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ORIGINAL PAPER

Optimized Hybrid Wind-Diesel Energy System with Feasibility Analysis

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Abstract The enormous percentage of people in the world; particularly in the developing countries; are living mostly in decentralized, rural and remote areas, those are geographically secluded from the main grid connection. The power distribution and continuous fuel transportation to generate electricity for these areas pretenses a very big challenge. By proper utilization of renewable energy resources in off grid hybrid energy systems will be an efficient solution of this crisis. Moreover, the high cost of renewable energy systems has led to its slow adoption in many developing countries. Hence, it is very important to find an appropriate size of system in order to reduce the energy cost and excess electricity generation as well as to maximize the available resources. Therefore, a hybrid energy system has been designed and simulated to support a small community considering an average load demand of 85 kWh/d with a peak load of 8.7 kW. The simulation and optimization of the system have been performed by the HOMER software using real time field data of solar radiation, wind speed and biomass of that particular area. The simulation results confirm that the system is suitably feasible with respect to the net present cost (NPC) and CO_2 emission reduction purpose. The simulation results also confirm that the NPC and CO_2 emission can be reduced about 32.45% and 29 tons per year respectively compared to the conventional power plants. The NPC of the optimized system has been found about USD $160,626 having per unit Cost of Energy (COE) about USD $0.431/kWh and the operating cost USD $10,779/yr.

Introduction

In present situation, the most challenging fact in the world is energy security and climate change. This complicated task of conducting research is extended radically where the attainment issues are social, economic, technological, environmental, risk management, and geopolitical [1, 2]. The most important part is the demand of energy which is rapidly growing. Moreover, the climate change and global warming are two main concerns because of the increase of greenhouse effects. The use of fossil fuel is increasing day by day at an alarming rate. Due to the excessive utilization of fossil fuel creating a detrimental effect on the environment.

Nowadays, voltage fluctuation due to the variation of wind speed is an important issue. Besides, a radical shift to a decarbonize energy supply will be required to stable the atmospheric concentrations of CO_2 which leads a significant climate change mitigation. So, it is very urgent to arrange the renewable energy resources for this critical issue [3, 4]. Usage of renewable energy resources for electricity generation is a priority research topic for this situation. Remarkable efforts to expand the sources of various forms of energy to intensify a deployment of renewable and sustainable energy slots have been increasing all over the humanity. The first priority in intensifying renewable energy deployment in 21st century is the combined effects

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of the depletion of fossil fuels and the awareness of environmental degradation [5, 6]. Therefore, the policy makers and researchers are paying more attention to conduct research in this area. For an instance, before 2020 the European Union countries aim to use the renewable sources and get at least 30% of its potential energy [7, 8]. There are various renewable energy resources such as biomass, wind, geothermal energy, solar, hydro-electric and tidal power. The hybrid renewable energy resources can reduce the emission of harmful gases and reduce the use of imported power [9, 10]. Australia is blessed with abundant resources especially the potential renewable energy, such as huge amount of wind sources, biomass and the larger global solar radiation contains due to its geographical position [11, 12]. During the last two decades, electrical energy consumption in Bangladesh has increased significantly due to dramatic economic expansion and the lack of measurement of energy preservation. It is expected that peak loads will reach to 65 GW in 2027 which causes over $100 billion might be the total investment. Therefore, for sustainable development, an imperative need to build up policies of energy conservation [13, 14]. The fossil fuels has been used to generate most of the electrical power [15], neglecting the use of its renewable energy resources such as wind, biomass and solar to generate electricity.

Aside from nearby preservation endeavors, with expanding burden interest and an unnatural weather change, arrangement producers are taking a gander at environment-accommodating sort of vitality and force assets to maintain the world's remained vitality for the future era individuals [9, 16]. For the force gadgets innovation, the utilization of integrator with the vitality assets and vitality payload space framework is the new development. To full fill the heap requests, the wind and sun powered assets can be assumed a noteworthy part [17, 18].

At present, the installation process of a hybrid energy system is getting easier and flexible. The hybrid energy system is economically, environmentally feasible, and reliable. As a result, the great attractions with the similar power production systems have been all over the world. However, the number of renewable energy resources has been increased dramatically [19, 20]. Meanwhile, there are some important factors such as regulations, costs, and incentives etc. which should be given priority for the rapid change of energy environment. For example, focus on Indonesian energy scenario of fossil fuel where it shows that there is an unfavorable effect on their economy. Mostly, they depend on these fossil fuels which are burned, causes the environmental effects i.e. greenhouse gas emission. Furthermore, rapid annual growth rate is about 7% of Indonesian energy consumption have been recorded after the economic recession in 1998. Although there is limited reservation of fossil fuels but still a high dependency on it. It is a clear indication of increased energy consumption as an economic recovery. After the household sectors, industrial and transportation sectors become the highest energy consumers [21, 22]. Therefore, time has come to take serious action to give priority by the government for adopting renewable energy [23]. Thus, solar energy, hydropower, geothermal energy are such renewable energy sources which can solve this problematic issue. This renewable energy supply can help to lower the emission and decrease the higher emission rate [24]. Utilization of renewable energy is effective only because of higher fuel price in world market [25]. So far, the expansion of electricity generation is badly affected due to hike the prices of fossil fuels and this increment varied about 1.5% in a year [26]. There are five main islands, such as Kalimantan, Sumatra, Sulawesi, Papua and Java which are surrounded by smaller Islands. Those islands are facing the problem of energy demand due to the dependence on the fossil fuels. Thus, it costs so high for transportation of fossil fuel supply from islands to islands [27]. If the natural sources of energy are broadly used then it may stable and balance the fuel price in the market. It may also minimize the dependency of non-renewable energy in near future. The electricity fuel mix for the 10 ASEAN countries in 2007 is illustrated in Fig. 1. The utilization of solar and wind energy system has become increasingly popular due to modular and environment friendly nature. The field of solar–wind has experienced a remarkable growth for the last two decades in its wide spread use of stand-alone to utility interactive solar–wind systems. The stand-alone hybrid energy system is getting the popularity day by day. Power is an imperative variable for industrialization, urbanization, money related development of any nation. There are diverse sorts of conventional and non-traditional vitality sources used to generate power. Sunlight based and wind vitality framework is a standout amongst the most conspicuous wellsprings of vitality. The usage of sun oriented and wind vitality framework has turned out to be progressively prevalent because of particular and environment well-disposed nature.

The scientists consider wind speed and load conjectures mistake and slope rate of ordinary warm units to decide framework hold edges in the wind-hydro-warm interconnected Swedish power framework. Thought is given to the connection of wind homestead gauges inside a locale and between diverse locales and connections there serve levels to a likelihood of as well low a recurrence because of the load and wind vacillations. The Swedish framework has a requirement to serve pool for recurrence control partitioned to that of the save apportioned or assigned for generator and transmission line trips. To be that it may not the situation in numerous power frameworks. Various researchers analyzed the effect of wind power limit on generator stacking levels, the framework hold accessibility furthermore, generator
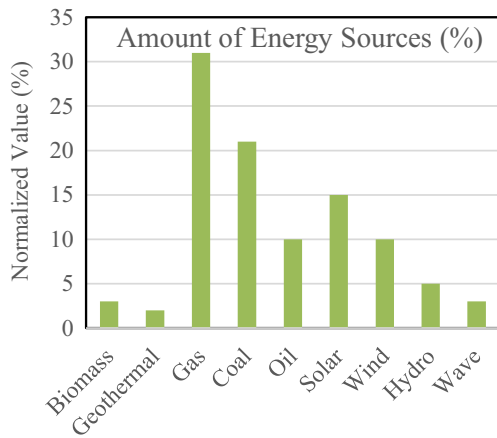
Fig. 1 Amount of energy sources contribution from all over the world [28]

inclining rates. The creators recommend the accessibility of framework will rely on upon whether the anticipated wind power is fused into the unit responsibility [28]. One of the researcher endeavors to measure the specialized results of high wind entrances regarding essential, auxiliary and long haul save as they apply to the interconnected German power framework furthermore, recommends it will bring about a considerable change in the interest for certain sorts of hold with the hybrid renewable energy system

Now, the electrification rate in Indonesia is about 71 % [29]. From the survey, it can be said that most of the remaining 29%, about 80% reside in rural areas and almost all outside of the most populated islands, Java and Bali. Most of the poor people in Indonesia live in the countryside, small islands where it's difficult to access or even limited access to electricity supply. Meanwhile, electricity demand also growing so fast in rural areas. In this study, renewable, non-renewable energy, and the importance of renewable energy is discussed. Besides, it has been illustrated the proceeding of reducing CO_2. Indonesia power producing through renewable system also report in this paper. Furthermore Section 7, proposed a technique that combined different renewable systems for overcoming the limitations of using individual renewable energy in Indonesia.

Methodology

In general, month to month besides annual wind velocity information have already gathered intended for monthly climatological data collected from Indonesian climatological office. Besides, the branch of Day Labor and Regulation (DLR), Germany has showed a strategy for usual wind speed yield is tried for particular separation of region besides commencing the Malaysian climatological division considered information has gathered for Indonesia.

In Fig. 2, a complete schematic diagram of a Wind-Diesel Hybrid renewable energy system has been illustrated. According to the meteorological data and the load demand, a complete design of hybrid energy has been introduced. An AC diesel generator has been connected with the AC Bus-bar. On the DC Bus-bar, the wind turbine and battery bank have been connected. The energy conversion process will be conducted through the number of converters. The battery storages and converters have been synchronized according to the load demand and the electrical appliances. The charge controller and voltage regulator also connected with the converter and power supply. Usually, the power distribution process is conducting according to the priority basis of power supply.

In NEM season, high wind speed and heavy rainfall affects the tourism business significantly. Consequently, the load profile of this resort is high during Southwest Monsoon (SWM; May to September), First Inter monsoon (FIM; March to April), and Second Inter monsoon (SIM; October to November) seasons and slightly low in Northeast Monsoon (NEM; December to February) season [30]. Estimated hourly load data of one year served as the input into HOMER software taking day to day load variance of 10% and time step of 15%. Estimated peak load and average load per day were 1,185kW and 13,048kW, respectively. The list of electrical appliances employed and their power rating is shown in Table 1, while the estimated load profile for one year is shown in Fig. 3. The flow chart in Fig. 4 describes the control and power management strategy of the off-grid HRES with diversion load. According to this block diagram and power management strategy, the master controller
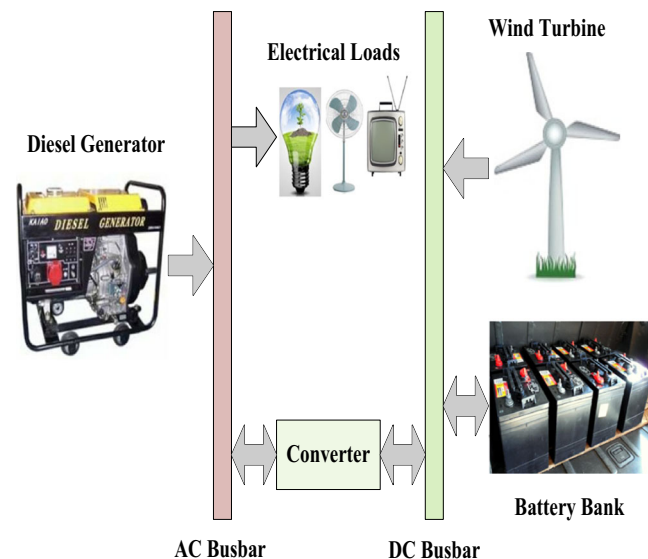
Fig. 2 Schematic diagram of a wind-diesel hybrid energy conversion system

Table 1 Assumed load and its power rating

Name of appliances	Qty.	Running hour/day	Power rating (Watt)
Air conditioning	50	12	1,400
Cable TV	45	5	160
Tube light	300	12	30
Table light	250	5	20
CFL bulb	50	8	42
Overhead projector	2	4	350
Slide projector	2	4	250
Microphone	10	2	15
Refrigerator	50	12	350
Hair dryer	50	3	2,400
Coffee maker	50	3	1,400
Ceiling fan	100	8	80
Oven	10	5	3,400
Desktop computer	10	12	120
Laptop computer	20	12	80
Freezer	35	12	400
Printer	2	3	100
Scanner	2	3	10

will always monitor the output power of PV, wind, diesel generators andstate of charge (SOC) of batteries. Besides, this master controller will make sure that the batteries are not charging with electricity from diesel generator. When the output power from renewable sources ($P_{ren.out}$) greater than load demand (P_{load}) then master controller will allow the battery to stores the renewable energy. The master controller will give a command to the auxiliary controller to operate relay connected to diversion load, when the SOC of battery is maximum. So, the diversion load will work only when the batteries are over charged or the system has excess electricity. On the other hand, when the output power from renewable sources ($P_{ren.out}$) is less than the load demand (P_{load}) then master controller will use storage batteries as back up until storage batteries reached at minimum SOC [31–34].

Techno-Economic Analysis

Techno-economic analysis is very essential to suggest an optimal combination of components in the HRES. The

Fig. 3 Estimated daily-monthly load profile of the resort

Estimated daily load profile in different month in a year
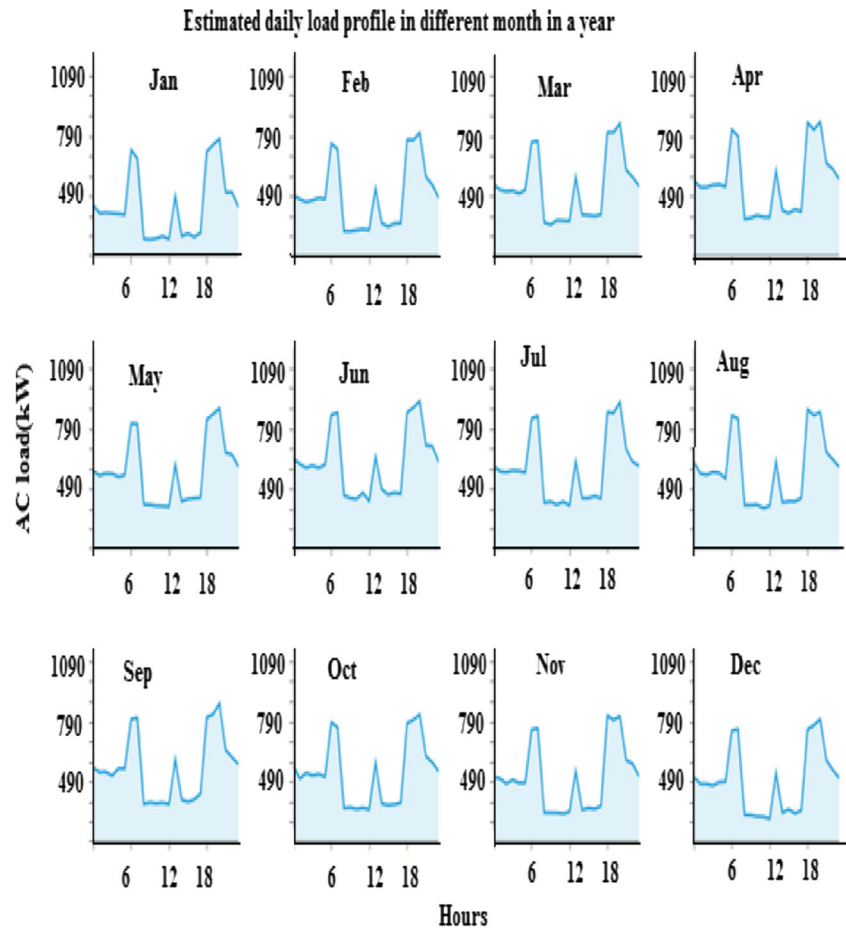
HOMER software has been used to perform this objective, and it is based on the net present cost (NPC) given as.

$$C_{-}(npc, tot) = C_{-}(ann, tot)/CRF(i, R\_proj) \quad (1)$$

where, $C_{ann,tot}$ is the total annualized cost ($/year), i is the annual real interest rate (%), R_proj is the project lifetime (year), CRF represents the capital recovery factor. The CRF is given by the following equation,

$$CRF(i, N) = (i(1+i)^{\wedge}N)/((1+i)^{\wedge}N - 1) \quad (2)$$

where, N is number of years. HOMER do not use nominal interest rate in the computations but real interest rate is computed from real interest rate using following equation.

$$i = (i' - f)/(1 + f) \quad (3)$$

In Eq. 3, f is the annual inflation rate and i' is the nominal interest rate. The lifetime of the project was considered 25 years with zero capacity shortage. The discount and

inflation rate for this study were considered 8 % and 2 %, respectively. The system cost in HOMER software was simulated in US dollars ($USD).

The price of per kWh of electricity is called cost of energy (COE). The COE is computed by dividing total annualized cost by annual electricity served to load which is defined as follows.

$$COE = C_{-}(ann, tot)/L_{-}(ann, load) \quad (4)$$

To calculate the CO_2 emissions from the hybrid energy system the following supporting equations has been introduced:

$$tCO_2 = 3.667 \times m_f \times HV_f \times CEF_f \times X_c \quad (5)$$

where,

$tCO_2 =$　Amount of CO_2 emissions.
$m_f =$　Fuel quantity (Liter)
$HV_f =$　Fuel heating value (MJ/L)
$CEF_f =$　Carbon emission factor (ton carbon/TJ)
$X_c =$　Oxidized carbon fraction.

Another factor must be taken into account that is 3.667 g of CO_2 contains 1 g of carbon. The other components are also detrimental to health as well. It expects that all that carbon gets discharged as either unburned hydrocarbons, CO, or CO_2. So, need to enter the outflows components for unburned hydrocarbons and CO. So, HOMER software can compute the amount of the aggregated carbon gets discharged in those two structures [35–37]. The rest gets discharged as CO_2. Commonly, just a small division of the carbon gets discharged as hydrocarbon and CO, so almost every last bit of it gets transmitted as CO2. On the off chance that needs to intrigue just in CO_2, need to set the UHC and CO emanations elements to zero [38, 39].

Results and Discussion

The modeling and simulation results have been processed by the HOMER software. According to the power management algorithm, the cost of energy and other parameters have been analyzed accurately. The optimized outcomes for a specific group of sensitivity parameters affiliated with average wind speed, global horizontal solar radiation, highest yearly capacity shortage, diesel cost, and renewable fraction are represented emphatically in that optimization software. An optimal hybrid renewable energy system has been designed by HOMER renewable energy software through large number of hourly simulations periodically. Various values for wind speed, solar radiation, diesel cost and least renewable fraction have been contemplated with simulations and these values assuring much more suppleness in the analysis. Figure 5 shows the simulation results considering an off-grid hybrid wind-diesel-battery diesel
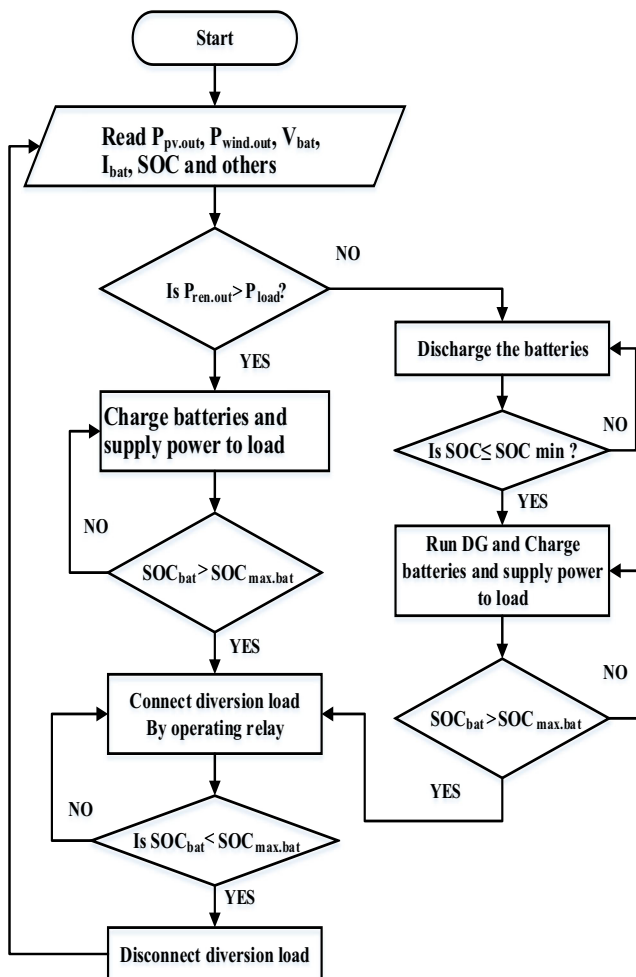

Fig. 4 Flow chart of power management for HRES including diversion load
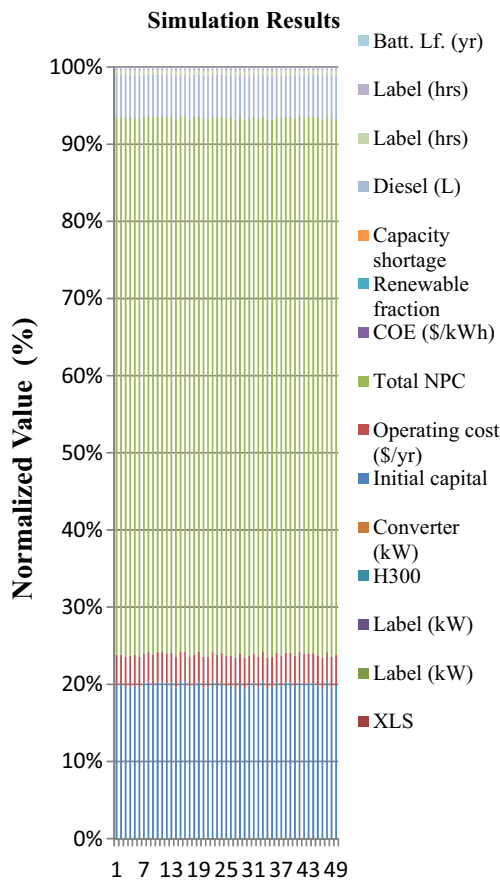
Simulation Results

Fig. 5 Overview of simulation results

cost of 0.4\$/L, highest capacity shortage of 0.03%.USD has been considered as the currency for all costs related with that hybrid system. Figure 6 shows the detail calculation, simulation results and cost analysis with system architecture, NPC, COE, Operating cost, Electrical energy produced by wind turbine diesel generator system, unmet load, excess
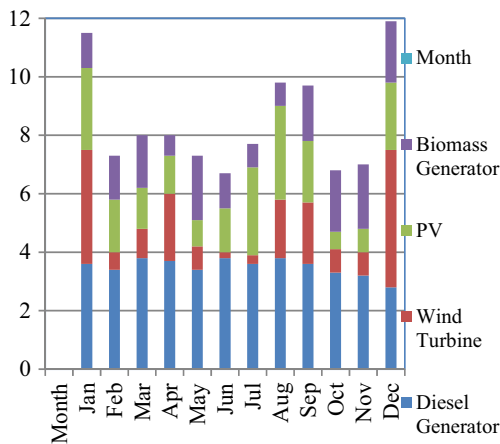
electricity, capacity shortage and renewable fraction of the most monetarily practicable hybrid energy system relevant for the preferred area in both simple case and best cast. At the same time, with a base NPC of USD 160,626 and base COE of USD 0.431/kWh, an off-grid hybrid PV, wind turbine, diesel generator and battery hybrid system is efficiently more feasible and this is observed by the sensitivity analysis. A hybrid energy system can be considered as a most feasible renewable energy system constituted of 18 kW PV module, two wind turbines (10 kW every), a diesel generation with a divisional power of 15 kW (utilizing 3 kW) and 25 storage batteries in cementation to 3 kW converters. In Fig. 7 the cost curve of wind turbines have been shown.

The simulation results reflect the analysis related with all the components. Be that as it may, in the remain solitary mode, the renewable vitality sources go about as present sources nourishing straightforwardly the heaps and the battery bank goes about as a voltage source controlling the AC transport voltage by charging or releasing. The battery converter directs the greatness and recurrence of the heap voltage. The individual RES units can be utilized for maximum power point tracking frameworks to have the most extreme power from the sun oriented PV and twist frameworks in the network associated mode. A similar thing can be relevant in the remaining solitary mode that the battery bank exists as a voltage source to control the AC transport voltage by charging or releasing.

As reported by the investigation and recreation comes about CO_2 emanations rate every year has been discovered 84689.023 Kilotons, which is 16 tones not as much as the customary power plants considering every year as in 2015 for Malaysian viewpoint [40]. The NPC can be shifted by fuel cost, hardware cost, life time, operation and upkeep cost. From that investigation, it can be unmistakably recognized that the NPC for the proposed cross breed vitality framework has been decreased in examination with the NPC
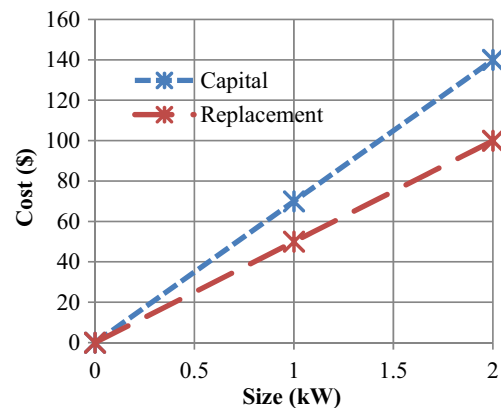

Fig. 6 Energy generated with practicability from the off-grid hybrid PV-diesel-wind-battery system

Fig. 7 Cost curve of wind turbine with the replacement and maintenance cost

Table 2 Comparison of CO_2 emission and NPC between the HRES and Conventional Power Plant

Parameters	Wind-Diesel Hybrid Energy System	Conventional Power Station
CO_2 Emission /Year (Kt)	17,347.984	189,467.00
NPC/Year ($)	160,626.00	293,000.00

for the traditional power station in Malaysian viewpoint as described in Table 2. The NPC for the planned mixture vitality framework is 29.65% which is not as much as the NPC for the traditional power plant considering every year the time of 2009 for Bangladesh atmosphere [41].

Conclusions

In Summary, oil and gas transportation to remote and decentralized area are very challenging issue and time consuming This optimization proposed a hybrid wind-diesel energy system for providing power supply to an off-grid community in isolated islands of specific countries. A detailed simulation has been performed by HOMER software considering manufacturing cost and efficiency for the proposed optimized hybrid wind-diesel energy system. The simulation results confirm that the COE of the optimized system is about USD 0.431/kWh and the NPC of the optimized system is about USD 160,626.00. The total sensitivity analysis, optimization and simulation process has been carried out by HOMER software. The proposed hybrid system also ensured 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 small scale integrated micro turbines. These hybrid energy systems can provide enhanced execution in correlation with alternate energy systems; furthermore we attempted to lessen the expense of force era, contrasted with the routine hybrid renewable energy systems. Sooner rather than later, some more helpful renewable vitality models and legitimate control energy systems can be presented for the hybrid vitality energy systems for the remote zones of the world. According to the optimization and simulation results it can be concluded that the proposed optimized hybrid wind-diesel renewable energy system will be applicable to all over the world where environment, climate, weather and meteorological conditions are comparable and predictable. For example, the countries are Australia, Indonesia, Bangladesh, Myanmar, Thailand, Singapore and other countries would be very potential zone for applicable this optimized hybrid wind-diesel renewable energy system.

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