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# Power Sharing and Cost Optimization of Hybrid Renewable Energy System for Academic Research Building

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**Abstract** – Renewable energy hybrid systems look into the process of choosing the finest arrangement of components and their sizing with suitable operation approach to deliver effective, consistent and cost effective energy source. This paper presents hybrid renewable energy system (HRES) solar photovoltaic, downdraft biomass gasifier, and fuel cell based generation system. HRES electrical power to supply the electrical load demand of academic research building sited in 23° 12' N latitude and 77°24'E longitude, India. Fuzzy logic programming discover the most effective capital and replacement value on components of HRES. The cause regarding fuzzy logic rule usage on HOMER pro (Hybrid optimization model for multiple energy resources) software program finds the optimum performance of HRES. HRES is designed as well as simulated to average energy demand 56.52 kWh/day with a peak energy demand 4.4 kW. The results shows the fuel cell and battery bank are the most significant modules of the HRES to meet load demand at late night and early morning hours. The total power generation of HRES is 23,794 kWh/year to the supply of the load demand is 20,631 kWh/year with 0% capacity shortage.

**Keywords**: Solar photovoltaic, Downdraft biomass gasifier, Fuel cell, HOMER, Fuzzy logic

## 1. Introduction

Energy has been universally diagnosed namely some about the just imperative parameters because of financial boom and ethnical development [1]. Globally, electricity sectors basically on conventional strength assets (coal, oil, gasoline etc.) for its electricity requirements [2]. However, the use of conventional energy assets leads to environmental and social troubles such as global warming, acid rain, health issues to human beings etc. Renewable power assets (solar, wind, biomass, micro-hydro, fuel cell etc.) offer substantial economic, environmental and social benefits [3]. The utilization of renewable electricity can furnish a sustainable access to electricity to customers in householder in rural area, academic institute, irrigation, food preservation, cooling and small scale industries [4]. The other extra promising renewable electricity systems are the off-grid or stand-alone hybrid energy system. This device combines multiple renewable power sources in imitation of extending the reliability that can't stand ensured along an odd renewable power source [5]. The combination of multiple sources consisting of biomass, photovoltaic PV, the wind, micro-hydro plants, battery, super capacitor, fuel cell sources are extra tremendous as these can suppress rapid modifications of the output electricity and additionally produce greater secure power [6]. Fig. 1 shows the block diagram of a solar photovoltaic, downdraft biomass gasifier and fuel cell HRES. The remainder of the paper is organized as follows. Site description and resource assessment in section 2. Load profile for academic research building in section 3. Fuzzy logic based HRES components cost analysis in section 4. Proposed simulation model and results discuss in section 5. Finally, the conclusion of this work is presented in Section 6.

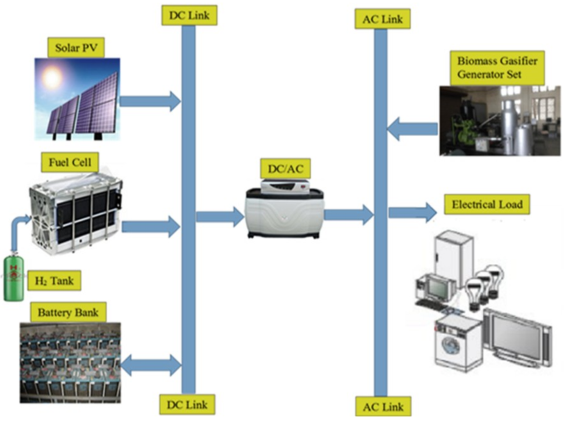


**Fig. 1**. Block diagram of proposed HRES

## 2. Site Description and Resource Assessment

Fig. 2 shows the location of study area Energy Centre, MANIT-B, India. Bhopal is located between canter of India solar strength additionally near because of 6-8 hours.

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**Fig. 2.** Location of study area energy centre, MANIT Bhopal, India. [7]

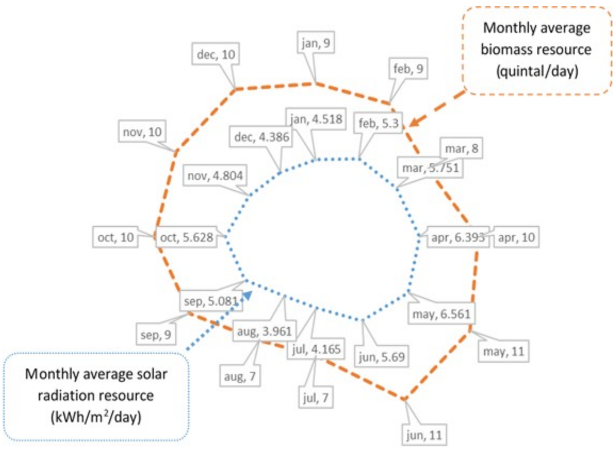


**Fig. 3.** Monthly average solar radiation and biomass resources

MANIT-B is situated among the guts of Bhopal about a stunning plateau including a callow 650-acre campus. This is absolutely massive campus including no of hostels, residential building, educational building, plants then sufficient quantity of biomass is available. On in order in conformity with a parent abroad most appropriate, viable configuration, the HOMER pro model is developed for more than a few combos of solar photovoltaic, biomass, wind, hydropower, hydrogen, fuel cell or existing power lines. Because concerning the intermittent characteristic regarding renewable power systems, the battery is back namely backup facilities. The irradiation at a location 23° 12' N latitude & 77°24'E longitude used to be performed from NASA Surface Meteorology.

Fig. 3. Discuss monthly average solar radiation and biomass resources of the proposed system [8]. The annual average was scaled to be 5.12 kWh/m$^2$/d. a considerable amount of solar power can be obtained.

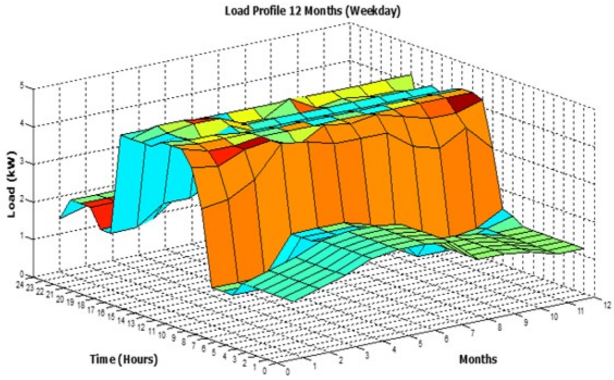


**Fig. 4.** 3D surface plot of 12-month load profile weekday days

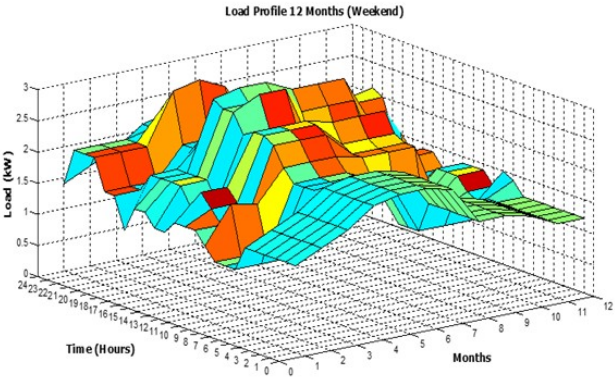


**Fig. 5.** 3D surface plot of 12-month load profile weekend day

## 3. Load Profile for Academic Research Building

The selected proposed area of academic research building, Energy Centre, MANIT-B, India [9]. Fig. 4. Shows the 3D surface plot of 12-month load profile weekday days and Fig. 5. Shows the 3D surface plot of 12-month load profile weekend days. This work 4.4 kW peak load has been considered weekday days and 2.9 kW weekend days, averaged load over an annual cycle, 56.52 kWh per day. The load profiles for singular home equipment vary. Some appliances are 'always switched on'. Other appliances are no longer constantly switched about yet rely on occupancy, toughness occupant behavior, and weather conditions, who fluctuate into buildings [10]. Energy Centre, MANIT-B the basic lay is required in conformity with use electric equipment kind of tube light, roof fan, experiment setup, computer, or machinery.

## 4. Fuzzy Logic based HRES Components Cost Analysis

The fuzzy logic system helps between conceptualizing the fuzziness into the law of a crisp quantify-able parameter

[11]. Thus fuzzy common sense in particular primarily based fashions execute be adapted for effective energy planning in conformity with coming at pragmatic solutions [12]. Fuzzy system good judgment deals with reality and it is a shape about many-valued judgment, [13, 14]. It affords together with a reasoning to that amount is broad object additionally linguistic values then again than crisp values [15]. Fuzzy common sense handles the idea of fact value that stages between totally true and completely false (0–1). A membership function worth over zero Implies so much the analogous element is sincerely now not an element of the fuzzy set, while a price on cohesion means up to expectation the factor absolutely belongs after the set. A grade of membership in between corresponds to the fuzzy membership to set fuzzy logic system has been utilized about awful disciplines. Fuzzy common sense or probability are particular methods in regard to expressing incertitude [16]. The fuzzy set concept uses the thought to fuzzy set membership whilst chance concept makes use of the idea of subjective probability. The variety of kinds of membership functions commonly used in fuzzy logic is 'Λ' triangular, 'Π' trapezoidal.

### 4.1 Biomass gasifier

The production of generator gas (producer gas) known as gasification, is incomplete combustion concerning sure gas (biomass) then takes place at temperatures over as regards $1000^0$C [17]. The reactor is known as a gasifier. In this paper expected energy unit capital cost 900 to 1000 \$/kW, replacement cost is 720 to 800 \$/kW. Biomass gasifier cost by using fuzzy logic programming most precise solution for the given cost ranges can be obtained. The trapezoidal curvature is a feature of a vector, $CBG_{min-max}$ or depends on four scalar limits longevity $CBG_1, CBG_2, CBG_3$, and $CBG_4$ as given in (1).

$$f(CBG_{min-max}; CBG_1, CBG_2, CBG_3, CBG_4) = \left\{\begin{array}{ll} 0, & CBG_{min-max} \le CBG_1 \\ \dfrac{CBG_{min-max} - CBG_1}{CBG_2 - CBG_1}, & CBG_1 \le CBG_{min-max} \le CBG_2 \\ 1, & CBG_2 \le CBG_{min-max} \le CBG_3 \\ \dfrac{CBG_4 - CBG_{min-max}}{CBG_4 - CBG_{13}}, & CBG_3 \le CBG_{min-max} \le CBG_4 \\ 0, & CBG_4 \le CBG_{min-max} \end{array}\right\} \quad (1)$$

### 4.2 Solar photovoltaic

A solar cell module is the basic element of each SPV system, which renovates the sun's rays or photons directly into electrical energy [18]. The solar PV panel's power output execute be positioned through means over multiplying the current or the voltage [19]. 1 kW solar PV energy system's capital cost ranges from 1000\$ to 1200\$ and replacement price vary 800\$ to 960\$. Solar PV cost by way of using fuzzy logic programming most precise answer for the provide cost tiers can be obtained. The trapezoidal curvature is a feature of a vector, $CPV_{min-max}$ or depends on four scalar limits longevity $CPV_1$, $CPV_2, CPV_3$, and $CPV_4$ as given in (2).

$$f(CPV_{min-max}; CPV_1, CPV_2, CPV_3, CPV_4) = \left\{\begin{array}{ll} 0, & CPV_{min-max} \le CPV_1 \\ \dfrac{CPV_{min-max} - CPV_1}{CPV_2 - CPV_1}, & CPV_1 \le CPV_{min-max} \le CPV_2 \\ 1, & CPV_2 \le CPV_{min-max} \le CPV_3 \\ \dfrac{CPV_4 - CPV_{min-max}}{CPV_4 - CPV_{13}}, & CPV_3 \le CPV_{min-max} \le CPV_4 \\ 0, & CPV_4 \le CPV_{min-max} \end{array}\right\} \quad (2)$$

### 4.3 Fuel cell

Fuel cell is an electrochemical device that transforms the chemical energy of $H_2$ fuel into electricity through an electrochemical reaction with $O_2$. The by-products of this chemical reaction are water and heat. Every FC has to join electrodes, certain high quality than one negative, called, respectively, the anode yet cathode [20]. Hydrogen is the primary fuel, but fuel cells additionally require oxygen. In this paper we assumed fuel cell capital cost is 4,000 to 4,500 \$/kW, replacement cost is 3,200 to 3,600 \$/kW. Fuel cell cost by using fuzzy logic programming most precise solution for the give cost ranges can be obtained. The trapezoidal curvature is a feature of a vector, $CFC_{min-max}$ or depends on four scalar limits longevity $CFC_1, CFC_2, CFC_3$, and $CFC_4$ as given in (3).

$$(CFC_{min-max}; CFC_1, CFC_2, CFC_3, CFC_4) = \left\{\begin{array}{ll} 0, & CFC_{min-max} \le CFC_1 \\ \dfrac{CFC_{min-max} - CFC_1}{CFC_2 - CFC_1}, & CFC_1 \le CFC_{min-max} \le CFC_2 \\ 1, & CFC_2 \le CFC_{min-max} \le CFC_3 \\ \dfrac{CFC_4 - CFC_{min-max}}{CFC_4 - CFC_{13}}, & CFC_3 \le CFC_{min-max} \le CFC_4 \\ 0, & CFC_4 \le CFC_{min-max} \end{array}\right\} \quad (3)$$

### 4.4. Electrolyzer

When a DC voltage is utilized in accordance with the electrolyzer, cloud molecules at the anode are oxidized in imitation of oxygen and protons, whilst electrons are released. The protons ($H^+$ ions) bypass via the PEM after the cathode the place that associates electrons out of the vile aspect of the circuit, reducing in imitation of hydrogen gas. In this paper we assumed electrolyzer capital cost is 1,000 to 1,200 \$/kW, replacement cost is 800 to 960 \$/kW. Electrolyzer cost by using fuzzy logic programming most precise solution for the given cost range can be obtained [20]. The trapezoidal curvature is a feature of a vector, $CEL_{min-max}$ or depends on four scalar limits longevity $CEL_1, CEL_2, CEL_3$, and $CEL_4$ as given in (4).

$$(CFC_{min-max}; CFC_1, CFC_2, CFC_3, CFC_4) = \begin{Bmatrix} 0, & CFC_{min-max} \le CFC_1 \\ \dfrac{CFC_{min-max} - CFC_1}{CFC_2 - CFC_1}, & CFC_1 \le CFC_{min-max} \le CFC_2 \\ 1, & CFC_2 \le CFC_{min-max} \le CFC_3 \\ \dfrac{CFC_4 - CFC_{min-max}}{CFC_4 - CFC_{13}}, & CFC_3 \le CFC_{min-max} \le CFC_4 \\ 0, & CFC_4 \le CFC_{min-max} \end{Bmatrix} \quad (4)$$

### 4.5. Battery

A rechargeable battery, storage battery, and accumulator is a type concerning electric battery which may remain charged, discharged into a load, and recharged many times [21]. A non-rechargeable then the fundamental battery is supplied completely charged, then discarded once discharged. The capital cost is 140$ to 160$ per battery. Battery capacity 2V, 742Ah. The replacement cost 112$ to 128$ [22]. Battery cost by using fuzzy logic programming most precise solution for the give cost range can be obtained. The trapezoidal curvature is a feature of a vector, $CBT_{min-max}$ or depends on four scalar limits longevity $CBT_1, CBT_2, CBT_3,$ and $CBT_4$ as given in (5).

$$f(CBT_{min-max}; CBT_1, CBT_2, CBT_3, CBT_4) = \begin{Bmatrix} 0, & CBT_{min-max} \le CBT_1 \\ \dfrac{CBT_{min-max} - CBT_1}{CBT_2 - CBT_1}, & CBT_1 \le CBT_{min-max} \le CBT_2 \\ 1, & CBT_2 \le CBT_{min-max} \le CBT_3 \\ \dfrac{CBT_4 - CBT_{min-max}}{CBT_4 - CBT_{13}}, & CBT_3 \le CBT_{min-max} \le CBT_4 \\ 0, & CBT_4 \le CBT_{min-max} \end{Bmatrix} \quad (5)$$

### 4.6. Converter

In HRES, the principle segments are power converter [23]. A power converter, or inverter, is an electronic gadget and circuitry up to expectation modifications direct current (DC) to alternating current (AC). The capital expense of converter is 350$ to 400$, substitution cost is 280$ to 320$ [24].Converter cost by using fuzzy logic programming most precise solution for the give cost ranges can be obtained. The trapezoidal curvature is a feature of a vector, $CCON_{min-max}$ or depends on four scalar limits longevity $CCON_1, CCON_2, CCON_3,$ and $CCON_4$ as given in (6). Fig. 6. shows the cost analysis of different components of proposed HRES.

$$f(CCON_{min-max}; CCON_1, CCON_2, CCON_3, CCON_4) = \begin{Bmatrix} 0, & CCON_{min-max} \le CCON_1 \\ \dfrac{CCON_{min-max} - CCON_1}{CCON_2 - CCON_1}, & CCON_1 \le CCON_{min-max} \le CCON_2 \\ 1, & CCON_2 \le CCON_{min-max} \le CCON_3 \\ \dfrac{CCON_4 - CCON_{min-max}}{CCON_4 - CCON_{13}}, & CCON_3 \le CCON_{min-max} \le CCON_4 \\ 0, & CCON_4 \le CCON_{min-max} \end{Bmatrix} \quad (6)$$

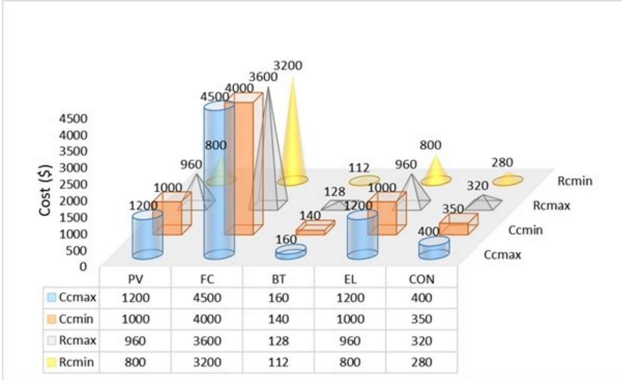


**Fig. 6.** Cost analysis of different components of proposed HRES

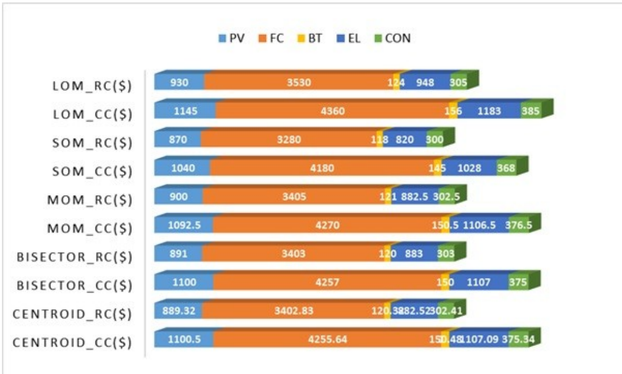


**Fig. 7.** Capital cost and replacement cost of different components of proposed HRES

### 4.7 Optimal results of capital & replacement cost using fuzzy logic

Based on the cost about components range pleasure strive in imitation of locating choicest capital value or replacement cost concerning specific factors about HRES through the use of the fuzzy reasoning process. This section shows that effects of fuzzy common sense programming because of the optimal capital cost & replacement cost of solar photovoltaic, downdraft biomass gasifier, fuel cell, electrolyzer converter, and then the battery. Fig. 7. show that capital cost and replacement cost of different components of proposed HRES. The outcomes mated because fuzzy logic rules well suitable outcomes discovered through SOM method. This result input parameter of HOMER pro software program discovering the superior optimized sizing & cost of energy.

## 5. Proposed Simulation Model and Results

The proposed simulation model has been designed by using HOMER Pro software. Fig. 8. shows a proposed system architecture HRES based on three renewable energy sources. In this HRES uses a combination of a solar

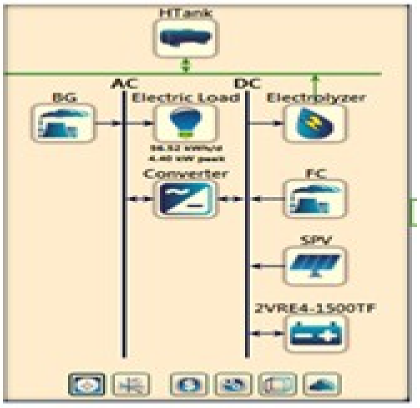


**Fig. 8.** The proposed system architecture of this HRES

photovoltaic, downdraft biomass gasifier, and fuel cell. The battery is an energy storage device, it acts as a source of energy when the load demands additional energy which cannot be satisfied by the power generating sources.

### 5.1 Economic model assessment criteria

Economic evaluation is durability critical to suggest an ultimate aggregate on factors between the HRES[25]. NPC The aggregate net present value of a provision is the current virtue over every the fee so much such incurs over its lifetime, minus the current virtue regarding entire the income to that amount such earns upstairs its lifetime [26]. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER pro analyses the total net present cost using the following (7).

$$C_{NPC} = \frac{C_{AT}}{CRF(i_r, N_{proj})} \quad (7)$$

$$CRF(i_r, N_{proj}) = \frac{i_r\,(1+i_r)^{N_{proj}}}{(1+i_r)^{N_{proj}-1}} \quad (8)$$

$i_r$ is Interest rate in % (6.18 %), $N_{proj}$ is (20 Years)

The total annualized cost of HRES is expressed as following (9).

$$C_{AT} = C_{A,Ca} + C_{A,Re} + C_{A,OM} + C_{A,Fu} \quad (9)$$

The annualized capital cost of a component can be calculated by using the following (10) [23].

$$C_{A,Ca} = C_{I,Ca} \times CRF(i_r, N_{proj}) \quad (10)$$

The annualized replacement cost of a component can be calculated by using the following (11) As:

$$C_{A,Re} = C_{Re} \times F_{Re} \times SFF(i_r, N_{comp}) - S\; SFF(i_r, N_{proj}) \quad (11)$$

When

$$N_{rep} > 0$$
$$F_{Re} = \frac{CRF(i_r, N_{proj})}{CRF(i_r, N_{rep})} \quad (12)$$
$$N_{rep} = 0$$
$$F_{Re} = 0$$

The replacement cost duration ($N_{rep}$) of the components is expresses as following (13).

$$N_{rep} = N_{comp} \times INT\left(\frac{N_{proj}}{N_{comp}}\right) \quad (13)$$

The salvage value of the component (S) and the remaining life of the component at the end of the project lifetime ($N_{rem}$) are described by the following (14). [27]. as

$$S = C_{Re} \times \left(\frac{N_{rem}}{N_{comp}}\right) \quad (14)$$

$$N_{rem} = N_{comp} - (N_{proj} - N_{rep}) \quad (15)$$

A sink fund factor is included in (16) in order to calculate the future value of a series of equal annual cash flows and is expressed as follows [28]:

$$SFF(i_r, N_{proj}) = \frac{i_r}{(1+i_r)^{N_{proj}-1}} \quad (16)$$

$$SFF(i_r, N_{comp}) = \frac{i_r}{(1+i_r)^{N_{comp}-1}} \quad (17)$$

In order to evaluate the financial viability of the project, the Levelized COE of generation has been calculated in (18).

$$COE = \frac{C_{AT}}{E_D} \quad (18)$$

$E_D$ is the total electrical demand.

### 5.2 Results analysis of proposed system

In this, section, partial eventualities choice keep considered within order to compare the overall performance regarding the HRES including different power structures which do keep devoted after providing the studied AC primary load. For every comparison, quantity net present cost, a cost of energy, unmet electrical load, and excess energy under the cycle charging strategy, HOMER pro simulates the long-term operation of all micro-power configurations. Table 1. Shows all viable configurations about the well-acquainted HRES. Indeed, these configurations are listed in the order (top to bottom) from the near profitable to least profitable. The number then the installed power of each component because every feasible configuration is proven into Table 1. The most feasible HRES consists of a 5 kW downdraft biomass gasifier set, 5 kW solar photovoltaic and 2 kW fuel cell to obtain the minimum total net present cost and

**Table 1.** Shows all viable configurations about the well-acquainted HRES with cost analysis

| SPV (kW) | FC (kW) | BG (kW) | BT | CON (kW) | COE ($) | NPC ($) | Operating cost ($) |
|---|---|---|---|---|---|---|---|
| 5 | 1 | 5 | 24 | 5 | 0.134662 | 31220.43 | 1021.44 |
| 5 | 2 | 5 | 24 | 5 | 0.149267 | 34821.16 | 970.2109 |
| 5 | 3 | 5 | 24 | 5 | 0.166455 | 38550.57 | 930.3623 |
| 5 | 3 | 5 | 24 | 5 | 0.181518 | 41800.37 | 1217.767 |

**Table 2.** Shows all viable configurations about the well-acquainted HRES with power analysis

| SPV (kW) | FC (kW) | BG (kW) | BT | CON (kW) | FC/ Power | BG/ Power | SPV/ Power |
|---|---|---|---|---|---|---|---|
| 5 | 1 | 5 | 24 | 5 | 2555 | 12147.36 | 8909.431 |
| 5 | 2 | 5 | 24 | 5 | 5097.936 | 9786.192 | 8909.431 |
| 5 | 3 | 5 | 24 | 5 | 5250.146 | 9540.807 | 8909.431 |
| 5 | 3 | 5 | 24 | 5 | 4841.719 | 8564.207 | 8909.431 |

**Table 3.** Shown that 20 years cost analysis of HRES different component

| Component | Cap($) | Rep($) | O&M($) | Salvage($) | Total($) |
|---|---|---|---|---|---|
| Solar PV | 5,200 | 0 | 28 | 0 | 5,228 |
| Fuel cell | 8,360 | 5,680 | 173 | -1,892 | 12,321 |
| Biomass gasifier | 4,590 | 4,125 | 126 | -30 | 8,811 |
| Battery | 3,480 | 2,767 | 136 | -507 | 5,875 |
| Converter | 1,840 | 610 | 28 | -302 | 2,177 |
| Electrolyzer | 206 | 67 | 5 | -33 | 244 |
| Hydrogen tank | 175 | 0 | 0 | -11 | 164 |
| System | 23,851 | 13,248 | 496 | -2,774 | 34,821 |

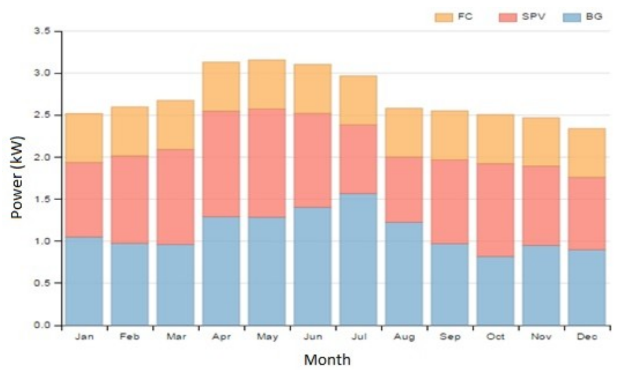


**Fig. 9.** Monthly average electricity production of HRES

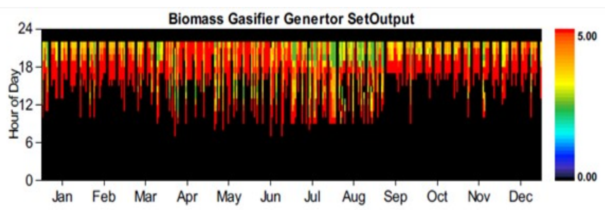


**Fig. 10.** Monthly average power of 5 kW downdraft biomass gasifier

cost of energy. Table 2. The most feasible HRES consists of a 9786.192 kWh/y downdraft biomass gasifier set, 8909.431 kWh/y solar photovoltaic and 5097.936 kWh/y

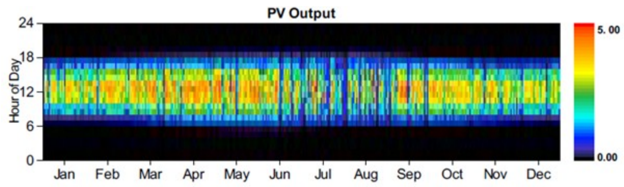


**Fig.11.** Monthly average power of 5 kW solar photovoltaic

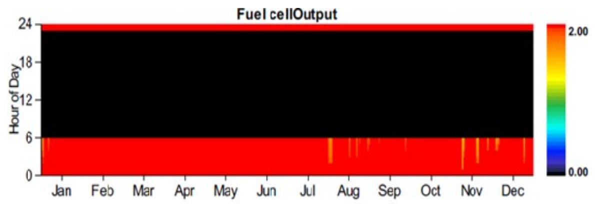


**Fig.12.** Monthly average power of 2 kW fuel cell

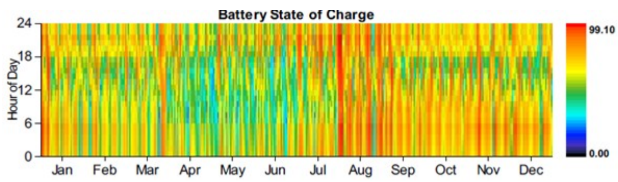


**Fig. 13.** Battery state of charge (SOC) in different month of a year

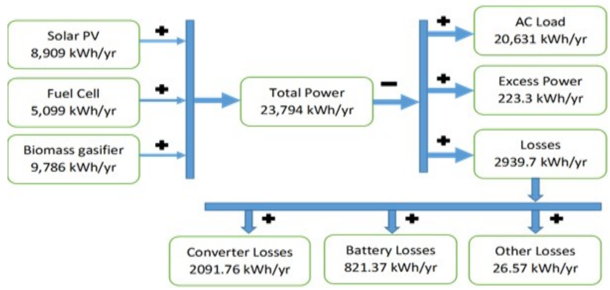


**Fig.14.** Energy flow diagram of proposed HRES

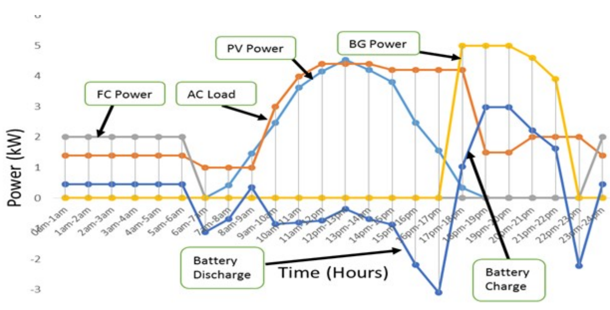


**Fig. 15.** Power flow diagram of proposed HRES

fuel.

The month-to-month average electrical energy production of a solar photovoltaic, downdraft biomass gasifier, and fuel cell is shown in Fig. 9. Simulation results of the same are given in Fig. 10 to 13. It can be seen that the energy production of the 5 kW downdraft biomass gasifier is 9,786 kWh/year, 5 kW solar photovoltaic energy production is 8,909 kWh/year, 2 kW fuel cell energy production is 5,098 kWh/year and battery state of charge. Fig. 14. shows the energy flow diagram of proposed HRES. The total power generation of HRES is 23,794 kWh/year to a supply of the AC primary load is 20,631 kWh per year. Hence for proposed HRES the excess of electricity 223.309 kWh/year with an unmet electrical load of 0 % and Capacity shortage 0 %.Fig. 15 presented hourly power flow analysis of HRES.

## 6. Conclusion

In this paper the combined power sharing and cost optimization concerning an HRES for the academic research building, MANIT Bhopal, India. The HRES proposed work consists of downdraft biomass gasifier, solar photovoltaic, fuel cell & battery in conformity with associate the electrical load demand over the academic research building. The almost feasible HRES consists of a 5 kW downdraft biomass gasifier, 5 kW solar photovoltaic then 2 kW fuel cell after attaining the minimal total net present cost or cost on energy along with nil percentage capacity shortage. The proposed system uses biomass gasifier or solar PV as the most important electricity sources & fuel cell electricity as a less source because of power generation. Using fuzzy logic programming discover the most effective capital and replacement value on components of HRES. The yield concerning fuzzy logic rule & HOMER pro software finds the minimum cost over the cost of COE about optimal configuration regarding HRES is rendered according to remain $ 0.1493 per kWh at the estimated NPC over $ 34,821.00.The quantity power generation regarding HRES is 23,794 kWh/year in accordance with a furnish over the AC predominant load is 20,631 kWh per year. Hence because HRES the extra electrical energy 223.309 kWh/ year along the unmet electrical burden of 0 % & capacity shortage 0 % together with free assign demand.

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