic assessment of a solar PV, fuel cell, and biomass gasifier hybrid energy system. Energy Reports., 2; 254-260.

Sinha, S. and Chandel, S. S. (2016). Analysis of fixed tilt and sun tracking photovoltaic-micro wind based hybrid power systems. Energy conversion and management., 115; 265-275.

Sinha, S. and Chandel, S. S. (2014). Review of software tools for hybrid renewable energy systems. Renewable and Sustainable Energy Reviews., 32; 192-205.

Sinha, S. and Chandel, S. S. (2015). Prospects of solar photovoltaic–micro-wind based hybrid power systems in western Himalayan state of Himachal Pradesh in India. Energy Conversion and Management., 105; 1340-1351.

Sinha, S. and Chandel, S. S. (2017). Improving the reliability of photovoltaic-based hybrid power system with battery storage in low wind locations. Sustainable Energy Technologies and Assessments., 19; 146-159.

Tiwary, A., Spasova, S. and Williams, I. D. (2019). A community-scale hybrid energy system integrating biomass for localised solid waste and renewable energy solution: Evaluations in UK and Bulgaria. Renewable energy., 139; 960-967.