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Techno-Economic Feasibility of a Hybrid Power Generation System for Developing Economies [†]

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Abstract: This work investigates the feasibility of hybrid power generation system using multiple energy sources to fulfil the electrical demand of a residential community. The system performance is evaluated against the capital investment, Cost of Electricity (COE), CO₂ emissions and Net Present Cost. Results indicate that the hybrid system reduces the COE by 47% compared to grid price and has a negative CO₂ emissions of 24,603 kg/yr due to supplying its surplus energy to the grid. Renewable sources contribute to 80.1% of the overall power produced by the hybrid system. The study finds that the hybrid systems could replace complete dependency on grids.

Keywords: renewable energy; power generation; HOMEREnergy; carbon emission

1. Introduction

Providing continuous power supply to communities has always been challenging in developing economies, especially in isolated areas, due to high costs, transmission losses and power shortages. According to International Energy Agency, 1.1 billion people, predominantly living in rural areas, did not have access to electricity in the year 2016 [1]. Renewable energy based power plants offer a potential solution for connecting societies with clean and cheap power supply [2]. However, the fluctuations in wind speed and solar radiation with seasons and day-night cycles can cause interruption in power supply and therefore possess risks in completely relying on a single renewable energy source. Overcoming this issue requires increasing the size of the renewable energy system, i.e., the solar photovoltaic (PV) modules or wind turbines, with more energy storage capacity thus making the technology financially unfavourable for developing economies.

A hybrid power generation system with more than one renewable energy source allows integration of the different energy resources into an optimum combination and can overcome the fluctuation in power supply. The high intensity availability of one energy source could subdue the unavailability of the other during a certain period, keeping the power production at required levels. Although hybrid systems provide a promising alternative to single source energy system, the sizing of individual energy system and limited operational experience increases the design complexity. Various probabilistic and deterministic approaches have been used to develop models of hybrid systems to find optimum combination of the available resources and assess the system's performance [3–6]. This work evaluates the techno-economic feasibility of a hybrid system generating power for a small community using wind turbine and PV along with grid connection to further ensure uninterrupted power flow.

2. Materials and Methods

The selection of suitable energy resources for the hybrid system is dependent on the factors involving load demand, site location, seasonal variations in load and intensity of energy resources,

etc. The initial step involves selection of an appropriate location with adequate solar radiation and wind speed. In this work, a hypothetical residential community with latitude 31.104605 and longitude 77.173424 has been selected. The data collected from NASA’s surface Meteorology and Solar Energy database for the selected site indicates that the annual solar radiation and monthly average wind speed ranges from 4.76–7.16 kWh/m²/day and 4.7–7.16 m/s, respectively. The annual average electricity consumption of the community is 165.29 kWh/day with a peak load of 24.57 kW. The daily average consumption by month, shown in Figure 1 indicates that the month of January has the highest average electrical consumption of 204 kWh and July has the lowest 136 kWh.

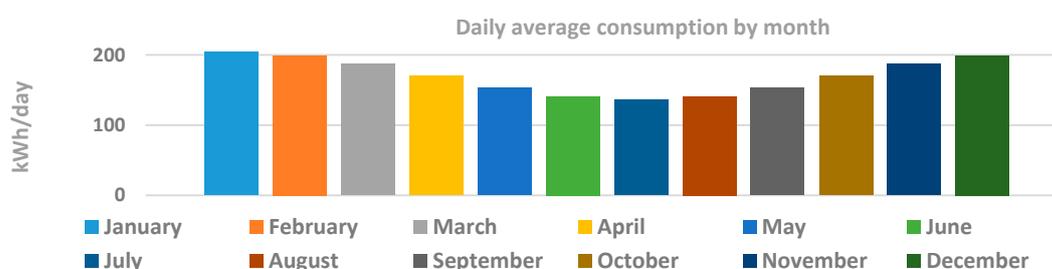


Figure 1. Daily average consumption by month.

The model of the hybrid power plant using a combination of solar, wind and grid is developed in HOMEREnergy, an optimisation tool for modelling energy systems. Any shortage in power generation from the renewable sources will be covered by supply from grid. Parameters such as solar radiation, wind speed, PV and wind turbine capacity, electrical load, equipment cost, operating and maintenance (O&M) cost etc. are used as inputs to the model. The optimisation procedure simulates every possible system configuration by varying capacities of each energy source. All feasible configurations that meet the required electrical load of the community are presented to the user. The selected PV system has an operating lifetime of 25 years and costs £1000 per kW including the cost of shipping, installation and control system [7,8]. The O&M costs were considered as £10 per year per kW. Wind turbines with 10 kW capacity and a lifetime of 25 years are selected for the project. The capital cost and annual O&M cost for one wind turbine unit (10 kW) is £16,000 and £100, respectively [9]. An inverter with 95% efficiency and 15 years of maximum lifetime is selected. The capital and replacement costs of the converter is taken to be £300 per kW. Lead-acid batteries with nominal voltage 12 V and nominal capacity 83.4 Ah or 1 kWh were selected. The maximum lifetime of the battery, regardless of usage i.e. float life is 10 years. The capital cost of each battery is £300 and the replacement cost is £240. The O&M cost is assumed to be £10 per year for each battery. The size of the PV, wind and battery units are calculated through simulations by HOMEREnergy. The optimum combination of the components will generate power at minimum cost.

3. Results and Discussions

The simulation results obtained indicate various system configurations that could be a possible alternative to a complete grid supply. HOMEREnergy performs the energy balance calculations for each system configuration to determine if specified electrical demand is met, and estimates the cost of installation and operation of the system over the project lifetime to calculate the COE for each configuration.

3.1. Power Generation by the Hybrid System

The simulation eliminates all infeasible systems that do not meet the required electrical load and presents the results as a list of optimal combinations of PV, wind turbine, grid, converter and battery, which could be implemented as a hybrid system setup. Table 1 shows the simulation results of the hybrid configuration with the lowest COE. The results indicate that the most optimised system have contribution from all three sources i.e., wind, solar and grid. This system will require a 46.5 kW PV

unit operating for 4377 h/year and one 10 kW wind turbine unit operating for 7168 h/year. It produces 123,814 kWh of electricity annually, with 80.1% coming from PV and wind turbine. The AC primary load of the community is 60,330 kWh, which is only 48.7% of the total production of 123,814 kWh by the hybrid system. The remaining 63,483 kWh of the excess energy is sold to the grid. The levelised COE from the hybrid plant is £0.029 per kWh, which is ~47% lower compared to the grid rate of £0.055. The payback for the hybrid system is calculated to be around 13.8 years.

Table 1. Simulation results for the hybrid energy system.

Quantity	Units	Value	Quantity	Units	Value
PV capacity	kW	46.5	Total electricity production	kWh/yr	123,814
Production by PV	kWh/yr	81,633	Renewable fraction	%	80.1
Wind capacity	kW	10	Total electricity consumption	kWh/yr	60,330
Production by wind turbine	kWh/yr	17,626	Energy sold to Grid	kWh	63,483
Energy purchased from Grid	kWh	24,554	Levelised COE	£/kWh	0.029

3.2. Costs Involved in the Hybrid System

Table 2 presents the summary of the costs (in £) involved in the hybrid system. The initial capital cost of the overall system is £62,820 and the O&M cost is -£15,961. The negative value of the O&M cost reflects the savings obtained in O&M costs of the grid as a result of supplying the excess electricity of 63,483 kWh produced by the hybrid system to the grid. This reduces the net present cost of the hybrid system to £47,044. The land area required for installation of the hybrid system is not taken into consideration for cost calculations.

Table 2. Cost summary of the hybrid power generation system.

Component	Initial Capital	Replacement	O&M	Fuel	Salvage	Total
10 kW Wind Turbine	16,000	0	1278	0	0	17,278
Lead Acid Battery	300	208	127	0	-28	608
Flat plate PV	46,509	0	5945	0	0	52,455
Inverter	10	4	0	0	-0.85	14
Grid	0	0	-23,312	0	0	-23,312
System	62,820	213	-15,961	0	-28	47,044

3.3. Environmental Aspects of the Hybrid System

A comparison between the hybrid system and grid based on carbon dioxide (CO₂), nitrous oxides (NO_x) and sulphur dioxide (SO₂) emissions is shown in Table 3. A complete power supply to the community from grid will emit 38,129 kgs of CO₂ per annum. On the other hand, a hybrid system has a negative CO₂ emission rate of 24,603 kg per annum since the excess electricity produced by the hybrid system using carbon free renewable resources is sold to the grid.

Table 3. Emissions from a hybrid system and a grid supply system.

Quantity	Units	Hybrid System	Grid
Carbon Dioxide	kg/yr	-24,603	38,129
Sulfur Dioxide	kg/yr	-107	165
Nitrogen Oxides	kg/yr	-52.2	80.8

3.4. Comparison of Hybrid System with Standalone System

In the standalone system, a diesel generator unit replaces the grid to maintain continuous power supply. The generator unit used has an operational lifetime of 15,000 h and costs £240 per kW of rated output. It's O&M cost is considered as £0.012 per hour and fuel price as £0.70 per litre. The simulation results indicate that the lowest levelised COE obtained for the standalone hybrid system consisting a

21.6 kW PV unit, two 10 kW wind turbine units and a 28 kW diesel generator unit is £0.255 per kWh; 4.6 times higher than the grid electricity price. The system produces 91,466 kWh/year in which the renewable's contribution is only 69.7% compared to 80.1% in case of the hybrid system with grid connection. The standalone system produces 27,928 kWh of excess energy that could not be sold since the system is not connected to the grid. The total costs involved in the lifetime of the standalone hybrid system are £196,831; four times higher than the grid connected hybrid system. The system also produces 18,041 kg/yr of CO₂ by burning diesel. The study shows that a standalone system should only be used where a grid connection is not available, i.e. extremely remote locations.

4. Conclusions

Both solar radiations and wind speed could show huge variations in their intensity at certain places and times, thus making them less reliable as a continuous source of energy for power generation. A well-designed power generation system combining both solar and wind energy can be more consistent and economical. This work examined the performance of a hybrid power generation system comprising a combination of solar, wind and grid designed to fulfil the electrical demand for a residential community. The findings indicate feasibility of the hybrid power generation system. The study also showed that the hybrid system can significantly reduce the COE by 47% and has a negative GHG emission.

Author Contributions: S.M. and A.A. conceived and designed the power generation system models used in the study. S.M. analyzed the data and A.A. contributed tools required for the work; S.M. and A.A. jointly wrote the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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