PRE-FEASIBILITY STUDY OF AN OFF-GRID HOUSE IN EDIRNE-TURKEY

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ABSTRACT

This paper presents a pre-feasibility study on options for providing power to an off-grid house in Edirne-Turkey. A hybrid system which is produced electrical energy from diesel generator, solar radiation via solar cells and wind energy for an off-grid house is considered. In this analysis, NREL's optimization tool HOMER software is used for the simulation, sizing and optimization of hybrid system. A number of energy component models are used to determine the suitable system based on cost and availability of resources. The results of example problem then used to demonstrate how the cost of energy is affected by the various combinations of diesel generator, wind turbine, PV array, battery, and power converter modules.
KEYWORDS: Hybrid energy systems; Pre-feasibility study; Renewable energy; Sizing hybrid energy systems

1. Introduction

In the recent time, many countries have considered renewable electricity production as an attractive way of reducing CO2 emissions, decreasing dependency on foreign fossil energy supplies, and generating domestic employment. Ever since the beginning of 1990s, many countries have had national programs for the stimulation of renewable electricity production. Generally, renewable sources of electricity production are divided into six main categories according to their source: geothermal energy, hydraulic energy, wind energy, wave energy, biomass, solar energy and can be converted to the electrical energy. Electrical energy can be produced from these renewable energies by using different application.

A complete renewable energy system includes all the other components required to create a functioning system, whether it be to feed energy in to the grid or to be used in stand-alone off-grid applications. In off-grid applications, currently, renewable electricity production is most competitive in isolated sites, away from the electric grid and requiring relatively small amounts of power, typically less than 10 kW. A review of the literature shows that off-grid or grid connected applications in different forms such as PV–diesel [1, 2], wind–diesel [3], PV–wind–diesel [4], grid–

PV–wind [5, 6], grid–PV–diesel generator [7] have been studied in the context of some specific sites. Generally, there are many energy alternatives being combined with energy conversion technologies and market forces. However, to produce electrical energy from wind energy using wind turbine and from solar radiation via solar cells are more popular applications than others.

This paper presents a pre-feasibility study on options for providing power to an off-grid house in Edirne-Turkey. We considered three power sources: photovoltaic, wind turbine, and diesel generator, as well as battery storage. The options for hybrid system is simulated by using the National Renewable Energy Laboratory (NREL)'s Micropower Optimization Model Software (HOMER version 2.16) [8]. A number of energy component models are used to determine the suitable system options based on cost and availability of resources. The results of example problem then used to demonstrate how the cost of energy is affected by the various combinations of diesel generator, wind turbine, PV array, battery, and power converter modules.

2. Description of hybrid system

2.1. General structure of hybrid system

The proposed hybrid system consists of a diesel generator, a wind turbine, a PV array, a battery and a power converter. A general scheme of a stand-alone small power generation system is shown in Figure 1. Electrical energy obtained from the diesel generator supports the combined system when the energy obtained from PV array and wind turbine is insufficient for primary electrical load. Wind and solar energy resources of Edirne's are considered for this study.

2.2. Photovoltaic array model

Photovoltaic systems convert the energy of the sun directly into electricity, which can then be stored and used where there is no power grid, or working together with centralized electricity networks to save energy and conserve fuel. Normally, the installation cost of PV arrays may vary from \$6.00 to \$10.00/W. In general, a 1 kW solar energy system's installation, and replacement costs are taken as \$7000 and \$6000, respectively [9]. In this analysis, twenty different sizes are considered, which ranges from 0 to 4 kW. The lifetime of the PV arrays are taken as 40 years and the slope of PV array is taken as 41 degree. Figure 2 shows PV power versus global solar irradiation in Edirne.

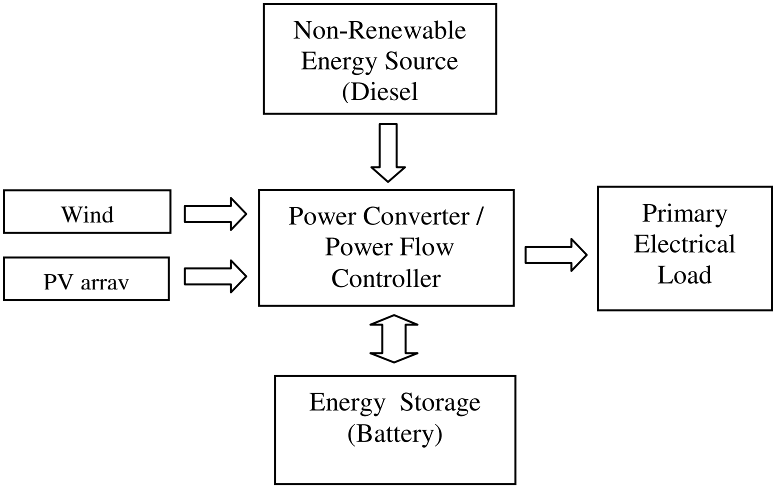

Figure 1. General scheme of an off-grid hybrid power system.

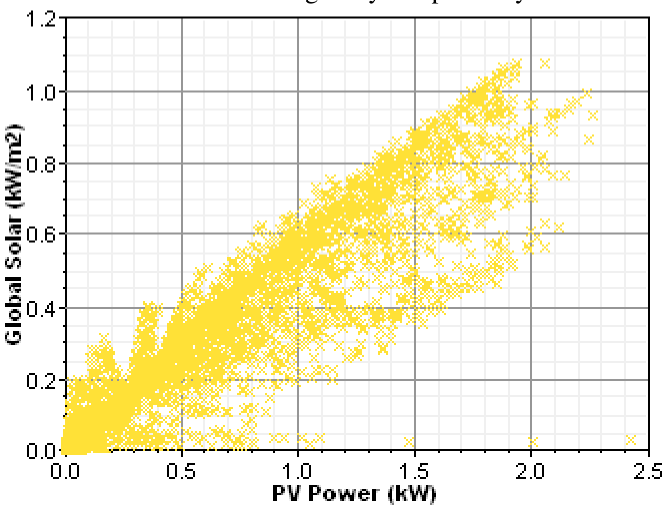

Figure 2. PV power versus global solar irradiation

2.3. Wind turbine model

Availability of electrical energy from the wind turbine depends significantly on wind speed. Wind system, itself, cannot satisfy constant load demands due to variation of wind speed from one hour to another. Therefore, the biggest problem in hybrid systems separately use of wind energy and solar energy is their discontinuity. In this analysis, Bergey Wind

Power's BWC XL1 model is considered (Figure 3). It has a rated capacity of 1 kW and provides 48 V DC as output. Cost of one unit is considered to be $3900 while replacement and maintenance costs are taken as $3900 and $100/year [10]. To allow the simulation program find an optimum solution, provision for using 0 (no turbine), 1 or 2 units is given. Lifetime of a turbine is taken to be 20 years.

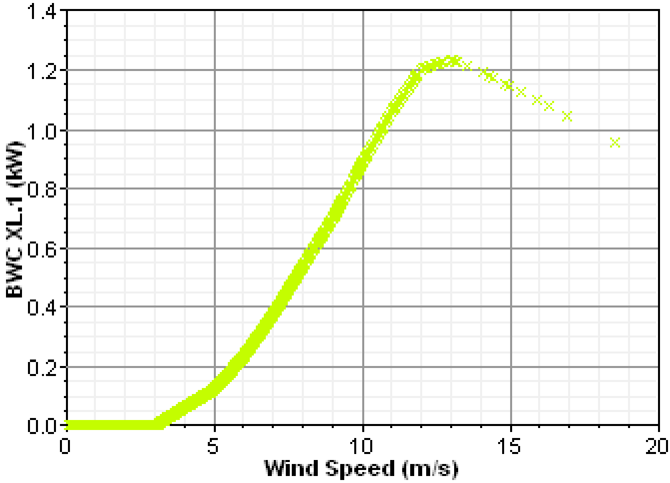

Figure 3. Wind turbine BWC XL1 versus wind speed

2.4. Diesel generator model

In general, the cost of a commercial diesel generator may vary from $250 to $500/kW [8]. In this analysis diesel generator cost is taken as $350/kW. Replacement and operational costs are assumed to be $ 300/kW and $0.150/h, respectively. Five different sizes considered, which are 0 (no diesel generator), 1, 2, 3 and 4 kW. Operating lifetime is taken to be 10,000 h [8]. Diesel price is used for sensitivity analysis and four discrete values (0.8, 1, 1.2, and 1.4 $/L) were introduced. At present, diesel price is around 1.2 $/L in Turkey and for a very remote location this could increase up to 1.4 $/L.

2.5. Battery model

Commercially obtainable models, such as Trojan Battery Company's Trojan L16P models (6 V, 360 Ah, 1,075 kW h) are considered in the hybrid system. Cost of one battery is $220 with a replacement cost of $220. The battery stack may contain a number of batteries (0-30).

2.6. Power converter model

A power electronic converter is required to maintain flow of energy between the AC and DC components. For a 1 kW system, the installation and replacement costs are taken as $750. Five different sizes of converter (1, 2, 3, 4 and 5.0 kW) are taken in the analysis. Lifetime of a battery unit is considered to be 15 years with an efficiency of 90%.

2.7. Economics and constraints

Taking into consideration the project lifetime to be 25 years, the annual real interest rate is taken as 8%. Maximum annual capacity shortage is 2% and operating reserve, as percentage of hourly load is 6.5%. For renewable output, this reserve is 25 and 25% for solar and wind energy, respectively.

3. Results

In example problem, the simulations are performed in the range of primary load from 10 to 20 kWh/d for different diesel prices. Obtained results given in Figure 4-8 and Table 1. The optimal system type graph shows that a wind-PV-diesel-battery system is the most suitable solution for stand-alone applications in Edirne. A wind-PV-diesel-battery system for distant homes having an energy rating of 10 kW h/d (1.65 kW peak) should include one 1 kW wind turbine, one 1 kW converter, one 2.0 kW PV array, one 1 kW diesel generator and 16 unit battery. Details of various cost indices are shown in Table 1.

Table 1 Wind-PV-diesel-battery system cost analysis

Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
PV Array	14,000	1,312	-62	0	0	1,250
BWC XL.1	3,900	365	38	100	0	504
Generator	350	33	28	25	343	429
Battery	3,520	330	217	64	0	611
Converter	750	70	19	0	0	89
Totals	22,520	2,110	241	189	343	2,882

Figure 4 shows the variation of renewable energy fraction and cost of energy for different diesel price and primary load. It is apparent that the highest values of renewable energy fraction are reported for the case of maximum diesel price. The maximum cost of energy is reported for the case of 10 kWh/d primary load and 1.4 $/l diesel price. It can be observed that the cost of energy increases as renewable energy fraction increases. The lowest renewable energy fraction and cost of energy is reported for the case of 14 kWh/d primary load and 0.8 $/l diesel price.

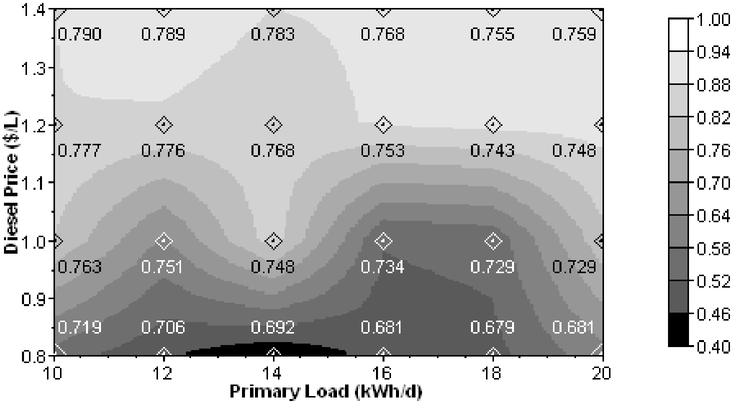

Figure 4. The variation of renewable energy fraction and cost of energy for different diesel price and primary load.

Figure 5 shows the variation of total annualized cost and renewable energy fraction for different diesel price and primary load. The total annualized cost increases as primary load and diesel price increases. The maximum total annualized cost is reported for the case of 20 kWh/d primary load and 1.4 $/l diesel price.

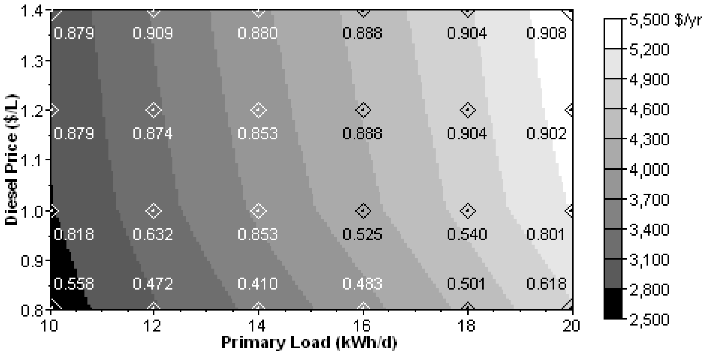

Figure 5. The variation of total annualized cost and renewable energy fraction for different diesel price and primary load.

Figure 6 shows the variation of monthly average electric production with diesel price 1.4 $/L and primary electrical load 10 kWh/d. As evident in Figure 6, PV array cannot provide a continuous source of energy due to the low availability during the no-sun period and winter. Also, wind system cannot provide a continuous energy during the summer. For this reason, electrical energy obtained from the diesel generator supports the combined system when the energy obtained from PV array and wind turbine is insufficient for primary electrical load.

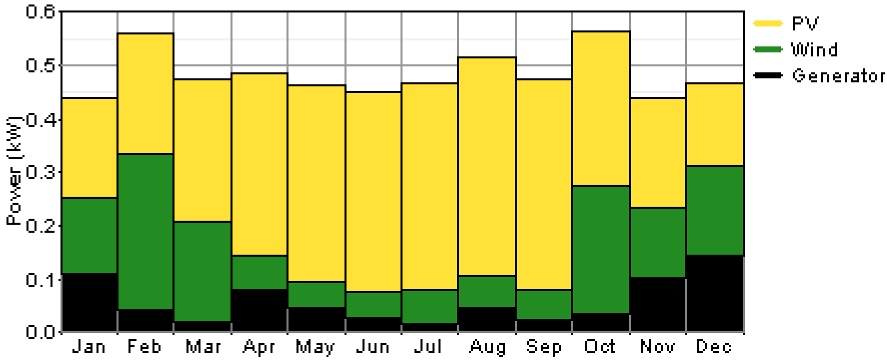

Figure 6. The variation of monthly average electric production with diesel price 1.4 $/L and primary load 10 kWh/d.

Figure 7 shows the power production of system components with diesel price 1.4 $/L and primary electrical load 10 kWh/d during the May and December respectively. Electrical energy obtained from the diesel generator and wind turbine increases as production of PV array decreases during the December. With increased solar energy during the May, production of wind system and diesel generator reduces in a proportionate manner.

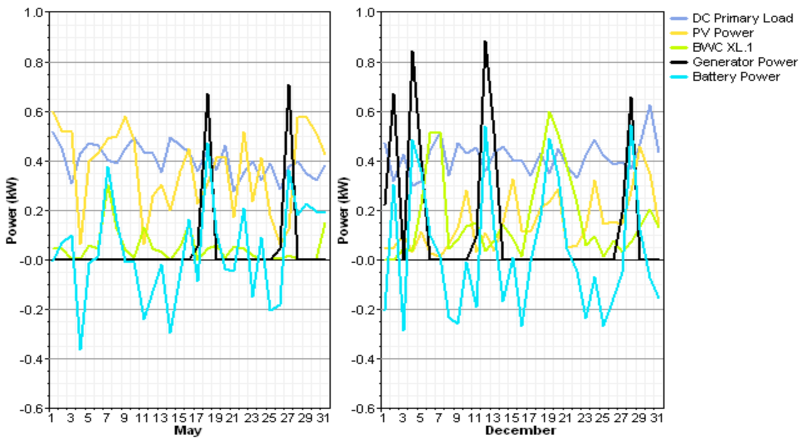

Figure 7. Power production of system components during the May and December with diesel price 1.4 $/L and primary electrical load 10 kWh/d.

Finally, electrification cost of stand-alone and grid extension is presented in Figure 8. Breakeven grid extension distance is 2.69 km. It is obvious that, instead of using single stand-alone units, electrification cost of a grid-connected system would be cost-competitive less than 2.69 km grid extension distance.

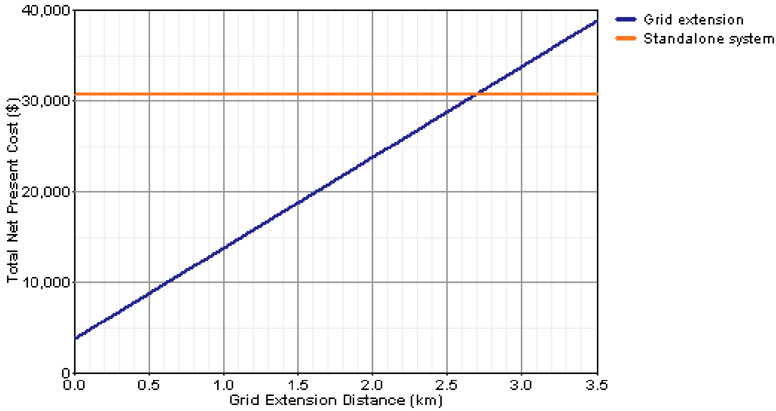

Figure 8. Electrification cost for grid extension and stand-alone system

4. Conclusion

A combination of energy sources (wind, solar, and diesel generator) and storage system (battery) were considered for providing power to an off-grid house in Edirne, Turkey. In this analysis, NREL's optimization tool HOMER software was used for the simulation, sizing and optimization of hybrid system. It is obvious that, renewable energy based solar and wind energy with storage is not cost-competitive against conventional fossil fuel based stand-alone or grid interfaced power sources. However, many countries have considered renewable power production as an attractive way of reducing CO2 emissions, decreasing dependency on foreign fossil energy supplies, and generating domestic employment. On the other hand, only for very cheap gasoline, very light winds and solar energy does HOMER recommend the generator/battery system without renewable power. The optimal system type graph shows that a wind-PV-diesel-battery system is the most suitable solution for stand-alone applications in Edirne. Cost of energy for such a small system in Edirne (delivering ~10 kWh/d, peak ~1.65 kW), is around 0.790 $/kWh. For a generator-converter or generator-battery-converter system, cost of energy is 2.062 $/kWh and 1.118 $/kWh respectively. Instead of using single stand-alone units, electrification cost of a grid-connected system would be cost-competitive less than 2.69 km grid extension distance.

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