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RESEARCH ARTICLE

Multi-Objective Optimization of Hybrid Energy Systems

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Abstract

Renewable energy generation can help countries achieve the Sustainable Development Goals by providing clean, safe, reliable and affordable energy. Conventional energy production is impractical due to shortages, high fuel prices and harmful emissions from fossil fuels. Convergence is the best way to address renewable energy issues, because it combines multiple renewable sources simultaneously. This research proposed a hybrid renewable energy system that combines energy from two or more locally accessible sources to meet demand in remote locations. A hybrid solar, wind and biogas grid system has been proposed, evaluated using the homer Pro software and an artificial intelligence technique called the genetic algorithm. The proposed strategy provided low cost, optimal volume, reduced emissions, high reliability. Comparing the results of GA-based optimization and Homer Pro, a clear trend emerged: GA-based optimization showed better performance stability and lower energy costs, which indicates a more economically efficient system. The GA-based optimization also proposed smaller sizes for Homer components, which reduced the net current cost and proved that a system with the same efficiency and reliability could effectively meet the energy requirements of the site.

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Keywords: Hybrid Energy Systems; Multi-Objective Function; Evolutionary Algorithm; Optimization of Energy Production.

1. Introduction

By analyzing operational data and equipment conditions, this work proposed a way to balance capacity and cost in integrated wind and hydrogen energy systems. To optimize the cost, he also created an improved multi-target algorithm for the gray wolf optimizer. However, changes can occur due to uncertainty in real capacity [1]. The SaMMEA algorithm, presented an alternative assisted multi-objective evolutionary technique to optimize a hybrid renewable energy system, in this study. It has been compared to current HR issues and uses a Gaussian Process model combined with a unique environmental selection technique to enhance the diversity of solutions [2].
With an emphasis on unit commitment and economic dispatch, the paper investigates the application of a multi-objective whale-differential evolution-genetic algorithm (WODEGA) to address environmental and economic dispatch problems in power plants. Algorithms inspired by nature are hybridized to reduce expenses and emissions [3]. Here, renewable energy forces such as solar energy, wind and water are used. For this reason, it is necessary to optimize the use of renewable energy, especially in hybrid systems that combine several energy sources. Optimization systems for renewable energy systems are a combination of several very important reasons: [4, 5]

- Resource optimization: with the help of optimization of each unit, existing renewable energy resources were exploited and used in the best possible way, reducing energy losses and increasing electricity production from these intermittent sources.
- Energy certainty: by combining different renewable energy sources, hybrid systems can provide a stable and continuous supply of electricity, reduced dependence on fossil fuels, and increased energy security.
- Cost efficiency: optimization systems can significantly reduce the total cost of energy production, have made renewable energy more economical for consumers, and helped countries move away from expensive and polluting fuels.
- Environmental impact: by improving renewable energy systems, it is possible to reduce greenhouse gas emissions and environmental impacts related to energy production.
- Energy access: for areas with limited access to conventional power grids, hybrid renewable energy systems can provide a stable and reliable source of electricity, improve the quality of life, and support economic development.
- Energy mix: as the world seeks to transition to cleaner energy sources to combat climate change, optimization systems for renewable energy mix systems have played a key role in this transition. Source delved into understanding how expert systems and neural networks work by presenting a range of issues in various fields of solar energy engineering.

This study provided insights into the liberated environment of energy generation. The aim was to measure the advantages of radial distribution feeding with concentrated load and distributed generation. The results showed a clear improvement in the missing lines, a better power factor, and normal parameters. New and modern technologies for distributed generation were discussed, such as fuel cells. Fuel cells can produce combined heat and power (CHP), thus increasing overall energy conversion efficiency and reducing fuel consumption. Distributed generation (DG) can alleviate energy supply issues in certain areas (weak grids, remote locations) and enable better utilization of local resources, enhancing sustainable development [6].

The study published in the literature on modeling common renewable energy systems has provided that such models are commonly used as a valuable tool for meeting specific energy needs. This paper examined grid-based penetration levels as the future of the generation capacity of Combined-Cycle Power Systems. This paper also presents future developments that allow expanding the market, especially in developed and developing countries [7- 8]. Various applications of expert systems and neural networks were used thematically, and not chronologically or in any other sequence. The results presented in this paper provided evidence of the applicability of artificial intelligence as a design tool in many areas of solar energy engineering [9]. Source presented a brief on a Spatial Decision Support System (SDSS) to select the best locations for installing distributed generation facilities on the island of Lesvos, Greece, where diverse renewable energy resources are available. A set of constraints and factors were identified that relate to environmental, energy, social, political, and economic issues. The results can aid in creating a developmental perspective for sustainable energy systems based on local natural resources and facilitate the translation of national energy and environmental policies toward sustainability [10].

2. Mathematical Modeling

Renewable energy conversion systems (HRES) must run design simulations under active operating conditions such as suitable weather conditions, solar radiation, wind speed and electrical loads.

2.1. Solar Photovoltaic (PV) System

Photovoltaic system is a well-known method of converting solar energy directly into electrical energy using cells. Today, photovoltaic cells are mainly made from a semiconductor material called crystalline silicon, which is abundant in the Earth's crust and is not a harmful substance. Modules made from a combination of crystalline silicon cells last for decades and are used to generate electricity from noise-free, fuel-free equipment. Solar energy is the only source for providing electrical energy through photovoltaic cells, which is endless [8-11]. Solar light source data represents the amount of global solar radiation (radial radiation coming directly from the Sun, plus scattered radiation from all over the sky) that hits the Earth's surface in a year. The data can be in one of three forms: hourly average global solar radiation on the horizontal surface, monthly average global solar radiation on the horizontal surface, or monthly average transparency index. The transparency index is the ratio of the solar radiation that hits the earth's surface to the solar radiation that is radiated to the top of the atmosphere. It is a number between zero and one, and the transparency index is a measure of the transparency of the atmosphere. Global horizontal radiation is the sum of solar radiation that occurs on a horizontal surface. This value is the sum of direct vertical radial radiation, scattered horizontal radiation and reflected radiation from the ground [12-13]. Ambient temperature: as important information for solar energy production calculations. Local temperatures have a significant effect on wind speeds, so hourly wind speeds are also considered in this study.

2.2. Wind Turbines

There are machines that use wind power to generate electricity using an electric generator. These wind energy conversion devices extract the wind's kinetic energy from the area covered by the turbine blades and create pressure differences across the blades that create pressure and airflow and drive an electric generator to produce electricity. Wind turbines include components such as the tower, blades, generation (the structure that controls the trigger) and the structure that controls the twist of the turbine blade. The tower is the most important part of the wind turbine that supports the gearbox and electric generator that are located in the generation. The winding mechanism is also an important component of wind turbines, which was used to guide the turbine trigger in the direction of the wind flow to extract the kinetic energy of the wind. The torque developed by the wind turbine is transferred to the gearbox and then converted into an electric generator. Electric generators produce electricity from converted mechanical energy [14-16]. Wind resources are identified using NASA's surface methodology and wind atlas, where the wind direction is considered at a height of 50 meters above the ground. Annual average wind speed is a good influencing factor for running a wind turbine at a particular location.

2.3. Biogas Generator

The electricity generated from the generator is usually used to meet the load demand. These biomass sources come in many forms (such as wood waste, agricultural residues, and animal residues) and may be used to generate heat or electricity. Access to this resource depends on human efforts to harvest, transport and store. Therefore, this resource is not usually intermittent, although it may be seasonal [17].

2.4. Converters

A converter is a device that converts electrical energy from direct current to alternating current or from alternating current to direct current. The energy produced by the solar panel system is direct current while the load is alternating current, so the energy converter converts the direct current produced by the solar panels into alternating current [18].

2.5. Power Grid

In the settings connected to the power grid considered for the analysis, it is assumed that the power grid provides all the needs of the system, and all the required energy is absorbed from it. A separate converter is also used to connect to the grid/utility [19].

2.6. Optimization Problem

Size optimization, economic operation, controller design, real and balanced power control, voltage and frequency, reliability control are the main factors of the optimization problem in the field of renewable energy systems. The optimization problem includes the knowledge of access to renewable sources for power generation, hybrid system design, connection of different sources with the help of a converter, load diagram of the area to be supplied, optimal operation, optimized cost, battery life, voltage and frequency regulation [20-24]. A large amount of research has been done into the optimal economic design of renewable systems using artificial intelligence techniques and algorithms. The economic design of renewable systems means finding the best combination of renewable or conventional generation sources with or without batteries that can meet the security of load demand. In this genetic algorithm research, Homer's optimization software is used for optimization algorithms that are used to control and optimize systems based on renewable energy.

The objective function is a mathematical function of decision variables that reflects the goal to be achieved in an optimization problem. In this research, the aim is to minimize the total energy cost, and the carbon emission emitted from the proposed renewable system. The optimization parameters include the number of solar arrays, wind turbines, biogas generator size and power converter size. All these parameters are optimized in a certain range between the maximum and minimum value Bio [25-27]. The total annual cost (TAC) of the system is considered, so the objective function is defined as:

$$Minimize\ (COE\ (x), Emission\ CO_2(x)) \tag{1}$$

where

$$COE\ = \frac{TAC}{E_{severd}} \tag{2}$$

The total annual cost is calculated by the following formula:

$$\text{TAC} = \sum C_{cap}\ (\text{PV/WT/Bio}) + C_{O\&M}\ (\text{PV/WT/Bio}) + C_{Rep}\ (\text{PV/WT/Bio})\ \text{FC (Bi)} - \text{SV (PV/WT/B)} + \text{Grid}_{\text{cost}} \tag{3}$$

Where C_{cap} is initial investment cost, C_{rep} is replacement cost, $C_{O\&M}$ is operation and maintenance cost, FC is fuel cost and SV is recycling cost.

$$C_{con} = (P_{PV}\ \times C_{PV} + P_{WT}\ \times P_{bio} + C_{bio} \times P_{con}\ ) \times \text{CRF} \tag{4}$$

$$CRF\ (i,T)\ = \frac{i(1+i)^T}{(1+i)^t-1} \tag{5}$$

Where P_{PV} is Power or capacity of photovoltaic (solar) panels, C_{PV} is Cost associated with photovoltaic (solar) panels, P_{WT} is The power or capacity of wind turbines, P_{bio} is Power or capacity of biomass, C_{bio} is cost associated with biomass energy, and P_{con} is Power or capacity of the construction project. The annual value of the present value equation is obtained by multiplying the present value by the capital recovery factor (CRF). Here it represents the profit rate, and T represents the useful life of the system. In this study, the interest rate is set to 6% per year and the useful life of the system is 20 years.

Setting the maximum and minimum values of the decision variables is highly dependent on the problem constraints (the complexity of the search space and the number of variables). The maximum and minimum values of the decision variables should be set so that the algorithm converges to the most optimal solution. These variables are usually adjusted to all possible values by trial and error, and finally the values that produce the best results are chosen [28-32].

$$10 \le \text{Number of Photovoltaic Panels } N_{pv} \le 30 \tag{6}$$

$$10 \le \text{Number of Wind Turbines } N_{wt}\ \le 20 \tag{7}$$

$$5 \le \text{Number of Inverters} N_{inv} \le 10 \tag{8}$$

3. Simulation Results

3.1. Components Information in Homer

Solar Panels (PV): The rated capacity of a solar panel array is the amount of power tested under standard test conditions of 1 kW/m2 irradiance and 25°C panel temperature. In HOMER software, PV array size measurements are always specified as rated capacity. The capacity rating considers both the area and efficiency parameters of the PV module, so neither of these parameters appear explicitly in HOMER. At each hour of the year, HOMER calculates the global solar radiation that falls on the PV array [37]. The technical characteristics of the solar panels introduced in the homer program is shown in Table 1, where the nominal power reached 335 watts, which is a typical value for commercial solar panels and expresses the maximum output under ideal conditions, while the oscillation range from 0 to 5 Watts indicated minor changes in the generated power as a result of environmental factors such as shading or changing the radiation angle, the efficiency of the listed panel of 88% is considered unusual and is likely to represent a partial efficiency within the system or a certain performance coefficient in the program and not traditional photovoltaic efficiency, which required checking its intended interpretation accurately within the simulation results.

TABLE 1: Solar panel specifications in Homer software.

Number	Details
335 (w)	rated power of the solar panel
0 – 5 (w)	output power fluctuation
88%	solar panel efficiency

Wind turbine: HOMER models a wind turbine as a device that converts the kinetic energy of the wind into direct or alternating current electricity. According to a plot of power output versus wind speed at axial height, HOMER assumes that the power curve applies at a standard air density of 1.225 kg/m3, which corresponds to standard temperature and pressure conditions. The specifications of the wind turbine in the homer program are shown in Table 2. It can be said that the important operational characteristics of this turbine were summarized. The wind speed was set at 5 m/s, which is the speed at which energy starts to be generated by the turbine. A high wind speed of 25 m/s was also shown as the cut-out speed, where the turbine stops to protect itself from damage. In addition, the table showed that the nominal wind speed was 20 m/s, which is the speed where the turbine reaches its maximum productivity. Finally, the rotor diameter of 3.2 meters is mentioned, which is a measure of the size of the area through which the turbine can capture wind energy.

TABLE 2: Wind turbine specifications in Homer software.

Number	Details
5 (m/s)	wind speed cut down
25 (m/s)	high cutting wind speed
20 (m/s)	nominal wind speed
3.2 (m/s)	rotor diameter

Biogas generator: A one cubic meter biogas refinery can produce 40.04 liters (0.04 cubic meters) of biogas [20].

Power grid: The project can be modeled in three modes in HOMER software: grid-connected, stand-alone and stand-alone system comparison with grid development. In grid-connected mode, electricity prices must be input to HOMER as real-time and scheduled rates. In the case of comparing the independent system with network development, the network development cost sharing distance will be calculated using three inputs including investment, operation and maintenance costs and network electricity price.

3.1.1. Economic Components

Each equipment in HRES has some cost data such as operation and maintenance cost, investment and replacement cost. Fuel price, grid traded electricity price, real efficiency rate, project lifetime, fixed system investment cost, fixed system operation and maintenance cost and economic emission penalty are other economic data that may be considered in HOMER. These costs are considered in the simulation and optimization stages and based on them; the net present cost (NPC) of each plan is calculated.

Investment cost: The investment cost of the system is the cost that occurs at the beginning of the project, regardless of the size or architecture of the system. The fixed investment cost of the system is added to the initial investment cost of the entire system, thereby adding to the total net present cost.

Replacement cost: The replacement cost of a component at the end of its life in the component model. This cost may differ from the initial investment cost for several reasons:

- All components do not need to be replaced at the end of their life.
- The initial investment cost may be reduced or eliminated by the donor organization, but the replacement cost may not be reduced.
- Fixed costs are accounted for, for example the cost of travel to the site. At the time of initial construction, these costs are shared by all components, but may not be shared at the time of replacement.

Operation and maintenance cost (O&M): The operation and maintenance cost of a component is the costs associated with the operation and maintenance of that component. The total O&M cost of the system is the sum of the O&M costs of each system component. For a generator, O&M costs are entered as an hourly value, and HOMER multiplies this value by the operating hours per year to calculate the annual O&M cost.

Network Cost: Because the network is different from any other component, HOMER calculates network-related costs in a unique way. Different types of network rates that can be used in HOMER are:

- Simple rates: it is possible to specify fixed power price, return price and sales capacity.
- Real Time Rates: Define hourly rates by importing a text file with time series data.
- Timing rates: allow setting different prices in every hour of the day and month of the year.
- Network development mode: compares the cost of network development with the cost of each independent system setup in the model.

3.1.2. System Control

In HOMER, there are two strategies to control the performance of energy and storage resources: Cyclical charging strategy and load tracking.

Cyclic charging: A dispatch strategy that operates at full output power whenever a generator needs to operate to serve the main load.
Cargo tracking strategy: A generator operates until it produces enough energy to supply the main load in a dispatch strategy.

3.1.3. View of the Proposed Combined Renewable Energy System

The view of the proposed hybrid renewable energy system is shown in Figure 1. The system consists of a solar photovoltaic system (size 0 to 150 kW) connected to the DC grid, a wind turbine (size 1 to 10 kW) connected to the DC grid, and a biogas generator (size 1 to 25 kW) connected to the grid. AC is connected, formed. The public power grid is also connected to the same AC group and this AC group supplies the load of the Faculty of Electrical Engineering, MPUAT University of Technology and Engineering, Odiapur. The load of this college is 100% AC load. A converter is also connected between the AC-DC bundle to convert the DC power generated by the solar and wind system into AC to supply the load. The system is also connected to the public power grid for support.

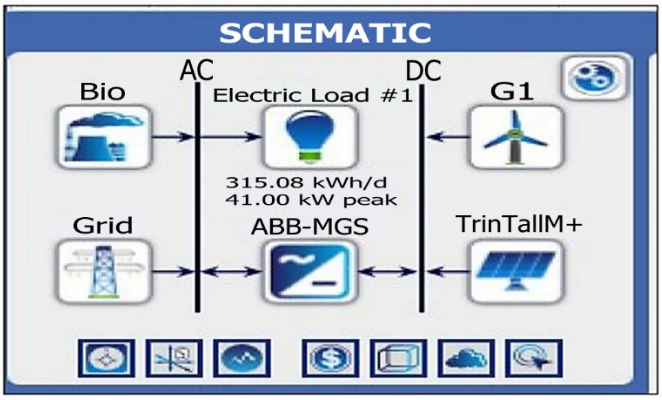

Fig. 1. Schematic diagram of the proposed HRES.

In Homer, specified the basic settings for optimizing the design of hybrid power systems is shown in Table 3. This included the calculation interval, allowing the capacity of multiple components (generators and turbines), renewable energy contribution limits with alerts for exceeding them, the accuracy of calculations, the maximum allowable power shortage, a mandatory percentage of renewable energy, as well as operating reserve ratios to cover load fluctuations and renewable energy generation. These settings guide the search for the best-balanced design solutions in terms of performance, cost and reliability.

TABLE 3: Homer optimization specification table.

Basic settings	Details
Time step duration in minutes	60
Let be systems with multiple generators	Yes
Let the systems have several types of wind turbines	Yes
The maximum penetration threshold of renewable energy	55
Warning about penetration of renewable energy	Yes
Maximum simulations	10000
Accuracy of system design	0.1
Accuracy of present gross cost	0.1
Maximum annual capacity shortage	10
At least part of renewable energy	50
Operating reservation as a percentage of hourly load	50
Operating reserve as a percentage of solar power generation	10
Operational reserve as a percentage of wind power generation	80

3.2. Homer Optimization Results

The monthly electricity production by each component is shown in Figure 2. From this graph, it is clear that the solar system produces the highest amount of energy in all months, while the wind turbine produces the fewest units in all months except June, July and August. The biogas generator also produces less electricity than the solar system, but it produces electricity throughout the year. The total electricity produced by each component per year is shown in Table 3. Solar PV system generated 54.2% of total electricity; Biogas generator produces 23% while wind generation is limited to only 3.2%. The grid will supply deficient energy, which is 19.5% per year. Table 4. Shows the total electricity consumption. The main AC load of the department consumes about 70% of the energy and 30% of the excess energy is sold to the grid, as shown in Table 5. The proposed system has an excess energy of 1,505 kWh per year, which is equivalent to 0.869%, and there is zero unnecessary load and zero capacity shortage. The renewable ratio of this system is 79.7% and the maximum renewable penetration is 139%.

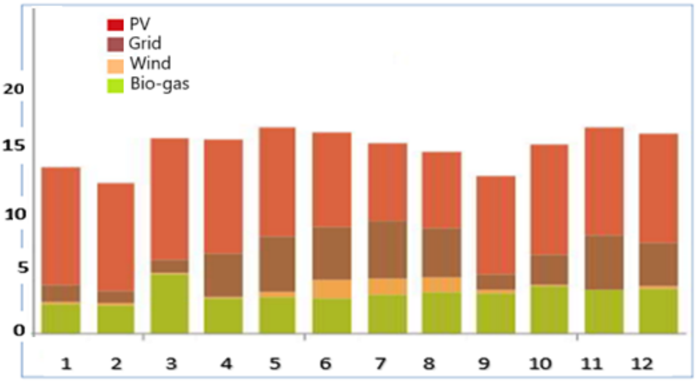

Fig. 2. Energy production from each component in different months of the year.

The digital data of electricity production for each element during a year is shown in Table 4. It is noted that solar panels (solar photovoltaics) are the main source of energy, producing 93,926 units of electricity, accounting for 54.2% of the total production. This was followed by the biogas biogas generator, which contributed 39,874 units (23.0%). As for wind turbines, they produced a much smaller amount of 5596 units (3.23%). Finally, 33,830 network purchase units were purchased, accounting for 19.5% of the total power consumed. The total production and consumption of electricity during the year amounted to 173,226 units, that is, by 100%.

TABLE 4: Numerical data of electricity production of each element in one year.

Component	Production	Percentage (%)
Solar PV	93926	54.2
Biogas genset	39874	23.0
Wind turbine	5596	3.23
Grid purchase	33830	19.5
total	173226	100

Table 5 provides numerical information on the electricity demand in the region, he found that the basic AC consumption (ac base load) is the largest, amounting to 115,003 units and accounting for 68.9% of the total power. There is no basic consumption of direct current (DC basic load) or deferred loads (deferred load), the value of which is 0%. What is striking is the presence of network sales in a significant amount of 51,817 units, such as 31.1% of the total produced or available capacity. The total power supplied or produced is 166,820 units (100%).

TABLE 5: Numerical information of electricity demand in the region.

Consumption	Production	Percentage (%)
AC primary load	115003	68.9
DC primary load	0	0
Deferrable load	0	0
Grid Sales	51817	31.1
total	166820	100

3.2.1. Solar Photovoltaic System Output

The rated capacity of the solar PV system is 58.2 kW with an average power of 10.7 kW and 257 kW per day. The capacity factor of the solar system is 18.4% and this system produces 93,926 kWh per year. The minimum output power of the solar system at night or when there is less solar radiation is 0 kW, and the maximum output power of the system at the time of high solar radiation is 60 kW. The penetration percentage of PV in the system is 81.7% and it works for 4144 hours in the year. The production cost per unit with solar PV system is Rs.2.16. Figure 3 shows that most electricity generation occurs during the time interval from 8 to 17 hours during the day, while very little electricity generation takes place during the time intervals of 0-6 and 18-24. Figure 4 shows the department's AC load, solar power generation for AC load and purchase of power from the grid in case of power shortage.

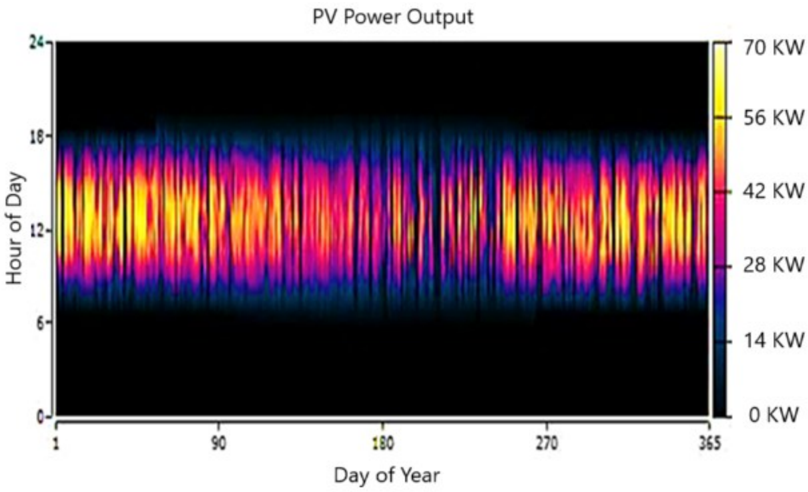

Fig. 3. Solar power during a year.

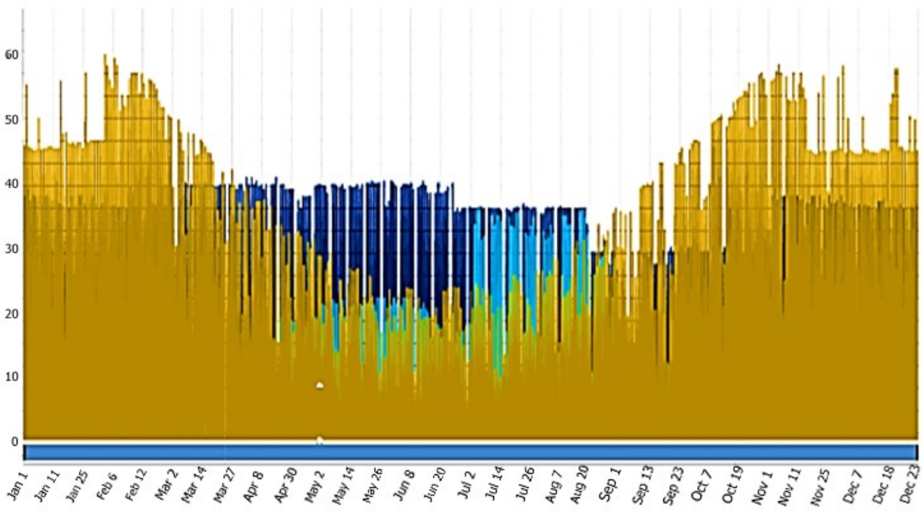

Fig. 4. AC load supply by solar power.

3.2.2 Biogas Generator Power Output

The consumption capacity of the biogas generator is 18 kW. The generator in this system operates up to 2,588 hours per year, and the number of annual start-ups is 425 times. The practical life of the generator is 7.73 years. The generator capacity factor is 25.3%, the fixed production cost of the generator is 5.66 rupees per hour, and its marginal production cost is 4.29 rupees per kWh, while the electricity production of the biogas generator is 39,874 kWh per year. The total fuel consumption by the generator is 121 tons per year. The average daily fuel consumption is 33 kg/day and the average hourly consumption is 12.5 kg/h, which is shown in Figure 5. Figure 6 shows the hourly fuel consumption of the generator during 365 days of the year. This figure shows that the minimum electric power of the generator is 9 kW and its maximum power is 18 kW. Its average electric power is 15.4 kW. It also shows that the operating hours of the generator are often from 0-8 hours and 18-24 days, when solar power generation does not provide electrical power. Specific fuel consumption is 2.12 kg per kWh and the average electrical efficiency of the system is 30.9%. The input fuel energy consumption is 1, 28,953 kWh per year. Figure 7 shows the hourly generator power for the whole year.

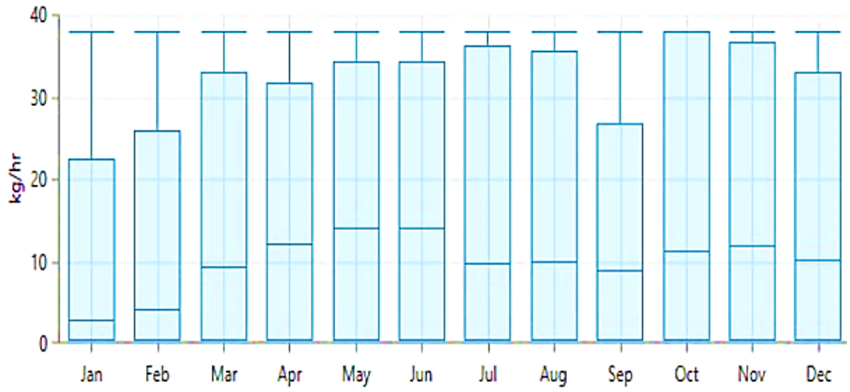

Fig. 5. Average monthly consumption of biogas.

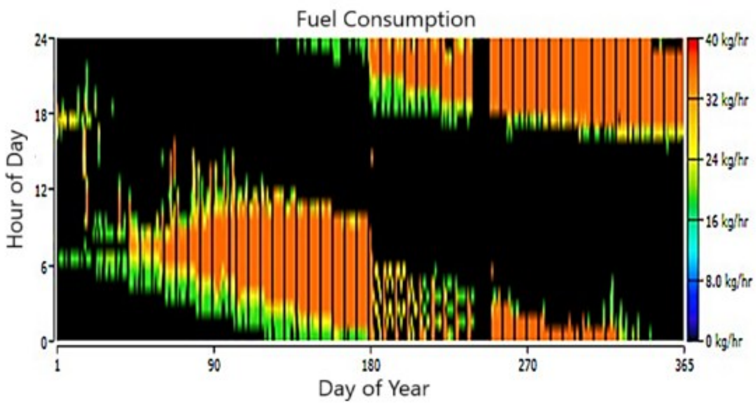

Fig. 6. Biogas consumption during one year.

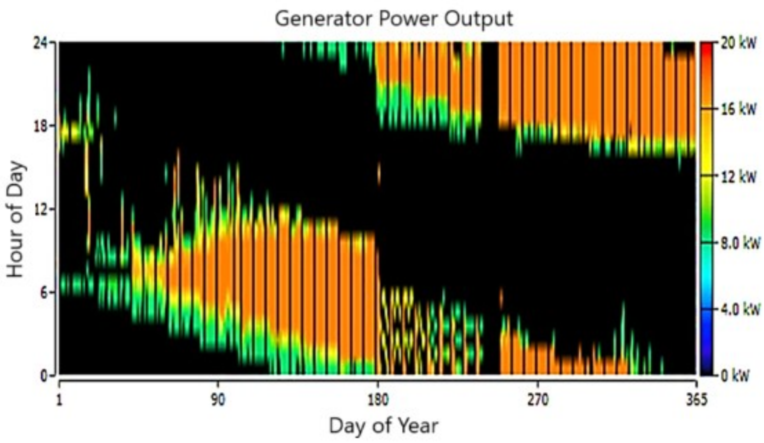

Fig. 7. Output power of biomass generator during one year.

3.2.3 Wind Turbine Output Power

Although the wind speed in the study location is not suitable for wind power generation, the wind turbines used in this study are suitable for low-speed winds, for example, 3 m/s. Therefore, wind turbines with small capacity are considered in this study. Based on the simulations and optimized system by HOMER, wind turbines with a capacity of 10 kW are considered. The average power of the turbine is 639 W and its capacity is 6.39%. The minimum output power of the turbine is 0 kW, and its maximum power is 6.86 kW. The wind penetration at HRES is 4.87% and the turbine operates during 6005 hours of the year. The cost of generating is always ₹ 7.15 per kWh with a wind turbine. Figure 8 shows the wind output power of the wind turbine hourly for the whole year. The figure shows that the maximum power is less than 1.4 kW during most of the year, and the maximum power, more than 4.2 kW, is produced in May, June and July.

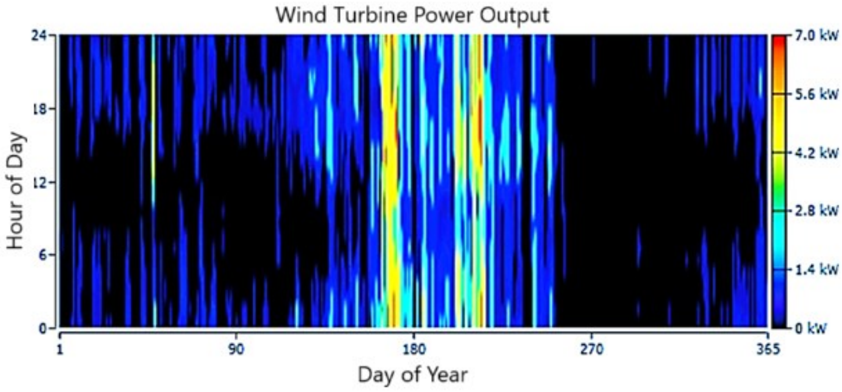

Fig. 8. Output power of wind turbine during one year.

3.2.4 Converter Output Power

The optimum size of the converter for HRES according to information obtained from HOMER is 44.2 kW. The converter used in this system is an online grid-connected converter that can be used as a converter or a rectifier, but in this study the converter only acts as a converter to convert the DC output power from the solar PV system to Convert AC power and supply the AC loads of the Faculty of Electrical Engineering. The average power of the converter is 10.6 kW, its minimum output power is 0 kW and its maximum power is 44.2 kW. The converter has a capacity factor of 24.1% and operates for 7630 hours of the year. The energy consumption to the converter is 98,017 kWh per year and the energy output is 93,116 kWh per year, while the losses are 4901 kWh per year. Figure 9 shows the hourly output power of the converter for the whole year.

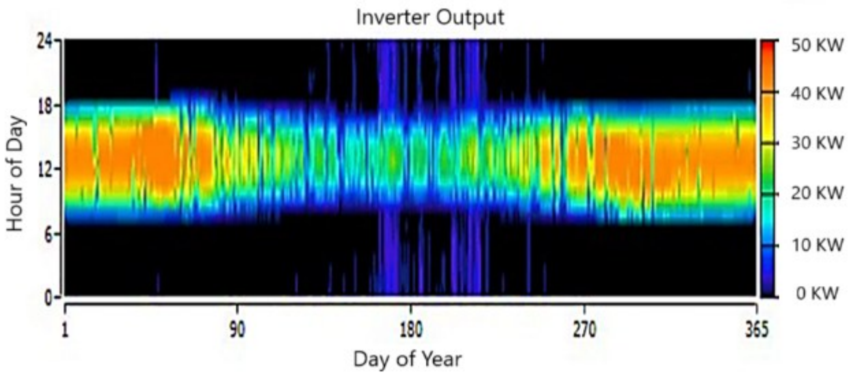

Fig. 9. Converter output power.

3.2.5 Grid Power System

In this proposed HRES, a grid-connected design is considered because the grid is used as a back-up power component and an additional energy absorber. Although a biogas generator is also available, the output of the bio gasifier is still dependent on the consumption of the feedstock input, which is again an intermittent renewable resource. The power grid supplies electricity at times when there are insufficient renewable resources to meet load demand and consumes electricity at times when excess energy is available. Connecting the network to the HRES system makes it more reliable and reduces LPSP. Table 6 indicates the monthly and annual exchange of energy with the electrical network. Show fluctuations in the amounts of energy purchased and sold, where the surplus was sold in some months and the deficit was bought in others. The table also recorded the peak monthly consumption, energy costs and grid-related demand. Annually, show the net sale of energy at specific total costs.

TABLE 6: Buying and selling electricity from the grid.

Month	Energy purchased	Energy sold	Net Energy purchased	Peak Load	Energy Charge	Demand Charge
January	1,395	2,391	-996	43.12	₹ 7,576.83	₹120.00
February	1,044	3,487	-2,443	41.21	₹3,121.87	₹135.76
March	1,832	2,692	-860	40.8	₹10,619.19	₹261.75
April	2,779	2,267	513	41.95	₹18,836.06	₹293.10
May	3,939	2,135	1,804	40.8	₹28,310.46	₹332.66
June	3,465	2,645	820	42.12	₹23,750.76	₹332.88
July	4,840	3,180	1,660	38.54	₹33,952.64	₹542.95
August	4,122	4,476	-353	37.58	₹26,264.37	₹538.00
September	1,578	5,986	-4,407	39.8	₹3,647.59	₹182.10
October	2,285	8,076	-5,791	42.5	₹6,163.44	₹270.00
November	3,510	7,624	-4,114	41.2	₹16,644.76	₹31500
December	3,040	6,860	-3,820	40.3	₹14,029.15	₹291.10
Annual	33,830	51,817	-17,987	45.41	₹192,917.12	₹3,615.30

Figure 10 and Figure 11 show that buying and selling energy from the network is done hourly. Figure 11 shows that the most purchases from the grid occur during 0-6 hours of the day and 18-24 hours of the day when the solar PV system is not generating electricity. Figure 12 shows that the maximum sales to the grid occur during 6-18 hours of the day because during these hours, solar-wind generation systems and biogas generators produce electricity, and the total renewable electricity generation is greater than load demand. Figure 13 shows a summary of the electricity load of the entire studied location, purchase from the network and sale to the network.

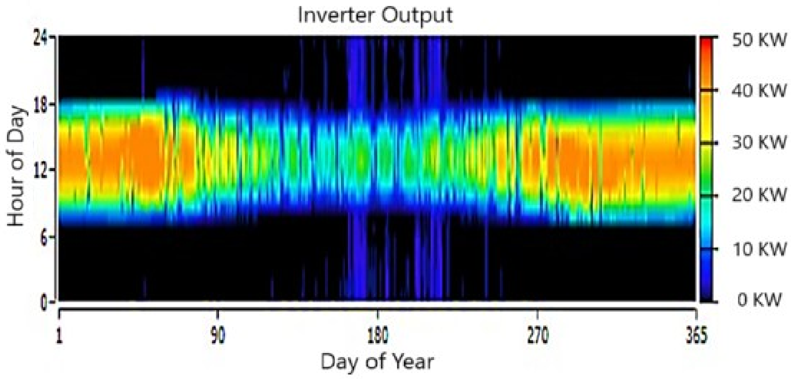

Fig. 10. Energy purchased from the grid.

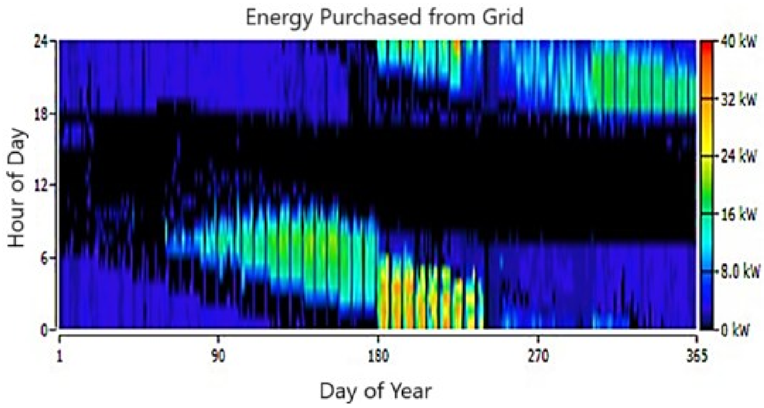

Fig. 11. Energy sold to the grid.

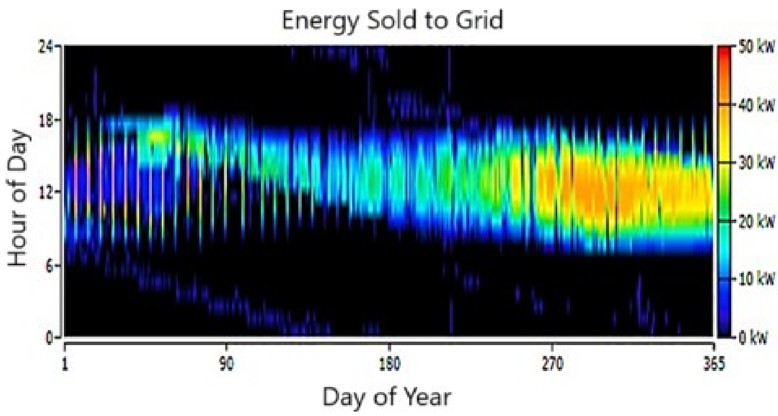

Fig. 12. Buying and selling electricity from the network with total demand.

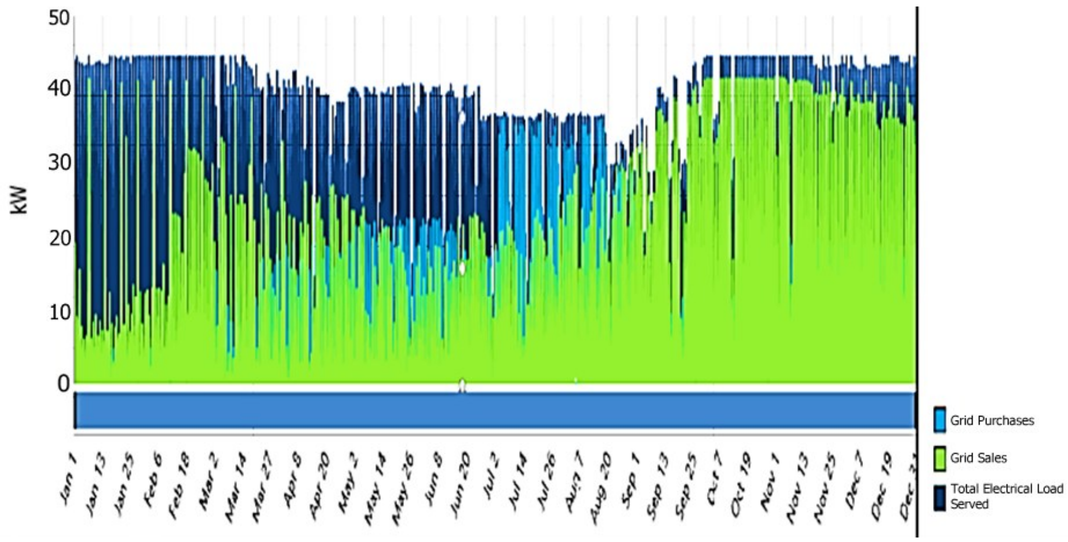

Fig. 13. Buying and selling electricity from the network with total demand.

3.2.6 Environmental Impact

Renewable energy sources cannot be the only source of electricity, but they can reduce the consumption of traditional energy sources. In this study, the environmental benefits of the combined solar-wind-biogas system have been evaluated in terms of emission reduction. To calculate the emissions of each pollutant associated with a net purchase from the grid, HOMER multiplies the net purchase from the grid (in kilowatt-hours) by the emission factor value (in grams per kilowatt-hour) for each pollutant. Although there are many types of emissions associated with power generation, emissions of CO2, sulfur dioxide, and nitrogen oxide are considered. CO2 is the largest part of the emissions associated with power generation in a traditional power generation plant and can be considered the largest environmental impact created by the power industry. The number of reduced emissions associated with meeting the load demand of the Faculty of Electrical Engineering for one year with the proposed grid-connected solar-wind-biogas hybrid system. Table 7 views the calculations of emissions of polluting gases in the homer program, we see annual estimates of various amounts of pollutants. Carbon dioxide (carbon dioxide) appeared as the largest emission in the amount of 21,402 kg per year. This is followed by sulfur dioxide (sulfur dioxide) for 92.7 kg per year, and then nitrogen oxides (Nox) for 45.5 kg per year, and a very insignificant amount of carbon monoxide (carbon monoxide) amounted to 0.241 kg per year. Remarkable is the absence of emissions of unburned hydrocarbons (unburned hydrocarbons) and fine particles (particulates), the value of which reached zero.

TABLE 7: Calculations of emission of polluting gases in Homer software.

Pollutant	Amount
Carbon Dioxide	21,402 kg/yr
Carbon Monoxide	0.241 kg/yr
Sulfur Dioxide	92.7 kg/yr
Nitrogen Oxides	45.5 kg/yr
Unburned Hydrocarbons	0
Particulate Matter	0

3.3 Genetic Algorithm (GA) Optimization

GA is an optimization technique based on genetic aspects and natural selection. Nature has always been a great source of inspiration for all humans. Genetic algorithms are considered a subset of a broader branch known as Evolutionary Computation. These algorithms are commonly used to find optimal or near-optimal solutions for complex problems that would otherwise take a lifetime to solve. Genetic algorithms are widely used in optimization problems, research, and machine learning. Genetic algorithms were developed by John Holland and his colleagues at the University of Michigan and have been extensively tested in solving various optimization problems with a high degree of success. The genetic algorithm is an optimization technique used to find solutions to complex optimization problems, with or without constrained parameters. It is a stochastic global search approach. The most common approach in genetic algorithms is to create a group of individuals randomly from a given population. Individuals are evaluated using a fitness function provided by the programmer. An indirect measure called fitness value is then assigned to the individuals, reflecting their fitness status. The best two individuals are used to produce one or more offspring, and random evolutions are performed on the offspring. Depending on the program's needs, the process continues until an acceptable solution is found or until a certain number of generations have passed. The stages involved in the genetic algorithm are as follows:

Step 1: Selecting a set of individuals as the initial population with random values for Nsol, Nwt, and Nbio.
Step 2: Defining the fitness function (objective function) and assigning a fitness value to each individual.
Step 3: Performing energy balance calculations and checking minimum and maximum values.
Step 4: Checking LPSP and RF constraints.
Step 5: Generating offspring until termination criteria are met.
Step 6: Selecting the top-performing individual to produce offspring.
Step 7: Generating new individuals through recombination and evolution.
Step 8: Calculating the fitness of the new individual.
Step 9: Terminating if termination criteria are met; otherwise, return to Step 4.

3.3.1. Genetic Algorithm Results

To optimize the hybrid renewable energy system, the optimal design obtained from HOMER pro is re-examined by the artificial intelligence technique, Genetic Algorithm (GA). To optimize each component, climate data and economic analysis are generated. This multi-objective GA (MOGA) technique implements a hybrid solar-wind-biogas system connected to the grid. The simulation time step is 1 hour and runs on data for 1 year. The maximum number of courses is 92.

3.3.2. Optimized System Cost and Size

The genetic optimizer runs for up to 92 generations and produces optimal volume and cost optimization results with appropriate selection, mutation, and combination. The result provided by this iterative technique is shown in Table 8. The optimized design by GA output breakdown includes 52.36 kW solar PV system, 10 kW wind turbine system and a 20 kW biogas generator. The proposed system is connected to the grid and the energy balance calculations are performed hourly (8760 hours). When the power calculated by renewable sources is less than the load demand of the location, network purchases are made, and when the load demand is less than the power produced by renewable sources, additional energy is sent to the network. The hourly load demand over a full year is shown in Figure 14 and Figure 15. Shows a zoomed-in view of the load profile for hours 70 to 160 years. The power produced by the selected system through solar energy is shown in Figure 16. The hourly energy produced by the wind turbine for a whole year is shown in Figure 17. The energy produced by the biogas generator is shown in Figure 18.

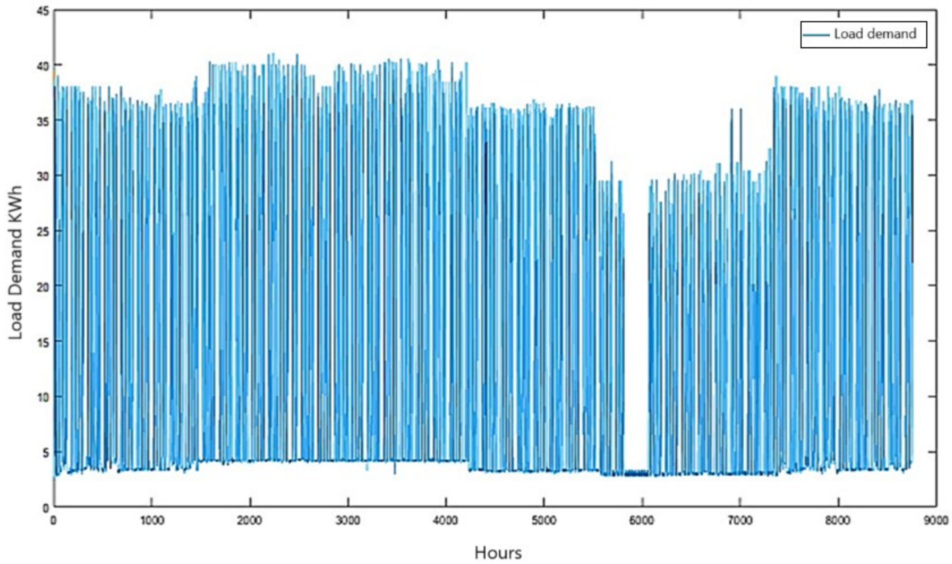

Fig. 14. Electricity demand during a year.

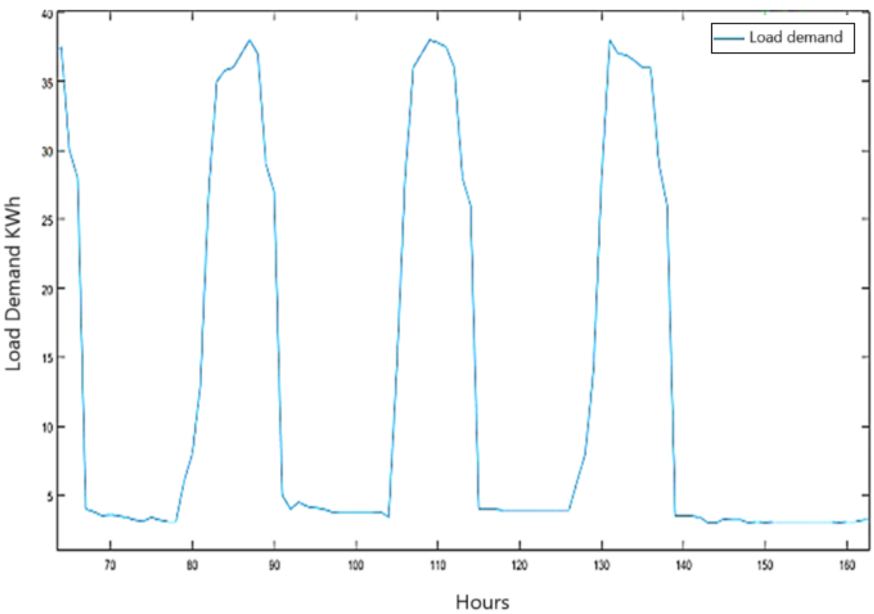

Fig. 15. Limited hourly electricity billing.

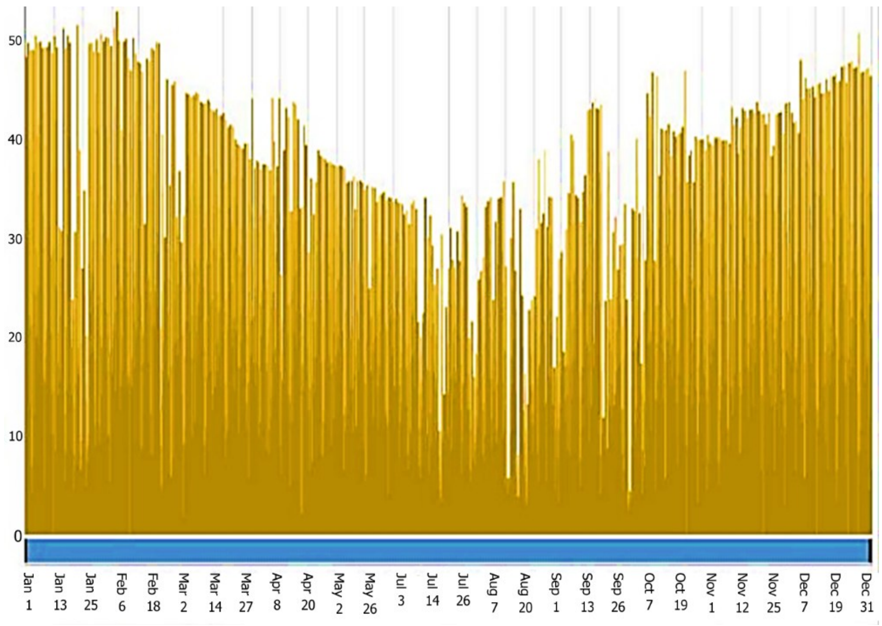

Fig. 16. Solar power output.

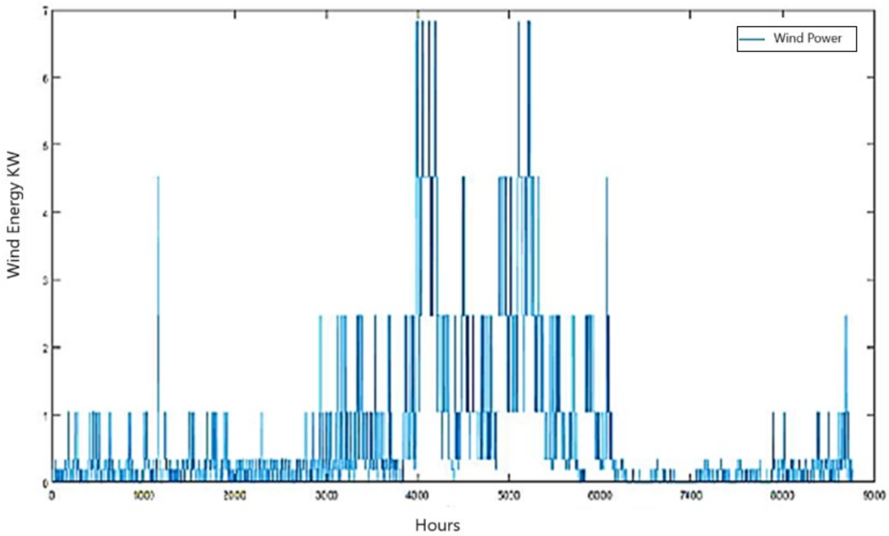

Fig. 17. Wind power output during one year.

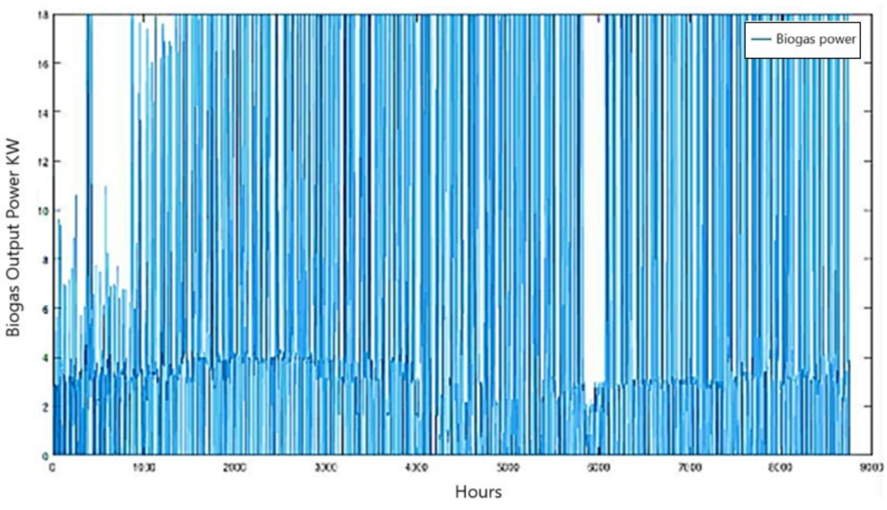

Fig. 18. Biogas generator output power and implementation by GOA algorithm.

The optimal solution for the hybrid power system and determined the sizes of the solar system (52.36 kW), wind turbine (10 kW), biogas generator (20 kW) is presented in Table 8. Estimated annual energy production(92505 ، 41 ، 585.6 ، 5 ، 270 ، kWh, respectively), as well as the annual costs of each of them and the costs of dealing with the network (purchase of 21,260 kWh, sale of 38,706 kWh).The table also presented the total annual cost of the system (5, 86, 640 dollars), the net current cost (78, 64, 500 dollars), the cost of energy production (3.5563 dollars per kWh).

TABLE 8: Optimal solution by GA.

Size	Solar PV System	52.36 KW
	Wind turbine	10 KW
	Biogas genset	20 KW
Energy Generated	Solar PV System	92,270 KWh
	Wind turbine	5585.6 KWh
	Biogas genset	41,505 KWh
Annualized cost	Solar PV System	₹1,75,320
		₹ 64,136
	Biogas genset	₹2,28,740
	Net grid cost	₹1,15,620
	Inverter cost	₹20,552
Grid exchange	Grid purchase	21,260KWh
	Grid Sales	38,706KWh
Annual Cost		₹5,86,640
Net Present Cost (NPC)	Wind turbine	₹78,64,500
Cost of Energy (COE)		₹3.5563

Figure 19 shows the amount of hourly energy purchased from the grid and sold to the grid for a full year, while Figure 20 shows the grid sales for the first 0-180 days of the year. It is clear from Figure 19 that in the early days, the amount of buying from the network was less than selling to the network. At that time, renewable energy sources produced more energy than the load demand. Figure 21 shows the load demand with the blue line, while the red line shows the total power produced by renewable energy sources and power purchased from the grid to meet the load demand.

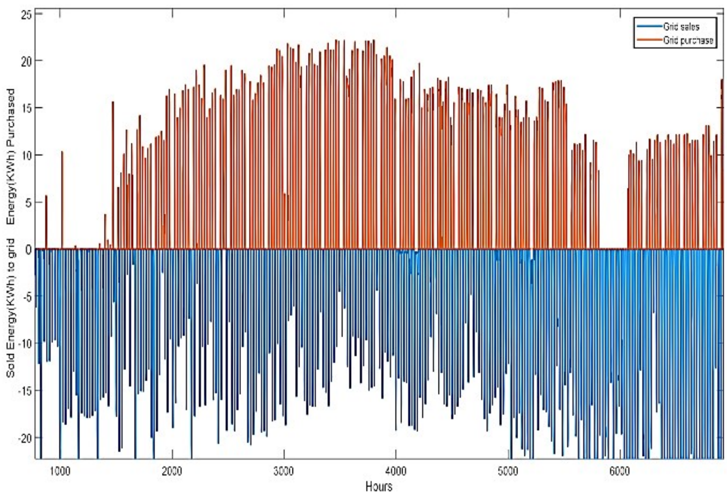

Fig. 19. Purchase and sale of electricity during one year and implementation by GOA algorithm.

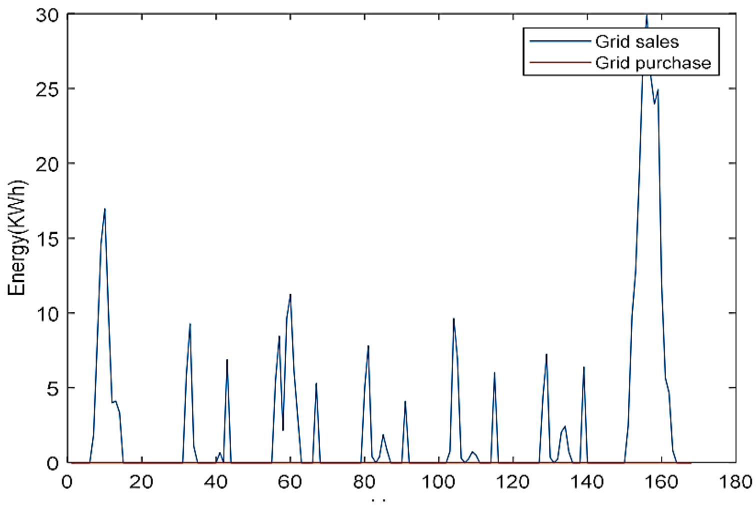

Fig. 20. Buying and selling electricity in a limited period of time.

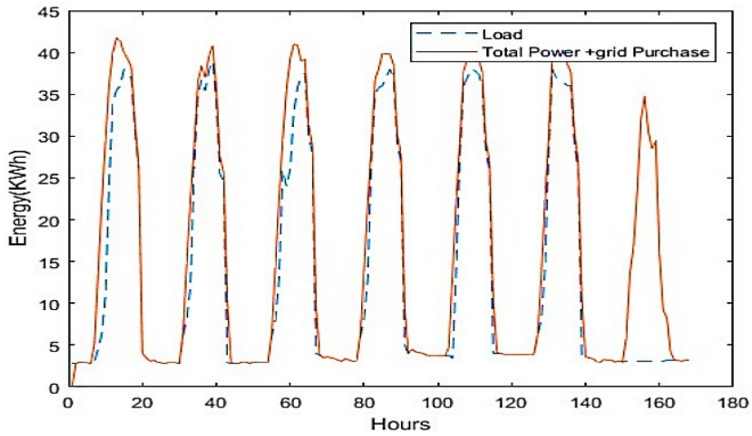

Fig. 21. Total power and demand graph in the time period 0-160.

Also, Figure 22 shows the load demand with a blue line, the red line shows the total energy produced by renewable energy sources and purchased from the grid in orange. This figure shows that enough energy is produced by the renewable energy system to meet the load demand and there is no need to buy from the grid for the first 180 days of the year. Figure 23 shows how the energy produced by renewable energy sources is proportional to the demand for load. From this figure, it is clear that all load demand is provided by the proposed renewable energy system and no-load demand remains.

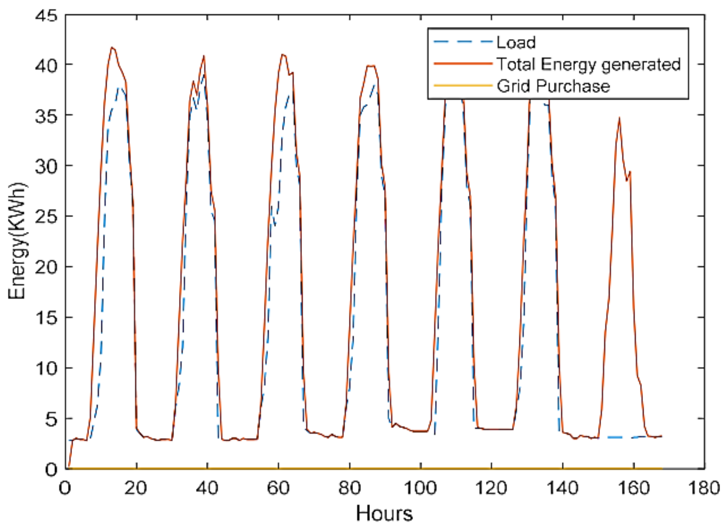

Fig. 22. Demand and total energy and purchase of electricity from the network in the period 0-160.

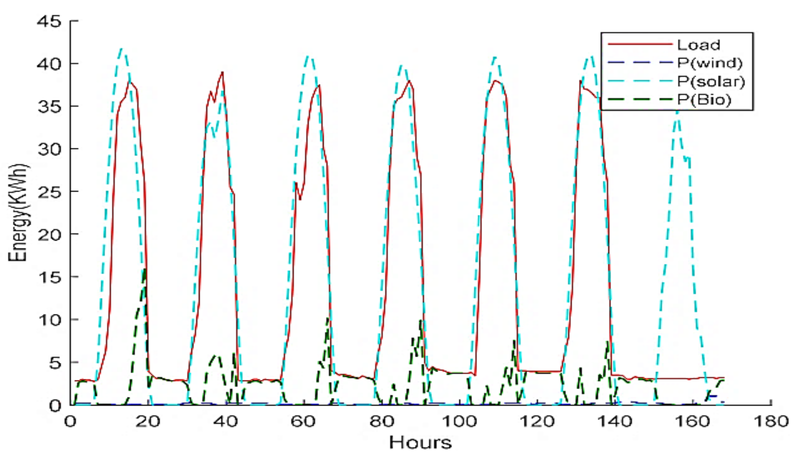

Fig. 23. Energy production by different components in the system.

4. Conclusion

The study highlights the effectiveness and potential superiority of a multi-objective genetic algorithm (GA) over HOMER Pro software in optimizing combined energy systems. The findings reveal a clear trend where the GA demonstrates better stability performance, notably achieving a lower Cost of Energy (COE), indicating a more economically viable system design. Furthermore, the GA-based optimization suggests the feasibility of utilizing smaller-sized components within the Hybrid Renewable Energy System (HRES). This not only leads to a reduction in the Net Present Cost (NPC) but also establishes that a right-sized, efficient system can effectively cater to the site's energy demands. In terms of environmental impact, the evaluation of emissions calculated by both methods shows that the GA-based approach could achieve emission reductions comparable to those calculated by HOMER Pro. This suggests that the proposed artificial intelligence technique is not only effective in system optimization but also exhibits an edge over industry-standard software in this crucial aspect. Overall, the research strongly supports the notion that the multi-objective genetic algorithm serves as a robust and valuable tool for optimizing hybrid energy systems, primarily due to its capacity to yield designs that are more economical, propose smaller component sizes, and deliver similar environmental benefits when compared to established software like HOMER Pro.

1. Comparison of Optimization Methods:
    - The study used both GA optimization and Homer Pro software to analyze the hybrid renewable energy system.
    - A key finding was that GA-based optimization demonstrated superior performance stability compared to Homer Pro.
    - GA optimization achieved lower energy costs, indicating that it leads to a more economically efficient system design.
2. System Sizing and Cost:
    - The GA-based optimization proposed smaller component sizes for the hybrid system compared to Homer Pro.
    - This reduction in component size directly contributed to a decrease in the net present cost of the system.
    - The study emphasizes that the GA optimization achieved a system with the same energy efficiency and reliability as Homer Pro's solution, but at a lower cost.

In essence, the conclusions highlight the effectiveness of using Genetic Algorithms to optimize hybrid renewable energy systems. The GA method not only maintains system performance but also offers a more cost-effective design by optimizing the size of the system's components.

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