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OPTIMAL WIND/PV/BIOMASS HYBRID POWER SYSTEM FOR FOREST WATCHTOWERS

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Abstract

This study presents the design specifications of an optimal wind/PV/biomass hybrid power system to meet the energy demand of a forest watchtower in the Longoz Forests, located in the Yıldız Mountains region of forest-rich city of Kırklareli. Forest waste is used as a source of biomass. Hourly wind and solar data on Kırklareli for the years 2012-2014 is taken from General Directorate of Renewable Energy. Having thus collected the wind, solar, and biomass data, the HOMER software is used to model the hybrid power generation system. Taking into account the cost of the energy and total net present cost, the results of the study are then used to determine the optimal wind turbines, solar panels, biomass generators, converters, and the number of batteries. The optimal hybrid power generation system needed to meet the energy demand is then configured, and a precision analysis is done using wind speed and biomass price ($/t).
Keywords: Forest watchtower, Hybrid power system, Wind/PV/biomass

ORMAN GÖZETLEME KULESİ İÇİN OPTİMUM RÜZGAR/PV/BİYOKÜTLE HİBRİT GÜÇ ÜRETİM SİSTEMİ

Özet

Bu çalışmada, bir tarım ve orman şehri olan Kırklareli ilinin Yıldız dağları bölümünde bulunan Longoz ormanlarındaki bir orman gözetleme kulesinin enerji ihtiyacını karşılayacak optimum rüzgar/PV/biyokütle hibrit güç üretim sistemi tasarlanmıştır. Biyokütle enerji kaynağı olarak tarımsal atıklar değerlendirilmiştir. Kırklareli'nde 2012-2014 yıllarına ait saatlik rüzgar ve güneş verilerine Yenilenebilir Enerji Genel Müdürlüğü'nden erişilmiştir. Rüzgar, güneş ve biyokütle verileri ışığında hibrit güç üretim sistemi modeli HOMER yazılımı kullanılarak modellenmiştir. Çalışmanın sonucunda enerjinin birim maliyeti ve toplam net maliyet dikkate alınarak, optimum rüzgar türbini, güneş paneli, biyokütle generatörü, dönüştürücü ve batarya sayısı belirlenmiştir. Enerji ihtiyacını karşılayacak optimum hibrit güç üretim sistem konfigürasyonu oluşturulup, rüzgar hızı ve biyokütle fiyatı ($/t) parametreleri kullanılarak hassasiyet analizi gerçekleştirilmiştir.
Anahtar Kelimeler: Orman gözetleme kulesi, Hibrit güç üretim sistemi, Rüzgar/PV/biyokütle.

1 Introduction

In today's world, energy is of vital importance in technological and economic developments. There are many living spaces not having connection with national energy grids and being located far away from these networks in the world. It is not possible to meet the requirements of these living spaces by means of conventional energy sources since distribution and transmission of energy to distant places from the network contain high costs [1]. Some factors such as rapidly increasing world population, technological developments and socio-economic development increase energy consumption in the world. However, while the amount of energy consumed is increasing, fossil fuel reserves decrease rapidly. As a result of the consuming fossil fuels, some gases such as CO2, NOx and CO released into atmosphere also lead to some negative results such as environmental pollution, global warming and seasonal changes by greenhouse gas effect. Together with all these negative effects; tendencies of countries to renewable and alternative energy resources to reduce foreign dependency increase day by day [2]. These energy resources whose sources are free and unlimited, environmentally friendly, clean, renewable and sustainable are wind, solar, geothermal, hydrogen, wave and biomass. When compared with conventional energy resources, CO2 emission, greenhouse effect and global warming effect of renewable energy resources are too little. In this context, using their own domestic resources by the countries is an important factor to reduce foreign dependency in energy. Even though using renewable energy resources have several advantages, they have also some disadvantages. When renewable energy resources are used alone, they are discontinuous interrupted resources. To meet this deficit, hybrid systems with which renewable energy resources (wind/PV/battery, PV/hydrogen/battery, wind/PV/biomass, etc.) are used together have been developed [3]. There are a lot of scientific studies in literature deal with hybrid power generating systems done by means of using HOMER software. If we summarize these studies; Maherchandani and friends planned a system that met electricity requirement economically by means of an off grid Biomass/PV/wind hybrid power generating system in a place in which the mains did not access. While main energy resource

of hybrid power generating system is biomass, PV panels and wind turbine are supportive additional resources. They made investigations on energy potentials of each energy resource at an off grid Biomass/PV/wind hybrid power generating system and made a simulation of the system by HOMER software by means of using the results obtained[4]. Similarly, Liu and friends made feasibility analysis for PV/wind/Biomass/battery hybrid power generating system to meet the electricity requirement of a place in Australia including mainly residential buildings. They analyzed a system having 200kWh/per day load in terms of environment and economy. In this study, some costs such as system cost, energy unit cost, emissions and greenhouse effect were calculated. They obtained monthly and daily wind speed and solar radiation data for six different districts in Australia by means of using RetScreen software. By means of using the data obtained, they made simulation of hybrid power generating system by HOMER software [5]. Maklad suggested PV/wind/Biomass/battery hybrid renewable energy system. He determined and evaluated optimization procedures to size off grid hybrid renewable energy system designed for urban residential buildings in Armidale, Australia [6]. Pradhan and friends evaluated the performance of PV/wind/biomass hybrid power generating system by means of considering the data of average solar radiation, biomass amount and average wind speed and using HOMER software at simulation works. They examined the simulation results for performance evaluation of an off grid PV/wind/Biomass generating unit of a place far away from the mains [7].

2 The potential of energy resources

The energy which will be produced at Wind/PV/Biomass hybrid renewable power generating system changes in proportion to the potential of energy resource types constituted hybrid power generating system in a place planned to be founded for a hybrid power generating system. Therefore, the potential of each energy resource must be evaluated separately.

2.1 Wind energy potential

Hourly wind speed data belonging to 2012-2014 period (years) in Kırklareli were reached from General Directorate of Renewable Energy. When these data were analyzed, it was seen that the lowest average wind speed was 3,3m/s in October, and the highest average wind speed was 4,9m/s [8].

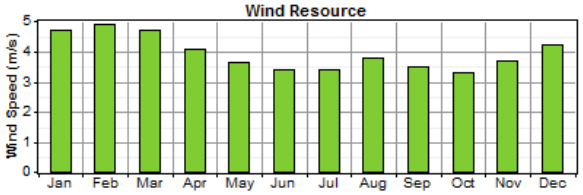

Figure 1. Monthly average wind speed values in Kırklareli region

By means of considering wind speed value, the hourly wind measurement data taken were transformed into frequency formand turned into Weibull probability density distribution curve. Thus, k and c parameters which are Weibull parameters were calculated by means of using HOMER software. k=1,56 and c=3,34m/s were obtained. Weibull distribution graphics is seen at Figure 2.

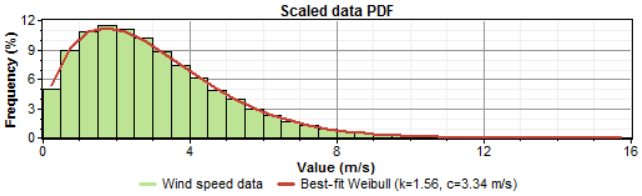

Figure 2. Weibull distribution for Kırklareli region

2.2 Solar energy potential

Hourly solar radiation data belonging to 2012-2014 period (years) in Kırklareli were reached from General Directorate of Renewable Energy [9]. Monthly average solar energy density value is seen at Figure 3. While annual average solar energy density value was being calculated as 4,425kWhm-2d-1, annual average clearness index was calculated as 0,506. By means of using HOMER Graham algorithm, solar radiation values for each hour of the year are determined. This algorithm produces real hourly data by means of using latitude information and monthly average data and can be applied easily.

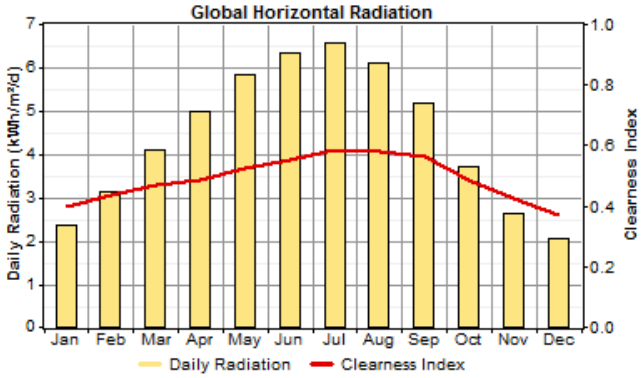

Figure 3. Solar radiation data for Kırklareli region

2.3 Biomass energy potential

Biomass potential is quite high in Thrace region. Agriculture and livestock breeding sector is developed in the region and it has the characteristics of being the locomotive in terms of sector in Turkey. If animal and agricultural wastes in Thrace region are utilized, they can contribute to meet energy requirements of the region. As biomass energy resource in Kırklareli, the energy potential which will be obtained from rice stalk will be evaluated. In this context, total rice stalk production in Kırklareli is 27.710 tons/year. The rice stalk to be used to produce energy by way of rice straw is calculated as total rice stalk x % 60. Hence, when the required calculations are made, this value is found as16.626 tons/year. However, HOMER software makes a transaction as ton/day as unit. Therefore, the value of 16.626 ton/year was transformed into the value of 45,55 ton/day. Energy production potential by way of rice stalk in Kırklareli is seen at Figure 4 [10].

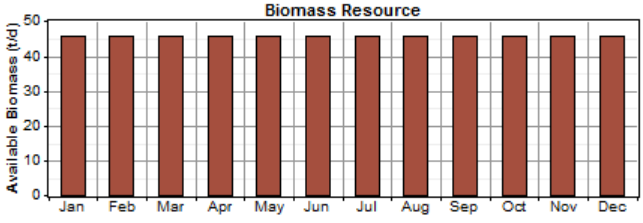

Figure 4 Energy production potential by way of rice stalk in Kırklareli

3 Components of hybrid renewable power generating system

Hybrid renewable power generating system consists of PV panel, wind turbine, biomass generator, inverter and battery. The block diagram of the system is seen at Figure 5.

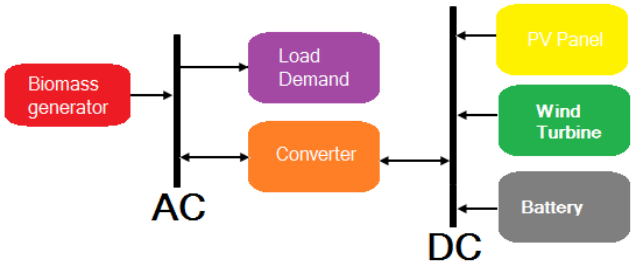

Figure 5. Component of the hybrid renewable power generating systems

3.1 Load

It is planned to meet the energy requirement of the Forest Observation Tower. Babatepe Forest Observation Tower whose energy requirement will be met and daily load profile of the tower are seen at Figure 6. The peak and average load values of the tower are 4,6kW, 6,92kW respectively. Daily 95kW average consumption is in question. Daily load profile of the Observation Tower is seen at Figure 6 [11].

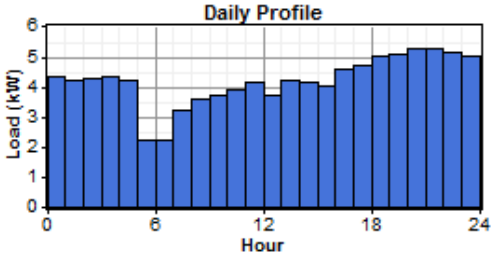

Figure 6 Daily load profile of the Babatepe Forest Observation Tower

3.2 Biomass generator

Biomass generator works by 1kW at AC. Capital and replacement cost of the generator are 4000$ and 3200$ respectively. At simulation phase, power-value range of the biomass generator is evaluated as 2,4,6,8 kW. The lifetime of the generator is 15.000h [12].

3.3 PV Panel

Each PV panel has 1000W nominal power and 12V nominal voltage. It must be taken into consideration that PV panel can produce energy at nominal power only from 6:00 in the morning to 18:00 in the evening. Otherwise, energy production at night cannot be realized during the period after 18:00. Therefore, PV panel output power is 0W. The cost of 1kW PV panel is 7000$ and its replacement cost equals to the cost of the panel. Operating and maintenance costs are neglected because they cost too little. At HOMER software, PV panel power values vary between (5, 10, 15, 20kW) values. The value range given for PV panel power is used to determine the optimum configuration of the hybrid system [13].

3.4 Wind Turbine

Wind turbines are used to produce useful available energy by way of wind. Wind turbine output is AC or DC. At hybrid system, Generic 10kW DC wind turbine has been chosen. The lifetime of the turbine is given as 15 years. Initial cost and replacement costs of the wind turbine is 32.700$, and 22.300$ respectively. Operating and maintenance cost is 560$/ year. By means of using HOMER software, the number of wind turbine is given at 0-4 range to determine the optimum configuration at hybrid power generating system. Hub height is given as 20m [14].

3.5 Battery

Surrette 4KS25P was chosen as battery at hybrid power generating system. Battery nominal capacity is 1900Ah (7,6kWh). Nominal voltage is 4V. By means of using HOMER software, battery number is given as (0-20-40-60-80-100) to determine the optimum configuration at hybrid power generating system. Capital, replacement and maintenance and operation costs of the battery are 231$, 210$ and 10,5$/year respectively [15].

3.6 Converter

The power produced by way of PV panel and wind turbine must be converted into AC power to be used to meet the load. Therefore, a converter is needed. Because hourly maximum load value of the Forest Observation Tower was 2,4kW, its converter power was chosen as 3kW and the efficiency was % 90. The initial cost is 900$/kW, the replacement cost is equal to the initial cost. Maintenance and operation cost is neglected because it costs too little. By means of using HOMER software, the converter power was chosen at (0- 3- 6kW) power range to determine the optimum configuration at hybrid power generating system [16].

4 Operating characteristics of hybrid power generating system

The principles and assumptions below mentioned were taken into consideration at hybrid system which was designed.

- Biomass generator, wind turbine and PV panel are the resources which will meet the load demand. After the load demand is met, the batteries will be charged by means of the remaining energy.
- The converter will be used to convert the load demand, AC into PV panel and again convert wind turbine outputs, DC into AC.
- In case of biomass generator, wind turbine and PV panel cannot meet the demand, the load demand will be met by means of the batteries.

- At sensitivity analysis, wind speed values were realized parametric analysis between (3m/s-7m/s), and biomass price varied between (0-30$/ton) range.
- The project lifetime was determined as 25 years.
- Annual interest rate was taken as % 8 from the data of Central Bank of the Turkish Republic [17].
- Renewable fraction rate of the hybrid system is %100.
- The system is environmentally friendly because it is completely renewable and does not contain emission.

5 Results and discussions

Aim of the optimization process is to determine optimal values of each decision variable such as wind turbine number, battery number, converter dimension, etc. At optimization process of this study, HOMER software determines all different system configurations, eliminates inappropriate system configurations and determines appropriate configurations as the lowest total net present cost of the optimum system configuration. In this study, techno economic analysis of hybrid system was made considering optimum values of hybrid system components as two economic parameters. They are total net present cost and cost of energy. Simulation period is 14 minutes and 10 seconds. When the graphics which was obtained following the realization of sensitivity analysis, it was observed that energy was not produced by way of wind turbine when wind speed was between 3m/s-3.6m/s range , therefore, the optimum hybrid power generating system in this range was PV/Biomass/Battery.

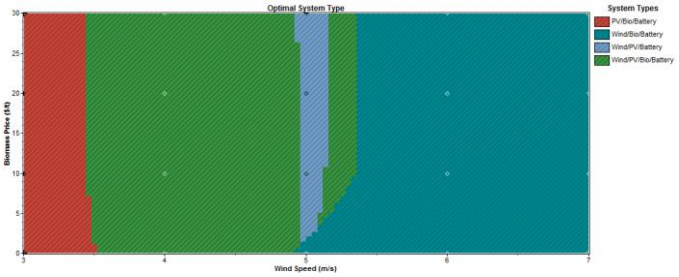

Figure 7 Sensitivity analysis for the Forest Observation Tower

It is seen that when the wind speed is at 3,7m/s - 4,9m/s range, biomass price does not have much effect and Wind/PV/ biomass/battery hybrid power generating system is the optimum configuration in this range. Wind/PV/Battery is the optimum configuration of hybrid power generating system in a section as small as a trapezoid area at 4,94m/s - 5,20m/s range. Similarly, at 5,21m/s – 5,45m/s range, Wind/PV/Biomass/ battery hybrid power generating system in a section as big as a trapezoid zone is the optimum configuration. At 5,46m/s – 7,0m/s range, Wind/Biomass/Battery is the optimum configuration because wind turbine production is at high levels in this range.

All of the hybrid system configurations are seen at Table 1 when it is taken into consideration that average wind speed in the district that the Forest Observation Tower in Kırklareli is located is 3,94m/s and biomass unit price is 20$/ton. When Table 1 is examined, it is seen that the optimum configuration is Wind/PV/biomass/battery hybrid power generation system by 0,880$/kWh cost of energy and 143.669$ total net present cost value. Here, the optimum configuration consists of 5kW PV panel, 1 kW wind turbine, 2kW biomass generator, 40 batteries and 3 kW converter. It is seen that initial capital and operating cost of this system are 87.640$ and 4,383$/year respectively. Biomass generator works 862 hours in total. Other options are presented at Table 1. (PV/Biomass/Battery, Wind/PV/Battery, Wind/Biomass/ Battery).

Table 1. Optimum hybrid power generating system configurations

PV Panel (kW)	Wind turbine (kW)	Biomass Generator (kW)	The number of Batteries	Converter (kW)	Initial Capital ($)	Operating Cost ($/yıl)	Total net present cost ($)	Cost of Energy ($/kWh)	Biomass	
									(ton)	hours
5	1	2	40	3	87.640	4.383	143.669	0,88	5	862
15	-	2	40	3	124.940	2.739	159.950	0,97	2	353
10	1	-	60	3	119.260	3.208	160.265	0,98	-	-
-	2	2	100	3	99.200	6.15	177.752	1,08	5	791
20	-	-	60	3	156.560	2.799	192.334	1,17	-	-

6 Conclusions

In this study, a hybrid power generating system has been designed which is environmentally friendly and consists of %100 renewable resources to meet the energy requirement of the Forest Observation Tower. Considering that average wind speed is 3,94m/s and biomass unit price is 20$/ton in the district where this system is planned to be founded:

- Wind/PV/biomass/battery hybrid power generating system is the optimum configuration.
- At hybrid power generating system, energy unit cost is 0,880 $/kWh and total net present cost is 143.669$.
- Optimum configuration of hybrid power generating system consists of 5kW PV panel, 1 kW wind turbine, 2kW Biomass generator, 40 batteries and 3 kW converter.
- Initial cost and operating cost of hybrid power generating system are 87.640$ and 4.383$/year respectively.
- At hybrid power generating system, working period of the biomass generator is 862 hours.

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