International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 6 Issue 10 Series I ǁ 2018 ǁ PP. 01-08

Optimization and Assessment of a hybrid Solar-Wind-Biomass Renewable Energy System for Kiribati Island

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ABSTRACT: *This paper presents a feasibility study of photovoltaic (PV), wind, biomass and battery storage based hybrid renewable energy system (HRES) providing electricity to residential area in Australia. The monthly daily mean global solar irradiance and wind speed data of the capitals of the seven regions of the six states and various territories of Australia (Queensland, Northern Territory, South Australia, Tasmania, Victoria, Western Australia and New South Wales) are generated by the RETScreen Clean Energy Project Analysis Software produced by Natural Resources Canada. The long term continuous implementation of the system is simulated. The software HOMER produced by the National Renewable Energy Laboratory is used as a simulating tool. Their cost and emissions are compared with each other among the systems. It is found that an off-grid PV-wind-biomass HRE system is an effective way of emissions reduction and it does not increase the investment of the energy system. An off-grid hybrid energy system has been designed as well as simulated to support a small community considering an average load demand of 165.29 kWh/d with a peak load of 24.57 kW. The simulation and optimization of operations of the system have been done by HOMER software using the real time field data of solar radiation, wind speed and biomass of that particular area. The simulation ensures that the system is economically and environmentally feasible with respect to net present cost (NPC) and CO_2 emission limitations. The result shows that NPC and CO_2 emission can be reduced about 31.65%; equivalent to 16 tons per year as compared to conventional power plants. The NPC of the optimized system has been found to be about USD 294,382.00, having the per unit Cost of Energy (COE) of USD 0.381/kWh. The analyzed hybrid energy system might be applicable for other regions of the world where there are similar climatic conditions.*
INDEX TERMS: *Renewable Energy; Homer; Optimization; Simulation; Sensitivity; Biomass; Island.*

Date of Submission: 27-12-2018 Date of acceptance: 12-01-2019

I. INTRODUCTION

Highlight Usage of renewable energy for electricity generation is currently a priority research area. Remarkable efforts are being made to expand the sources of various forms of energy, and to intensify the deployment of renewable and sustainable energy slots all over the globe. The foremost reason for intensifying the deployment of renewable energy in the 21st century, is the combined effects of fossil fuel depletion and the ever increasing awareness of environmental degradation [1]. Thus, policy makers and researchers are paying more attention into this research field.

For an instance, the aim of European Union countries is to replace its total energy consumption by renewable sources by at least 30% before 2020 [2]. There are several promising renewable energy resources such as biomass, wind, geothermal energy, solar, hydro-electric and tidal power. Hybrid renewable energy resources can reduce the emission of harmful gases and reduce the use of imported power [3, 4]. There is an abundance of resources in Bangladesh, specifically the potential from the huge amount of wind currents, biomass and the intense solar radiation footprint because of its geographical position [5]. During the last two decades, electrical energy consumption in Bangladesh experienced a dramatic increase as a direct result of the economic growth and industrial expansion. It is expected that peak loads will reach 65 GW by 2027, which will in turn demand over $100 billion worth of infrastructure development. Therefore, for sustainable development, it is imperative to build up policies for energy conservation [6]. Up until now, fossil fuels have been used to generate most of the electrical power [7], neglecting the use of renewable energy resources such as wind, biomass and solar to generate electricity.

Aside from adjacent protection attempts, with extending load interest and an unnatural climate change, course of action makers are looking at environment-obliging kind of imperativeness and power advantages for keep up the world's remained essentialness for the future time people[3]. For the power devices advancement, the usage of integrator with the imperativeness resources and essentialness payload space structure is the new progress. To full fill the stack asks for the wind and sun fueled resources can expect a vital part [8]. At present, the installation process of a hybrid system is very quick and easy. As a result, there has been an increase in interest of similar power production systems all over the world; as documented in [9], the number of renewable energy resources has been increasing significantly. So a legitimate administration is needed to facilitate the appropriate usage of these assets and to enhance the practicality, and much improved quality of mixed renewable vitality framework [10, 11]. Bangladesh is a country with geographically horizontal and flat surface area. The expansion of electrical matrix for the expanding development of is quite costly and not achievable given the current economic environment. The only feasible option suitable for this circumstance are sources like "half and half" renewable force plants.[12, 13]. The other method for making "half and half" power plants would be similar to PV-wind-diesel, PV-diesel-battery and so on.

The continuation of examination with renewable vitality framework has shown that, if the framework is streamlined legitimately, it will be a more compelling force source as compared to other force sources [14, 15].Recently, Bangladesh's first nuclear power plant in Dhaka's east coast is projected to add 30MW to Dhaka's grid by the second quarter of 2016, with the aim of offsetting some 200,000 tons of CO_2 emissions annually. The advancements of renewable energy sources in Saudi Arabia cannot be considered as an aristocratic model, but it is an environmental friendly model and an improvisation in petroleum manufacturing strategy [16, 17]. The research on local ecology analysis has concluded, that the use of energy effectiveness resources and renewable energy gives significant environ-mental benefits [18, 19]. There are some previous works on hybrid energy systems consisting of wind energy, fuel cell (diesel generator) and photovoltaic array for different regions of the world [20]. A maximum power point tracking (MPPT) system is also discussed on wind and photovoltaic energies by various scientists [21-23]. A grid-connected hybrid generation system has been modeled and synthesized with a control system by fellow researchers [24]. A stand-alone wind solar energy system with battery storage has been investigated with dynamic performance analysis by multiple research works [25].**Fig. 1** shows the geographical position of Kiribati island (Lat.: 1° 52.3' N, Long.: 157° 25.7' W) [26]. DLR method used the data collected from the satellite for various factors such as rainfall, water vapor and vaporizer optical depth, cloud cover, water vapor to Calculate GHI. To calculate wind resources data, Bangladeshi Meteorological Department has measured wind speed for a specific year by maintaining the height of 30 m upwards from the ground surface level.

Figure 1: Geographical Position of Kiribati (Lat.: 1° 52.3' N, Long.: 157° 25.7' W) [27].

Renewable energy analysis with wave energy had not been fruitful yet, because of insufficiency of electrical power generation.

Tidal research stations were set up by Bangladesh Meteorological department and Bangladesh Renewable Energy Committee for the practicability analysis of tidal energy [28]. The result was not up to expectation, and that is why just the wind, solar and average temperature data have been considered for the formulation of the most efficient hybrid renewable energy system. **Fig. 2** shows the schematic diagram of hybrid energy system. **Fig. 3** shows the block diagram of a complete hybrid energy system with the operational work flow.

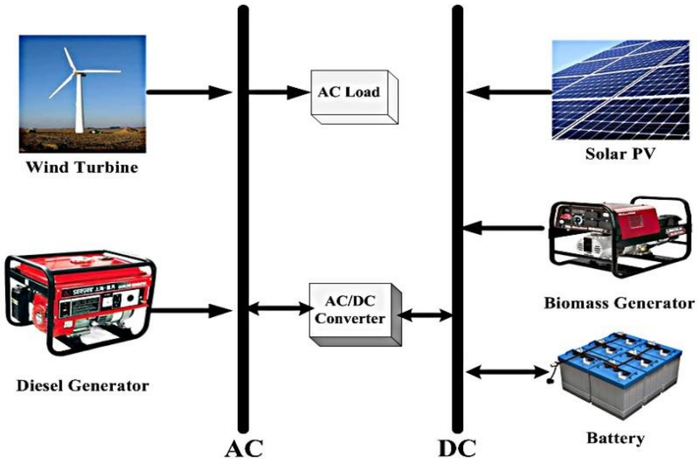

Figure 2: Schematic diagram of hybrid energy systems.

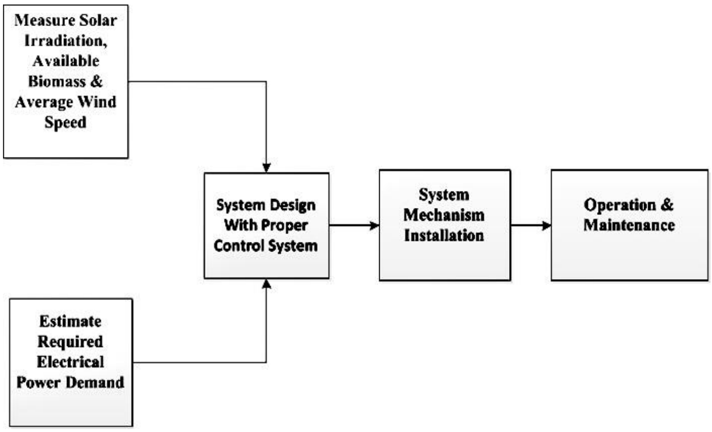

Figure 3: Block Diagram of a complete hybrid energy system.

II. HYBRID ENERGY SYSTEM COMPONENTS

A. Solar Energy (Photovoltaic) System Module

The electrical energy generation as an output of a photovoltaic system can be estimated by a widely accepted equation as follows:

The annual average solar radiation data can be collected from the meteorological department.

$$E = A \times r \times H \times PR \quad (1)$$

Table 1: Photovoltaic array expense assumption and procedural factors

Factor	Value
Net Cost	50 $/kW
substitution Cost	40 $/kW
Maintenance and Operation Cost	1 $/kW
life span	20 Years
Derating factor	80 %
Tracking System	N/A

The Performance ratio, i.e. the value of losses coefficient ranged from 0.5 to 0.9 (build in rate= 0.75), r is the ratio of electrical power (in kWp) of a particular PV module divided by the area of a particular module. PR (Performance Ratio) can be considered as a very important value for estimating the eminence of a photovoltaic installation. This factor included with all fatalities.

Under consideration is a PV module of 250 Wp with an area of 1.5 m^2 can which can be operated with the standard ratio under standard experiment conditions, such as radiation of 800 W/m^2, speed of wind 2 m/s with the factor "Watt-Peak" [29]. With this it can be found that the global horizontal yearly irradiation incident on a PV panels with a specific preference (incline, lean) and direction.

Monthly average global radiation data has been taken from Bangladesh Meteorological Department

[30]. From the longitude and latitude data of the considered area can be used to calculate the clearness index through HOMER renewable energy software. The synthesized 2304 hourly values for a year can be created by HOMER renewable energy software through the utilization of the Graham algorithm. USD 50/kW has been considered as the rate of PV component, taking into consideration the mechanism for coastal areas of Bangladesh. The life span of the system has been predicted as 2 decades. There are 3 types of module that has been considered for PV modules: 5 kW, 18 kW and 30 kW. Table 1shows the factors of PV module related with the simulation. **Fig. 4** shows yearly global horizontal radiation data for Kiribati Island.

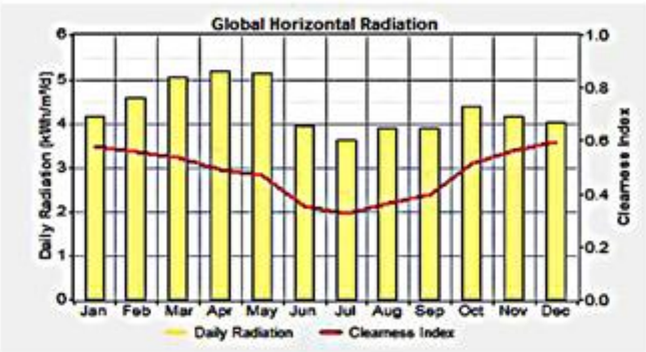

Figure 4: Global Horizontal Radiation for Kiribati Island, Bangladesh

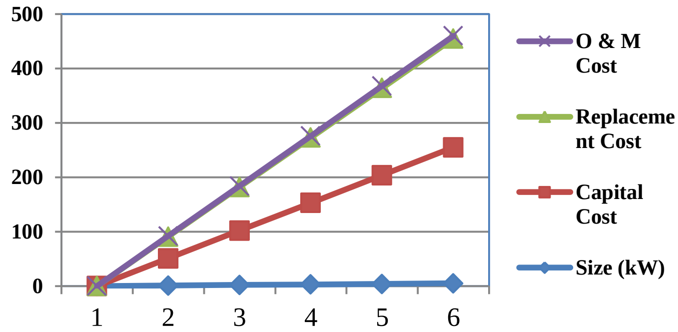

Figure 5: Cost Curve of PV array.

Fig. 5 shows the cost curve of solar representing module. The cost curve has been drawn according to the current market price, power generation process and other costs.

B. Wind Energy (Wind Turbines) System

A rotor combining of two or more blades mechanically joined to an electrical generator can generate electricity from wind's kinetic energy; can be captured by the wind turbines. From the following equation, it can be found that the mechanical power generated from wind speed using the wind turbine is [31]:

$$P_m = 0.5\rho A C_p v^3 \qquad (2)$$

The highest value of the power coefficient has been preferred to be as 0.59 theoretically. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The pitch angle refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis. The linear speed of the rotor to the wind speed has been addressed by TSR [32].

$$TSR = \lambda = \frac{\omega R}{v} \qquad (3)$$

Table 2 represents the financial and methodological factors for preferred wind turbine.

Table 2: Financial and procedural factors of wind turbine.

Factors	Value
Rated Wind Speed	8 m/s
Starting Wind Speed	3 m/s
Cut-off Wind Speed	10 KW
Rated Power	15 m/s
Net Cost	60 $/kW
Substitution Cost	50 $/kW
Lifetime	15 Years
Maintenance and Operation expense	1 $/kW

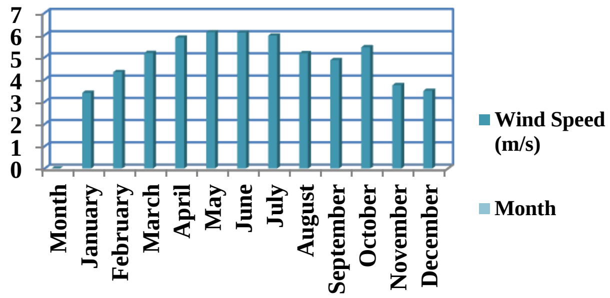

Figure 6: Average Wind speed of every month of Kiribati Island.

Fig. 6 show average wind speed of every month for a specific year for the Kiribati Island.

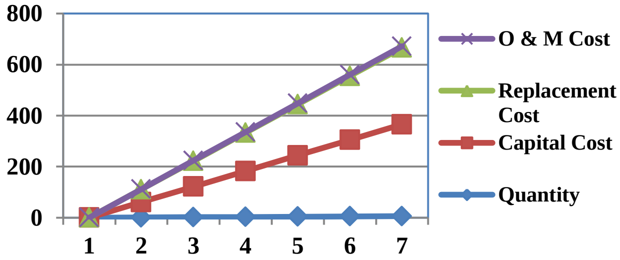

Figure 7: Cost Curve of wind turbine.

Fig 11 shows the cost curve of a wind turbine.**Table 3**shows the assumptions of cost for a biomass generator and the other factor related with power generation and range of capacity [33].

Table 3: Procedural parameters with cost conjecture for biomass generators.

Factors	Value
Net Cost	70 $/kW
Substitution Cost	60 $/kW
Maintenance and	0.025 $/kW
Operation expense	900000 Minutes
Lifetime	(15,000 Hours)
Least Load quotient	30 %
Gas Curve Slope	0.5/h/kW $_{output}$
Gas Curve Intercept	1/h/kW $_{rated}$

Fig. 8 shows the cost curve of a biomass generator.

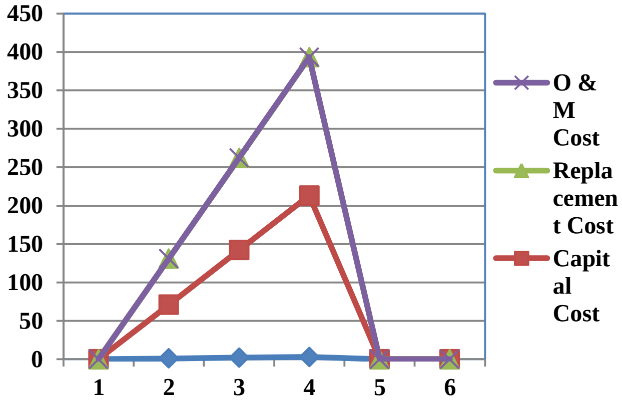

Figure 8: Cost Curve of Biomass Generator.

III. SIMULATION, OPTIMIZATION RESULTS AND DISCUSSION

For the assessment of the performances of different hybrid renewable energy systems in this research, HOMER simulation mechanisms have been used to perpetrate optimal systems performance analysis. The optimized outcomes for a specific group of sensitivity parameters akin to average wind speed, global horizontal solar radiation, biomass resource, highest yearly capacity shortage, diesel cost, and renewable fraction are represented emphatically in that optimization software [34]. An optimal hybrid renewable energy system can be designed by HOMER renewable energy software through a large number of hourly simulations. Various values for wind speed, solar radiation, diesel cost and least renewable fraction have been contemplated to conduct simulations and these values assures a much more robust analysis [35]. **Fig. 9** shows the electrical energy generated with practicability from the off-grid hybrid PV-diesel-biomass-wind-battery system. At the same time, with a base NPC of USD 294,382.00and base COE of USD 0.381/kWh, an off-grid hybrid PV, wind turbine, diesel generator and battery hybrid system is efficiently more feasible and this is observed by the sensitivity analysis.A community of 6 shops and 78 households has been considered in accordance with average load demand of that area in this analysis. 1 fan (Star standard ceiling fan, 50 W), 4 energy savings bulbs (Philips tornado bulb, 20 W each), 1 television (Sony bravia, 50 W) and a table lamp (Emen 69076, 5 W) for each family and 3 energy savings bulbs (20 W each), 1 fan (Star standard ceiling fan, 50 W) and a table fan (DF23C, 25 W) for every shop and total 3 refrigerators (160 W each) have been calculated and considered for the load demand analysis.

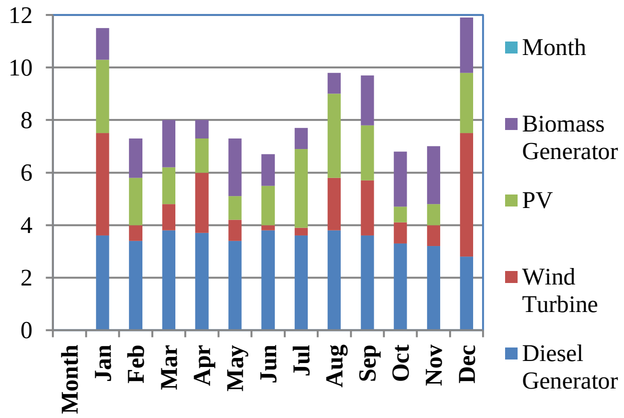

Figure 9: Energy generated with practicability from the off-grid hybrid PV-diesel-wind-battery system.

IV. CONCLUSION

The hindrance of transportation of fossil fuel supply to the remote territories alongside its awful effect on environment makes it economically unsuitable, with the only remaining option being to seek renewable sources based on half breed framework for zap of rustic or off-network groups. This study proposes a PV-wind-biomass-diesel-battery hybrid energy system for providing the power supply to an off-grid community in northern islands near the Bay of Bengal of Bangladesh. A detailed simulation has been performed by HOMER

considering manufacturing cost and efficiency for the proposed optimized hybrid energy system. The result shows that the COE of the optimized system is about USD 0.381/kWh and the NPC of the optimized system is about USD 294,382.00. The total sensitivity analysis, optimization and simulation process has been conducted through HOMER renewable energy software. The proposed hybrid system also ensures the reduction of CO_2 emission about 1600 tons per annum which indicates a significant environmentally friendly effort. From the simulation results it is clearly indicated that the proposed hybrid energy system is economically and environmentally feasible in comparison with other conventional power generation systems. As the generator can decrease the issue would bear sienna wind turbines or in PV board. This framework can give enhanced execution in correlation with alternate framework; furthermore we attempted to lessen the expense of force era, contrasted with the routine mixture vitality frameworks. Sooner rather than later, some more helpful renewable vitality models and legitimate control frameworks can be presented for the "half and half" vitality framework for the remote zones of the world. From the analysis and simulation results it can be said that the proposed hybrid energy system will be applicable all over the world where the environment and other situation are similar. Other countries like
Malaysia, Australia, Singapore and would be very potential zone for this hybrid energy system.

ACKNOWLEDGMENT

This work has been carried out by the financial support ofthe research grant of Uttara University, Dhaka, Bangladesh.

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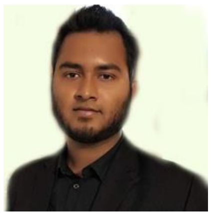

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