Journal of Solid and Fluid Mechanics (JSFM), 14(3): 17-20, 2024

Shahrood University of Technology

Journal of Solid and Fluid Mechanics (JSFM)

DOI: 10.22044/jsfm.2024.14276.3845

Manufacturing Engineering of Iran

Simulation and Optimization of a Hybrid Renewable System for Providing Electrical and Thermal Energy at the Faculty of Engineering, Golestan University

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Received: 05/03/2024 Revised: 13/04/2024 Accepted: 20/07/2024

Abstract

The energy demand is growing daily due to the growing population, rising electricity consumption, and widespread usage of sophisticated equipment. The environmental damage caused by fossil fuels and their economic and political implications in countries worldwide has prompted a quest for alternative energy sources. One of the key advantages of renewable energy sources is their ability to combine with other energy sources to create hybrid renewable energy systems. Hybrid renewable systems are structures that utilize more than one energy generation source to fulfill the required electrical and thermal loads. In this study, a hybrid renewable energy system has been designed for the Faculty of Engineering of Golestan University located in Gorgan City, utilizing Homer software. This system, which includes solar panels, wind turbines, diesel generators, and grid integration, fulfills the energy needs of the facility. Additionally, heating needs are fulfilled using a boiler and heat controller. The results indicate that the optimized system has a total current cost of $214,266, with a cost of energy production per kilowatt-hour amounting to $0.0159. The renewable resource contribution is 71.7%. Furthermore, sensitivity analysis reveals that the total current cost of the project is directly correlated with the inflation rate and inversely correlated with the discount rate.

Keywords: Hybrid Renewable System; Solar Energy; Clean Energy; Simultaneous Electricity and Heat Supply; Renewable Energy.

1. Introduction

Today, energy is a key resource for the social and economic development of every country. In fact, focusing on energy issues is essential for achieving the United Nations' sustainable development goals for the global community. One of the challenges we will face in the coming decades is the transition of the global economy and energy sector towards sustainability [1]. In recent years, the development of energy in countries and various industries has been moving towards energy savings and carbon reduction. Decarbonizing the power grid by moving away from fossil fuels and towards renewable energy sources is crucial for reducing greenhouse gas emissions and combating climate change. Energy, which mainly comes from fossil fuels, accounts for about 80% of global consumption. In contrast, only 16% comes from low-carbon alternatives such as renewable energy and nuclear power. Burning fossil fuels is responsible for emitting about 34 gigatons of carbon dioxide per year, which significantly contributes to global warming [2]. Additionally, energy supports productive activities like small-scale businesses, agriculture, and industry, leading to increased productivity and improved livelihoods. After the Industrial Revolution, energy consumption has significantly increased in recent decades, leading to the depletion of fossil fuel resources like oil and natural gas. Due to the rising use of fossil fuels, these resources are being depleted, with estimates suggesting that coal reserves may last 114 years, natural gas 52 years, and oil 50 years. However, these predictions depend on various factors, including energy demand, consumption patterns, extraction technology, and resource availability. As a fundamental part of human activities, energy supports the global economy's development alongside scientific and technological advancements. Currently, electricity generation is mainly dominated by thermal power production, but other methods like solar power, wind power, hydropower, and biomass energy are emerging [3].

Hybrid renewable energy systems, which utilize two or more energy sources, are seen as a promising solution for achieving sustainable and reliable energy production. These systems offer numerous benefits compared to individual energy systems, including increased energy efficiency, enhanced energy security, and reduced greenhouse gas emissions. One of the key advantages of hybrid renewable energy systems is their ability to provide consistent and stable energy. By combining multiple energy sources, these systems can mitigate the limitations of individual resources and create a more reliable energy supply. For example, a hybrid system consisting of wind and solar energy can provide power during periods of low wind or limited sunlight power, hydropower, and biomass energy are emerging.

The HOMER software is widely regarded as a suitable tool for designing and evaluating hybrid renewable energy systems. This software allows users to input specifications such as component pricing, electrical load profiles, energy resource information, and economic constraints to generate useful outputs. Based on specific load requirements, these outputs include the optimal sizing of various components like photovoltaic panels, wind turbines, batteries, diesel generators, and power converters. HOMER also provides important statistics such as the total project cost, energy production and consumption, cost of energy production, excess energy, and energy efficiency. These capabilities enable decision-makers to make informed choices and optimize the design of hybrid systems, leading to cost-effective and efficient solutions.

In this study, heating and electricity supply for the Faculty of Engineering at Golestan University is examined using a combination of renewable and fossil fuel sources. One of the innovations in this study is the use of normalized consumption curves for weekends and weekdays leading to more accurate calculations of hourly electricity and heating demand. Additionally, the simultaneous provision of heat with an electrical boiler with the use of excess electrical energy is another innovation of this study. The inclusion of a pollution reduction incentive scheme and consideration of its impact on economic parameters is another innovative aspect of this plan [4].

2. Methodology

The Faculty of Engineering at Golestan University is located in the city of Gorgan, at geographic coordinates 36.83°N and 54.48°E. The faculty building is a three-story structure comprising offices, classrooms, laboratories, a prayer room, and a conference hall. The working hours of the faculty, given its use, are from 8 AM to 6 PM. As shown in Figure 1, the faculty is situated near the city in a foothill area.

Figure 1. Faculty location

The HOMER software can simulate annual electrical load profiles in hourly intervals, so the hourly electrical load must be calculated first. To do this, the monthly electricity consumption is initially extracted from monthly bills, and then simplifications are made based on conditions and assumptions to obtain daily values. By applying the normalized curve to the daily values, the hourly load profile can be calculated. A normalized curve is a chart that shows what proportion of the daily load is consumed in each hour. Figure 2 depicts the load curves for weekdays and weekends for electrical load, and Figure 3 shows the curves for heating load.

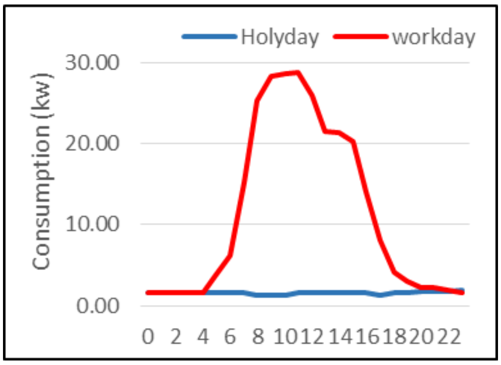

Figure 2. Electrical load curves

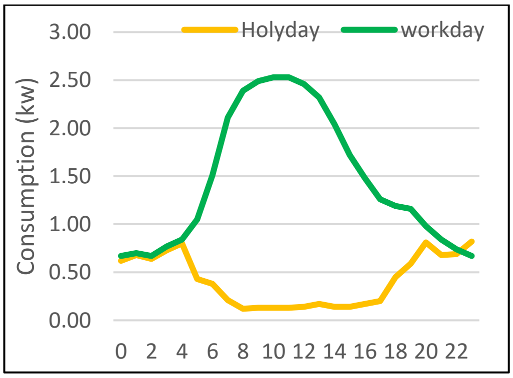

Figure 3. Thermal load curves

Iran, located between latitudes 25° and 40°N, has significant potential for solar radiation. The annual solar radiation in Iran is approximately 1800-2000 kWh per square meter, which is higher than the global average [5]. Additionally, based on the wind energy atlas and NASA's surface meteorological data, the study area experiences 15 hours of peak wind speed, with an average annual wind speed of 4.75 meters per second at a height of 40 meters. When the system is connected to the grid, it can sell its excess energy production. Additionally, the system can draw power from the grid whenever it is unable to meet its own electricity needs. During the night, when solar energy is unavailable, or whenever renewable energy sources cannot produce enough electricity, a diesel generator can be used to prevent capacity shortages. Batteries help the system store excess energy produced during peak production times, which can then be used when needed, especially in off-grid systems without grid backup. An electrical converter is also used to convert electricity into the appropriate current needed by the system.

To evaluate the project, various indicators are used across three domains: economic, technical, and environmental. In the economic domain, indicators such as Net Present Cost (NPC), Cost of Electricity (COE), payback period (PP), and initial cost (IC) are considered. In the technical domain, indicators include excess electricity (EE), excess heat (EH), and the share of renewable resources(RF). In the environmental domain, the focus is on indicators like CO2, SO2, and NOX emissions [6]. For providing the electrical and heating energy needed for the Faculty of Engineering at Golestan University, the project utilizes solar and wind resources, as well as a diesel generator, as shown in Figure 4, based on the potential of the region.

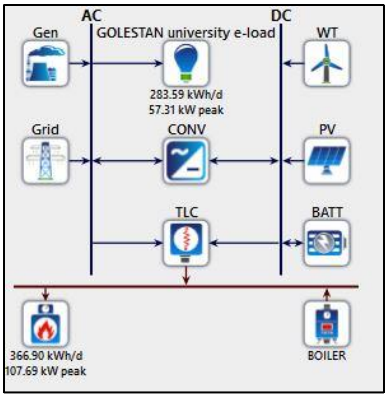

Figure 4. Hybrid renewable energy system configuration

3. Results and discussion

After hourly simulations, various configurations of sizes and economic parameters were generated, as shown in Table 1. Among many, five configurations were selected, and the results of each combination are discussed below. The technical indicators are shown in Table 2, economic indicators in Table 3, and environmental indicators in Table 4.

Table1. The results of the simulation

scenario	1	2	3	4	5
PV (kw)	284	142	240	568	142
WT	0	0	0	0	142
DG (kw)	10	0	10	0	10
BATT	0	88	55	0	0
GRID (kw)	0	5	5	5	5
TLC (kw)	100	100	100	100	100
CONV (kw)	231	89.5	245	585	258

Table2. The TECHNICAL results

scenario	1	2	3	4	5
RF (%)	71.7	64.6	67.6	88.2	65
EH (kwh/yr)	5418	20029	38.4	96.9	703
EE (kwh/yr)	11504	30692	237	432	771

Table3. The ECONOMIC results

scenario	1	2	3	4	5
PP (Yr)	4.89	0	18.5	19.8	NA
IC ($)	202271	160913	24153	425368	760736
COE($/kwh)	0.0159	0.0598	0.02	0.0186	0.156
NPC ($)	214266	293961	310091	369928	1700000

Table4. The ENVIRONMENT results

scenario	CO2 (kg/yr)	SO2 (kg/yr)	NOX (kg/yr)
1	-226126	-1252	-47.1
2	-62448	-394	-193
3	-176149	-1042	56
4	-600784	-2739	-1339
5	-144050	-903	124

In this section, the performance of the equipment in Scenario 1, which was selected as the optimal scenario, is examined. In this scenario, the amount of electricity produced by the solar panels is 566,411 kWh per year, and the generator produces 87,600 kWh per year. Therefore, 86.6% of the electricity is generated by the solar panels and 13.4% by the generator. This electricity is used as the electrical load, sold to the grid, and partly lost in the converter during the conversion from direct current (DC) to alternating current (AC). The thermal controller uses the remaining excess electricity. In this configuration, 80% of the electricity produced is sold to the grid, and 15.5% is consumed by the users. This setup generates ongoing revenue for the system. Selling electricity to the grid generates income, which helps reduce annual costs. The total annual cost of the components is $41,775, which, with the $23,122 income from selling electricity, results in a net annual cost of $18,653. The heating energy required for the network is supplied by the thermal controller and the boiler. The annual heat production from the thermal controller and the boiler is 11,504 kWh and 127,831 kWh, respectively, indicating that the thermal controller contributes 8.26% to the total heat supply. Fuel consumption in this system occurs through the diesel generator and the gas-fired boiler. According to the results, the boiler consumes 15,229 cubic meters of natural gas annually, and the generator consumes 29,258 liters of diesel fuel. The solar panels operate for 4,384 hours annually, producing a total of 566,411 kWh of power. Figure 5 shows the annual performance of the solar panels. Figure 6 illustrates the amount of electricity sold to the grid each month. As shown, the highest electricity sales to the grid occur in the first half of the year. Additionally, Figure 7 depicts the relationship between inflation rates and discount rates with the total present cost of the project in the absence of a carbon incentive scheme.

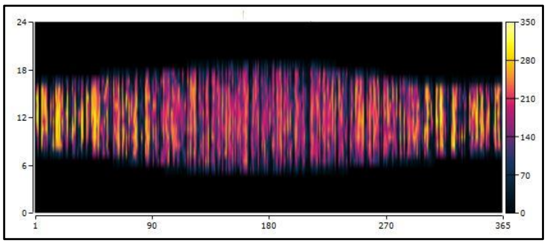

Figure 5. Annual performance of the solar panels

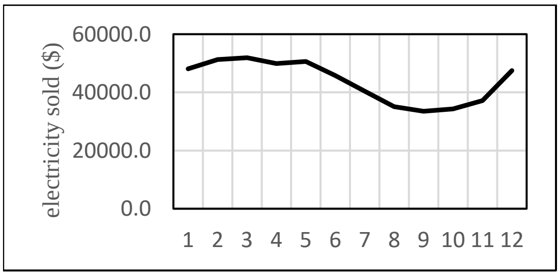

Figure 6. Electricity sold to the grid

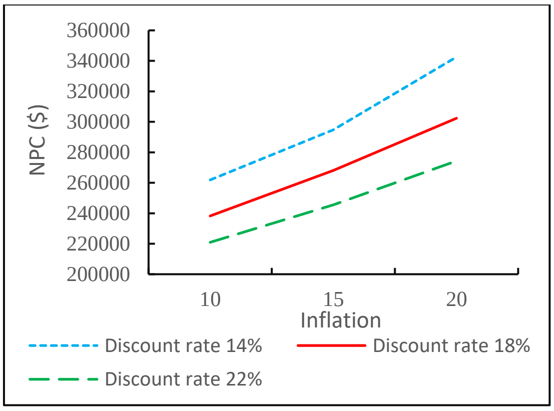

Figure 7. Sensitivity analysis of NPC

4. Conclusion

To design a hybrid renewable system for providing electrical and heating energy to the Faculty of Engineering at Golestan University, hourly electricity and heating consumption were first calculated using electricity and gas bills and applying normalized curves to these values. Then, by examining and selecting available energy sources, the desired power plant was simulated. Ultimately, after optimization, the system with the lowest total present cost was chosen as the optimal system. Sensitivity analysis was conducted on the economic parameters to examine uncertainties in the input data.

- The hybrid renewable system introduced in this study consists of solar panels and a diesel generator for electricity generation, and a thermal converter and boiler for heating. The capacities of the solar panels, diesel generator, thermal converter, and electrical converter are 284 kW, 10 kW, 100 kW, and 231 kW, respectively.
- Due to the high cost of wind turbines compared to other energy sources, their use was not economically justified and was not included in the optimal system. For instance, in Scenario 5, providing 142 kW of electricity from wind turbines increased the total project cost by a factor of 8, and placing such a number of wind turbines would be impractical.

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