Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 7- Issue 1, January 2024
Paper : 92

Modelling and techno-economic optimization of grid-tied hybrid renewable energy framework for rural electrification

Mayank Nehra
Department of Electronics Engineering
J C Bose University of Science & Technology, YMCA
Faridabad, Haryana, India
msnhra@rediffmail.com

Sheilza Jain
Department of Electronics Engineering
J C Bose University of Science & Technology, YMCA
Faridabad, Haryana, India
sheilzajain@gmail.com

Abstract— **In developing countries, rural areas often lack continuous 24*7 access to the grid due to infrastructure limitations. There are frequent interruptions and low voltage power supply. Infact, a continuous and uninterrupted energy supply is vital for the development and sustainable agriculture. To address this issue, the developed hybrid renewable energy framework offers an alternative for providing power in such locations. This research focuses on the creation of a grid-connected hybrid model, utilizing available renewable energy sources (RES). The suggested model incorporates regional RES like solar, wind, and biomass, along with batteries for storage. The primary aim of the research is the optimization and sizing of PV panels, wind turbines, biomass generator, and batteries while considering net metering from the grid. The system's net present cost (NPC) has been reduced, taking into account factors such as power reliability, state of charge of batteries, and upper and lower limits of solar PV and batteries. Considering the different scenarios examined, the optimal configuration includes a 3228 kW solar PV system, 1255 kW wind system, 500 kW biomass generator, 999999 kW grid connection and 2077 converters, and 1 kWh battery. Furthermore, the optimization results yield a minimum cost of energy (COE) of 0.0072 $/kWh and an NPC of $ 999,216 with a renewable fraction of 91.2%.**

Keywords— Hybrid renewable energy system; On-grid; Optimal system configuration; Rural electrification; Techno-economic analysis

I. INTRODUCTION

Energy has emerged as a critical driver of progress and a fundamental necessity for all aspects of the digital era and modern life. As concerns over climate change and environmental sustainability continue to grow, the focus on RES has intensified. Among these, solar energy has emerged as a frontrunner, offering immense potential to reshape the global energy landscape. Technological advancements in solar panels, energy storage systems, and grid integration have drastically improved the efficiency and reliability of solar energy. As a result, the costs of solar installations have steadily declined, making solar power increasingly competitive with conventional energy sources. This affordability has driven widespread adoption, with solar installations becoming more prevalent in rural applications such as dairy farms, tele-medicine, Tele-education, domestic applications, and other areas for sustainable development [1, 2].

Rural India has an irregular, unreliable, and interrupted power supply. The power outages were due to factors such as inadequate infrastructure, insufficient transmission and distribution networks, voltage fluctuations, and overloading. These issues were often attributed to a lack of investment, maintenance, and upgrade of the electricity infrastructure in rural regions. The solutions are alternate power supply with the help of RES. This also helps in the mitigation of climate change. The cons of RES are their reliance on specific geographical locations and unpredictable climate patterns [3, 4]. Table I presents a compilation of various studies carried out on the optimization and sizing of hybrid renewable energy systems (HRES). In the present work, a techno-economic optimization and sizing of a HRES with grid connections are carried out using HOMER Pro software.

II. STUDY AREA AND PROPOSED HRES MODEL

In the present study, the three villages of the state of Haryana (Ranoli, Pranpura, and Kishanpura), connected to the grid, have been chosen for the investigation. A total of 715 households reside at the geographical site situated at a latitude of 27.59° N and a longitude of 76.33° E, as shown in Fig. 1. The study focuses on analyzing the load requirements of the site during summer and winter in a year. The region possesses abundant biomass resources and solar energy, which can be harnessed as renewable sources. To mitigate the intermittent nature of solar PV and improve system reliability, a battery storage component has been incorporated. The biomass generator is planned to run for 8 hours during peak load periods to fulfill the load demand and maintain system reliability. The proposed hybrid model for the selected site involves the integration of solar, biomass, battery, and the grid, as illustrated in Fig. 2. The load curve for a proposed site and the schedule for the biomass generator are depicted in Fig. 3 and 4, respectively.

The electrical load demand is assessed to be 5738.80 kWh/day with a peak load of 461.98 W, obtained through interviews and field surveys conducted in the villages. The assessment of available resources is carried out using the NREL and NASA databases within the HOMER Pro software. Fig. 5 illustrates the solar irradiation and clearness index for the site under investigation. The region experiences low average wind speeds, making it suitable for small wind turbines (1-10 kW), as depicted in Fig. 6. The combined annual biomass potential for the three villages is taken to be 2127.42 metric tons, with crop residue contributing 1529.09 metric tons and livestock manure contributing 598.32 metric tons [12]. However, for ease of calculations and considering potential future increases in biomass availability due to the benefits of biogas plants, the average available monthly biomass is assumed to be 6 tonnes per day. Table II presents the economic and technical

Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 7- Issue 1, January 2024
Paper : 92

parameters of the designed HRES model. Subsequently, techno-economic optimization of the HRES model is conducted using the HOMER Pro software.

Table I Related work of HRES Specifications across the world

Authors	Architecture	Applications	Country	Year	Parameters	Reference
Kumar J et al.	SPV/GRID/BS	On-Grid	India	2019	NPC, COE, RF	[5]
Kumar A et al.	SPV/WT/DG/BS	Microgrid	India	2018	NPC, COE, RF	[6]
Barun KD et al.	SPV/GRID/BS	Standalone/ On-Grid	Bangladesh	2020	NPC, COE	[7]
Agyekum & Nutakor	SPV/WT/DG/BS	Off-Grid	Ghana	2020	NPC, COE, PP	[8]
Zhou Li et al.	WT/DG/BS	Off-Grid	China	2020	NPC, COE, RF	[9]
Ahmad et al.	SPV/WT/BIOMASS/BS	Off-Grid	Pakistan	2018	NPC, COE, RF	[10]
Suresh V et al.	SPV/WT/BIOMASS/FUEL CELL/BS	Off-Grid	India	2020	NPC, COE, RF	[11]

Where SPV- Solar Photovoltaic, WT- Wind turbine, DG- Diesel generator, PP- Payback period, BS- Battery system, RF- Renewable fraction

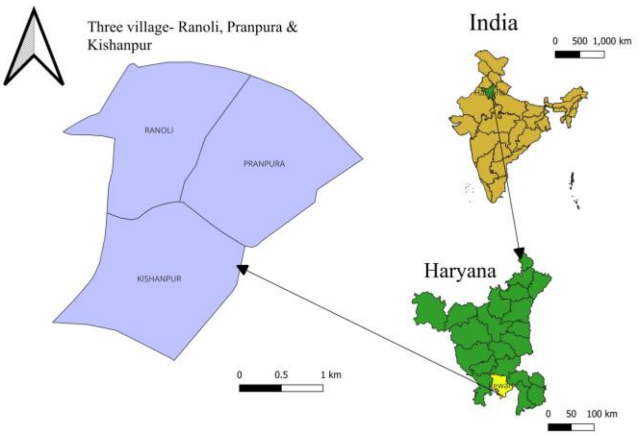


Fig. 1 Geographical location of selected site in Haryana, India.

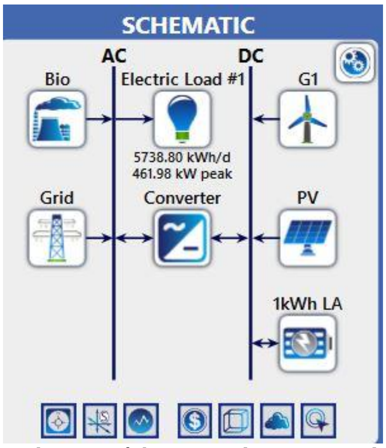


Fig. 2 Schematic of the proposed AC-DC coupled HRES model.

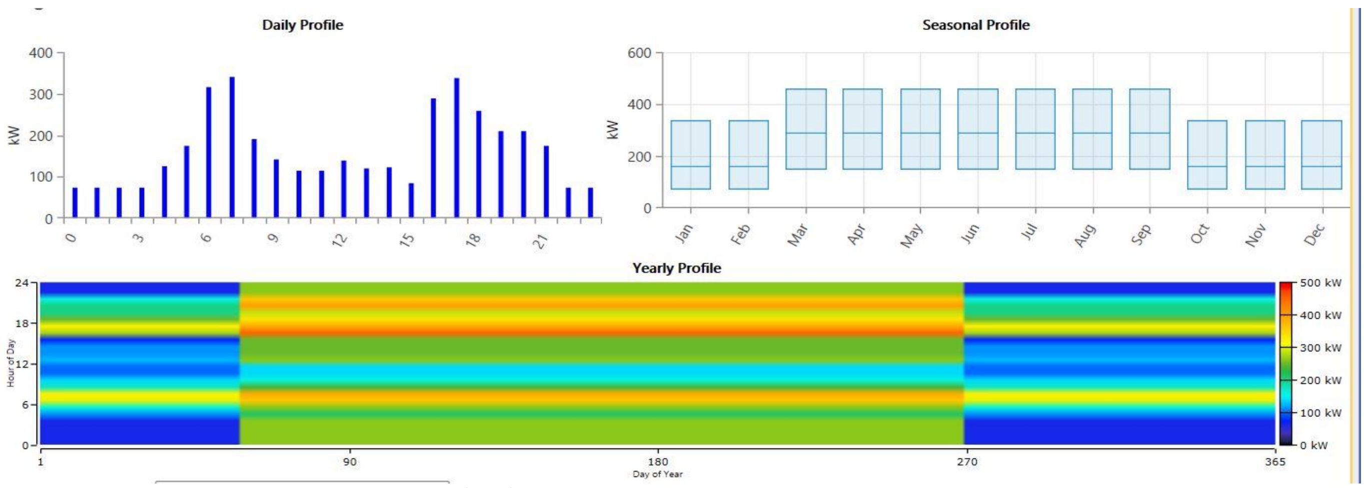


Fig. 3 The daily, seasonal and annual electric load profile of selected site in kW.

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 7- Issue 1, January 2024
Paper : 92

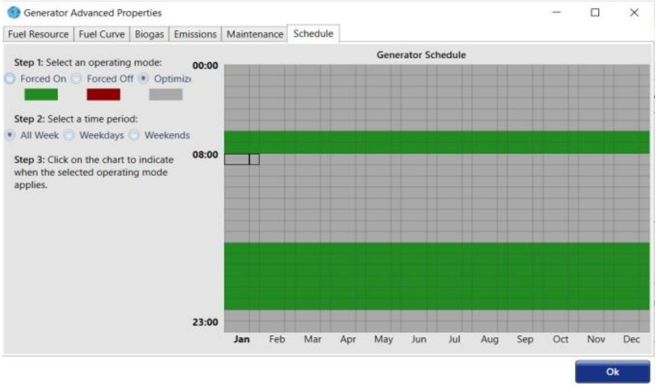


Fig. 4 Scheduling of biomass generator for the proposed site to meet peak electrical load.

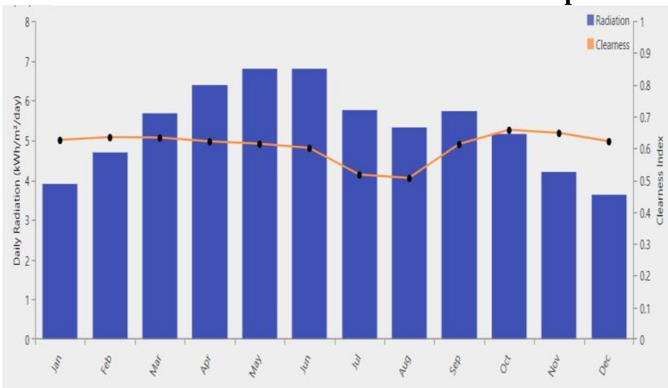


Fig. 5 Daily Solar Global Horizontal Irradiance (GHI) and clearness index of study area

Table II Designing components of the IRES [14, 15]

Parameters	SPV	Wind (G1)	Biomass Generator (Bio)	Battery	Convertor
Model name	Generic flat plate SPV	Generic	Generic	Generic Lead acid (Kinetic battery model)	Generic
Power capacity	1 kW	1 kW	500 kW	1 kWh	1 kW
Capital cost ($/kW)	630	300	200,000	162.66	300
Replacement cost ($/kW)	-	300	150,000	162.66	300
O & M cost ($/kW)	10	20	1	5	3
Life time	25 yr	20 yr	-	10 yr	15 yr
Derating factor	80%	-	-	-	-
Ground reflection	20%	-	-	-	-
Hub height	-	17 m	-	-	-
Fuel price	-	-	0.4 $/kW	-	-
Annual throughput	-	-	-	800 kWh	-
Inverter Efficiency	-	-	-	-	95%
Rectifier Efficiency	-	-	-	-	85%

Table III Emissions generated by optimum SPV/Battery/Wind/Biomass/Grid-based system.

Pollutant emission	Value (Kg/yr)
Carbon dioxide	412,133
Carbon monoxide	4.38
Unburned hydrocarbon	0
Particulate matter	0
Sulphur dioxide	1,785
Nitrogen oxides	876

Fig. 6 Month-wise average wind speed of study area

III. COMPONENTS OF THE HRES MODEL

The components of HRES model are presented as follows:

A. Solar PV array model

The output power of the solar PV array is evaluated by equation (1) as follows [15, 16]:

$$P_{PV} = P_{rated} \times F_{derating} \times \frac{I_{PV}}{1000} \times [1 + \alpha(T_C - T_S)] \quad (1)$$

Where, P_{rated} is rated power on the PV module, $F_{derating}$ is a derating factor of PV module due to soiling on the solar panels and ambient temperature effect, I_{PV} is the current due to solar radiation on solar PV module, α is the temperature coefficient, T_C is the temperature of the PV cell and T_S is the temperature of PV cell at standard test condition.

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 7- Issue 1, January 2024
Paper : 92

B. Wind turbine model

The output power of the wind turbine is estimated using equation (2) as follows [15, 17]**:**

$$P_{wind} = \frac{1}{2} \times \rho \times A \times \upsilon^3 \times \beta \times \eta_w \qquad (2)$$

Where, P_{wind} is the rated wind turbine power, ρ is the air density, A is the wind's cross-sectional area, υ is the wind velocity, β is the performance coefficient, η_w is the wind turbine efficiency.

The wind velocity at various heights of the turbine hub is determined using Equation (3) [4, 17, 18]. The hub height chosen for this study is 17 meters.

$$\frac{V(t)}{V_{ref}} = \left(\frac{H}{H_{ref}}\right)^{\omega} \qquad (3)$$

Where, $V(t)$ is the velocity at various heights, V_{ref} is the velocity at the reference height, H is the altitude of the wind turbine hub in meters, H_{ref} is the reference height in meters, ω is the Hellman coefficient.

C. Biomass generator model

The mathematical model of biomass generator is described as [11, 21]:

$$P_{BMG} = \frac{A_{BM} \times CV_{BMG} \times \eta_{BMG} \times \Delta t}{365 \times 860 \times h_{BMG}} \qquad (4)$$

Where, P_{BMG} is the rated biomass generator power, A_{BM} is the biomass availability (kg/yr), CV_{BMG} is the calorific value of biomass gasifier (4015 kcal/kg), η_{BMG} is the efficiency of biomass generator, Δt is the hourly simulation in a step, h_{BMG} is the number of operating hours per day.

D. Electrical grid model

The operation of the grid is mainly in two modes. The modeling of the grid electricity purchase and sale is described by equations (5) and (6) respectively [20].

$$Grid_{purchase} = Cost_{purchase} \times Unit_{purchase} \qquad (5)$$

$$Grid_{sellback} = Cost_{sellback} \times Unit_{sellback} \qquad (6)$$

Where, $Grid_{purchase}$ and $Grid_{sellback}$ are purchase and sellback price of the grid; $Cost_{purchase}$ and $Cost_{sellback}$ are a cost of energy per kWh purchase and sellback to the grid; $Unit_{purchase}$ and $Unit_{sellback}$ are purchase and sellback unit to the grid.

E. Battery model

The capacity of the battery bank available at hour t during the charging process can be determined using equation (7), taking into account that the total generation of energy exceeds the hourly electrical energy demand [18].

$$E_{bat}(t) = E_{bat}(t-1)(1-\alpha) + (E_{gen}(t) - E_{load}(t)/\eta_{inv})\eta_{bat} \qquad (7)$$

Equation (8) can be used to calculate the capacity of the battery bank at hour 't' during the discharging state, considering that the electrical energy demand exceeds the total generation of energy.

$$E_{bat}(t) = E_{bat}(t-1)(1-\alpha) - (E_{load}(t)/\eta_{inv} - E_{gen}(t))/\eta_{bat} \qquad (8)$$

Where, $E_{bat}(t)$ and $E_{bat}(t-1)$ represents the storage of battery at time t and t-1 in kWh, $E_{load}(t)$ is the load energy demand, $E_{gen}(t)$ is the hourly energy generation, α is the self-discharge rate of the battery, η_{inv} and η_{bat} are the efficiency of inverter and battery respectively.

IV. RESULTS AND DISCUSSION

The simulations of hybrid systems is performed by taking into account various factors such as solar radiation, wind speed, biomass availability, grid supply, and hourly electrical energy demands. The economic data for each system component including capital cost, maintenance cost, and replacement cost is utilized to perform simulation. HOMER systematically explores different combinations of components using the provided data, simulating each combination to optimize system costs while adhering to user-defined constraints. In the context of this study, a total of 44638 solutions were simulated, with 35260 of them deemed feasible while the remaining solutions were rejected due to capacity shortage constraints. The primary drawback of oversizing a stand-alone system is the wastage of excess power that cannot be utilized. However, in the present case study where a utility grid is available, the possibility of oversizing the system is reduced. A grid-connected HRES based on solar PV, wind, biomass, and battery technology is considered, which allows for selling the surplus generation to the grid and purchasing energy during periods of a shortfall. This practice enables revenue generation and leads to a decrease in NPC and COE. A comparison of various feasible system configurations depending on economic considerations is shown in Fig. 7.

The most favorable optimized solution, utilizing a combination of SPV/Battery/Wind/Biomass/Grid, follows a cycle charging (CC) strategy. It has a NPC of $ 999,216 and COE of $0.0072 per kWh. The ideal configuration for this

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 7- Issue 1, January 2024
Paper : 92

system comprises a 3228 kW solar PV array, 1255 kW wind energy system, 500 kW biomass generator system, 1 kWh battery bank storage system, 999999 kW grid connection, and 2077 converters. Accounting for both economic and environmental factors, SPV/Battery/Wind/Biomass/Grid-based system emerges as the most optimal arrangement. Motjoadi et al. 2021 calculated NPC and COE to be R6,583,640 and R0.1511 respectively for SPV/Wind/Battery/Grid system [21]. Mishra et al. 2022 estimated NPC and COE for SPV/Biomass/Grid/Battery system to be 13.07 million INR and 4.66 INR/kWh respectively [20]. Nehra and Jain, 2023 reported higher NPC ($7.08M) and COE (0.181 $/kWh) for standalone SPV/Battery/Wind/Biomass-based generator system compared to grid-connected system in the present paper [22].

In Fig. 8, a cost summary is provided for the SPV/Battery/Wind/Biomass/Grid-based system that represents the optimum configuration. Fig. 9 illustrates the monthly electric production of various energy systems within the optimal configuration for the entire year. Specifically, Fig. 10(a) to 10(f) depict the output power of the solar PV system, wind turbine, biomass generator system, energy purchased and sold to the grid, inverter and rectifier, and the state of charge of the battery, respectively. Additionally, Table III presents the emissions generated by the optimal configuration. Fig. 11 depicts the cash flow of various components for optimum configuration in 25 years. In Fig. 12, the impact of a higher renewable energy fraction (RF) on the operating cost is depicted. It demonstrates that the operating cost of the microgrid remains at its lowest level, regardless of the various sizes of the SPV system and inverters utilized [21]. Fig. 13 illustrates a comparison between RF and annual electric production. The findings reveal a significant rise in the RF as the annual electric production increases. This indicates that the solar PV system possesses the highest potential for generating more power in the event of grid system failures [23].

V. Conclusion

The primary focus of this investigation is to model a grid-connected HRES that is both affordable and reliable, with the purpose of supplying power to a specific rural area. The electricity requirements for the chosen location are estimated, and it is determined that these needs can be met through a combination of available resources and grid connectivity. It is evident that a grid-connected HRES offers greater reliability and cost-effectiveness in comparison to a stand-alone system. The optimization results for the most favourable configuration include a 3228 kW solar PV system, 1255 kW wind system, 500 kW biomass generator, 999999 kW grid connection and 2077 converters, and 1 kWh battery. The COE is calculated as 0.0072 $/kWh, with the RF of the optimal configuration reaching 91.2% and net energy is sold to the grid. In situations where RES are unable to meet the energy demand and the battery bank is not charged, the grid serves as a backup. Future work could involve exploring this system alongside demand-side management, power quality improvement, and stability considerations.

Architecture								Cost					System	
PV (kW)	G1	Bio (kW)	1kWh LA (#)	Grid (kW)	Converter (kW)	Dispatch		NPC ($)	LCOE ($/kWh)	Operating cost ($/yr)	CAPEX ($)		Ren Frac (%)	Total Fuel (tons/yr)
3,211	1,332	500		999,999	2,079	CC		$997,642	$0.00716	-$120,239	$3.25M		91.4	2,190
3,228	1,255	500	1	999,999	2,077	CC		$999,216	$0.00720	-$119,476	$3.23M		91.2	2,190
3,557		500		999,999	2,079	CC		$1.13M	$0.00873	-$103,240	$3.06M		87.0	2,190
3,577		500	5	999,999	2,079	CC		$1.14M	$0.00872	-$103,850	$3.08M		87.1	2,190
3,198	1,405			999,999	2,079	CC		$1.31M	$0.0101	-$93,733	$3.06M		88.3	0
3,165	1,557		5	999,999	2,064	CC		$1.32M	$0.0101	-$94,225	$3.08M		88.7	0
3,557				999,999	2,079	CC		$1.48M	$0.0122	-$74,084	$2.86M		82.2	0
3,577			5	999,999	2,079	CC		$1.48M	$0.0122	-$74,697	$2.88M		82.3	0
	844	500		999,999	461	CC		$2.38M	$0.0481	$95,724	$591.562		56.8	2,190
	892	500	6	999,999	486	CC		$2.38M	$0.0476	$94,640	$614,458		57.8	2,190
		500		999,999		CC		$2.49M	$0.0570	$122,413	$200,000		30.5	2,190
		500	50	999,999	3.61	CC		$2.51M	$0.0576	$123,199	$209,216		30.5	2,190
	1,123			999,999	608	CC		$2.76M	$0.0605	$119,948	$519,419		43.1	0
	1,111		12	999,999	657	CC		$2.77M	$0.0601	$119,625	$532,432		43.4	0

Fig. 7 Simulation results of different possible configurations of HRES after hourly simulation

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1 kW	$376,500.00	$235,688.86	$469,421.35	$0.00	($157,233.05)	$924,377.16
Generic 1kWh Lead Acid	$162.66	$230.52	$93.51	$0.00	($45.29)	$441.41
Generic 500kW Biogas Genset	$200,000.00	$218,910.77	$40,957.48	$0.00	($21,924.93)	$437,943.33
Generic flat plate PV	$2,033,758.13	$0.00	$603,737.20	$0.00	$0.00	$2,637,495.33
Grid	$0.00	$0.00	($4,063,788.08)	$0.00	$0.00	($4,063,788.08)
System Converter	$623,245.22	$438,621.10	$116,559.56	$0.00	($115,679.21)	$1,062,746.68
System	$3,233,666.01	$893,451.26	($2,833,018.99)	$0.00	($294,882.47)	$999,215.81

Fig. 8 Cost summarization of optimum SPV/Battery/Wind/Biomass generator-based system.

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 7- Issue 1, January 2024
Paper : 92

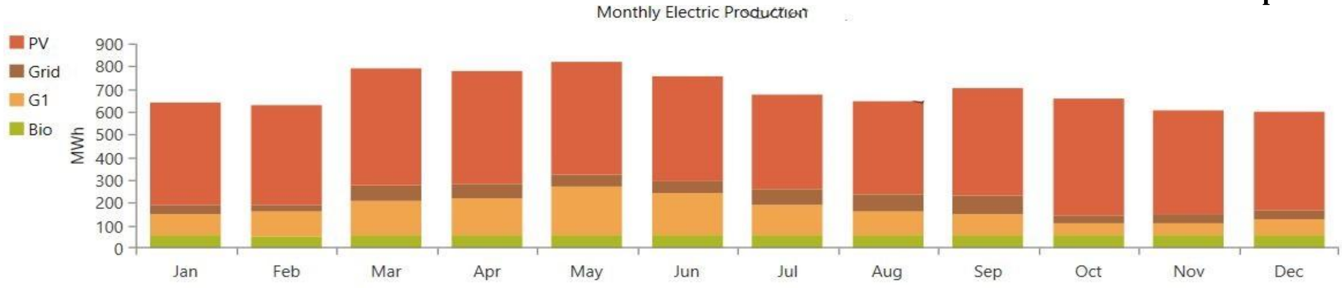
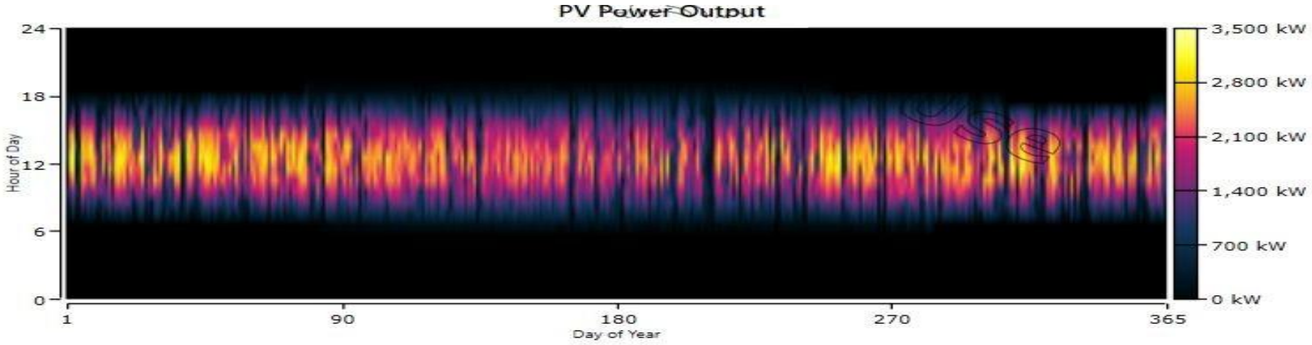
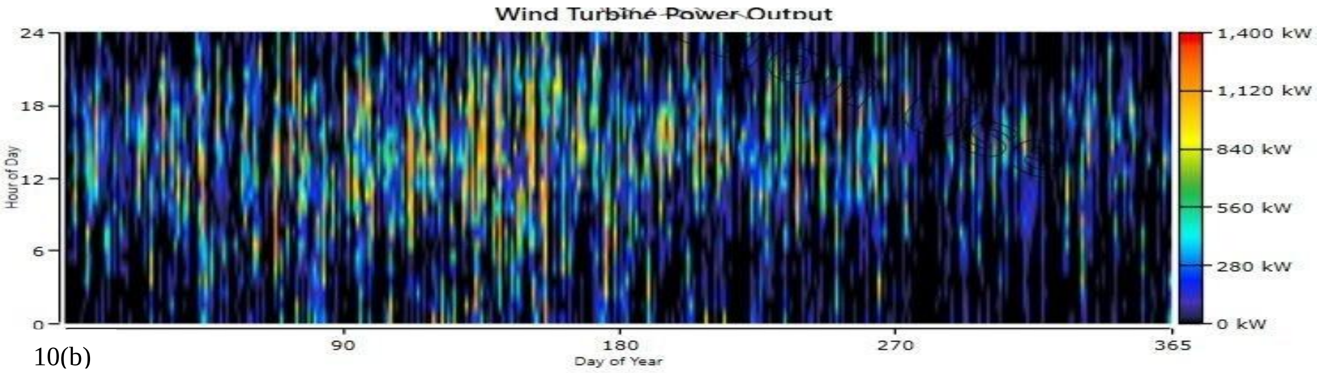


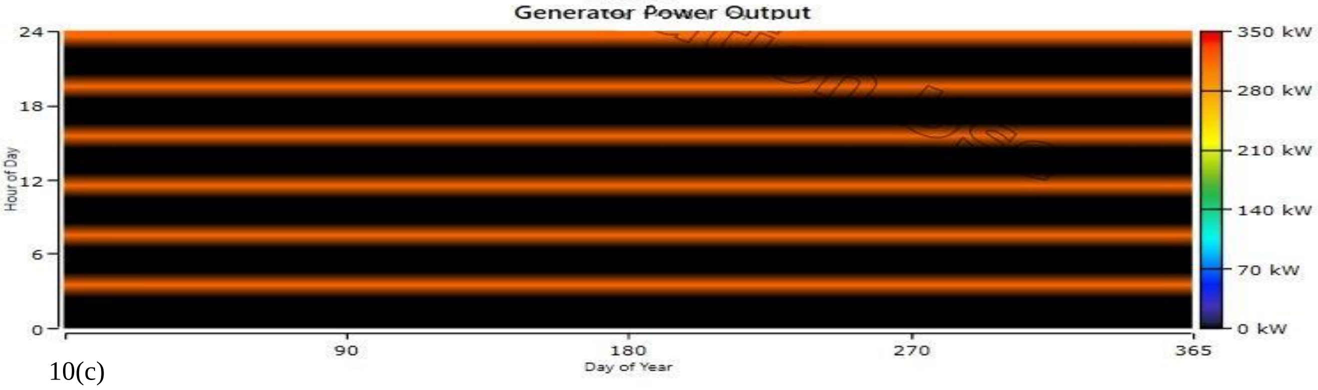
Fig. 9 Electrical production of different energy system for optimum configuration.



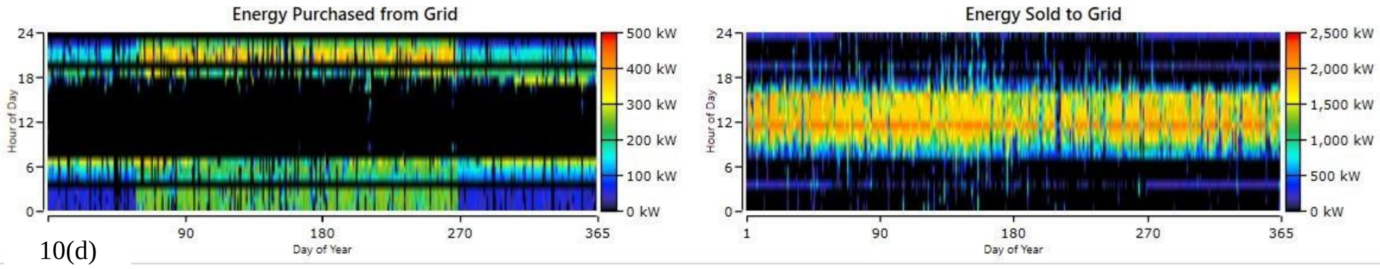
10(a)



10(b)



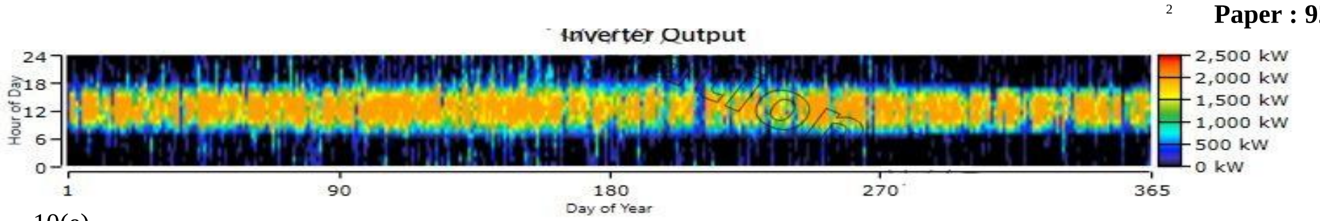
10(c)



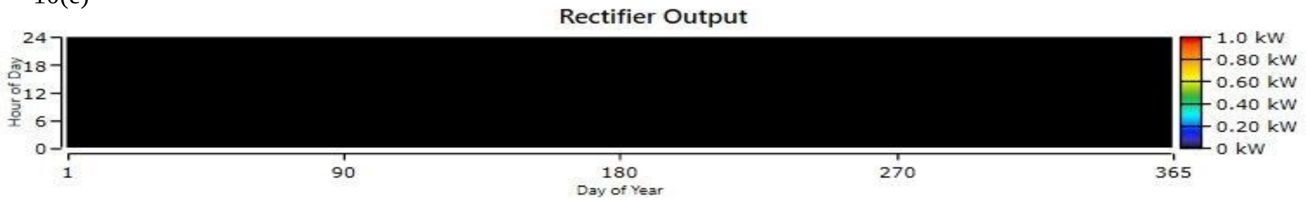
10(d)

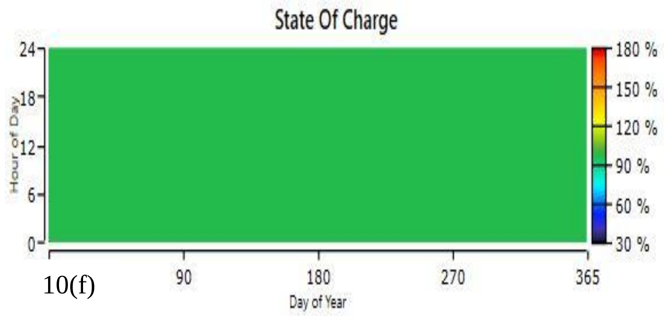
Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 7- Issue 1, January 2024
Paper : 92



10(e)





10(f)

Fig. 10 Power output of various energy system used in HRES.

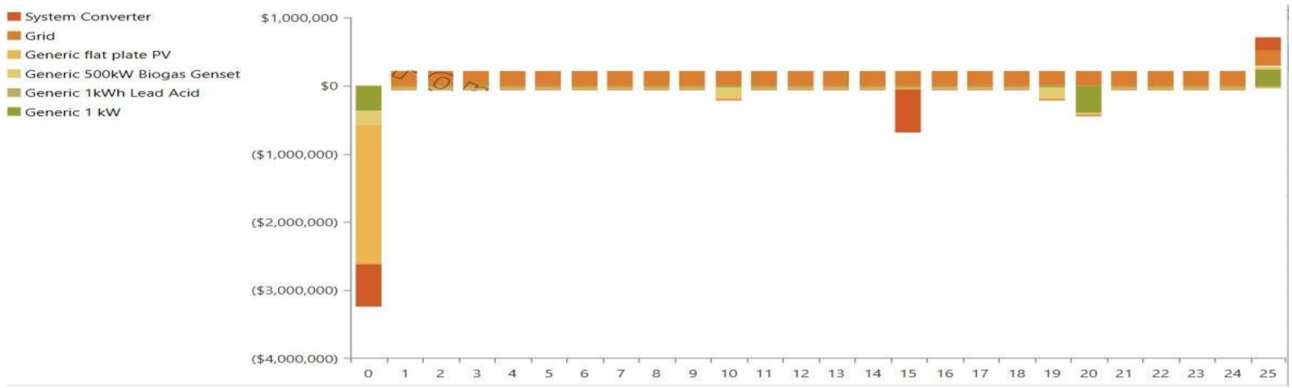


Fig. 11 Total Cash flow for optimum configuration during the project lifetime.

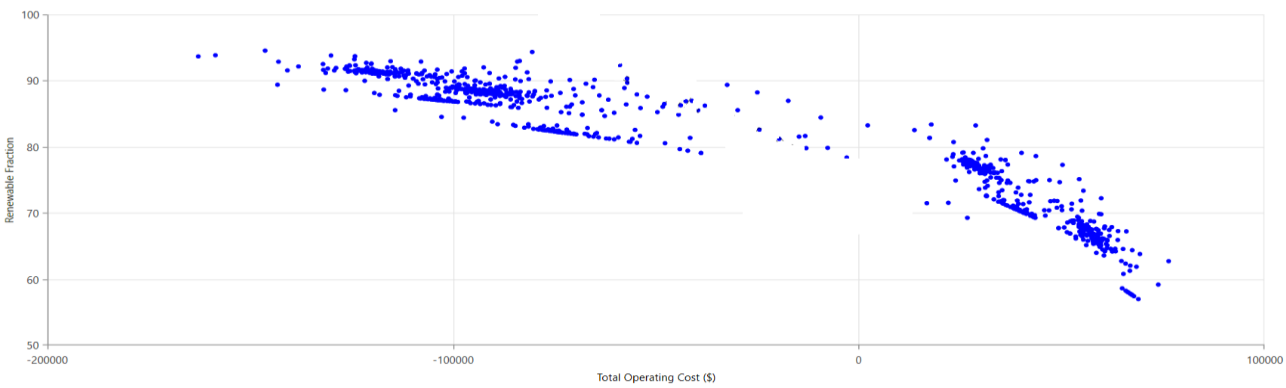


Fig. 12 Drawing a comparison between Renewable fraction and total operating cost.

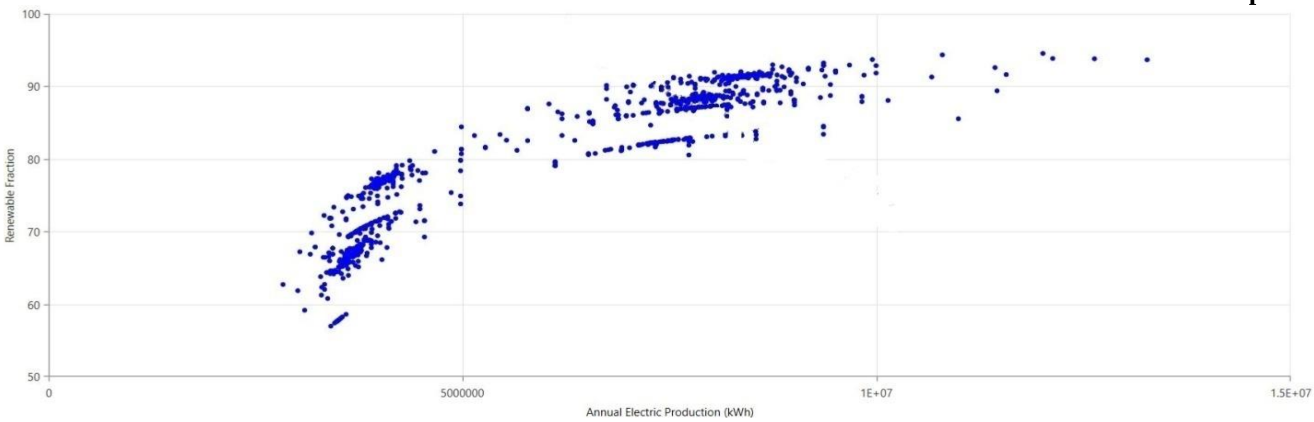


Fig. 13 Examine the relationship between Renewable fraction and annual electric production

REFERENCES

[1]. Mohd. R. Shaikh, "A review paper on electricity generation from Solar Energy," *International Journal for Research in Applied Science and Engineering Technology*, vol. V, no. IX, pp. 1884–1889, 2017. doi:10.22214/ijraset.2017.9272

[2]. N. Kannan and D. Vakeesan, "Solar Energy for future world: - A Review," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 1092–1105, 2016. doi:10.1016/j.rser.2016.05.022

[3]. F. A. Khan, N. Pal, and S. H. Saeed, "Optimization and sizing of SPV/wind hybrid renewable energy system: A techno-economic and Social Perspective," *Energy*, vol. 233, p. 121114, 2021. doi:10.1016/j.energy.2021.121114

[4]. B. K. Das, M. S. Tushar, and R. Hassan, "Techno-economic optimisation of stand-alone hybrid renewable energy systems for concurrently meeting electric and heating demand," *Sustainable Cities and Society*, vol. 68, p. 102763, 2021. doi:10.1016/j.scs.2021.102763

[5]. J. Kumar, B. V. Suryakiran, A. Verma, T.S. Bhatti, "Analysis of techno-economic viability with demand response strategy of a grid-connected micro grid model for enhanced rural electrification in Uttar Pradesh state India," Energy, vol. 178, pp. 176-85, 2019.

[6]. A. Kumar, A. R. Singh, Y. Deng, He X, P. Kumar, R.C Bansal, "A novel methodological framework for the design of sustainable rural microgrid for developing nations," IEEE Access, vol. 6, pp. 24925-51, 2018.

[7]. K. D. Barun, "Optimal sizing of stand-alone and grid-connected solar PV systems in Bangladesh". Int J Energy a Clean Environ (IJECE), vol. 21(2), pp. 107-24, 2020.

[8]. E. B. Agyekum and C. Nutakor, "Feasibility study and economic analysis of standalone hybrid energy system for southern Ghana," Sustainable Energy Technologies and Assessments, vol. 39, Article 100695, 2020.

[9]. C. Li, D. Zhou, H. Wang, Y. Lu, and D. Li, "Techno-economic performance study of stand-alone wind/diesel/battery hybrid system with different battery technologies in the cold region of China," Energy, vol. 192, Article 116702, 2020.

[10]. J. Ahmad, M. Imran, A. Khalid, W. Iqbal, S. R. Ashraf, M. Adnan, et al, "Techno economic analysis of a wind-photovoltaic-biomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar," Energy, vol. 148, pp. 208–234, 2018.

[11]. V.Suresh, M. Muralidhar and R. Kiranmayi, "Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas," *Energy Reports*, vol. *6*, pp. 594–60, 2020. doi:10.1016/j.egyr.2020.01.013

[12]. M. Nehra, S. Jain, "Feasibility assessment of biomass for sustainable power generation to mitigate climate change in a rural cluster: a case study in India," Biomass Conv. Bioref. (2023). https://doi.org/10.1007/s13399-023-04351-1

[13]. M. Hossain, S. Mekhilef, L. Olatomiwa, "Performance evaluation of a standalone PV-wind-diesel-battery hybrid system feasible for a large resort center in South China Sea," Sustain. Cities Soc, vol. 28, pp. 358-366, 2017.

[14]. M. Ramesh, R. P. Saini, "Dispatch strategies based performance analysis of a hybrid renewable energy system for a remote rural area in India," Journal of Cleaner Production, vol. 259, 2020, 120697, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.120697.

[15]. M. H. Jahangir and R. Cheraghi, "Economic and Environmental Assessment of solar-wind-biomass hybrid renewable energy system supplying rural settlement load," *Sustainable Energy Technologies and Assessments*, vol. 42, p. 100895, 2020. doi:10.1016/j.seta.2020.100895

[16]. A. Chauhan *et al.*, "Techno-Economic Assessment and environmental analysis of an optimal hybrid system under novel Demand Response Scheme for a remote region of India," *Energy Reports*, vol. 8, pp. 284–291, 2022. doi:10.1016/j.egyr.2022.05.200

[17]. F. A. Khan, N. Pal, S. H. Saeed, and A. Yadav, "Modelling and techno-economic analysis of standalone SPV/wind hybrid renewable energy system with lead-acid battery technology for Rural Applications," *Journal of Energy Storage*, vol. 55, p. 105742, 2022. doi:10.1016/j.est.2022.105742

[18]. M. H. Amrollahi and S. M. Bathaee, "Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response," *Applied Energy*, vol. 202, pp. 66–77, 2017. doi:10.1016/j.apenergy.2017.05.116

[19]. A. Chauhan and R. P. Saini, "Size optimization and demand response of a stand-alone Integrated Renewable Energy System," *Energy*, vol. *124*, pp. 59–73, 2017. doi:10.1016/j.energy.2017.02.049

[20]. S. Mishra, G. Saini, A. Chauhan and S. Sinha, "Optimal Designing of Grid-Connected Hybrid Renewable Model Using Harmony Search Algorithm," 2022 IEEE Silchar Subsection Conference (SILCON), Silchar, India, 2022, pp. 1-5, doi: 10.1109/SILCON55242.2022.10028820.

[21]. V. Motjoadi, M. G. R. Kilimi, P.N. Bokoro, Design and simulation of grid-tied power supply system using HOMER: a case study of lebowakgomo in South Africa, in 2022 30th Southern African Universities Power Engineering Conference (SAUPEC), 2022, pp. 1–9, 10.1109/SAUPEC55179.2022.9730770.

[22]. Under publication paper 3

[23]. K. Roy, K. K. Mandal, A. C. Mandal, "Energy management system of microgrids in grid-tied mode: a hybrid approach," Energy Sources Part A Recover. Util. Environ. Eff., pp. 1–23, 2021. https://doi.org/10.1080/15567036.2021.2002479.