Analyzing of hydel, wind and fuel cell hybrid system for rural electrification with reduced cost of energy

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Abstract. In this work, a Hybrid Renewable Energy System (HRES) is proposed to electrify remote areas. Hydroelectric and wind energy potential are exploited, and they could be converted into chemical energy and stored in hydrogen fuel cells. By this technique, carbon emissions is substantially reduced and helps to control climate change and global warming. In this proposed work, surplus amount of electrical power is diverted to the production of hydrogen through electrolysis, the stored hydrogen can be used as a energy reserve which could be utilized based on requirement. The hydrogen fuel cell acts as a backup to the grid. A simulation study was carried out using Hybrid Optimization of Multiple Energy Resources (HOMER) software. The simulation study reveals that the Cost of Energy has been significantly reduced.

1. Introduction

Renewable energy is obtained from natural resources that are not depleted once used, like the wind or solar energy. There has been increasing interest in renewable energy sources as an alternative to the standard conventional energy sources due to depletion of natural resources and their consequential environmental impact [1]. In recent years there has been a tremendous advancement in the development of solar energy since it has low carbon profile. Although it is expected to become the most competitive renewable energy power, it still faces several challenges, such as large-capacity power accommodation and long-distance transmission [2].

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Wind energy is considered to be the least harmful to the environment [3]. It is also the most cost-effective renewable energy source.Hydropower is accepted as a clean renewable energy source with instant output adjustment and flexibility in storage and discharge. The use of green sources of energy is increased in isolated area due to the high cost of transmission lines and higher transmission losses. A stable energy system is possible by combining two or more renewable energy sources, such as solar, wind, hydro, diesel, etc., in comparison to nonrenewable energy system [4]. On taking account of the above-mentioned facts, the shortcomings of one source could be sufficed by another resource through hybridization.

Hybrid Renewable energy system has high reliability, more efficiency and reduced energy storage capacity [5]. Previous study shows that, the hybrid systems have been considered as preferred for remote systems like radio telecommunication, satellite earth stations, or at sites far away from a conventional power system [6–9]. For a grid - connected applications, the existing single source system (PV, Wind or hydro) can be converted to a hybrid system [10]. Hybrid systems captures the maximal output of each energy resource and can provide grid-quality electricity.

The following study with a Wind-PV-diesel hybrid power system developed using HOMER software for a small town in Saudi Arabia which is powered by the annual contributions of wind, solar Photo Voltaic (PV) and the diesel generations being 4713.7, 1653.5, and 11,542.6 MWh, respectively helped in avoiding 4,976.8 tons of greenhouse gases into the atmosphere annually [11,32]Studies conducted at Nangal village in India showed that hybridization reduced the cost of energy (COE) to $0.032 per kWh while average COE in India is $0.080 [12,33].

As demand grows, new systems need to be installed, often only to meet the peak demand for a few hours per year. New distribution lines may be difficult or expensive to build in such condition the shortage of energy could be met with the help of stored energy [13,34]. Energy storage systems play a vital role in powering standalone or off-grid networks. Electricity could be made available at remote locations with the help of energy storage system thereby improving connectivity, internet penetration and enablesrural electrification. Pumped Storage Hydropower (PSH) is the widely used energy storage system. Although PSH is technically viable to operate as on-peak generation power plants, the economic drawbacks of PSH due to its high capital cost and its cycle efficiency limit its feasibility [14,35]. By maximizing the utilization of renewable resources, and also storing excess energy in a storage system, the dependency of utilization of grid can be reduced [15, 36].

In the case of chemical energy storage systems, energy is stored in the form of hydrogen. Surplus or off-peak electrical power is used to make hydrogen and this stored hydrogen is used as fuel in a power plant when electricity is required. Hydrogen has a high mass energy density [16]. Water is the only combustion product which substantially reduces its environmental footprint. Versatility of hydrogen is attributed to its numerous applications.

Enormous hydropower resources and excellent solar conditions are distributed across the regions of Africa, South America, Central Asia, and Southeast Asia.There lies a huge potential for power development. However,the regions where the energy resources are available are far from load centers, requiring long-distance power transmission, thereby undermining the economic feasibility of such energy sources [2]. Electrification of the rural area has long been done through means of grid extension. Connection to the grid is challenging due to geographical remoteness, thick jungles, rugged terrains, high costs of supply, low household incomes, low consumptions, dispersed settlement of consumers, and inadequate road infrastructures [17,37,38].The challenge of long-distance power transmission could be resolved by utilizing surplus amount of electrical power to produce hydrogen through electrolysis process, the stored hydrogen can be used as an energy reserve which could be transported to the load centers. Through this process the transmission losses are substantially reduced.

In this work a system consisting of hybridized wind and hydro power sources is proposed. During off-peak hours the excess electricity produced from the power plants is utilized for the production of hydrogen. The produced hydrogen is transported to load centers then it is converted into electricity. This mechanism plays a crucial role in powering remote standalone systems since establishing transmission lines is not feasible.

2. System Description

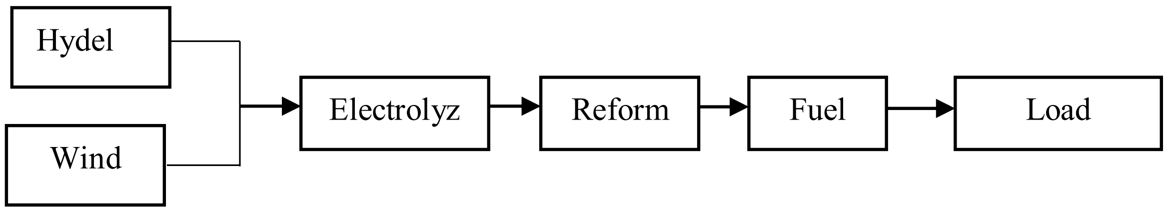

Fig 1. Schematic diagram of Hybrid Renewable Energy System (HRES)

The schematic diagram of the system involved in this work is presented in Figure 1. The system is equipped with two power generators (hydro turbine and wind turbine), an energy storage device, the electrolyzer, a reformer, a converter system and a load.

The reformer stores excess electricity from intermittent sources in the system (hydro and wind) for use during periods of insufficient generation to meet the demand for electrical load. The operating principle of the HRES can be explained briefly, as follows. During a period of excess energy supply, the surplus hydro or wind power is used to electrolyze water to produce hydrogen. Later, when a supply-demand imbalance occurs, the stored hydrogen is combusted in a fuel cell, thus enabling electricity production. The proposed system has been implemented using HOMER software as illustrated in Figure 2. The proposed system is an off-grid system, The grid component on the HOMER's schematic presentation was introduced for the purpose of comparing the proposed autonomous system with grid extension.This study reveals that, the levelized cost of energy of the HRES system is lower than the conventional power system. In addition, HOMER’s programmer has to enter all costs into the system in terms of constant dollars [18, 19]. In this study, the calculations related to energy cost have also been performed in terms of dolla

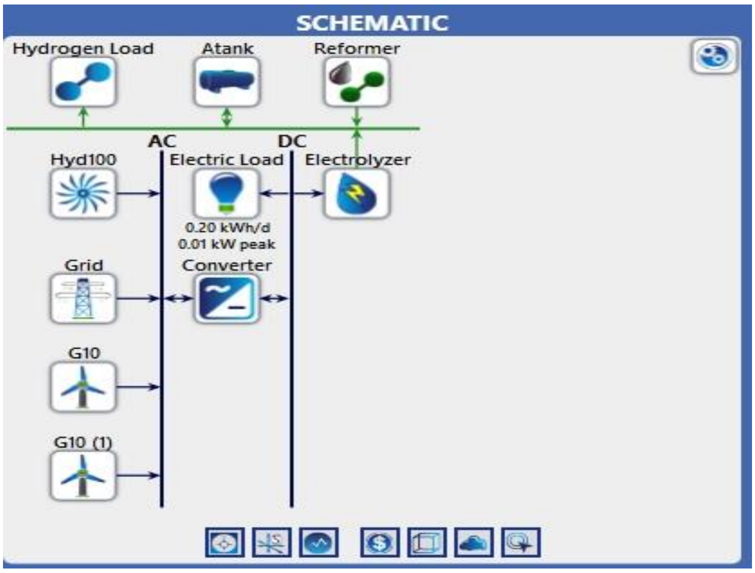

Fig 2. The proposed hybrid system in HOMER

3. System Analysis

3.1 Hydro Turbine

The model of Generic Hydro turbine adopted in this simulation study has a rated power of 100 KW. The electrical power output of the Hydro turbine is calculated using the following equation:

$$P_{hyd} = \frac{\eta_{hyd} \cdot \rho_{water} \cdot g \cdot h_{net} \cdot Q_{turbine}}{1000W/kW} \quad (1)$$

Where,

P_{hyd} = Power output of the hydro turbine [kW]
η_{hyd} = Hydro turbine efficiency [%]
ρ_{water} = Density of water [1000 kg/m^3]
g = Acceleration due to gravity [9.81 m/s^2]
h_{net} = Effective head [m]
$\mathring{Q}_{turbine}$ = Hydro turbine flow rate [m^3/s]

Table 1 Hydro turbine module specifications [20]

Module parameter	Value
Type	100KWGeneric
Lifetime	25 years
Available head	10 m
Minimum flow ratio	50%
Maximum flow ratio	110%
Efficiency	85%
Pipe head loss	10%
Output current	AC
Capital Cost (Including generator, controls, transformers and transmission system)	$459,845
Maintenance cost	$13,795/year

3.2 Wind Turbine

The model of Generic G10 wind turbine of rated power 10KW has been considered for this simulation study. The electrical power output of the wind turbine is calculated using the following equation:

$$U_{hub} = U_{anem} \cdot \left[\frac{Z_{hub}}{Z_{anem}}\right]^{\alpha} \quad (2)$$

Where,

U_{hub} = Wind speed at the hub height of the wind turbine [m/s]
U_{anem} = Wind speed at anemometer height [m/s]
Z_{hub} = Hub height of the wind turbine [m]
Z_{anem} = Anemometer height [m]
α = Power law exponent

Table 2 Wind turbine module specifications [21]

Description	Specification
Manufacturer	Bergey Wind Power
Model	Bergey excel 10-R
Nominal power	10 KW at 12 m/s
Cut-in Wind Speed	2.5 m/s
Cut-Out Wind Speed	None
Furling Wind Speed	14–20 m/s
Max. Design Wind Speed	60 m/s
Hub height	30 m
Type	3 Blade Upwind

4. Integrated Electrolyzer and Fuel cell model

Electrolyzer generates hydrogen from water by utilizing the excess electricity. Whereas fuel cell is used to convert chemical energy into electrical energy. Electrolysis of water is the reverse of the fuel cell reaction [22]. A fuel cell can act as both fuel cell and water electrolysis cell based on the direction of the electrical current. In this work the process of integration has been proposed to nullify the need for an electrolyzer also it paves way for the reuse of discharged fuel cell thereby reducing electronic waste generation. The efficiency of hydrogen production is calculated as follows [22]:

$$Electrical\ Efficiency_{(HHV)} = \frac{HHV of H_2 produced}{Electricityused} \quad (3)$$

The efficiency of fuel cell is calculated as follows [11]:

$$Electrical\ Efficiency = \frac{Electricity\ produced}{HHV\ of\ fuel\ used} \quad (4)$$

5. Availability of resources

The global gross hydropower potential is estimated at 52.0 PWh/year, which is sufficient to suffice one-third of current global energy need [23]. Hydropower is distributed across different geographic locations, mostly being remote areas. Therefore, an enormous potential is untapped. The per capita calculation presented in figure (3) reveals that 41 countries have sufficient potential per capita hydropower energy within their boundaries to cover the needs of the average citizen. Figure (4) shows that energy per capita is higher in North America compared to Asia and Europe.

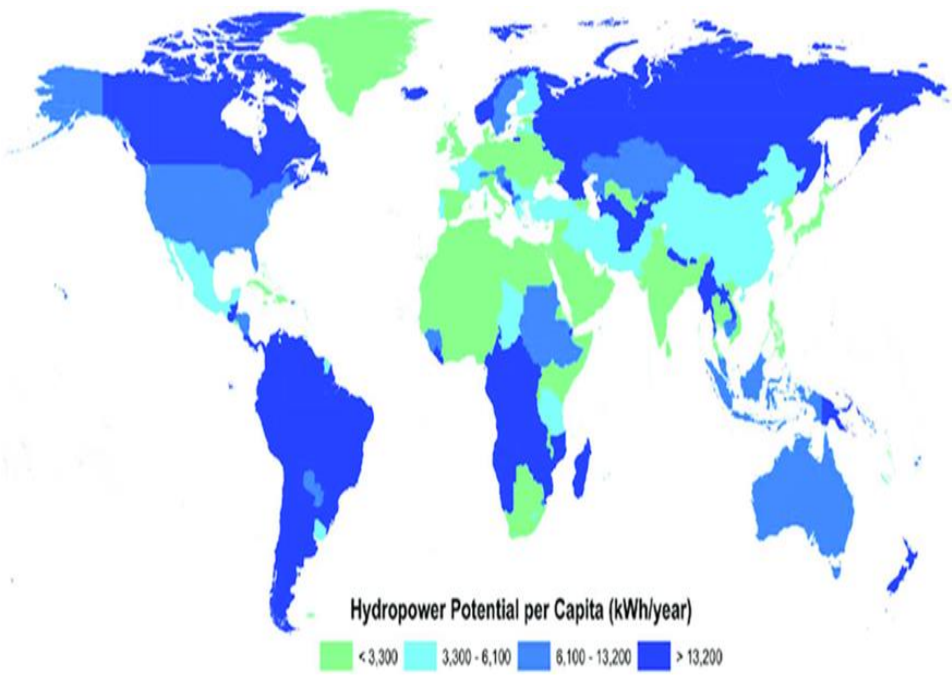

Fig 3. Global map of hydropower per capita per country [23]

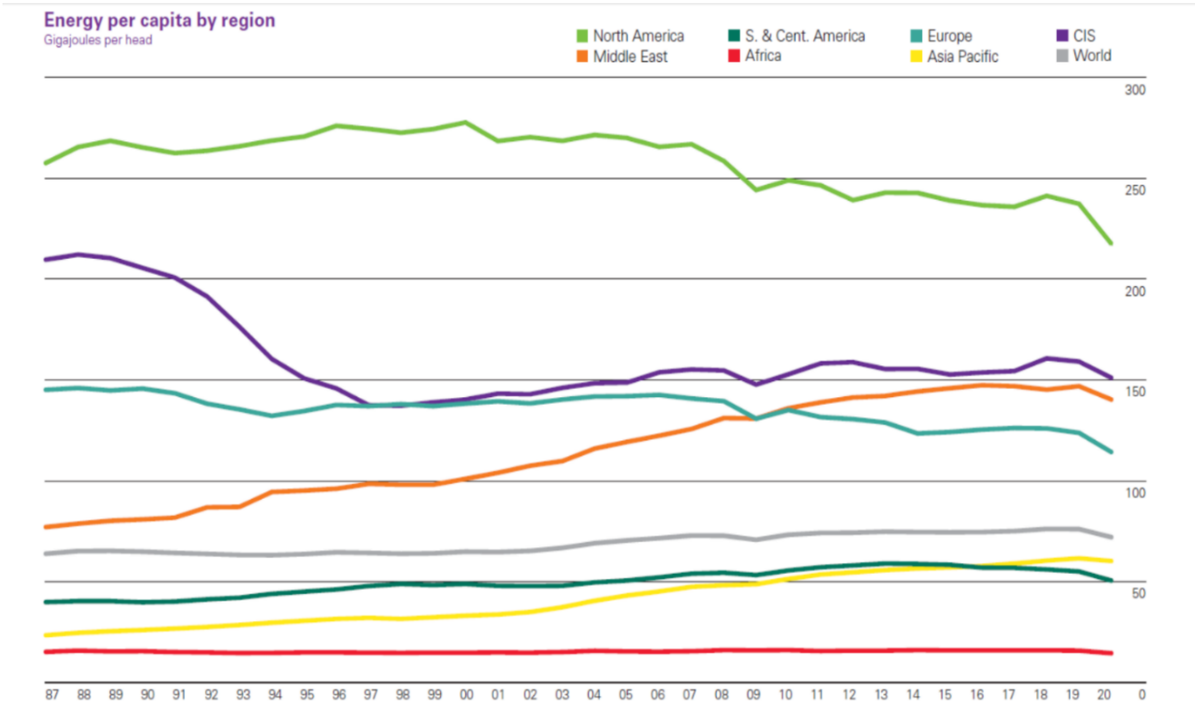

Fig 4. Energy per capita by region (GJ/head) [24]

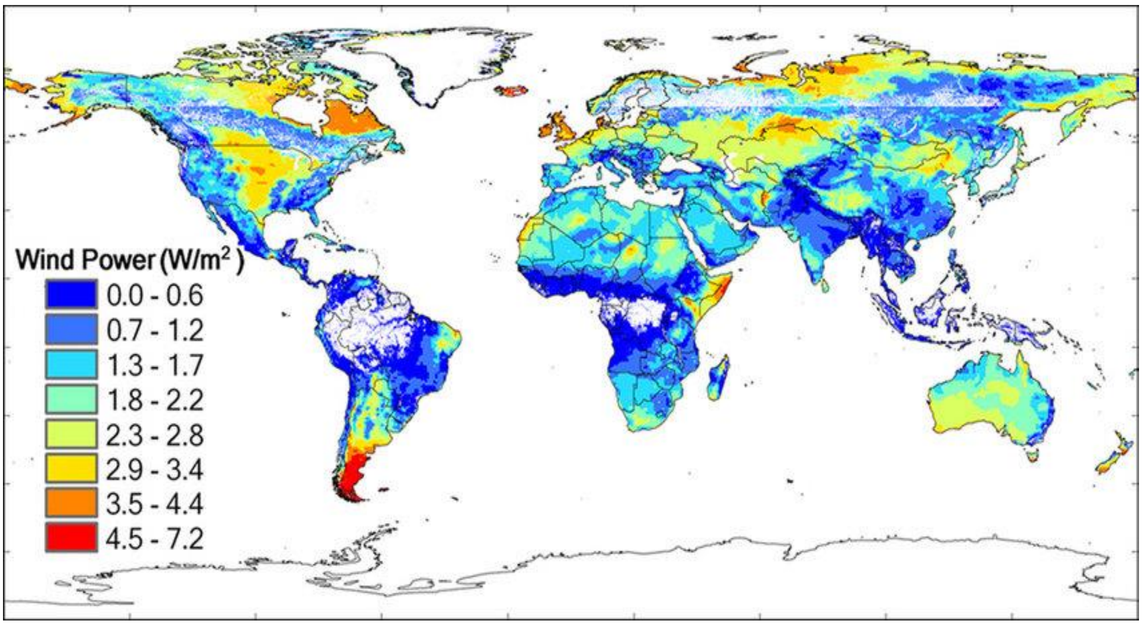

Fig 5. Global distribution of annual average onshore wind power potential

The global wind energy potential is estimated at 690,000 TWh/year [25]. Figure (5) reveals that the wind energy potential is higher in the regions of Central America, Asia and parts of South America. International Energy Agency (IEA) has stated that even though wind capacity additions have almost doubled in, more efforts are still needed [26]. The growth of renewable energy is not sufficient to achieve net zero emission target of the IEA which is attributed to the challenges involved in the development of renewable energy systems such as low productivity, voltage instability and wind speed fluctuations [27,39, 40]. Uncertainties in wind energy could be resolved with energy storage systems. In this work hydrogen fuel cell based energy storage system is proposed.

6. Load Assessment

Hydrogen powered fuel cell-based energy system is proposed to power telecommunication network. The telecommunication plays a vital role in communication between people around the world. The main challenge faced by this industry is to provide the required energy for its towers in the remote rural areas in the absence of the grid [28].Diesel generators is being widely used to power the network which has a serious impact on the environment and also reduce the cost of energy [29] .

In this section the feasibility of fuel cell powered telecom network has been analyzed. Studies conducted in India revealed that 70 percent of the mobile towers face electrical grid outages in excess of 8 hours a day [30]. The energy deficit could be resolved with hydrogen powered fuel cell. The average demand of a telecom base station is 2.52 kW/day [30]. Which translates to 920 kW/year. A hydrogen reformer output of 60,386 Kg/year has been obtained in the simulation studies. Hydrogen has energy content value of 33.3 kW/Kg. Calculations reveals that the output from the reformer could power 2,185 telecom towers annually.

7. Result Analysis

The simulation studies performed with HOMER showed that among the 14,620 system configurations of the HOMER search space, 12,190 were feasible.Its cost of energy (COE), operation cost and total net present cost (NPC) were $0.2869/KWh, $260,341.70 and $37,87,892 respectively. The breakdown by component and cost type of the NPC, has been presented in the Figure 6. This figure shows that 62% of the NPC was dominated by the capital cost of the system. The hydroelectric turbine was the most important component in terms of costs and accounted for 63% of the total capital cost. Fuel cost of $ 381189.8 was incurred by the generic reformer system. For this configuration, the total annual electricity production was 1,032,984 kWh/year, 91% dominated by the production of hydroelectric turbine. A significant gain of $ 660,201/year was made as electricity was sold to the grid this enumerated the net profit and boosted return of investment as represented in figure (6).

Figure (7), which displays the monthly distribution of electrical generation, shows that the power generation from hydroelectric powerplant was higher during the rainy season than the dry season. Figure (8) shows the generation of hydro power to meet the daily demand.

This microgrid required 165 kg/day and has a peak of 20 kg/hr. In the proposed system, the generic reformer serves as the hydrogen source. The Generic Reformer has a rated capacity of 100 kg/hr. The annual production is 60,386 kg/yr. Figure (9) depicts the total production of hydrogen by the configuration. Figure (10) represents the annual production of the generic reformer.

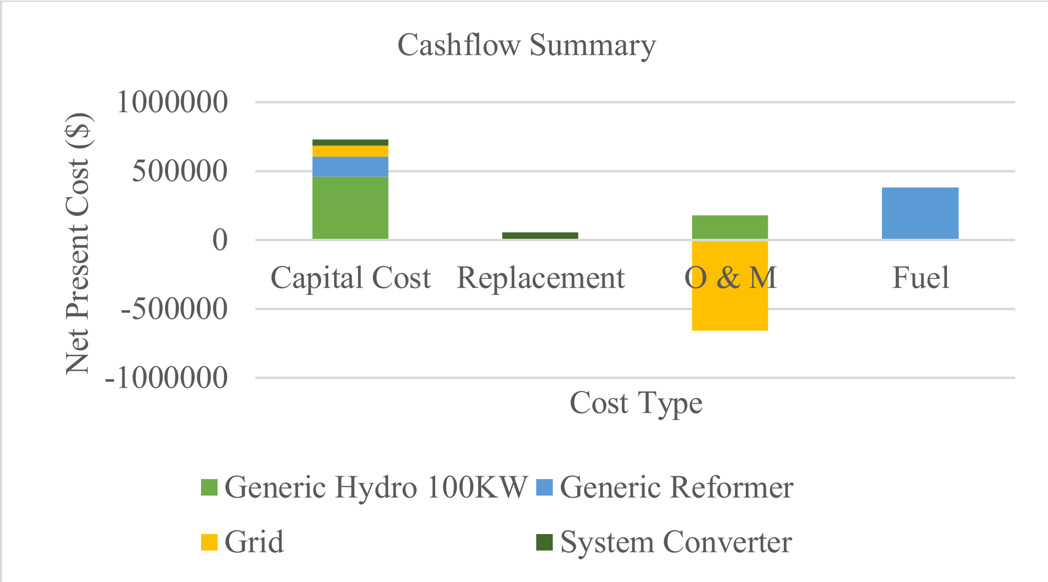

Fig 6. Cash flow summary based on the HOMER simulation

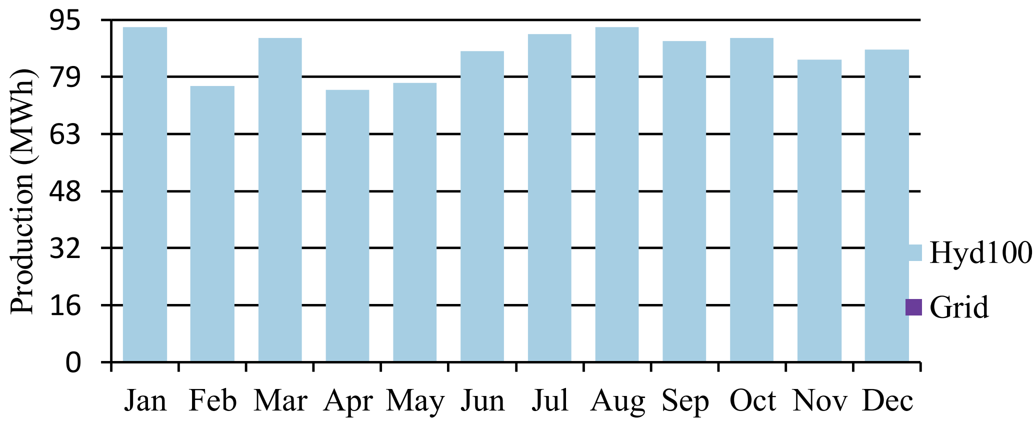

Fig 7. Monthly average electrical output of the system

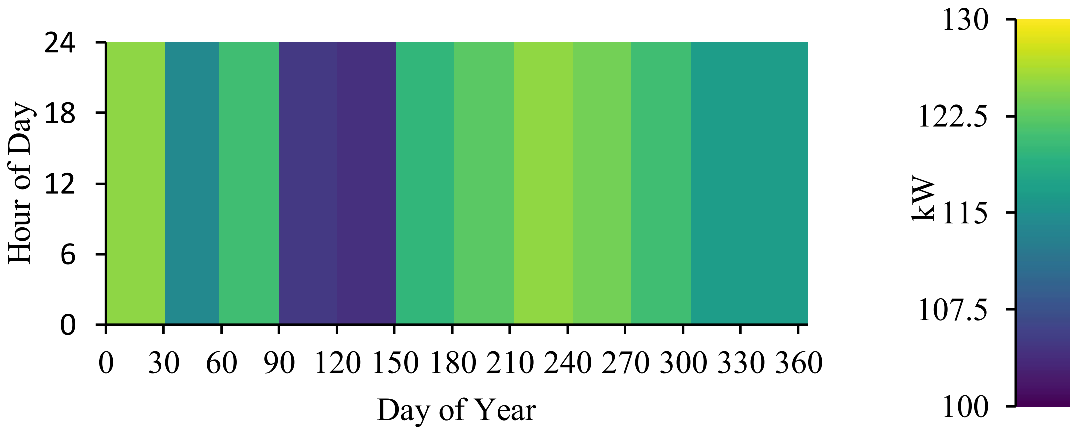

Fig 8. The Hydro-Electric output

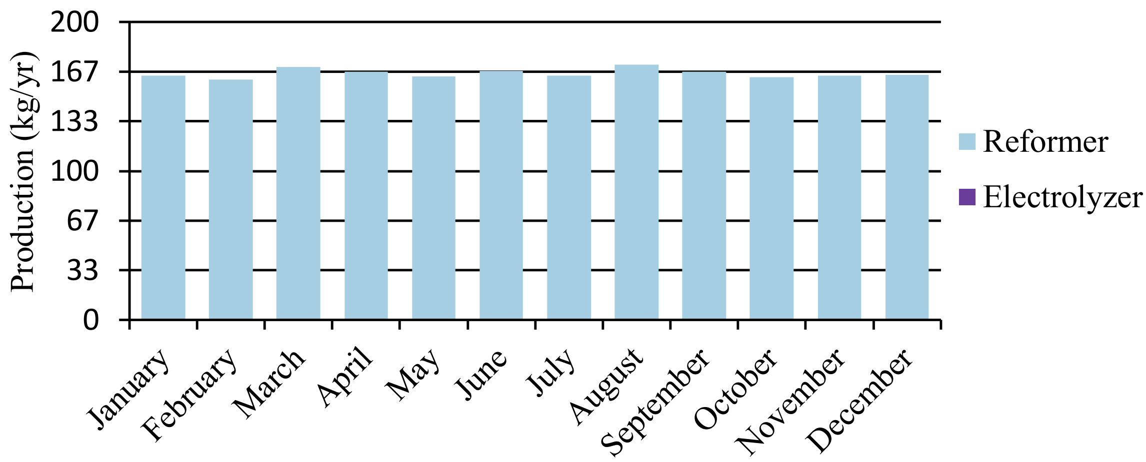

Fig 9. Monthly average hydrogen production

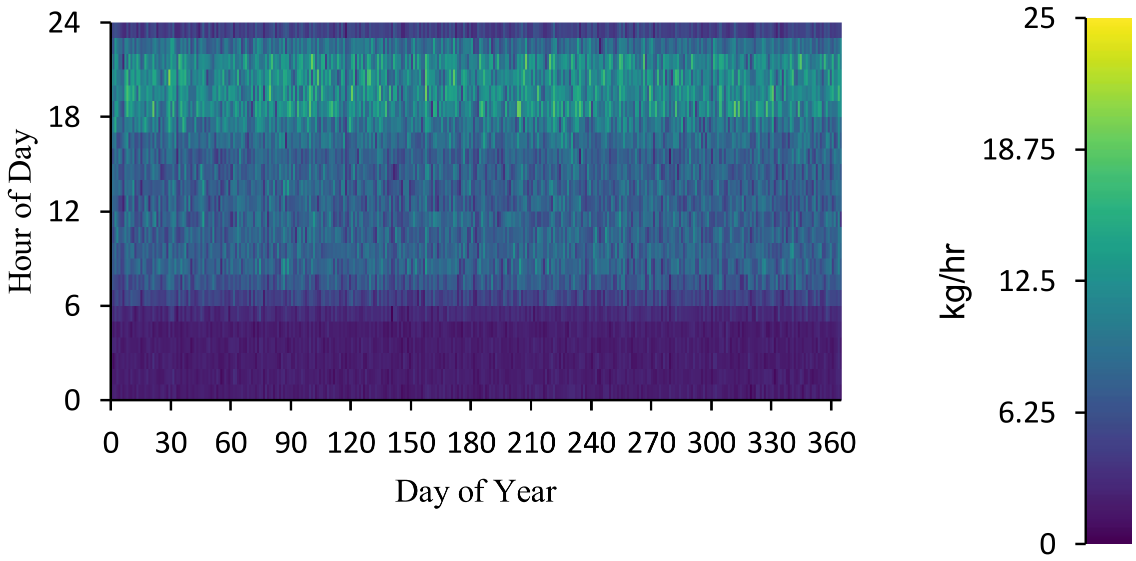

Fig 10. The reformer output

8. Conclusion

In this paper, a hybrid renewable energy systemhas been proposed and simulated using HOMER software. HRES comprising of hydel power, wind energy and fuel cell is investigated in this work. Hydrogen fuel cell is expected as one of the promising energy storage solutions. Energy storage systems are essential in increasing renewable energy penetration. Simulation studies revealed that the COE of HRES is lower than the average COE prevalent across grids. HRES provides autonomy to standalone systems by reducing their dependency on grids. It reduces transmission losses by a huge fraction thereby facilitating swift transmission between power stations and load centres. This ensures electrification of remote areas and improves connectivity. Renewable energy is a clean source of energy and green hydrogen produced from the electrical power reduces the environmental impact significantly.

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