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Techno-Economic-Environmental Assessment of Stand-alone Hybrid Renewable Energy System for Different Batteries using HOMER-Pro

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Abstract
The whole world is now widely using green energy compared to fossil because of the depletion of fossil fuels, the rising temperature of the earth, and changing weather conditions, all these things are becoming a big threat to the life of the earth. This study proposed a stand-alone hybrid renewable energy system using different types of batteries. This model includes photovoltaic arrays, wind turbines, diesel generators, converters, and batteries. Lead-acid and lithium-ion batteries have been compared for the selection of optimal battery based on hybrid renewable energy system and sustainable development requirements. The purpose of this study is to find the optimal configuration, and techno-economic characteristics, using the hybrid optimization of multiple energy resources technique. The results of Lithium-ion and Lead Acid have been compared and it is found that the best configuration is photovoltaic arrays/wind turbines/ diesel generators /Battery/converter with lithium-ion Batteries. The net present cost and cost of energy are found to be 1.64M and 0.144$ respectively, for the selected study location. The carbon dioxide emission for configuration with LI batteries is 107314 kg/year as against the LA batteries which have 351288 kg/year. The results show LI batteries are technically as well as economically better than the LA batteries.

Keywords- Optimal sizing, Hybrid, Renewable energy system, Battery, HOMER-Pro, Grid.

1. Introduction

In the last few decades, the use of non-renewable energy due to automobile, residential, and industrial, gadgets have increased significantly and due to this carbon emissions are also increasing. Along with this, the demand for energy is also increasing, which is why the use of renewable energy is increasing. (Nirbheram et al., 2024). Renewable energy includes photovoltaic, wind turbine, hydro and biomass, these resources are environment friendly. To generate electricity, it is necessary to use renewable energy resources (Guelleh et al., 2023). Renewable energy resources do not harm nature and are available in abundance. For this reason, a lot of attention is being paid to renewable energy resources to generate affordable electricity and reliability (Singh et al., 2022). The Government of India provides 40 percent subsidy to promote renewable energy (India, n.d.). The full cost of installing renewable energy resources, including year of maintenance and operation of the renewable energy system, is very low (Bilal et al., 2023). Stand-alone HRES are used in remote areas and villages, where there is no grid system or power interruption, is a problem (Singh et al., 2023a). On the other hand, grid-connected systems are used in urban areas where the grid is already functional or established. Hybrid system is the best application for generating electricity using renewable energy resource system (Merrington et al., 2023). Climatic conditions are not the same all the time and electricity is also not available all the time, so hybrid systems have been created. Here many energy resources are used to generate energy. When one source is not able to produce energy, the other source produces energy (Hassan et al., 2022). Batteries use as back up supply when no other source can generate sufficient energy. The battery will be used for charging when all resources are producing sufficient energy and access energy is available. The battery is environmentally friendly and does not cause pollution (Sawle, 2022; Thirunavukkarasu and Sawle, 2020; Yadav et al., 2023). To increase the reliability of the renewable energy system, it will also include a diesel generator to avoid additional battery costs and maintenance expenses. Then hybrid optimization of multiple energy resources (HOMER) technology will be used to find the optimal sizing. Using this technique, the optimal configuration will be achieved (Das and Zaman, 2019). A stand-alone HRES system for remote rural areas using HOMER is proposed that utilizes photovoltaics, wind turbines, diesel generators, and batteries to provide sustainable energy services in Nigeria. That the healthcare system will be better (Olatomiwa et al., 2018). A grid-connected hybrid system model with PV, BG, battery, and CON is developed. A discrete harmony search algorithm was adopted to optimize this system. So, the result for various optimal configurations includes 30kW biomass, 83.50kW solar PV, 78.70 CON, and 38.40 kWh battery bank. The optimization result yields the minimum energy cost and net current cost of 4.46 INR/kWh and 13.07 million INR, respectively (Mishra et al., 2023). Developed the model using the tunicate swarm algorithm. The need for a hybrid energy system is shaped by intermittent renewable sources. This module is based on the optimal size of the standalone HES. The goal is to create a grid-connected set that can be more reliable and cost-effective than stand-alone HES. The tunicate swarm algorithm is a popular method compared to the metaheuristic method; It helps with problem-solving (Singh et al., 2021). For the villages of the Champa district, a new model HRES with the configuration of PV-Micro-Hydro-Diesel-Battery was proposed. Solar and water resources are available locally, so energy production is good. A total of 18 combinations are optimized in terms of COE. The combination using the PSO algorithm is the most cost-effective. Environmental constraints, renewable fractions, and CO_2 emissions are also calculated with the help of EIR. The main objective is to minimize COE. In this parameter, artificial neural network (ANN) and hydrological estimation techniques are used, and the shape optimization of the hybrid system is performed by particle swarm optimization. So, the COE is Rs 5.37 per kilowatt hour and the TNPC is around Rs 26 million (Kumar et al., 2019). The research proposed a new model for renewable energy sources using Gray Wolf optimization for the optimal size of the hybrid model. The configuration of the component is Solar/Biomass/Biogas/Battery installed in various houses in villages of Haryana state, India. Both configuration comparisons compare off-grid and grid-connected using the GWO algorithm, so the grid-connected configuration is best for the study area. The total NPC and COE valuation is $636,923.07 and $0.88/kWh, respectively (Anand et al., 2019). A Stand-alone system has been developed for the optimal sizing of HRES using the black widow optimization technique, which promotes nature apostle algorithms and BWO origination, cannibalization, and convergence (Singh et al., 2023b). The voltage control problem and renewable energy resource problem were solved with the help of the stochastic optimization technique. The Latin Hypercube Sampling (LHS) method is used to cover the full range of variables. The created optimization scheme is tested on the IEEE 24 bus Reliability Test System (RTS) (Momoh and Salkuti, 2016). The authors presents the various type of renewable energy sources like geothermal, biomass and hydropower etc. (Chisale et al., 2023). The **Table 1** is showing the summary of the literature review on HRES.

Table 1. Literature review of HRES.

Reference	Configuration	Location	Methodology	Stand-alone/ Grid connected	Parameter investigate
Bilal et al. (2023)	PV/G1/BATT/ GRID	New Delhi	modified salp swarm algorithm	Grid-connected	NPC, COE
Guelleh et al. (2023)	PV/G1/GRID	Urban household in Tadjourah	HOMER	Grid-connected	NPC, LCOE
Hassan et al. (2022)	PV/G1/BG/MHT/GEN/ BATT	Bangladesh	non-dominated sorting genetic algorithm-II	Standalone	create 0.7396 jobs in the community.
Kumar et al. (2019)	PV/GEN/BATT	Chamba in Western Himalayan Himachal Pradesh	particle swarm optimization, artificial neural network	Standalone	18 possible combinations
Mishra et al. (2023)	PV/BG/BATT/GRID	Shahdol	Discrete Harmony Search	Grid-connected	NPC, COE

***Motivation*:** In this century the demand for electricity is increasing a lot, the reason for this is increasing population and increasing industrialization and fuel is also getting exhausted and electricity is also necessary to make life better and more comfortable. It is a good alternative to renewable energy. It contains components that generate electricity by converting nature's energy, which is present in large quantities in nature. This electricity can be used in remote places where there is no electricity or electricity is not available. Therefore, a standalone system has been designed which is hybrid, its special thing is that it does not require any electricity grid, it also uses battery and diesel generator, which is used to use electricity at night. So that it can become cheap and reliable power producer.

To the best of the authors' knowledge, the selection space and combination of sources (PV/G1/ GEN/CON/BATT) have been designed to optimally size the HRES for two different types of batteries.

Therefore, this paper finds the optimal size to minimize COE with two different types of LA and LI batteries using HOMER-PRO software. The contributions of the study can be summarized.
(i) Optimal sizing of HRES using HOMER-Pro software.
(ii) Techno-economic and environmental assessment is conducted.
(iii) Comparison of different configurations is conducted.
(iv) The comparison of LA and LI batteries for the selection of optimal battery.
(v) The optimization is done for the minimization of NPC, COE and carbon emission.

The rest of the paper is organized as follows: Section 2 describes the geographical location of the study area. Modelling of hybrid energy units, formulation of optimization objectives, and methodology are presented in Section 3. The results of the optimization are discussed in Section 4, Section 5 compares lead-acid and lithium-ion batteries, and conclusions are drawn in Section 6.

2. Proposed Approach

This **Figure 1** flow chart is divided into four sections. In the first section Here will describe site selection, the site for the project should have favourable conditions like sunlight, wind, etc. In the second section, input data such as load data, NREL data, and component parameters are collected. The resources in the third section feed the data into the HOMER-pro software (Homer Pro, n.d.). HOMER-pro software is used for optimization in this section, which means HOMER-pro software gives optimal sizing of HRES. The fourth section looks at cost generation, optimal configuration, component efficiency, battery performance, carbon emissions and graphic representation. Understand the entire flow chart and research paper with the help of this data.

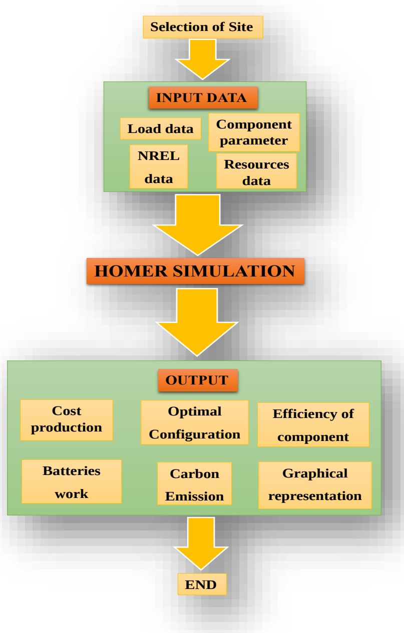

Figure 1. Flow chart of proposed approach.

2.1 Location

Gwalior, a city located in the central Indian state of Madhya Pradesh, is recognized as a smart city. It has an average elevation of 197 meters and is located at 26.218287°N latitude and 78.182831°E longitude. The city experiences a subtropical climate, with hot summer starting in the first week of March and ending in the first week of July. The wet monsoon season usually begins in late June and lasts until early October, while the winter season begins in early November and lasts until late February as shown in **Figure 2**.

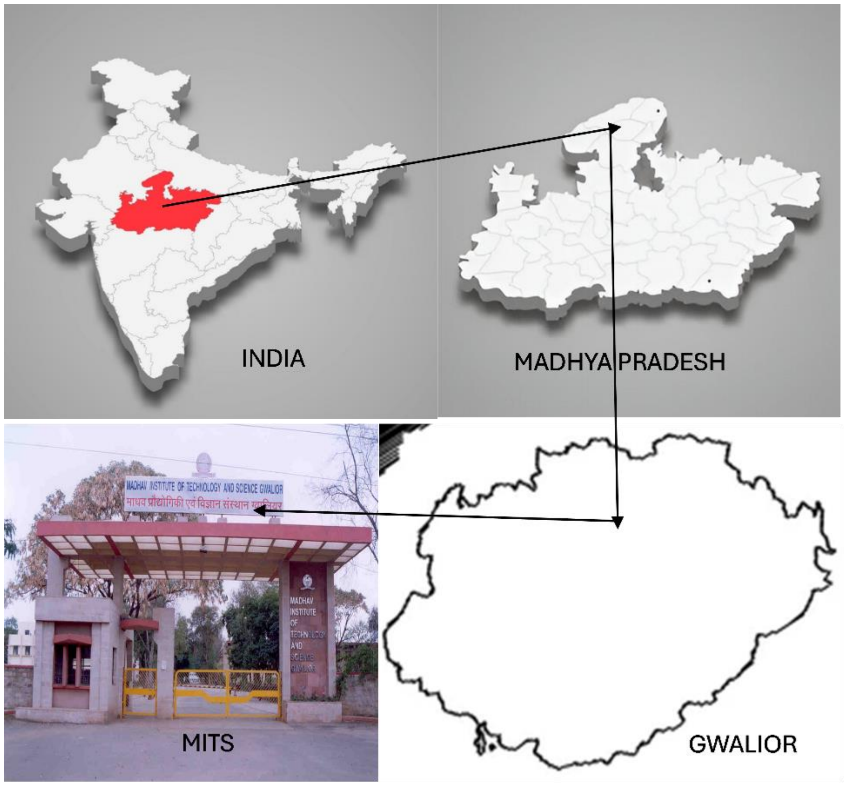

Figure 2. Geographical location of the case study.

2.2 Case Study

Solar radiation, wind speed, and clarity index data have been collected from the National Renewable Energy Laboratory (NREL) for renewable energy research (NREL, n.d.). **Figure 3** shows the hourly global solar irradiance for a year, with different months of solar irradiance available. The irradiance reaches about 0.60 in January but increases slightly in February, March, April, May, and June. The graph will fall again in July and August. At the end of the year, the graph will appear in a decreasing form. The maximum irradiance around 0.80 is found in May and the minimum irradiance is around 0.60 in December as shown in **Figure 3**.

will describe here, the monthly mean global solar irradiance with a clearness index, showing the clearness index on the right and the daily radiation on the left. The purpose of the clarity index is to the light emitted from the Sun that is easily transmitted through our atmosphere and easily detected by our PV to generate maximum power. It measures the clarity of the atmosphere. The size of the battery depends on the clarity index. The clearness graph starting from January, which has an initial value of about 5 and goes down slightly in July, finds the lowest value, which is about 4, and then the graph will end up with a value of about 5 by December. The left side shows daily radiation means the amount of solar radiation that falls on a specific place at a specific intensity or good intensity, the irradiance graph starts rising from January and then will fall and then rise a bit and then it will fall. The maximum daily radiation that can occur is around 7 and the minimum daily radiation in December is around 4, as shown in **Figure 4**.

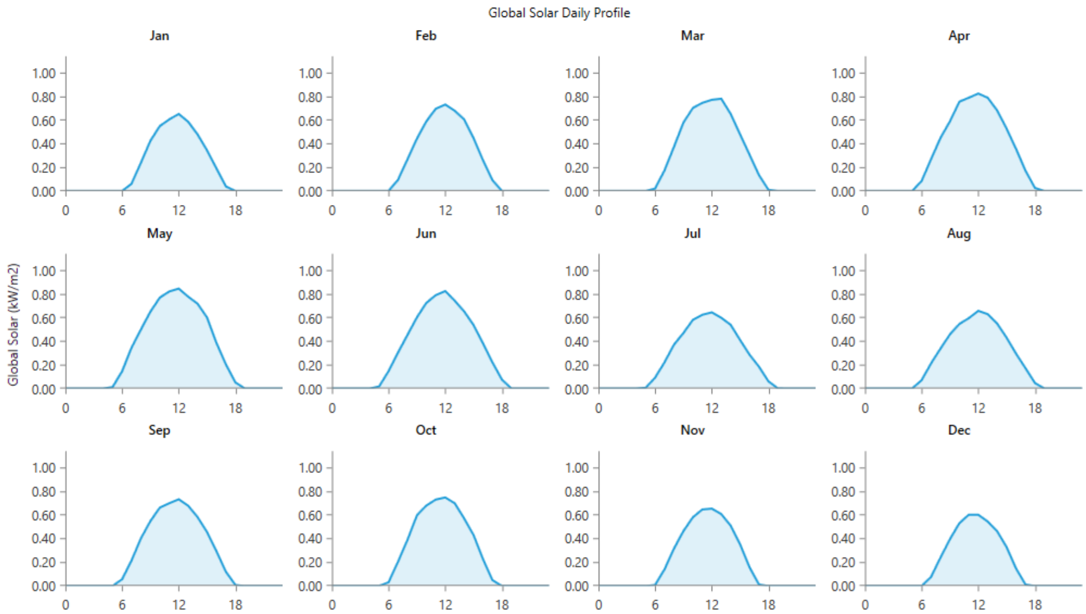

Figure 3. Hourly global solar irradiance for a year.

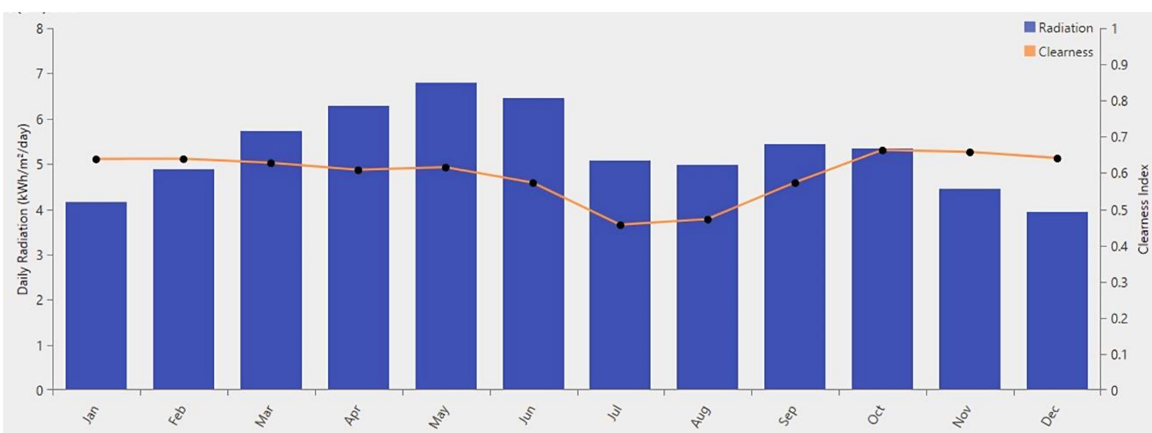

Figure 4. Monthly average global solar irradiance with a clearness index.

The hourly wind speed for a year shows the variation in speed from month to month in the initial months from January to June the wind speed gradually increases but in July and August the wind speed will decrease. The wind speed increases slightly in September and like in October, the speed will decrease again in November and December. The maximum speed is around 6.5 in April and May and the minimum speed is around 4.5 in December. Wind speed data helps in the assessment of wind resources in specific locations. Wind speed also affects the output of a G1. If the speed is high, the output will also be high, as shown in **Figure 5**.

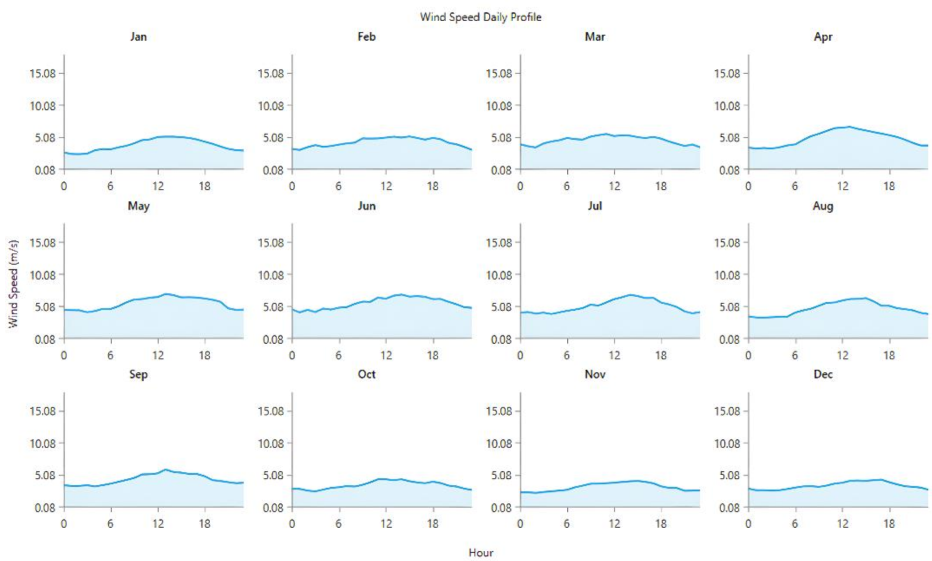

Figure 5. Hourly wind speed for a year.

The frequency of wind speed is very important for a site, site selection can be easier based on frequency. Frequency wind speed means a specific wind speed at specific locations. The energy output of a G1 depends on the frequency of the wind movement. The performance of grid-on HRES is evaluated by the frequency of wind movement. The graph in **Figure 6** shows the frequency with respect to time. This graph starts at about 1 frequency and then increases over time. Its maximum point is around 9 frequencies with respect to the timescale of 4 hours and its minimum point is around zero with respect to the timescale of 17 hours.

In **Figure 7** the load demand for an ordinary day, in this graph the initial hour is constant as being constant the load usage in the ensuing graph decreases slightly, and again the graph will increase to attain a maximum point which is approximately 140 kW in the middle of the day then the graph decreases and reaches our pre-level stage.

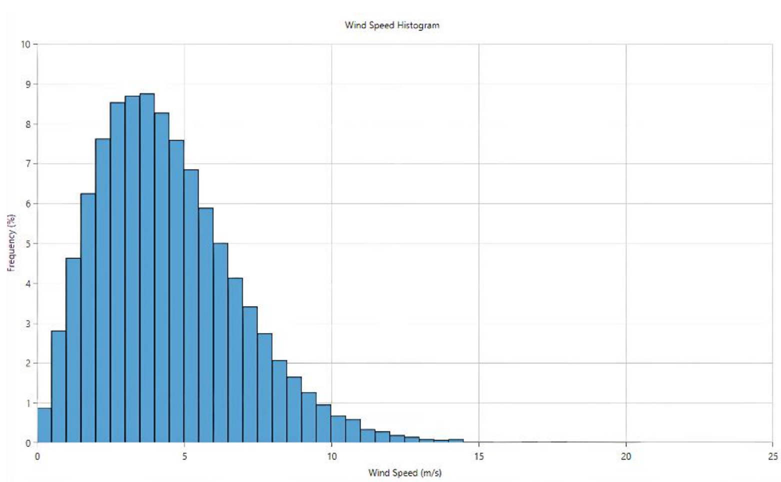

Figure 6. Frequency of the wind speed for a site.

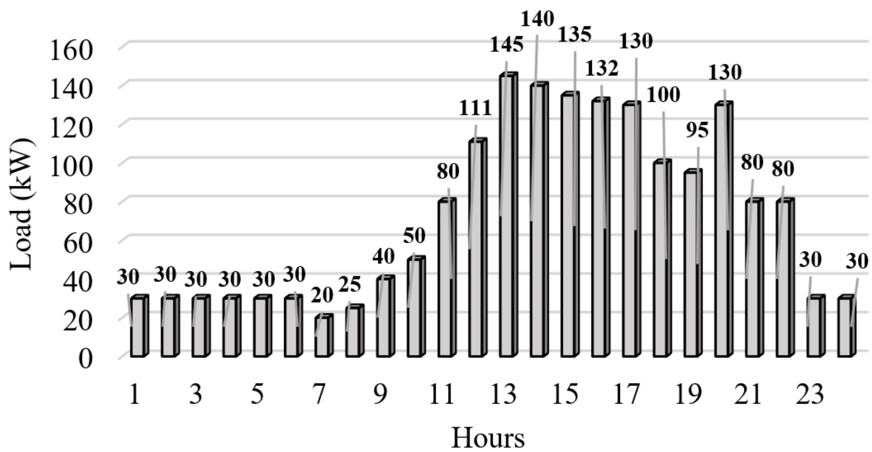

Figure 7. Load demand for a sample day.

Here will describe, the hourly load demand for one year on **Figure 8**. This graph shows electricity demand data for the entire year. The maximum load in the graph is found in April which is less than about 400 kW due to heat. Due to winter in February the minimum load is found to be around 150 kW. With the help of load demand, the cost of the upcoming project is estimated. Load demand also helps in designing a project. Analysis of hourly load demand prevents wasted energy or use of excess energy. If we detect overload demand in a particular hour, after knowing the reason, we can try to reduce that overload with the help of that hourly load demand. Also, roughly calculate all the situations that will occur while the project is running.

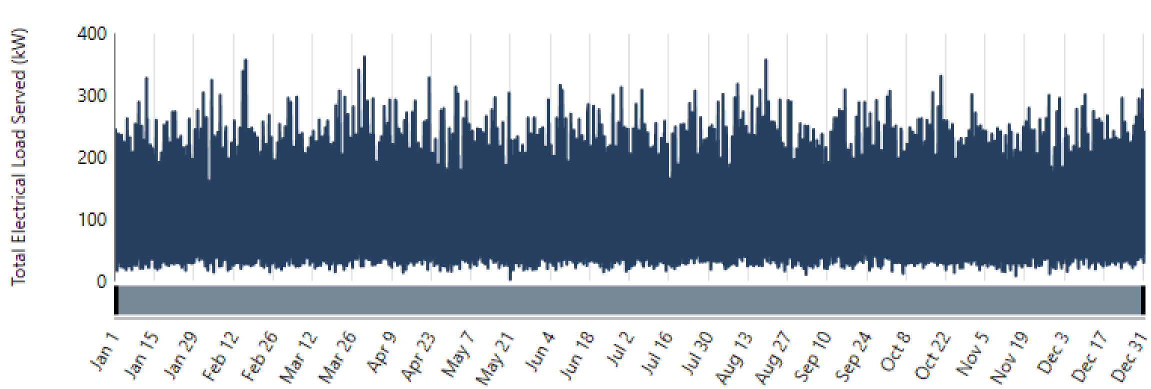

Figure 8. Hourly load demand for a year.

3. Component Formulation and Objective

Homer-Pro software is a simulator, which simulates pre-collection data such as load demand, component cost, component capacity, etc. Generate outputs such as optimal size, cost analysis, CE, and battery performance. It is assumed that all conditions are based on techno-economic characteristics. HOMER-Pro works at three levels, the first level estimates the loads and resources, the second level with the help of techno-economic analysis to derive the achievable configuration, performance characteristics, and limits of the components, and the third level with the help of carbon-based restrictions. Emissions, renewable fraction, duty factor, and results for various configurations. The main of this study is to get the optimal configuration in the HRES.

3.1 Photovoltaic Array

Photovoltaic (PV) arrays consist of several solar panels that convert sun radiation into electricity using the photovoltaic effect. PV is made of a semiconductor material, which is crystalline silicon. PV arrays can be connected in series and parallel connections. The dimensions of PV arrays can depend on the energy requirement, calculate the output of the PV array from Equation (1) (Upadhyay and Sharma, 2015).

$$P_{PV}(t) = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}}\right) \left[1 + \alpha_P (T_C - T_{C,STC})\right] \tag{1}$$

where, Y_{PV} is the rated capacity of the PV array, meaning its power output under standard test condition [kW], f_{PV} is the PV derating factor [%], G_T is the solar radiation incident on the PV array at the current time step [kW] /m2], $G_{T,\ STC}$ is the standard test condition [1 kW/m^2], α_P is the temperature coefficient of power[$\%/C$], T_C is the PV cell temperature at the current time step[C], $T_{C,STC}$ is the PV cell temperature under standard test conditions 25 Celsius.

3.2 Wind Turbine System

The G1 system consists of rotor blades, a hub, a pitch system, a gearbox, a yaw system, generators, a CON and the nacelle. G1 system generates electricity with the help of kinetic energy harnessed by G1. The rotor blades capture the wind and transfer it to the hub, which is connected to the generator. The cut-in speed is the minimum wind speed required to drive the turbine, calculating Equation (2) given below.

$$A_W(\mathrm{t}) = \begin{cases} 0 & H \leq H_{Cut-in} \text{ and } H \geq H_{Cut-Out} \\ \frac{B_r (H - H_{Cut-in})}{(B_r - H_{Cut-in})} & H_{Cut-in} \leq H < H_r \\ B_r & H_r \leq H < H_{Cut-out} \end{cases} \tag{2}$$

where, B_r is the turbine rated power, H_r is the rated wind speed, $H_{Cut\text{-}in}$ is the cut-in speed and $H_{Cut\text{-}out}$ is the cut-out speed (Maleki et al., 2015).

3.3 Diesel Generator

GEN are used as backup power sources, as fuel is an essential requirement for GEN to operate and generate electricity. For isolated, remote areas, industrial and construction GEN are the best examples of that area. It plays an important role in off-grid system. It can tell manually or automatically. Its reliability, durability and lifetime make it more demanding, calculating Equation (3) given below.

$$C = \left(C_{0,DG} \times M_{DG}\right) + \left(C_{1.DG} \times C_{DG}\right) \tag{3}$$

3.4 Battery

LA and LI batteries were used in the study. Battery are electrochemical devices that are used to store and release energy due to chemical reactions. Battery plays an important role in electric vehicles, isolated area, off-grid or stand alone and renewable energy systems. To analyze the effect of charging and discharging pattern on battery life, the charging and discharging patterns of a battery are calculated using the Equations (4) to (6).

$$S_E(t) = PV_P(t) \times \eta_{inv} + A_W(t) + C_{DG}(t) \tag{4}$$

$$L_E(t) = (1-\mu) L_E(t-1) + \left[\frac{S_E(t) + C_{DG}(t)}{\eta_{inv}}\right] \times \eta_{batt} \tag{5}$$

$$L_E(t) = (1-\mu) L_E(t-1) + \left[\frac{-S_E(t) - C_{DG}(t)}{\eta_{batt}}\right] / \eta_{batt} \tag{6}$$

3.5 Net Present Cost

The NPC of the component is the current purchase price, installation, operation and maintenance costs of the component during its lifetime, minus all current revenues from the component during its lifetime known as the net present cost. This is the NPC Equation (7).

$$NPC = I_C + I_{O\&M} + I_R \quad (7)$$

where, I_C is initial cost, $I_{O\&M}$ is operation and maintenance cost and I_R is replacement cost.

3.6 Cost of Energy

The cost required to produce a specific amount of energy is called the COE. It depends on the location, geographical area, government policies, fuel prices etc. This can be expressed as a ratio of total annual cost [TAC($/year)] and total electrical load saved (kW/year) shows Equation (8).

$$COE = \frac{NPC \times CRF}{E_{served}} \quad (8)$$

where, NPC is net present cost, CRF is capital recovery factor and E_{Served} is total electrical load served(kWh/yr).

4. Result and Discussion

Main aim of this study is minimization of cost of energy which is an economical factor, where loss of power supply probability reflects the technical factor. The different emissions present the environmental factor. In the schematic diagram in **Figure 9** shows the HRES where, Gen, G1 and electric load have been connected to an AC bus respectively, on the other hand, PV array has been connected to a DC bus. A CON is connected to both buses for benedictional converting (AC-DC, DC-AC). **Figure 9** shows the schematic diagrams of HRES with LA and LI battery.

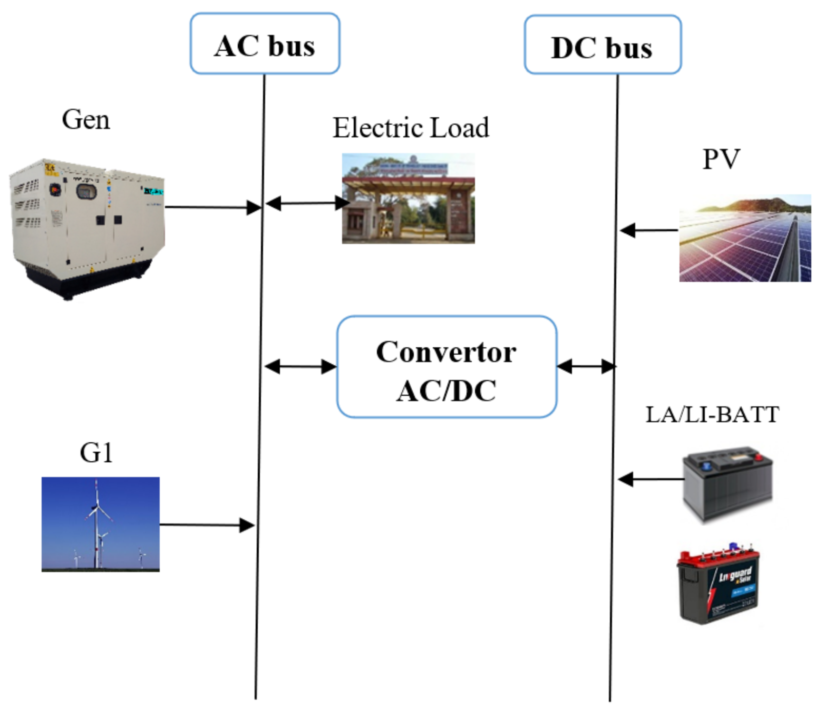

Figure 9. Schematic diagram of proposed HRES with LA battery and LI battery.

Table 2 provides various data about the economic details of power sources such as PV, G1, GEN, CON, LA, and LI batteries. **Table 2** also helps in analysing the project expenditure and understanding the details of capacity, initial cost, replacement cost, O&M cost, and lifetime of the component. The PV has an initial cost of $300 per 1kW of capacity, a replacement cost of $300, a required operation and maintenance cost of $10 per year, and an expected lifetime of 25 years. The initial cost of the wind generator is $630 per 1 kW of capacity, its replacement cost is the same as the initial cost, the operation and maintenance cost is $20 per year and its lifetime is 20 years. The GEN has an initial cost of $220 per 1 kW, a replacement cost of less than $200 per kilowatt, an operating and maintenance cost of .030$ per operating hour, and an expected long life of 15,000 hours or 1.7 years. The initial and replacement cost of the CON is 300$ per 1 kW of capacity. Its required operation and maintenance cost is $3 per year. And its expected lifetime is 15 years. The initial and replacement cost of a LA battery is $162.66 per 1kwh of capacity. 5$ is required for operation and maintenance. And its expected lifetime is 10 years. LI battery have an initial cost of $190 per 1kW of capacity, replacement cost is $150, LI battery have no O&M cost and have a lifetime of 15 years (Ramesh and Saini, 2020).

Table 2. Economic description of power sources (Ramesh & Saini, 2020).

Sources	Capacity	Initial cost ($)	Replacement cost ($)	O&M cost ($/year)	Lifetime (year)
PV	1kW	300	300	10	25
G1	1kW	630	630	20	20
GEN	1kW	220	200	0.030($/op.hr)	15000(hr)
CON	1kW	300	300	3	15
BAT(LA)	1kWh	162.66	162.66	5.00	10
BAT(LI)	1kWh	190	150	0.00	15

4.1 Optimization of HRES for LA Battery

Table 3 shows the optimal result of HRES for different configurations using LA batteries. Lead acid batteries have become a favourite for optimization due to their low cost. Lead acid batteries are widely available and have been used in a variety of applications for many years. This **Table 3** helps to find the best configuration based on minimum COE. The 2nd row of **Table 3** contains all the different sources of HRES. In the 2nd row, the values of PV/G1/ GEN/ES/CON are 2005kW, 915,400kW and 106,307 respectively. The values of NPC and COE are 4.03M$, and 0.352$ per kWh, respectively. In the 3rd row, the PV/GEN/ES/CON values are 2930kW, where G1 is absent, the values are 400kW, 9kWh,306kW, and the NPC/COE values are 4.03M$, and 0.394$ per kWh, respectively. In the last row, where PV is absent combination, the optimal value of G1/GEN/ES/CON has been 1151,400kW,969kWh,1431kW and NPC, COE is 4.31M and 0.377($/kWh) respectively in this **Table 3**.

Table 3. Optimal results of HRES for different configurations using LA battery.

Configuration	**Combination**	**PV (kW)**	**G1**	**GEN (kW)**	**BATT (kWh)**	**CON (kW)**	**NPC ($)**	**COE ($/kWh)**
1	PV/G1/ GEN/LA-BATT/ CON	2005	915	400	106	307	4.03M	0.352
2	PV/ GEN/ LA-BATT /CON	2930	-	400	9	306	4.51M	0.394
3	G1/ GEN/ LA-BATT /CON	-	1151	400	969	1431	4.31M	0.377

The cost summary of LA shows the cost distribution of various parameters such as Auto Size Genset, Generic 1kW, Generic kWh LA, Generic Flat-Plate PV, and System CON. Here auto size genset has a max cost of around 2500000$, generic 1kw has a second max cost which is around 1200000$, and generic 1kw LA is almost nil. The generic flat plate PV cost is around $450000, and the system CON cost is around zero as shown in **Figure 10**.

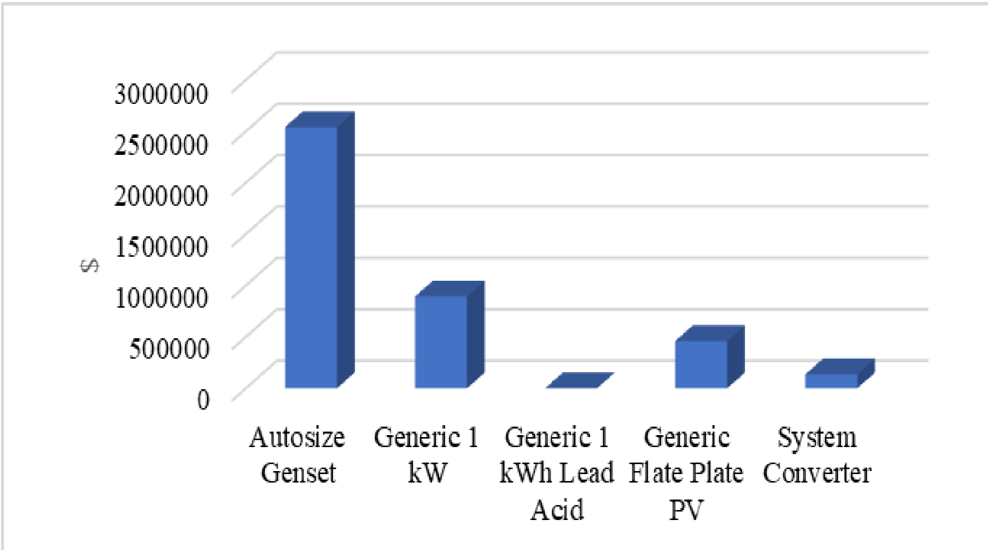

Figure 10. Cost summary of LA.

Figure 11 Generic flat plate PV power output of LA shows the variation in output from day to day. In the graph from the beginning, the output will gradually increase. In the middle of the graph, the output will again increase more than the previous output and then the graph output will decrease. The maximum power that will be achieved at the final output is approximately 2000kW. With the help of this graph, the analysis of PV power output will become easy.

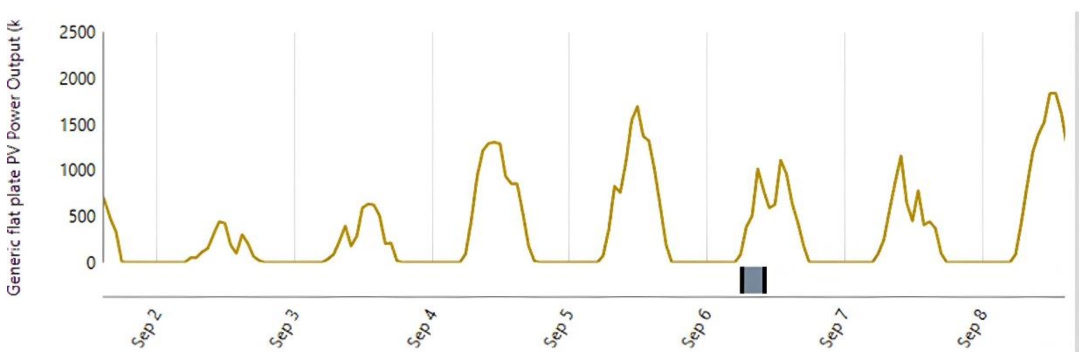

Figure 11. Generic flat plate PV power output of LA.

Figure 12 shows the variation in output from day to day for a typical 1 kW power output. In the graph from the beginning, the output is around 600kW, but suddenly the output will drop. Therefore, the fluctuation continues until the output power is reached, which is about 850kW, and after a few days of output increase, the output will suddenly decrease and reach the maximum power, which is about 900kW, and again increases, decreases, and so on. From this simple graph, we understand the generation of electricity generation.

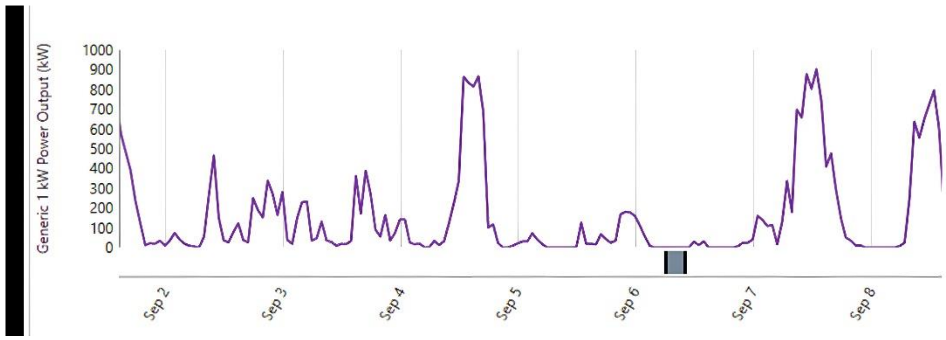

Figure 12. Generic 1kw power output.

Figure 13 shows the low variation of the auto size genset power output indicating that the GEN is underutilized. GEN is used whenever renewable is not able to generate electricity, mostly electricity generation is around 100 kW. The maximum output of the auto size is about 250 kW which shows that now renewable energy sources are less producing energy. Between the 4th and 5th of September, production will be near zero which means that renewable energy sources are producing a good amount of energy.

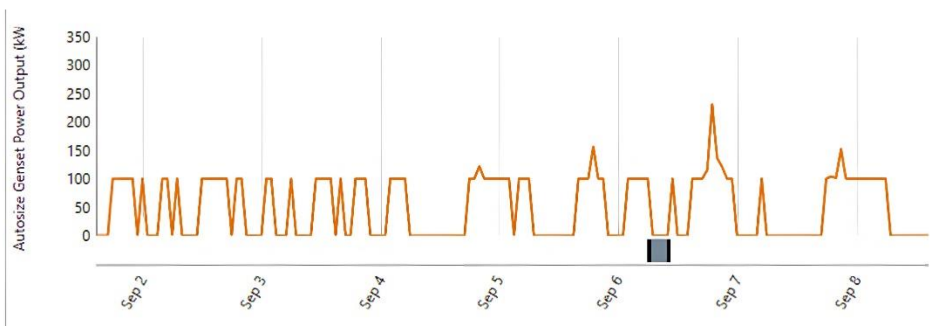

Figure 13. Auto size genset power output.

Figure 14 State of charge of a generic 1 kWh LA charge shows the state of charge in percentage, this graph output will show that LA battery does not over-discharge which is a good sign for the project. Its maximum charging point is around 100 and minimum around 80kW. This means that renewable sources produce a good amount of energy. Show no more fluctuations means less battery usage.

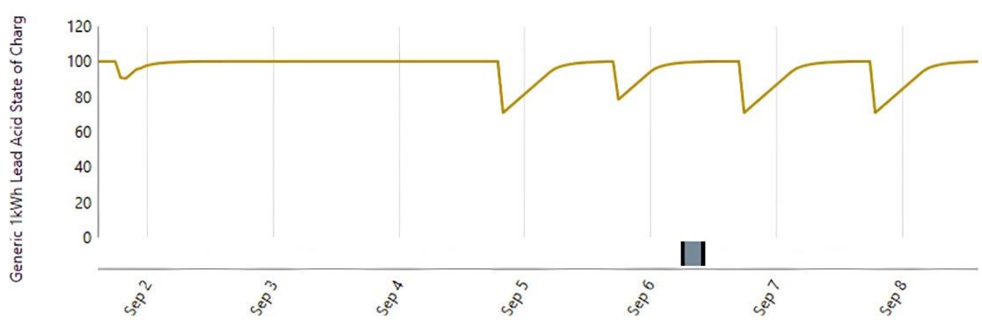

Figure 14. Generic 1kw LA state of charge.

This graph representation of the LA battery input power in **Figure 15** is quite complex. It shows the representation of the input for the entire year. It starts from zero on January 1st, the maximum point is about 20 kW, and the minimum input is about - 30. It also showed the power storage of the battery.

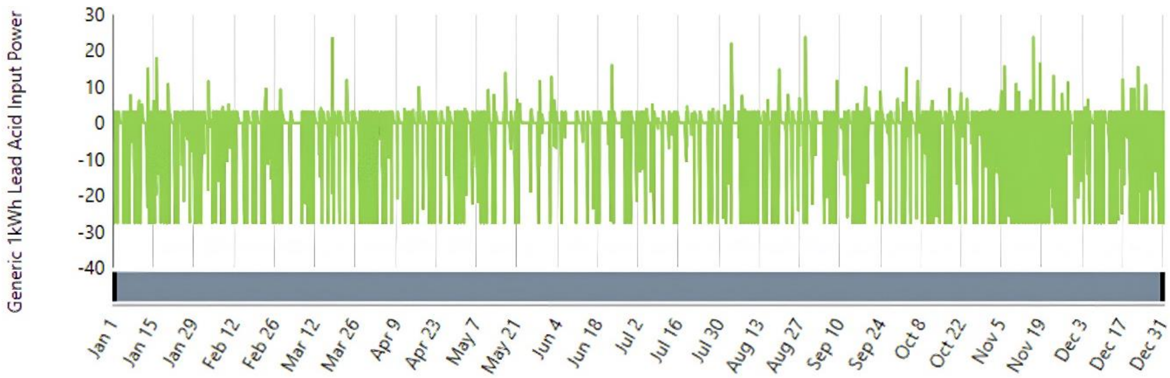

Figure 15. LA battery input power.

Figure 16 shows the monthly power output of an LA battery from PV, GEN and G1. This graph helps to understand the annual electricity generation status and contribution of different renewable sources. The graph shows that PV is the maximum contribution of G1 and minimum of Gen. The maximum power generation month of the year can be attributed to the maximum radiation incident frequency and wind speed in a typical month, which is approximately 500MWh. Due to this shortage, December is the lowest month for electricity, which is around 400MWh. Normal power generation remains constant throughout the month.

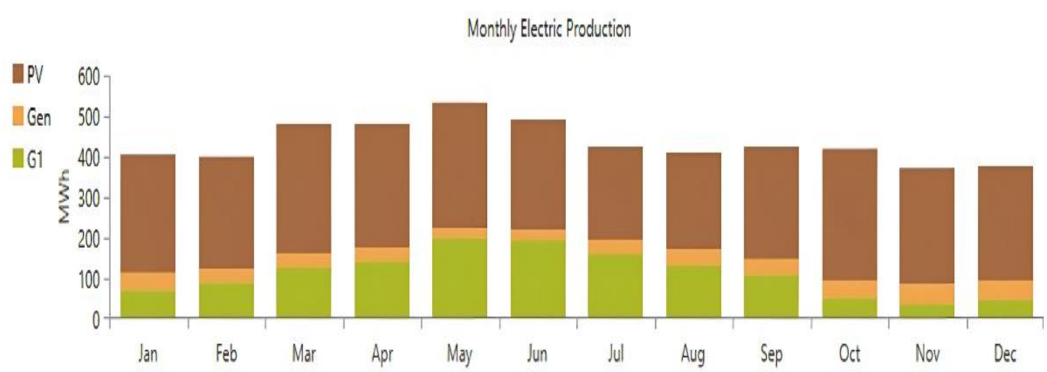

Figure 16. Monthly electric production of LA battery.

Figure 17 Power balance between load and power output for the week means that here are all the outputs of various sources such as total electrical load, auto-sizing genset power output, typical 1 kW power output, typical flat plate PV power output, typical 1 kW LA input power. A power balance graph helps to understand which source is beneficial for the project and identify the amount of production or output. The most used output source identified here is the common flat plate PV power output.

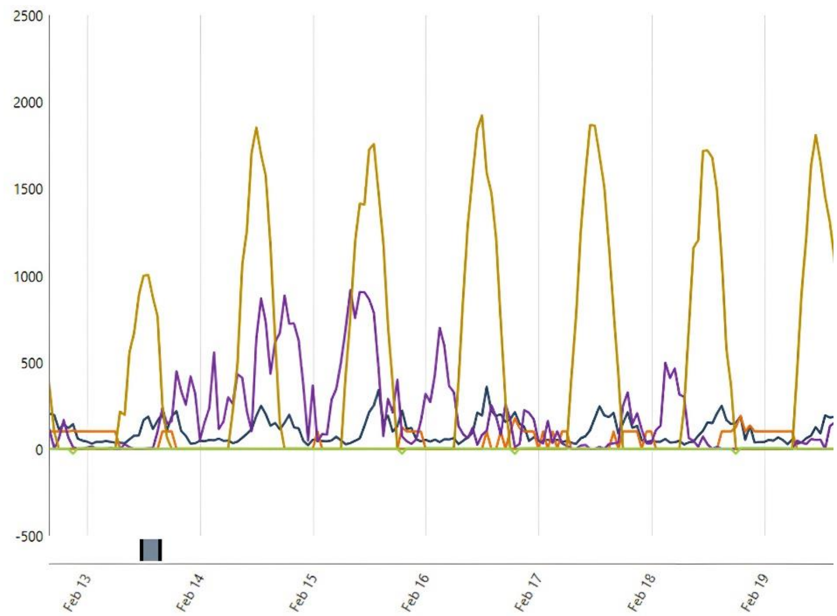

Figure 17. Power balance between load and power generation for week.

4.2 Optimization of HRES for Li Battery

Table 4 shows the optimal result of HRES for different configurations using LI batteries. This configuration helps to achieve the optimal configuration. Lithium-ion batteries are more efficient than lead-acid batteries. Lithium-ion batteries produce less greenhouse gases than lead acid batteries. Lithium-ion battery has longer lifespan, higher cycle efficiency, and requires less replacement. Due to all these reasons, lithium-ion battery is good for the environment. The first row of this **Table 4** contains all the combinations like PV/G1/Gen/BATT/CON. In the first row, the PV/G1/GEN/BATT/CON values are 776kW, 362kW, 400kW, 1000kWh, 319kWh respectively, and the NPC and COE values are 1.64M$, and 0.144$ per kWh respectively. In the second row, the value of PV/GEN/BATT/CON is 1367kW, where G1 is absent, respectively, the value of 400kW, 1000kWh, 332kW and the value of NPC/COE is, 2.24M$, 0.196$ per kWh. In the last third combination row, the G1/GEN/BATT/CON values at this speed, absent PV, are 1127kW, 400kW, 932kWh, 1589kW, and the NPC/COE values are 4.23$M and 0.369$ per kWh, respectively.

Table 4. Optimal results of HRES for different configurations using LI battery.

Configurations	Combination	PV (kW)	G1	GEN (kW)	BATT(LI) kWh	CON (kW)	NPC ($)	COE($/kWh)
1	PV/G1/ GEN/BATT-LI/CON	776	362	400	1000	319	1.64M	0.144
2	PV/G1/ GEN/BATT-LI/CON	1367	-	400	1000	332	2.24M	0.196
3	PV/G1/ GEN/BATT-LI/CON	-	1127	400	932	1589	4.23M	0.369

Figure 18 Cost Summary of LI shows the distribution of cost across various sources such as auto size Genset, Generic 1 kW, Generic 1 kW LI-ion, Generic flat-plate PV, and system CON, where auto size Genset is the maximum cost which is around 800000$. Then generic 1kW costs around 300000$, generic 1kWh LI-ion are the lowest cost which is almost zero. The cost of generic flat plate PV is the same as generic 1 kW which is 300000$ and the final system CON cost is around 100000$.

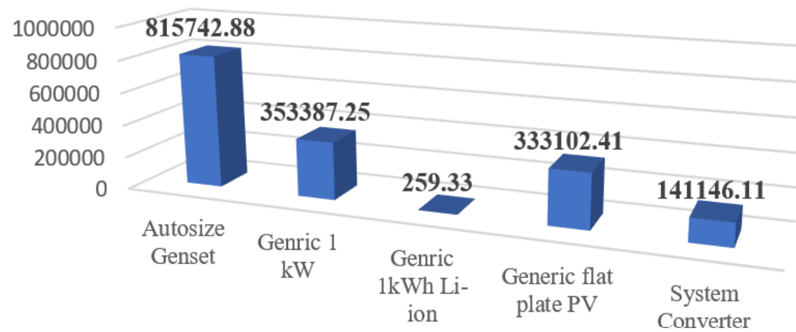

Figure 18. Cost summary of LI.

Figure 19 generic flat plate PV power output of a LI shows the variation in output from day to day. The output will gradually increase from the beginning of the graph. In the middle of the graph, the output will again increase more than the previous output and then the graph output will decrease. The maximum power that will be received at the final output is approximately 700kW. With the help of this graph, the analysis of PV power output will become easy.

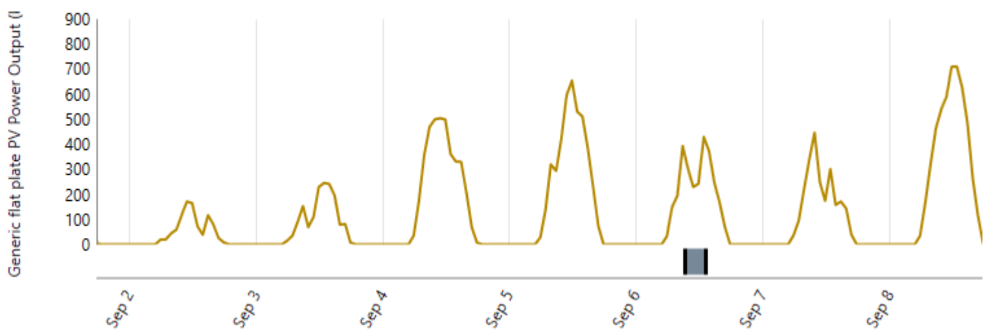

Figure 19. Generic flat plate PV power output of LI.

Figure 20 shows the variation in generation from day to day for a generic 1 kW power generation. The beginning of this graph starts from around zero. So, this fluctuation continues till the output attains the maximum power, which is around 350kW, then suddenly the power output decreases. And the ups and downs go on till the end. Fluctuations in this measurement mean that battery usage is high.

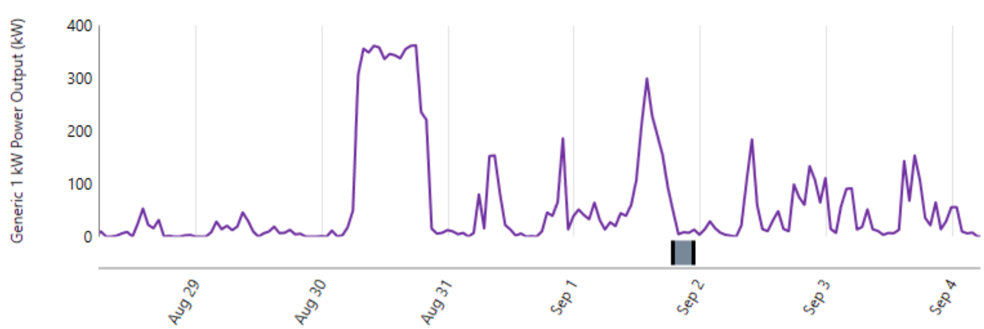

Figure 20. Generic 1kW power output.

Figure 21 shows the low variation in auto size genset power output. In the LI case, the generator's battery usage is low due to the efficient production of renewable energy. This graph will have 6 fluctuations which are less than in LA battery. This is a good sign for us. So, the gain of inductance is about 100 kW. CE also come down. Due to less use of GEN.

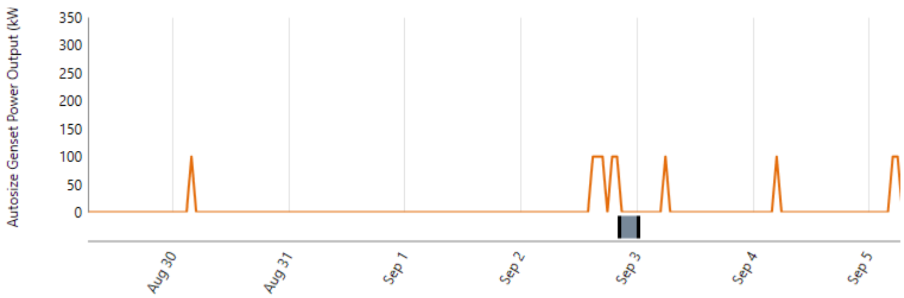

Figure 21. Auto size genset power output.

Figure 22 typical 1kWh LI state of charge showing the battery state in percentage. In this graph starting from around 30kWh and increasing to 60kWh power output again the graph will fall, and this fluctuation will continue until the graph reaches around 100kWh, so this graph will be stable for some time again the graph will fall that power is around 20kWh. In such a situation, these ups and downs will continue till 9 September.

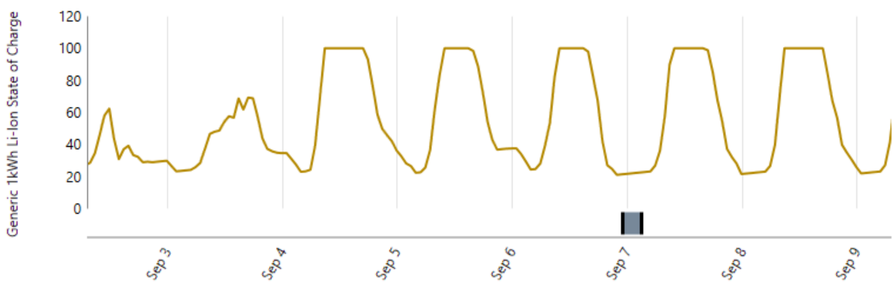

Figure 22. Generic 1kwh LI state of charges.

The typical 1kWh LI input power in **Figure 23** is a rough representation, with the graph starting at zero and peaking at about 250kW. Therefore, its drop again increases to 300kW. Its maximum value is about 400kW, and the minimum is about 100kW.

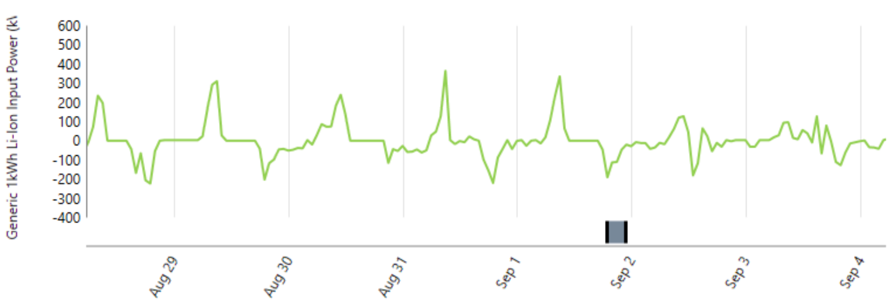

Figure 23. Generic 1kWh LI input power.

Figure 24 shows the monthly electricity generation of LI electricity from PV, GEN, and G1. This graph helps to understand the annual electricity generation status and contribution of different renewable sources. Here Gen stands for GEN and G1 stands for G1 It is seen in the graph that the maximum contribution of PV is again G1 and the minimum of Gen. The maximum power generation month of the year can be attributed to the frequency of maximum radiation incidence and wind speed in a specific month, which is about 200 MW. Due to this shortage, December is the lowest month of electricity production of the proposed energy system, which is about 150MWh. There is a slight fluctuation in the generation of electricity throughout the month.

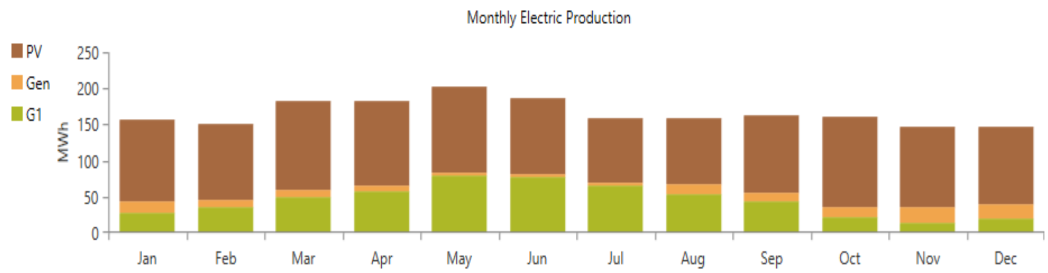

Figure 24. Monthly Electric production of LI.

Figure 25 Power balance between load and power output for a week means all outputs of different sources such as total power load, auto-sizing genset power output, typical 1kW power output, typical flat plate PV power output, Typical 1 kW LI input power. Power balance graph helps to understand and identify which source is beneficial for the project. The most commonly used output source identified here is the typical flat plate PV power output.

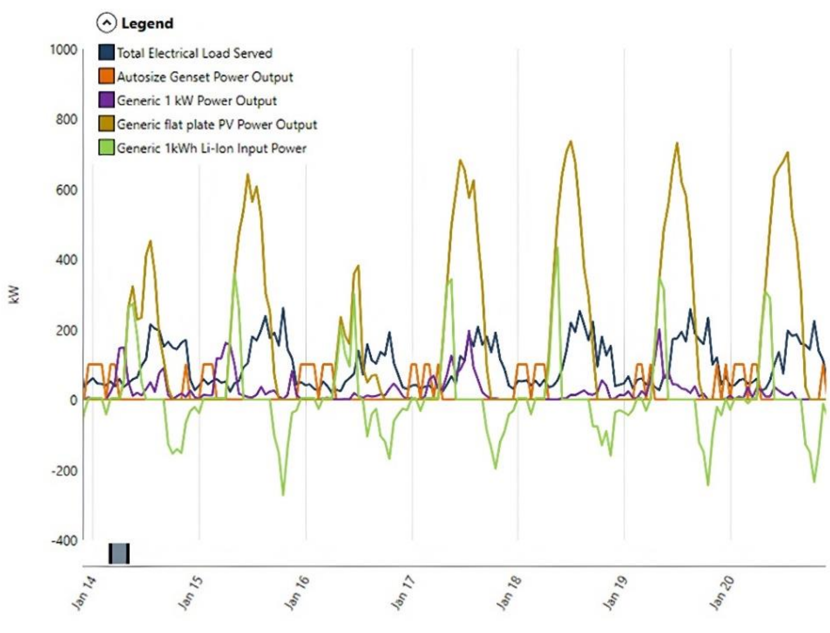

Figure 25. Power balance between load and generation for week.

5. Comparison of LA and LI

Table 5 is presenting the comparison of optimal results of HRES for LA and LI batteries. The first row presents the results of LI battery. The optimal values of PV/G1/GEN/BAT/CON are found to be 776kW, 362kW, 400kW, 1000kWh, 319k, and 1.64M$ per kWh respectively and the value of NPC and COE are 1.64M and 0.144$/kWh respectively. The second row has been shows the results of LA battery. The optimal values of PV /G1 / GEN / BAT /CON are found to be 2005kW, 915kW, 400kW, 106kWh, 307kW. The NPC and COE are 4.03M$, and 0.352$ per kWh respectively. In both cases, LI battery has been performed better than LA battery. LI battery has a lower NPC and COE than LA battery. The comparison of different emissions has been presented in **Table 6** for LA and LI batteries for. The first column pertains to LA battery. The value of all CE, carbon dioxide, carbon monoxide, unburnt hydrocarbons, particulate matter, sulfuric dioxide, and nitrogen oxides are 315288, 2214, 96.6, 13.4, 840, and 2080 kg per year respectively and the second column has been related to LI battery, the value of all CE, carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulfuric dioxide, and nitrogen oxides are 107314, 676, 29.5, 4.10, 263, and 635 kg per. years respectively. Based on CE compared to LA and LI, batteries have lower CE than LA battery. So, the LI battery is the best battery from an economic, technical, and environmental point of view which is shown in **Table 6**. Lithium-ion batteries have a higher energy density than lead acid batteries. Lithium-ion batteries have a longer lifespan than lead acid batteries. Lithium-ion batteries lose less energy while charging. These are all reasons why lithium-ion batteries are the optimal battery.

Table 5. Comparison of optimal results of HRES for LA and LI batteries.

Configuration	Combination	PV (kW)	G1	GEN (kW)	BATT (kWh)	CON (kW)	NPC ($)	COE ($/kWh)
1	PV/G1/ GEN/LI-BAT/CON	776	362	400	1000	319	1.64M	0.144
2	PV/G1/ GEN/LA-BAT/CON	2005	915	400	106	307	4.03M	0.352

Table 6. Comparison of LA and LI batteries for various emissions.

Emission	**LA** (kg/year)	**LI** (kg/year)
Carbon Dioxide	351288	107314
Carbon Monoxide	2214	676
Unburned Hydrocarbon	96.6	29.5
Particulate Matter	13.4	4.10
Sulphur Dioxide	860	263
Nitrogen Oxides	2080	635

6. Conclusion

In this study, a stand-alone hybrid renewable energy system has been proposed for the campus of Madhav Institute of Technology and Science, Gwalior. The hybrid system constructed using the solar, wind, diesel generator and battery for the optimization of optimal sizing with HOMER Pro software. The results for LA and LI batteries have been compared for finding the optimal battery based on economic and environmental assessments. The optimal size and configuration of the HRES depend on the selected optimization goal. The geographical parameters and load of the site also have a significant impact on the optimal solution. The following conclusions are drawn from this study:

- When comparing the different configurations of LA battery and it is found that the optimal configuration is PV/G1/ GEN/BATT-LI/CON with 2005 kW solar panel, 915 kW wind, 400 kW diesel generator, 106 kWh battery, and 307 converters.
- Similarly, for LI battery the best configuration found that PV/G1/ GEN/BATT-LI/CON with 776 kW solar panel, 362 kW wind, 400 kW diesel generator, 1000 kWh battery, and 319 converters.

- The optimal battery is found to be LI with 776kW PV, 362kW G1, 400kW GEN, 1000kWh BATT, 319kW CON while the optimal COE and NPC are 0.144kWh/$ and 1.64M$ respectively and the carbon emission of LI battery is 107314 kg/year.
- The performance of LI and LA batteries has been compared, and the results showed that LI batteries are superior economically, technically and environmentally.

The configuration of this research can be combined with some other renewable energy resources, battery technology and control system to create some new configurations that can increase the overall productivity of the system. This standalone system provides flexibility and reliability and hence can be integrated with the electricity grid as a result of which larger electricity demand can be met.

Conflict of Interest

There is no conflict of interest in this paper.

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Nomenclature

PV	Photovoltaic arrays
G1	Wind turbines
GEN	Diesel generators
CON	Converter
LA	Lead-acid
LI	Lithium-ion
BATT	Battery/ Batteries
HRES	Hybrid renewable energy system
HOMER	Hybrid optimization of multiple energy resources
COE	Cost of energy
NPC	Net present cost
CE	Carbon emission
O&M	Operating and maintenance
NREL	National Renewable Energy Laboratory
MITS	Madhav Institute of Technology and Science
BG	Biogas
MHT	Microhydro turbine

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