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GEOTHERMAL ENERGY BASED HYDROGEN ENERGY STORAGE AND CHARGING STATION SYSTEM

JEOTERMAL ENERJİ KAYNAKLI HİDROJEN ENERJİ DEPOLAMA VE ŞARJ İSTASYONU SİSTEMİ

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Abstract

Since the beginning of the 21st century, with the increase in energy demand, the governments of the countries have had to face the increase in the consumption of limited energy resources and environmental pollution. Conventional energy sources are dependent on fossil fuels, which are rapidly declining and have many impacts such as global warming, pollution and high costs. Renewable energy sources (RES) constitute an alternative to energy sources in the future. However, one of the most important disadvantages of RES is that energy is not available continuously and at all times. For the continuous transfer of energy, the sources must be used in conjunction with energy storage systems. Hydrogen energy storage systems (HESS) and their integration into the grid with RES have the greatest potential for energy generation and storage. It controls the grid demand to increase energy sustainability. This paper is based in Aydın, a province rich in geothermal energy resources and focuses on hydrogen energy production and storage with geothermal. Thus, an important alternative for sustainability and a clean environment has been put on the agenda and useful and efficient results have been achieved for energy storage systems.

Keywords: Fast charging station, geothermal energy, hydrogen storage, RES.

Öz

21.yüzyılın başında itibaren enerji talebinin ve tüketiminin artışı ile bilim insanları, dünyamızın enerji kaynaklarının çok sınırlı olduğu ve enerji tüketiminin sınırlı kaynakları tükettiği ve dünyayı kirlettiği sorunuyla yüzleşmek zorunda kaldılar. Geleneksel enerji kaynakları fosil yakıtlara dayalı olup, hızlı çalışmaları yenilenememelerinin yanı sıra küresel ısınma, kirlilik ve yüksek maliyet gibi birçok etkiye sahiptir. Yenilenebilir enerji kaynakları (YEK) gelecek vaat eden alternatiflerdir. Ancak YEK 'in en büyük sınırlamalarından biri, sürekli olmayan enerji sağlamaları ve çoğuna her zaman ulaşılamamasıdır. Sürekli güç sağlamak için bu enerji kaynaklarının enerji depolama sistemleriyle entegre edilmesi gerekmektedir. Hidrojen enerjisi depolama sistemleri (HydESS) ve bunların YEK'ler ile şebekeye entegrasyonu, enerji üretimi ve depolaması için en büyük potansiyele sahiptir. Enerji sürdürülebilirliğini artırmak için şebeke talebini kontrol eder. Bu makale jeotermal enerji kaynağı olarak zengin bir il olan Kütahya'da yapılmış olup jeotermal ile hidrojen enerjisi üretimine ve depolanmasına odaklanmaktadır. Böylece sürdürülebilirlik ve temiz çevre için önemli bir alternatif gündeme alınmış olup enerji depolama sistemleri için faydalı ve verimli sonuçlara ulaşılmıştır.

Anahtar Kelimeler: Hidrojen depolama, jeotermal enerji, şarj istasyonu, YEK.

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1. INTRODUCTION

As a precursor to economic expansion, energy is essential for modern economic and social growth. The recent increase in energy demand and environmental issues are two of the world's defining global challenges. Fossil fuels are the most widely used conventional energy source in the last century and have a major impact on climate and environmental pollution. Sulfur oxide and nitrogen oxide gases produced from the burning of fossil fuels cause air pollution and acid rain, as well as carbon dioxide, a greenhouse gas that contributes significantly to global warming. Moreover, fossil fuels will run out in the next few years. Therefore, RESs with different technologies are being investigated based on their sustainability and cost-effectiveness. One of the major limitations of RESs is that they provide intermittent energy, and most of them are not always available (Valverde et al., 2016). Hydrogen energy storage is one of the most recent techniques for storing surplus energy generated during off-peak hours. Considered the energy source of the future and the subject of much research, hydrogen is recognized as an alternative energy source rather than a conventional one. For hydrogen to be used as an energy source in the future, it is essential to solve the economic and technical problems in the production, storage, and transportation processes using RES technologies. Stored hydrogen can also be used as fuel for hydrogen-powered vehicles to generate electricity during peak hours (Luo et al., 2015).

In the literature, studies have been conducted on the sizing of hydrogen storage systems using MATLAB simulation algorithm (Kavadias et al., 2018). They investigated the integration of a hydrogen storage system into an offshore wind farm designed to mitigate the negative effects of wind energy (Recalde Melo & Chang-Chien, 2014). An integrated storage system based on CCPP with wind energy and hydrogen storage system is designed (Gao et al., 2014). It is stated that intermittent solar and wind renewable energy sources can be integrated with coal-fired CCPP using hydrogen (Kamal et al., 2016). A design for a hybrid standalone system combining a hydrogen storage system, wind turbines, electrolyzers and PV panels is presented (Trifkovic et al., 2014). Focused on a storage system consisting of a metal hydrogen accumulator and an alkaline electrolyzer (Gonzatti & Farret, 2016). Management techniques for stored hydrogen energy are examined experimentally and theoretically (Valverde et al., 2016). A microgrid system combining wind and hydrogen energy in Scotland is simulated, and the results are interpreted (Valverde-Isorna et al., 2016). They used methane as a synthetic natural gas, evaluating the requirements of the electrolysis process in energy-to-gas technology (Bailera et al., 2017). Briefly cover recent developments in projects and technologies based on hydrogen fuel and provide a description of the advantages of using renewable energy sources for sustainable hydrogen production (Mulla et al., 2020). Considered the future energy sector in the Leshukonsky region based on wind energy and producing up to 100 tons of "green" hydrogen per year, which will reduce harmful emissions in the region and ensure regional development (Elistratov & Denisov, 2023). Alkaline (AEC), proton exchange membrane (PEMEC), and solid oxide electrolysis cell (SOEC), offering expert opinions on the future capital cost, lifetime and efficiency of these three electrolysis technologies (Schmidt et al., 2017). Canan and Ibrahim compare in detail the economic, environmental, social, and technical performance and reliability of different hydrogen production sources and systems and some hydrogen storage options (Acar & Dincer, 2019). Proposes the use of electrolyzers to produce hydrogen from excess energy, using the existing Spanish natural gas network for storage (Brey, 2021). In order to contribute to the hydrogen energy economy in China, renewable energy sources were evaluated with the fuzzy AHP-fuzzy TOPSIS method. With this new approach, uncertainties in decision-making processes can be eliminated and alternative options can be evaluated comprehensively (Liu et al., 2023). The competition between renewable and nuclear energy sources for hydrogen production is elucidated. Furthermore, a comprehensive economic model, the Taiwan General Equilibrium Model-Clean Energy (TAIGEM-CE) model, is used for production forecasting. Analytical results based on certain assumptions reveal that the most promising way to produce hydrogen is to use wind energy, while geothermal energy claims to be the most sensitive to external investment as a power source for hydrogen production. According to the assumptions made in this study, nuclear energy is not as competitive as most renewable energy sources in terms of hydrogen production (Lee, 2012). The first presents a brief summary of existing and emerging hydrogen production technologies, followed by a comparative evaluation of the cost and environmental aspects of hydrogen production based on different energy sources (Ghazvini et al., 2019). Discussed a new hydrogen production technique combining an electrolytic cell with photovoltaics and proposed this combination as one of the most promising methods in terms of stability and efficiency (Jeon & Min, 2012). Presented a study on hydrogen production and liquefaction based on geothermal energy and made an economic analysis. This study proposed seven different configurations for hydrogen production and liquefaction (Yilmaz et al., 2012). Studied the variation of the efficiency of the electrolysis process and other parameters by increasing the feed water temperature with geothermal energy. In order for hydrogen production to be a truly green process, both the electricity to be used in electrolysis and the heat required for the feed water were met by geothermal energy (Kanoglu, 2016). The technical and economic analysis of a hybrid system consisting of grid-connected, renewable energy sources (solar and wind energy) was carried out using the HOMER Pro program as a simulation to meet the energy needs of the electric vehicle charging station at Batman University West Raman Campus (Yilmaz et al., 2023). The safety risks of electric vehicles, hydrogen-fueled vehicles, and fuel cell vehicles and how they are energized are examined (Demir, 2022).

In this study, using the HOMER program, the costs of using different storage tools, such as hydrogen storage and battery electric storage, to store some of the energy obtained from a geothermal power plant were analyzed, and the optimum choice was made. During the energy exchange with the grid, the costs and operating conditions of the system were analyzed. In this study, the feeding of electric vehicle fast charging stations with electrical energy obtained from geothermal energy and stored with different types of energy storage techniques is seen as an innovation in the literature. It is thought that this paper will be a reference source for future studies. The remainder of this paper is organized as follows: In Chapter 2, the system units are explained, and the methodology of the study is presented. The findings and graphs are explained in Section 3, and the results are presented in Section 4.

2. MATERIALS AND METHODS

2.1. System Information

In order to meet the electricity demand with non-conventional sources instead of conventional sources, the system in Figure 1 has been established. Part of the energy obtained from the geothermal power plant will be stored as hydrogen to run the fuel cell, and the other part will be stored as electricity to meet the electrical energy demand of the grid. The economic and electrical results of the two systems, hydrogen storage and electricity storage in the battery, are compared to meet the energy demand at peak times.

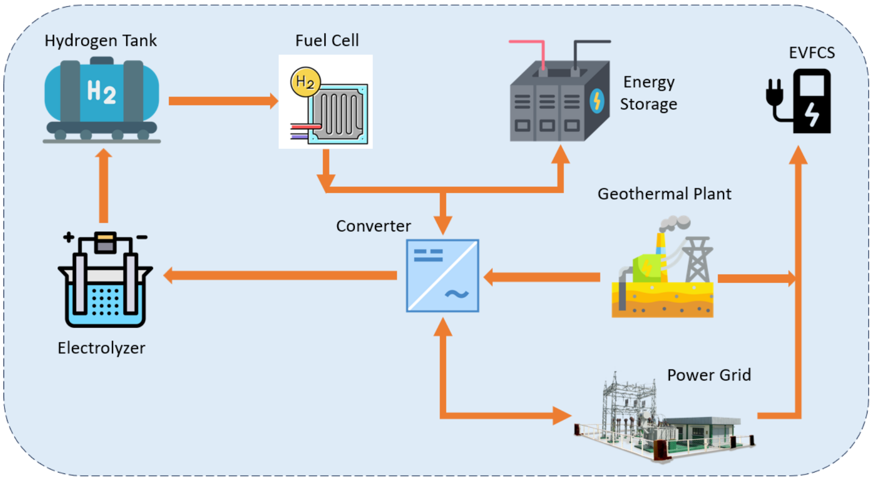

Figure 1. System Schematic

Figure 2 shows the map of Bozdagan (37°49,6' N, 28°17,5' E) district of Aydın province in the Aegean Region of Turkey, which has been identified as an important reserve area in terms of geothermal power plant potential. The research and data obtained are for a district with a population of 33650. The consumption values of Bozdoğan district, which were determined as the load, were obtained from the analysis reports of ADM Electricity Distribution company at the end of 2023. As a result of the calculations made using this data, the daily energy requirement of the region is 310.442,27 kWh, and the daily peak value is 45.644,55 kW.

Figure 2. Project Location Map Information

As it is known, HOMER is used to analyze the physical behavior of the power system and its life cycle cost, which includes the installation or capital cost and the operating cost over the entire lifetime of the power plant in question. At this point, the design of the project was modeled using HOMER software, as shown in Figure 3.

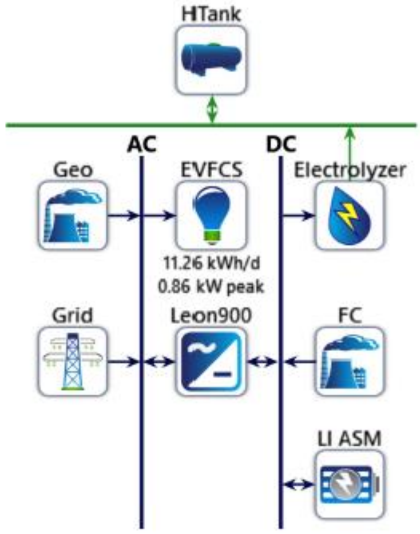

Figure 3. System Configuration

2.2. System Units

2.2.1. System converter

Conversions between AC and DC voltages take place through converters. A converter is needed to maintain the flow of energy between the DC and AC components of the system. The converter efficiency of this system is assumed to be 90%. (Lau et al., 2010). The cost of the converter used in the system is 800000₺, the replacement cost is 800000₺ and the operation and maintenance costs are 20000₺/year.

2.2.2. Elektrolyzer

An electrolyzer produces hydrogen through the process of electrolysis, a well-known electrochemical process for the production of hydrogen by converting electrical energy into chemical energy. Electrolysis is the process of using electricity to split water into hydrogen and oxygen (Khadem et al., 2017). The cost of the electrolyzer, which is assumed to have 90% efficiency in the system, is 600000₺, the replacement cost is 520000, and the operation and maintenance cost is 10000₺/year and included in the simulation.

2.2.3. System geothermal power plant

Geothermal energy is a renewable energy source based on the use of the heat of magma deep in the earth, which can be used in different areas around the world. Our country can only utilize 6,3% of the available geothermal potential. The fact that CO_2, NO_x, SO_x emissions are very low in modern power plants based on geothermal energy makes the use of this resource in electrical energy production attractive (Karakoulidis et al., 2011). In the system, a geothermal power plant capable of generating 725 kW of electricity is considered to be used.

2.2.4. System hydrogen tank

The simplest method for storing the hydrogen obtained in the electrolyzer is the use of a hydrogen tank. Hydrogen is stored as compressed gas in a hydrogen tank (Gospodinova et al., 2019). The cost of the tank is calculated as 400000₺, the renovation cost is 400000₺, and the and the operation and maintenance cost is 30000₺. 0 kg, 100 kg, and 1000 kg were preferred as tank sizes and included in the simulation. The reason for this is to find the best choice that can be integrated.

2.2.5. System grid connection

The grid connection is the system component that allows the system to meet the needs of the load by selling electricity to the load in cases where the energy produced by the system cannot meet the needs of the load or to generate income by selling the excess electricity produced by the system to the grid (Güven et al., 2021). In the case of purchasing electricity from the grid, the cost for 1 kWh is 1,40₺, and in the case of selling electricity to the grid, the profit is accepted as 1,20₺ for 1 kWh and included in the simulation.

2.2.6. System Fuel Cell

An electrochemical device that continuously converts the chemical energy of fuel and oxidant into electrical energy and heat as long as the fuel and oxidant are fed to the electrodes is called a fuel cell. A fuel cell consisting of an electrolyte membrane sandwiched between two electrolyte membrane catalyst-coated electrodes (anode and cathode) is shown in Figure 4. Hydrogen passes through one electrode, and oxygen passes through the other electrode. Fuel cells are basically the reverse of electrolysis-hydrogen Hydrogen fuel cells are very efficient and produce only water as a by-product, but they are expensive to obtain ("Fuel Cells: Current Technology Challenges and Future Research Needs," 2013). In the anode section, hydrogen gas releases electrons and oxidizes them, forming ions. At the cathode, oxygen reacts with electrons from the electrodes and H^{+}ions from the electrolyte and from water. Here water is the waster product and taken out from the cell. Equations (1)-(3) express the chemical reactions taking place at the anode and cathode. (Khadem et al., 2017).

Anode equation:

$$2H_2 = 4H^+ + 4e^- \quad (1)$$

Cathode equation:

$$O_2 + 4e^- + 4H^+ = 2H_2O \quad (2)$$

$$O_2 + 2H_2 = 2H_2O + heat + electricity \quad (3)$$

In the system, the cost of the fuel cell with 250 kW of energy generation capacity is simulated as 2000000₺, the replacement cost is 1500000₺, and the operation and maintenance cost per hour is 5000₺.

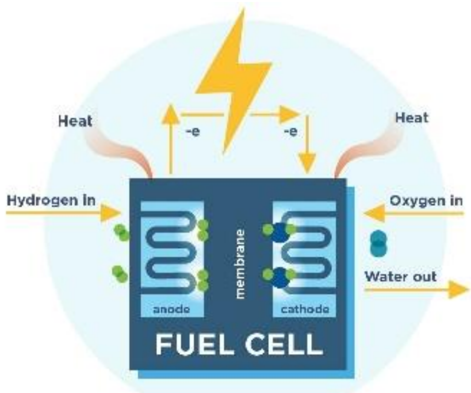

Figure 4. A Typical Fuel Cell

2.2.7. System battery

A battery is a system component that converts electrical energy into chemical energy, stores it, and, when necessary, obtains electrical energy from chemical energy and meets the need. Batteries store energy as DC voltage (Salihoglu et al., 2019). The preferred battery in the system is a 100-kWh lithium-ion battery. The cost of the battery is simulated as 400000₺ the renewal cost as 400000₺ and the annual operation and maintenance cost as 20000₺.

2.2.8. System electric vehicle fast charging station

Fast charging stations are used in places where energy needs to be supplied urgently, in places with heavy traffic flow, and in recreational facilities. This type of charging station is considered safe as it is produced with special protection elements. The classification of these EVFCS with average power values ranging between 50 and 150 kW according to the levels of charging units is shown in Figure 5 (Kaya & Akar, 2024). It is assumed that the fast-charging stations used consume 960 kWh of power for 24 hours.

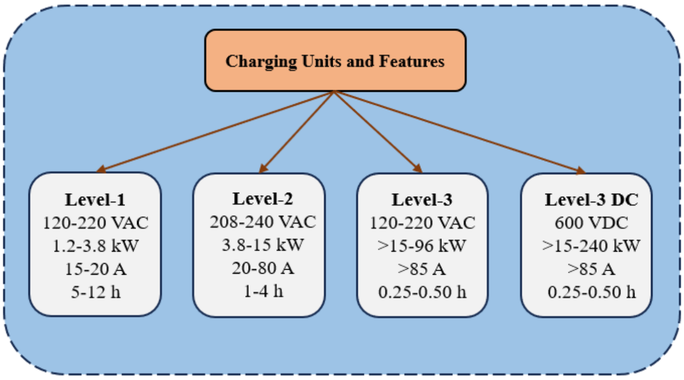

Figure 5. Electric Vehicle Charging Station Units Specifications

2.3. Economic Parameters of The System

To calculate the economic results of the prepared system, many financial measures such as initial costs, net current costs (NPC), capital recovery factor (CRF), electricity costs (COE) and annual savings are used. The following equations (4)-(6) are used to calculate these criteria (Rahman et al., 2021).

$$CRF(i, N_{project}) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (4)$$

$$NPC = \frac{C_{ann}}{CRF(i, N_{project})} \quad (5)$$

$$COE = \frac{C_{ann}}{L_{AC} + L_{DC} + E_g} \quad (6)$$

Where;

C_{ann} is the total annualized cost,
i is the interest rate,
N is the number of years,

$N_{project}$ is a project life time,
L_{AC} is the AC primary load server per year,
L_{DC} is the primary load served per years,
E_g is total grid sales.

3. FINDINGS AND DISCUSSION

Figure 6 shows the images and values generated after running the HOMER program, representing the optimal electrical and economic results for both the hydrogen storage and battery storage energy storage. When the network purchase and sale prices are examined in Figure 6a, the sales price of the energy obtained from the hydrogen stored in the hydrogen tank is higher than the energy obtained from the energy stored in the battery; therefore, it is not preferred. When the energy cost graph is examined in Figure 6b, it is seen that energy production costs increase more when an 800 kg hydrogen tank and more than one battery are used. In Figure 6c, the increase is proportional to the increase in cases in which both hydrogen tanks and batteries are used most intensively in geothermal electricity production. In Figure 6d, electricity production from fuel cells is only efficient when a 400 kg hydrogen tank is used. When daily sales charts are examined in Figure 6e, it is seen that they show a similar distribution in every period of the year, with a value of 0,50. In Figure 6f, energy sales to the grid occurred only in January, and there were no sales to the grid in other months. In Figure 6g, the monthly electricity production reached its highest level in January and showed a similar change in the other months. When the net financial return is examined in Figure 6h, the system provides a total annual profit of approximately 4,5 billion ₺. In Figure 6i, monthly AC load value is between 0,3-0,65 kW on average in all time periods of the year. When battery usage was examined in Figure 6j, 100% usage was achieved for every period of the year.

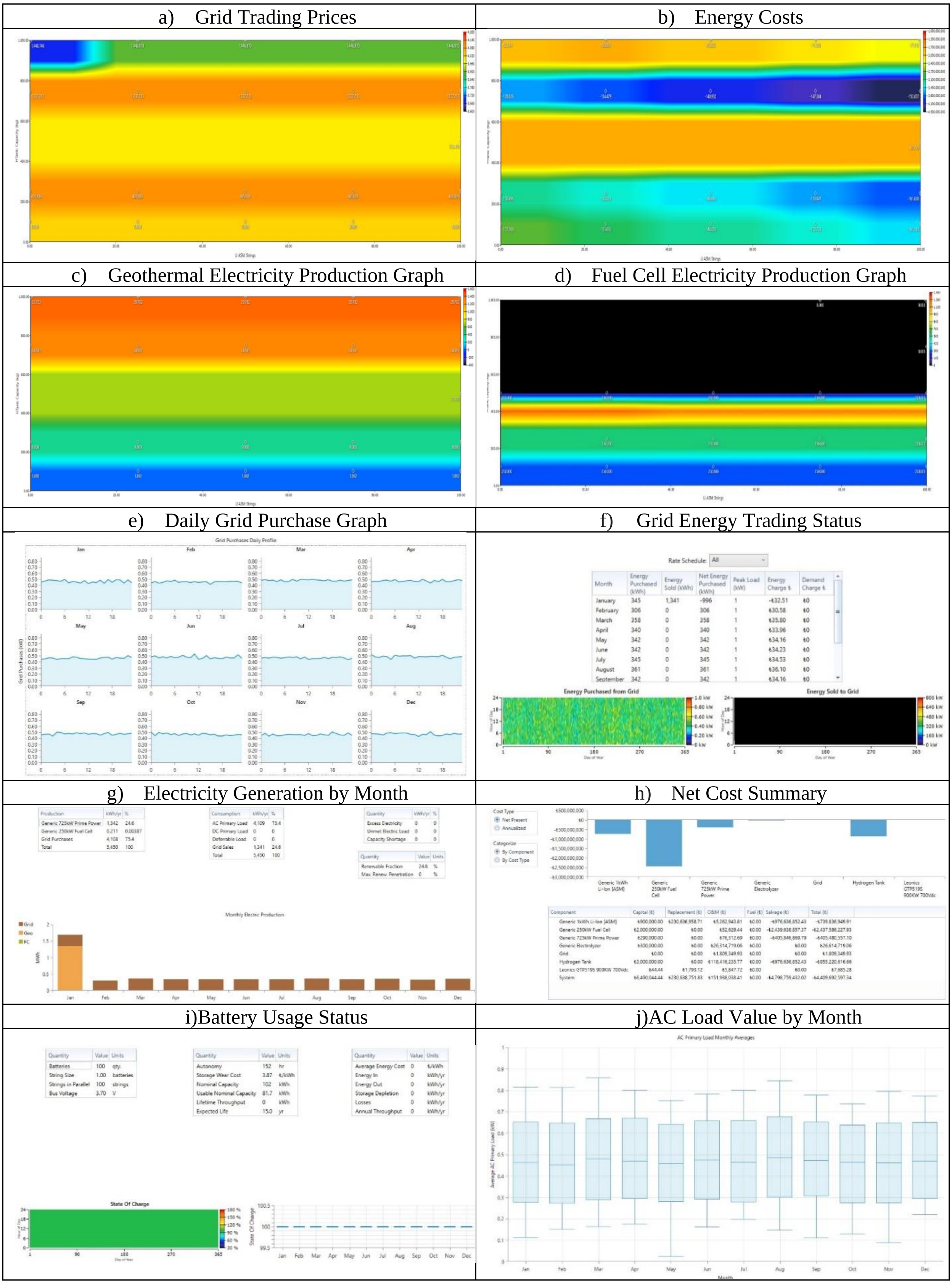

Figure 6. Economic and Technical Results of The Simulation

4. CONCLUSIONS

In this study, using meteorological data for Bozdoğan district of Aydın province, which is a region rich in geothermal resources, the electricity produced with geothermal energy sources is both produced hydrogen and stored in the tank as hydrogen and stored as electricity in the battery. It was examined in cases of need. The study was designed using a hydrogen storage tank, electric vehicle fast charging stations as an electric load, a geothermal power plant for energy generation, an electrolyzer, a battery for electricity storage, a fuel cell to generate electricity from stored hydrogen, a converter, and a grid for electrical energy conversions. The most economical value of the study was found to be 4.409.692.597,34₺. The system, which has an annual operating hour of 4289 hours per year, operates for an average of 11,75 hours per day. The electrical energy produced was found to be 11342 kWh per year. As a result of the widespread use of energy conversion systems, their importance in terms of a clean world and sustainability is better understood and implemented day by day. It is seen that energy conversions have beneficial results in terms of both cost and efficiency.

Contribution of The Authors

The authors declared that they contributed equally to this paper.

Conflict of Interest

The authors declare that there is no conflict of interest.

Statement of Research and Publication Ethics

Research rules and publication ethics were followed in the study.

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