ENERJİ SİSTEMLERİ MÜHENDİSLİĞİ ÇALIŞMALARI

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İÇİNDEKİLER

EXAMINATION OF ENERGY STORAGE SYSTEMS IN TURKEY IN TERMS OF GRID FLEXIBILITY WITHIN THE FRAMEWORK OF THE 12TH DEVELOPMENT PLAN AND OTHER REGULATIONS

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1. INTRODUCTION

Supplying energy, which is the basic input of economic and social development, with safe, sustainable and competitive costs are important parameters for a country. In addition to these factors, minimizing the impact of energy; on household budget, industry costs and current account deficit is an indispensable and irrevocable goal for every country. An uninterrupted, high quality and bearable energy supply is one of the basic element which is necessary for an economy to grow in a sustainable manner and to situate among the top economies of the world. At the point of meeting the increasing energy need, studies are continuing worldwide to obtain maximum benefit from renewable energy sources, to provide a predictable market structure and to generate energy with national and domestic resources.

Türkiye meets 74% of its energy demand from foreign countries [1]. Diversification of transmission lines and energy sources in order to increase energy supply security forms the basis

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of Turkey's energy strategy. Increasing the use of domestic and renewable energy resources in line with the determined policies and development plans is the basic energy policy. The main subjects that constitute the parts of Türkiye's energy strategy are [2]:

- Diversification of routes and resources in the supply of fossil fuels,
- Take part as a trade center in energy,
- Increasing share of domestic resources in electricity production,
- To include nuclear power in its energy mix.

Türkiye is increasing the rate of renewable energy sources in energy production. Türkiye is the 12th country in the world and the 5th in Europe in terms of total installed capacity of renewable energy facilities [3]. The share of renewable energy resources in total electricity generation rose to 32.5% in 2018 from 28.9% in 2013, while the share of electricity generated from indigenous coal resources rose to 14.9% from 12.6% over the same period. Türkiye has transformed its energy sector by large quantities of growth in renewables in the past two decades driven by a favor investment climate, increasing demand and appropriate energy policies. Energy production from renewable sources has approximately tripled in the last 10 years and constitutes approximately 42% of electrical energy production [4]. Türkiye intends to keep encouraging the development of renewable resources. In addition to this capacity, an important development has been achieved for the country by expanding the electrical energy transmission and distribution infrastructure through investments. Within the scope of strategies on energy supply security; there are targets to diversify primary energy resources, reduce foreign dependency and increase energy efficiency by using the resources effectively. Thus, it is aimed to ensure a continuous and low-cost energy and raw material supply.

In this study, the current situation of Türkiye's electricity grid is examined taking into account the country's development plan [5] and other future policies. In this context, the problems that have arisen with the addition of facilities that produce electricity using renewable energy sources, which have increased in recent years, to the grid and will increase in the future, are discussed. Energy storage systems have been proposed to solve the problems and their benefits have been examined.

2. CURRENT SITUATION ANALYSIS OF ELECTRICAL NETWORKS

High fuel prices, inflation and supply chain crisis, climate targets, and the wars on the world affect energy sector in a wide area. Capital expenditures on renewable technologies in the energy sector are expected to increase year by year. Risks and crisis in the energy market have emerged after pandemic. Investments in energy transitions have remained in a relatively good level, but it is still far from levels sufficient to meet sustainably increasing demand [6].

World energy investment is increased by more than 8% in 2022 and reached total of 2.4 trillion USD, and this value is above pre-Covid levels. Investments are increasing in all parts of the energy sector, but the main increase in recent years has come from the particularly renewable energy, grid investments, and efficiency. The overall share of investments in the supply of oil, gas, coal, and low-carbon fuels decreased from pre-pandemic levels. Due to extremely high fuel prices, the income of global oil and gas producers is predicted to triple to 4 trillion USD in 2022. After years of decline, the costs of solar panels and wind turbines have increased between 10% and 20% since 2020 [6].

High level of energy prices caused some countries to accelerate their fossil fuel investments as they prioritize security of supply. However, clean energy investment is starting to recover and is over 1.4 trillion USD in 2022, which accounts for almost three-quarters of growth in total energy investment. After five years following the signing of the Paris Agreement in 2015, the average annual growth rate in clean energy investment was just over 2%. By the year 2020, the ratio has increased to 12%, though well below what is needed to meet climate targets. The highest clean energy investment levels in 2021 were seen in China (380 billion USD), followed by the European Union (260 billion USD) and the USA (215 billion USD) [6].

These increases have been supported by the increased cost competitiveness of energy technologies, policy and fiscal measures to support post-pandemic recovery efforts. In year 2022, it is estimated that countries have allocated 710 billion USD for clean energy and energy efficiency investments. Renewable energy sources like wind and solar continue to be the least expensive choice for building new power plants even though the cost of energy technologies has increased in 2022. With the renewable energy investment, grid and storage investments constitute nearly 80% of the total energy sector investments. Solar photovoltaic (PV) accounts for almost half of new investments in renewable energy. Investments of PV are mainly coming from utility scale projects and distributed solar systems. The focus of wind energy is shifting towards the offshore installations. While 2020 was a record year for onshore capacity commissioned, 2021 was a record year for offshore with an expenditure of 40 billion USD and more than 20 GW of capacity commissioned [6].

It is stated that energy sector investment in developing countries requires a Compound Annual Growth Rate (CAGR) of over 25% to reach net zero emission levels. This means that the modest 3% investment growth rate seen in developing countries between 2019 and 2022 needs to be increased nearly 10 times for reaching climate targets [6].

Over the past ten years, Türkiye has seen a rapid increase in demand across all energy sector. With an annual growth rate of 5% since 2002, Türkiye has seen the OECD members' fastest growth in electricity demand. Turkey has decided to take rapid action to achieve its energy-related goals of increasing energy efficiency, reducing greenhouse gas emissions, increasing security of supply, creating a sustainable energy sector and a well-functioning energy market. Türkiye's installed capacity has reached 95.9 GW in 2020 and 99.8 GW in December 2021, and nearly 104 GW in December 2022 [4].

In the years between 2007 and 2022, the majority of the capacity additions in Türkiye have been realized as a result of the investments made by the private sector. The share of the private sector in electricity generation increased from 40% in 2002 to 83% in 2022, along with the decreasing share of Build-Operate and Build-Operate-Transfer power plants during the period [4].

Türkiye decided to open its electricity market to private sector in 2001. This was a turning point for Turkey as the EU (European Union) provided the design and legal basis for the new market. Energy Market Regulatory Authority (EPDK) was established in 2001 to carry out regulation and supervision functions in energy markets, and in 2013, the new Electricity Market Law No. 6446 was published and the privatization processes of 21 distribution companies were completed. The electricity market law is largely compliant with the EU's third energy package. Additionally, the Turkish electricity system is operated in conjunction with the Continental European system. Turkey's electricity grid was integrated into the Continental European Synchronous Zone of the European Network of

Transmission System Operators for Electricity (ENTSO-E) in January 2016. [7].

Additionally, in 2015, Energy Exchange Istanbul (EPİAŞ) was established to organize wholesale electricity and gas markets. Apart from the operation of spot markets, EPİAŞ is also in charge of the settlement of balancing power market, ancillary services market, the system imbalances and YEKDEM (Renewable Energy Support Mechanism of Türkiye). EPİAŞ publishes information on price and capacities on its transparency platform. Under wholesale electricity markets, up until now, EPİAŞ has been operating the day-ahead and intra-day markets and Power Futures Market was launched recently on 1 June 2021 [7].

Hydro and wind resources constitute the vast majority of Türkiye's renewable energy capacity, accounting for 31.5 GW and 11.3 GW respectively of the total installed capacity of 103.8 GW by the end of 2022. In year 2022, 1.2 GW solar PV and 1.8 GW wind energy power plants were commissioned. In year 2022, 326.1 TWh of energy were produced with 42.2% from renewable sources (20.6% from hydropower, 10.8% from wind, 4.7% from solar, and 6.1% from other sources) [4].

The regulatory framework continues to be developed to foster the unutilized potential of renewables. In this context, by-law on Storage Activities in Electricity Market was published in the Official Gazette on May 9th, 2021. The by-law regulates the storage activities for the producers, consumers, system operators and independent suppliers, except for the pumped hydro. Furthermore, the Renewable Energy Guarantee of Origin Certificate (YEK-G) system, as well as the regulations and procedures for the operation of the organized market for these certificates, are described in legislation. Furthermore, as a result of recent revisions to Electricity Market Law No. 6446, municipalities, industrial, and agricultural irrigation consumers now have the option to construct renewable energy power plants with a capacity up to double that of their connection power [8].

The general strategic framework document of Türkiye is the 12nd Development Plan 2024-2028 [5]. Security of supply and optimal use of domestic and renewable resources are also highlighted in the plan, which are important pillars of Türkiye's energy policy. The energy policy determined by the development plan is to meet the energy needs of economic and social development in a continuous, high-quality, safe and sustainable manner through an open competitive market. Planning and investment studies will be carried out to develop electric networks, taking into account potential renewable resource areas and the pace of development of renewable energy and electric vehicles [5].

The most important component of the country's energy strategy is to support the production of energy using renewable resources in order to reduce dependence on foreign countries for energy. To this end, incentive schemes such as feed-in tariffs and various legislative regulations were carried out to pave the way for green energy investments. For instance, the Renewable Energy Zone of Türkiye (YEKA) investment model was introduced in order to ensure efficient and effective use of renewable energy resources by setting up large scale renewable energy zones in selected areas. As of today, onshore wind, with a total capacity of 2.850 MW, and solar power, with a total capacity of 3000 MW competitions were completed. The commissioning of the first YEKA competition, which was held in 2017 as solar based in Karapınar region with a total capacity of 1000 MW, was completed in February 2023. On the other hand, the first onshore wind tender was announced in 2017 [6].

Türkiye has declared its net zero emission target for 2053 [9]. In this context, especially domestic and renewable energy is of great importance. As of the end of December 2022, approximately one-fifth of electricity installed capacity consists of wind and solar energy. The fact that the average annual total sunshine duration is high due to the characteristics of geography and that wind energy potential is at a good level both on land and in the sea due to location surrounded by sea on three sides constitutes an important advantage for reaching the 2053 targets.

Ministry of Energy and Natural Resources prepared long term Türkiye National Energy Plan covering the period between 2020-2035 [10]. The Plan constitutes a base for the net-zero target of Türkiye by 2053 and includes recommendations for the 2035-2053 horizon. These modeling studies provides a scientific baseline to analyze the place of all energy sources (renewables, fossil fuels and other alternative fuels and technologies such as hydrogen and storage) in primary energy supply and also in power generation. The plan covers all sectoral activity of the economy (industry, agriculture, household, transport and service), population and fuel prices with future assumptions. Key findings of the study for the years 2020-2035 are as follows;

- Increase in primary energy consumption to 205.3 mtoe;
- Increase in electricity consumption to 510.5 TWh;
- Increase in the share of electricity in final energy consumption to 24.9%;
- 35.3% decrease in energy intensity;
- Increases in the installed capacity to:
- 189.7 GW in total;
- 52.9 GW in solar power;
- 29.6 GW in wind power;
- 7.2 GW in nuclear power;
- with a projected capacity expected to be put into operation of 96.9 GW;

- Increase in the share of renewable energy sources and intermittent renewable energy sources in electricity generation to 54.7% and 34.2%, respectively;
- Increase in the share of renewable energy sources and intermittent renewable energy sources in installed capacity to 64.7% and 43.5%, respectively;

In order to meet the need for flexibility:

- an increase in battery capacity to 7.5 GW (2 hours charging time);
- an increase in electrolyzer capacity to 5.0 GW;
- an increase in demand-side response to 1.7 GW.

Investing in flexibility is a rising topic for electricity security. Reliable electricity is at the main position as its share in final consumption increases from 20% today to 40% in the IEA's Announced Pledges Scenario (APS) in 2050 and 50% in the NZE (Net Zero Emissions) Scenario. The need for flexibility quadruples by mid-century in both scenarios due to rising variability in electricity supply and demand. Demand-side response and battery storage both grow more significant, meeting a quarter of the APS's flexibility demands by 2050 [11].

Electric grid investments are long-term investments that will be ensured by improving the business and investment climate under reformative policies; it is creating a strong business ecosystem that will increase flexibility through high institutional capacity.

The share of renewable energy sources in electricity production is increasing day by day. The necessary planning and investments must be made as soon as possible to integrate these resources into the grid. The operation of energy infrastructure could be maintained by flexibility in an effective and safe manner.

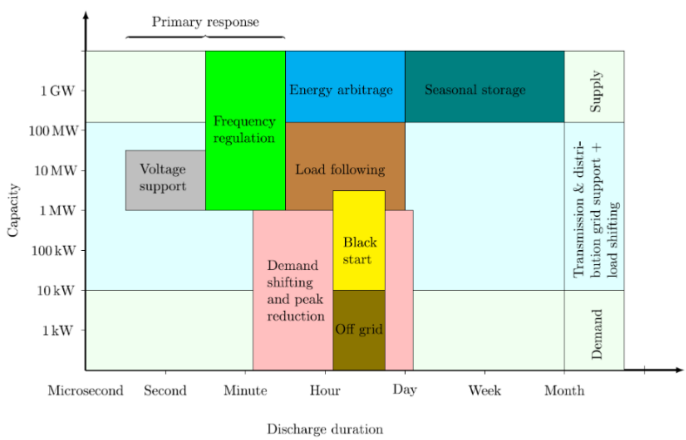
It is expected that transmission investments will play a major role in realizing the targets set in terms of ensuring electricity supply security. The electricity transmission system acts as a bridge between distribution and generation, and the transmission system has a special importance in the realization of the determined targets. Operating within the scope of the Decree Law No. 233 in Türkiye, TEİAŞ is an economic state enterprise with a public legal personality, which is responsible for the planning, installation and operation of the transmission system at the national level within the framework of the Electricity Market Law. Transmission system operator is responsible for the operation of the electricity system at very high voltage level, at 400 kV and 154 kV levels, within the framework of the transmission license issued by regulatory authority. In this context, it is important to meet the demand for electrical energy on time, uninterruptedly and with the defined quality parameters. In addition, the operation of the balancing power market in order to ensure the healthy functioning of the electricity market is one of the main activities of transmission system operator [12].

3. STORAGE SYSTEMS' BENEFITS TO THE GRID

Electricity is an essential part of life and fundamental objectives of electricity is consuming it with sustainable, environmentally sensitive and bearable costs. The sustainability of electricity for all consumers depends on the quality and continuity of the electricity network in the generation, transmission and distribution services that constitutes parts of the network throughout the country. At this point, the electrical transmission system is functioning as a bridge between generation and distribution, in particular with system management and system security. The existence of long distances between the points of electricity generation and consumption in a country generally requires a careful approach to the management and planning of the transmission network. In addition, the share of renewable energy and domestic coal plants in production will continue to increase in the framework of maximizing utilization from domestic resources. Also, nuclear power plant projects that commissioned will be base load function for the network and these resources will have to be transmitted to the consumption points via transmission lines. If the increasing demand for electrical power and consumers' orientation to new trends is not addressed with new approaches, the situation will become increasingly difficult in terms of network management.

Many energy storage system solutions can be used for various problems. Although there are storage solutions according to the second, hour, daily, weekly, monthly and even seasonal storage needs, it is necessary to evaluate criteria and act according to the financial possibilities in order to make the right choice among them. Figure 1 shows capacity and discharge time of storage applications [13].

Figure 1. Battery usage due to capacity and discharge spesifications

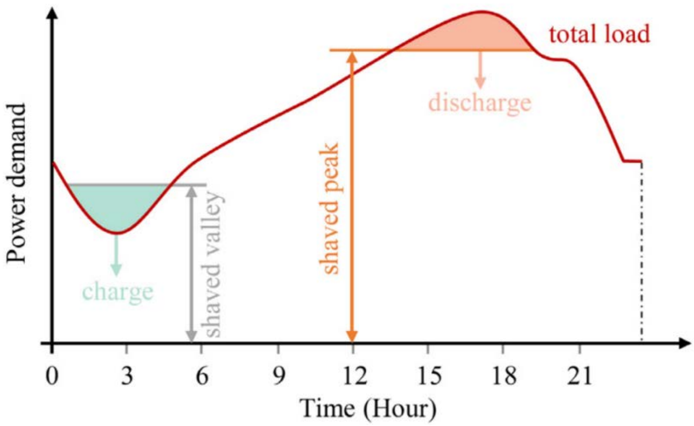


The cost-benefit analysis will be favorable if energy storage combines multiple advantages. The broad deployment of energy storage devices will be successful when evaluating various utilization advantages collectively. It has been demonstrated by using security constrained scheduling optimization in United Kingdom grid modeling that battery storage can only be a feasible investment by using four or five contributions together [14]. Storage's advantages for the electricity markets will make the idea of return on investment evident, leading to a rise in investments in the energy storage industry. Energy storage applications are categorized into supply side applications; energy arbitrage, capacity firming, renewable integration, demand change, and peak load reduction. Grid side benefits are considered as postponing network investments, ancillary service contribution (voltage support, power quality, black start) and constraint management. Consumer side applications are load leveling and power quality.

In cases where there is excess energy supply in the electricity network, the supply-demand balance is achieved by storing the excess energy and using the stored energy when needed. In this method, profits can be made by charging a storage device at low prices and then supplying that electricity to the grid when electricity prices are high. Consequently, arbitrage is mentioned as bulk energy application which could provide both generation and load, contribute improving the load factor of generation [15].

In order to reduce energy demand, peak shaving is done using options such as energy storage and on-site production. In other words, the peak regions of the peak shaving demand graph are cut. With load shifting, energy demand is shifted from peak times to off-peak times. Figure 2 is given below for demand reduction and peak shaving application [16].

Figure 2. Peak Shaving Application



Following a loss of generation, the frequency of the system degrades, with the rate of frequency decay being inversely proportional to the total inertia of the grid. The energy storage technologies should provide the grid primary frequency response during the operating phase in order to restore system stability. This assistance lasts through the period of recovery, when the grid's stability is fully established [13].

Energy storage technologies support the electricity grid in terms of providing flexibility and balancing to renewable energy sources that provide unreliable and intermittent power supply. As clearly stated in the country's 12th Development Plan, the flexibility of electricity grids will be increased in order to reduce the negative effects of production from intermittent renewable energy sources on the grid. Here, the goal can be achieved with the effective use of energy storage systems [5].

4. BATTERY STORAGE CURRENT STATUS IN TÜRKİYE

The majority of solar power plant installed power in investors in Türkiye generally have unlicensed solar power plants with less than 1 MW of installed capacity on different locations and these power plants can cause electrical disturbances in distribution systems such as voltage drop and rise, flicker, current harmonics and direct current injection. Electricity distribution and retail sales are subject to service quality regulations that make the distribution companies accountable for the level of service they offer to customers [17].

The Electricity Market Law requires energy storage units equal to the installed power for individuals and organizations that will install renewable energy facilities by applying. In addition to this, the existing license holders would be allowed to increase the renewable capacity up to the installed capacity of the promised storage capacity [18].

In addition, energy storage systems could participate in the ancillary services and the balancing power market if they meet the conditions specified in the legislation. These regulations will promote system security and flexibility by ensuring that energy delivered to the grid by intermittent energy sources is stored and becomes stable. In this way, it is aimed to ensure system and supply security by providing a more balanced market to the system operator.

Regarding the storage activity to be carried out by the production facilities included in YEKDEM, which is a kind of incentive mechanism in which price and purchase guarantees are given to power plants that generate electricity from renewable sources such as hydraulic, wind, solar, geothermal, biomass, waves.

According to latest developments firstly energy storage activity is defined in the Electricity Market Law. Solar and wind connection capacity has been assured in the event that the investor has the same value of energy storage in order to increase the proportion of renewable energy in the installed capacity. Before this amendment, it was not possible to install solar and wind capacity before allocating connection capacity for these types of generation technologies. It is also now available for energy storage technologies to benefit from YEKDEM mechanism. YEKDEM application price and the domestic contribution price will be applied for the electrical energy produced in renewable sources and supplied to the system after being stored in the integrated storage unit. YEKDEM price and domestic contribution price will not be applied for electricity that is withdrawn from the grid and stored. The price application and durations for the amount of electrical energy produced in wind and solar plants with storage but delivered to the grid without storage will be different price application and durations envisaged for wind and solar power plants without storage units [19].

It is of great importance to ensure the supply of electrical energy in a continuous and high-quality manner. At this point, Value of Lost Load (VOLL) concept is currently a financial indicator used to indicate the expenses associated with a disruption in the supply of electricity [20]. VOLL is expressed as Euro paid per kilowatt hour (Euro/kWh) of electrical energy not delivered to the consumer. For Spain it has been assumed as 4.39 Euro/kWh [21]. If Gross Domestic Product (GDP) of Türkiye is one third of Spain, we can accept VOLL value of Türkiye as nearly one third of the Spain's value. As a result of the calculations, the annual average VOLL for Türkiye has been determined as 1.46 Euro/kWh. The cost of VOLL varies depending on the region, sector, time, duration and other factors.

5. CONCLUSION

The current level of energy consumption per capita of Türkiye, which is less than half of the OECD average, points to a significant growth potential and indicates that electricity demand will grow faster than the demand for other energy types, especially when evaluated in terms of widespread use of electrical energy in daily life including such developments as electrification and demand from electrical vehicles.

On the other hand, the fact that a country does not have sufficient wealth in terms of energy resources makes it necessary to closely monitor international and regional developments. In this context, foreign dependency in energy, which weakens the security of supply, should be considered by all perspectives accordingly. Developed countries closely monitor status of security of supply progress and take precautions with regard to preparation of energy plan. Diversification of primary energy resources, reduction of foreign dependency and rational use of domestic resources are of great importance for the country's economy.

Within the scope of the 2053 net zero emission targets, all the studies carried out in order to bring country to an independent position in energy with a renewable focused approach in energy continue on the basis of energy supply security. This includes designing a balanced and robust energy system in a way that will prepare the energy supply security for all adverse conditions, implementing energy reforms step by step, planning the transformation of resources in energy and a realistic approach, by taking into consideration the current conditions. In this context, in addition to the investments made in renewable energy, the first unit of 1,200 MW of Akkuyu Nuclear Power Plant, which consists of 4 units with a power of 4,800 MW, which can generate electricity without emitting greenhouse gases to the environment, is planned to be commissioned in near time. It is obvious that Türkiye will reach a more flexible position in energy resource management by including nuclear energy in electrical energy generation portfolio with investments.

Developments, particularly energy storage devices, provide opportunities to improve network operation and reliability. Electrical energy storage systems have a wide area of use for the electrical network. Electric energy storage systems come to the forefront as a subject that closely concerns and contributes to all users in the electricity value chain, as electricity has the feature of being used in generation, transmission, distribution and consumers.

Energy storage systems could be analyzed by improved energy efficiency and the faster deployment of variable renewable energy generation. These improvements will require more flexibility, such as the system ability to adapt to changing needs of the grid and it will become more complex to manage variability and uncertainty of demand and supply across all relevant timescales. Energy storage systems provide variety of solutions based on electricity grid needs.

REFERENCES

[1] Republic of Türkiye Ministry of Energy and Natural Resources, “EİGM Raporları”, Retrieved June 01, 2023, from https://enerji.gov.tr/eigm-raporlari

[2] Republic of Türkiye Ministry of Foreign Affairs, “Türkiye’s International Energy Strategy”, Retrieved June 01, 2023, from https://www.mfa.gov.tr/turkeys-energy-strategy.en.mfa

[3] International Renewable Energy Agency, “Renewable Energy Statistics”, Retrieved June 01, 2023, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Renewable_energy_statistics_2022.pdf

[4] Turkish Electricity Transmission Corporation, “Installed Capacity Reports”, Retrieved June 01, 2023, from https://www.teias.gov.tr/kurulu-guc-raporlari

[5] Presidency of Republic of Türkiye Presidency of Strategy and Budget, “Eleventh Development Plan”, Retrieved April 01, 2024, from https://www.sbb.gov.tr/wp-content/uploads/2023/12/On-Ikinci-Kalkinma-Plani_2024-2028_11122023.pdf

[6] International Energy Agency, “World Energy Investment 2022”, Retrieved June 01, 2023, from https://www.iea.org/reports/world-energy-investment-2022

[7] Republic of Türkiye Energy Market Regulatory Authority. “6446 Electricity Market Law” Retrieved September 01, 2023, from https://enerji.gov.tr/info-bank-investors-guide-for-electricity

[8] Republic of Türkiye Ministry of Energy and Natural Resources. “Investor's Guide for Electricity” Retrieved

September 01, 2023, from https://www.epdk.gov.tr/Detay/Icerik/23-2-3/mevzuat

[9] Anadolu Agency. "Investor's Guide for Electricity" Retrieved September 01, 2023, from https://www.aa.com.tr/en/energy/turkey/turkey-to-become-party-to-paris-climate-agreement-on-nov-10/33807

[10] Republic of Türkiye Ministry of Energy and Natural Resources, "Türkiye National Energy Plan", Retrieved June 01, 2023, from https://enerji.gov.tr/Media/Dizin/EIGM/tr/Raporlar/TUEP/T%C3%BCrkiye_Ulusal_Enerji_Plan%C4%B1.pdf

[11] International Energy Agency, "Energy Security in Energy Transitions", Retrieved June 01, 2023, from https://www.iea.org/reports/world-energy-outlook-2022/energy-security-in-energy-transitions

[12] Turkish Electricity Transmission Corporation, "Activity Reports", Retrieved June 01, 2023, from https://www.teias.gov.tr/faaliyet-raporlari

[13] Botha M. M. & Kamper C., Wang M.J. & Sebitosi R.J., Levelised Cost of Storage Comparison of Energy Storage Systems for Use in Primary Response Application. Electronical Journal, 2021

[14] Andre F. R., Iftekhar A., Daryoush H. &Thair S. M. Placement and sizing of utility-size battery energy storage systems to improve the stability of weak grids. International Journal of Electrical Power & Energy Systems, 144, 2023

[15] Nikolaidis P., & Poullikkas A. Comparative review of electrical energy storage systems for better sustainability. Journal of Power of Technologies, 97, 220-245, 2017

[16] Jinqiang L., Chao H., Anne K. & Zhaoyu W. Uses, Cost-Benefit Analysis, and Markets of Energy Storage Systems for Electric Grid Applications. Journal of Energy Storage, 32, 2020

[17] Republic of Türkiye Energy Market Regulatory Authority, "Service Quality Regulation on Electricity Distribution and Retail Sales", Retrieved June 01, 2023 from https://www.epdk.gov.tr/Detay/Icerik/3-6740/elektrik-dagitimi-ve-perakende-satisina-iliskin-hizmet-kalitesi-yonetmeligi

[18] Republic of Türkiye Energy Market Regulatory Authority, "6446 Numbered Electricity Market Law", Retrieved June 01, 2023 from https://www.epdk.gov.tr/Detay/Icerik/3-14650/guncel-6446-sayili-elektrik-piyasasi-kanunu

[19] Republic of Türkiye Energy Market Regulatory Authority, "Presidency Decision on the Prices and Periods to be Applied for Electricity Generation Facilities Based on Renewable Energy Sources with a Certificate of Renewable Energy Source and Updating the Prices Resolution", Retrieved June 01, 2023 from https://www.resmigazete.gov.tr/eskiler/2023/05/20230501-7.pdf

[20] Schröder T., Kuckshinrichs W. Value of Lost Load: An Efficient Economic Indicator for Power Supply Security? A Literature Review. Front. Energy Res., Sec. Sustainable Energy Systems, 3, 2015

[21] Linares, P. & Rey, L., The costs of electricity interruptions in Spain. Are we sending the right signals?, Energy Policy, Elsevier, 61(C), pages 751-760, 2013

A CASE STUDY ON INVERTER SELECTION ANALYSIS FOR PHOTOVOLTAIC SYSTEMS

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1. INTRODUCTION

According to the data of the Ministry of Energy and Natural Resources of the Republic of Turkey, the country's electricity production in 2022 will be 34.6% coal, 22.2% natural gas, 20.6% hydraulic energy, 10.8% wind, 4.7% solar, 3%, 3% was obtained using geothermal energy and 3.7% from other sources [1]. When evaluated in light of the 2015 United Nations Climate Change Conference, also known as the 2015 Paris Agreement to Combat Climate Change, where participating countries agreed to work to keep the global temperature increase below 2 C^o compared to pre-industrial levels, the data appear to indicate a problem [2]. The Republic of Turkey signed the Paris Agreement together with representatives of 175 countries at the High Level Signing Ceremony held in New York on 22 April 2016 [3]. The Paris Agreement requires all countries to take steps to reduce greenhouse gas emissions as quickly as possible. In addition to direct environmental benefits such as increasing the use of renewable energy resources and reducing pollution caused

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by energy production, it also has social benefits such as developing an economical and more flexible energy infrastructure, ensuring a more competitive energy market, and opening new markets and sectors for growth [4].

The demand for electrical energy is constantly increasing worldwide. At the same time, the use of renewable energy sources such as solar, wind and biomass for electrical energy production has increased due to their sustainability and low carbon emissions. Among renewable energy sources, solar energy stands out because its production is quiet and the risk of malfunction is less. In recent years, with the development of new technology, the decrease in the cost of solar panels makes solar energy more attractive for users. Today, most photovoltaic (PV) systems are installed as distributed generators connected to the electrical distribution grid. PVs can improve the quality and safety of the distribution system when installed with proper planning [5,6].

College campuses are primary targets for implementing PV technology for many reasons [7]. The main reason for this is the low ratio of consumed electrical power to residential area. In addition, universities leading the use of this innovative electricity generation system will set a positive example for the society in general.

Since the amount of solar energy production depends on the amount of radiation, there are many studies in the literature aiming to determine PV locations based on geographical location [8-16]. In one of these studies, [8], the required installation capacity to provide 1% of the national electricity consumption from PV for each European country was determined using the European solar radiation database. In [9], optimal rooftop PV locations in Osnabrück, Germany, were determined using the ArcGIS Desktop Model Builder application. Similarly, in [10], a solar map was created using the Solar Radiation Tool in ArcGIS for a four square mile area surrounding the University of Arizona, USA. Within the scope of the study, suitable roof areas with high solar radiation, facing south and not being too steep were determined. In [10], a methodology is presented to assist end users to analyze the solar energy potential of selected rooftops in Kingston, Ontario, using LIDAR data. Strzalka et al. [11] used a geographic information system to estimate the PV potential of building roofs at the city scale. Lukac et al. In another study, researchers presented a solar energy potential estimate for building roofs in urban areas using LIDAR data [12]. To accurately estimate the required irradiance for PVs, cloud cover and atmospheric scattering, tilt and orientation, the shadowing effect from nearby objects, and the surrounding terrain are taken into account. These studies in the literature reveal that the use of geographic information system is an effective tool with wide application for PV layout design.

The inclusion of PVs in existing power systems significantly affects the system losses and voltage profile. Because traditional distribution systems are designed to operate without any production on the end user side [5,17,18, 19]. Establishing more effective PV systems requires a comprehensive approach combining geographical, economic and technical aspects, otherwise the system may become disadvantageous due to its different characteristics [20].

According to the Turkey Solar Energy Potential Atlas (GEPA), the annual average total sunshine duration is calculated as 2,741 hours and the annual average total radiation value is calculated as 1,527.46 kWh/m2 [21]. Calculations show that solar energy has the potential to be an important energy source to provide clean energy for the country in the coming years. Since weather conditions cannot be known instantly, providing energy needs entirely from renewable energy sources raises doubts and calls into question the fact that the energy provided from these sources is uninterruptedly sustainable. Additionally, due to the high cost of storage technology, investments in the field of PV need to be planned in detail.

Large-scale integration of single-phase PV systems affects not only grid planning but also the operation of the distribution network [22]. Due to the increase in the installation of single-phase PV systems, grid demands regarding the integration of PV systems with the grid need to change [23]. Low-voltage residential grid-connected PV systems should be designed to disconnect from the grid within a certain period of time when a fault occurs at the common connection point [24]. As the number of low voltage PV systems increases, disconnection may have negative effects on system stability and reliability [22, 25-27]. As a result of the increasing number of PV systems, grid interconnection standards are becoming more restrictive [28]. Next generation PV systems will play an important role, like conventional power plants, in participating in grid regulation. Requirements such as low voltage transition related to reactive current injection and voltage control via reactive power support are already being considered [29, 30, 31].

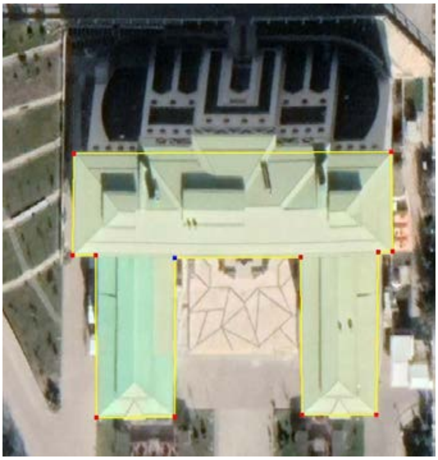
It is extremely important that the location and component selection of the solar power plant to be established is made primarily through simulation programs. In this way, production results can be predicted virtually and details of the investment can be planned. In order to obtain results closest to reality with accurate data, the currentness, accuracy and analysis parameters of the simulation program used are extremely important. PVsyst is one of these modeling programs.

Determining the optimal size and location for PV units has been a major challenge for distribution system planners and researchers. Inverter selection is one of the PV installation stages such as determining the required power, determining the power that can be obtained per unit panel depending on geographical conditions and aspect, and component selection. The heart of a solar PV system is the inverter, so it is also responsible for the quality of the power produced. Inverter selection seriously affects voltage fluctuation, frequency range and power quality. In this study, the off-grid PV system of Ankara Yıldırım Beyazıt University 15 July Şehitler Campus roof, which has a roof area of 1488.61 m², was designed by making two different simulations and three-dimensional modeling with two different inverters in PVsyst 7.3 software. Within the scope of the study, panel placement, number of panels and panel power were determined. After the installation was completed, 2 different inverters were used, their advantages and disadvantages were presented, energy production analyzes and efficiency comparisons were made.

2. METHOD

Using Google Earth software, the latitude of the facility was determined as 39.971073°, the longitude as 32.818133° and the effective roof area as 1488.61 m² (Figure 1).

Figure 1. Google Earth Roof Area View



Using the architectural project and the information in Google Earth, 3D modeling of the existing facility was made with the Sketchup program (Figure 2a) and transferred to the PVsyst program (Figure 2b). Here, any shadow on the panels is prevented during the dimensioning.

Figure 2. a) Modeling the facility in Sketchup program, b) Modeling the facility in PVsyst program

Elin brand 550 W PV panels were preferred in the simulation, and the total installed power consisting of 576 PV panels is 317 kWp. Changing current, voltage and temperature coefficient values depending on the panel brand affect the design (Table 1).

Table 1. Electrical properties of PV panels used in design [32].

Panel Power (P)	550 Wp
Open Circuit Voltage (Voc)	49,9 V
Short Circuit Current (Isc)	14 A
Rated Voltage (Vn)	41,96 V
Rated Current (In)	13,11 A
Temperature Coefficient for Voltage	% -0,27/C
Temperature Coefficient for Power	% -0,35/C
Temperature Coefficient for Current	% +0,05/C

Inverters have to fulfill some important requirements when operating. These criteria; The electromagnetic compatibility of the device is that it sends a fully sinusoidal alternating current to the network and that this current is within certain limits specified in the regulations in terms of harmonics. In addition, it must adjust the frequency and voltage values according to the frequency and voltage values in the network. The most important safety criterion of inverters is islanding. In case of a power outage in the network, the inverter should turn itself off, eliminating the risk of electric shock.

In the first modeling, a 36 kW Huawei brand inverter was preferred. This inverter has surge protection on both DC and AC side. Huawei inverters do not have suitable optimizers for 550 W panels [33]. In the second modeled system, a 33.3 kW SolarEdge brand inverter was preferred. The SolarEdge inverter receives monitoring data from each power optimizer and transmits it to the central server [34]. Both inverters receive input from 8 PV arrays, these inputs are grouped in 4 MPPT circuits and the maximum power point of the PV arrays is monitored.

Meteonorm data were obtained for the region where the building where the PV system will be installed is located through the PvSyst program. As a result of the data obtained, it is seen that the annual average temperature is 13° and the wind speed is 2.2 m/s. The orientation angles and azimuths of the panels were adjusted to be equal to the roof angles. In the calculations made for the suitable parts of the roof areas, it was determined that a maximum of 576 modules could be placed.

3. RESULTS AND DISCUSSION

There are two main materials in PV systems: panel and inverter. For the system to be created using Elin 550 W panel and Huawei 36 kW inverter, the nominal ambient temperature is 25 ºC, including ΔT temperature difference, β voltage temperature coefficient and V_{oc} open circuit voltage, and the lowest operating temperature of the inverter is -40 ºC to determine the maximum number of panels. Using $V(T_{min})$ panel minimum operating voltage is calculated as follows.

$$V_{(T_{min})} = \left(1 + \left(\Delta T.\frac{\beta}{100}\right)\right).V_{OC} = \left(1 + \left((-40 - 25).\frac{-0{,}27}{100}\right)\right).49{,}9 = 58{,}66V \quad (1)$$

While V_{inv_max} is the maximum inverter voltage, the maximum number of panels that can be connected to a series, N_{max}, is calculated as 18 (Equation 2).

$$N_{max} = \frac{V_{inv\_max}}{V_{T_{min}}} = \frac{1100}{58{,}66} = 18{,}75\ adet \quad (2)$$

In order to determine the minimum number of panels that can be connected, where Vn is the nominal operating voltage of the panel, the highest operating temperature of the inverter is 85 ^{o}C, using the catalog information, $V(T_{max})$ panel maximum operating voltage is calculated as follows.

$$V_{(T_{max})} = \left(1 + \left(\Delta T.\frac{\beta}{100}\right)\right).V_n = \left(1 + \left((85 - 25).\frac{-0{,}27}{100}\right)\right).41{,}96 = 36{,}16V \quad (3)$$

While V_{inv_min} is the minimum inverter voltage, the minimum number of panels that can be connected to a series is calculated as N_{min}=6.

$$N_{min} = \frac{V_{inv\_min}}{V_{T_{min}}} = \frac{200}{58{,}66} = 5{,}69\ adet \quad (4)$$

Inverter loading ratio (Input Power/Output Power) was chosen as 1.35 considering standard applications. Since the power of the inverter used is 36kW, the input power can be preferred as 48.6kW. Since each inverter has 8 inputs, 48.6/8=6.075kW modules can be connected to each input. Knowing that the number of modules that can be connected to each input is 550W; It is calculated as 6.075/0.55=11 pieces and 88 panels can be connected to each inverter. It will be sufficient to use 7 inverters for 576 panels. In practice, some series were left blank and worked as 16-panel series. Accordingly, where N is the number of panels in the array and VOC is the open circuit voltage, the maximum array voltage of the 16-panel arrays is calculated as follows.

$$V_{str-max} = NxV_{OC}x\left(1 + (\Delta \text{Tx}\beta/100)\right) = 16x49{,}9x\left(1 + \left(\frac{(-40-25)x(-0{,}27)}{100}\right)\right) = 938{,}52V \quad (5)$$

This value is appropriate because it is lower than the limit value of 1100V. Minimum string voltage;

$$V_{str-min} = NxV_{OC}x\left(1 + (\Delta \text{Tx}\beta/100)\right) = 16x49{,}9x\left(1 + \left(\frac{(85-25)x(0{,}27)}{100}\right)\right) = 669{,}06V \quad (6)$$

This value is appropriate since it is above the limit value of 200V. Maximum MPPT voltage;

$$V_{MPPT-max} = NxV_{mpp}x\left(1 + (\Delta \text{Tx}\beta/100)\right) = 16x41{,}96x\left(1 + \left(\frac{(-40-25)x(-0{,}27)}{100}\right)\right) = 798{,}18V \quad (7)$$

This value is suitable because it is lower than the limit value of 1000V. Minimum MPPT voltage;

$$V_{MPPT-min} = NxV_{mpp}x\left(1 + (\Delta \text{Tx}\beta/100)\right) = 16x41{,}96x\left(1 + \left(\frac{(85-25)x(0{,}27)}{100}\right)\right) = 562{,}6V \quad (8)$$

This value is appropriate since it is above the limit value of 200V. MPPT nominal current value;

$$I_{MPPT-n} = 2xI_{mmp} = 2x13{,}11 = 26{,}22A \quad (9)$$

This value is appropriate because it is lower than the limit value of 88A. MPPT short circuit current;

$$I_{MPPT-sc} = 2xI_{sc} = 2x14 = 28A \quad (10)$$

This value is appropriate because it is lower than the limit value of 120A. In the second design, SolarEdge brand 33.3kW inverters were preferred. First of all, the compatibility of the solar panel and the optimizers in the inverter structure was checked. In Equation 1, the minimum operating voltage of the panel was calculated as 58.66V. Maximum number of optimizers that can exist in an array;

$$N_{max} = \frac{V_{opt_{max}}}{V_{T_{min}}} = \frac{125}{58,66} = 2,13\ adet \qquad (11)$$

In Equation 3, V_{Tmax} panel maximum operating voltage was calculated as 36.16V. Minimum number of panels in the series;

$$N_{min} = \frac{V_{opt_{min}}}{V_{T_{max}}} = \frac{12,5}{36,16} = 0,36\ adet \qquad (12)$$

Thus, at least 1 and at most 2 optimizers must be used in each array. Maximum inverter current depending on temperature;

$$I_{MPPT-T_{max}} = I_{SC}x\left(1 + \left(\frac{\Delta \mathrm{Tx}\beta}{100}\right)\right) = 14x\left(1 + \left(\frac{(85-25)x0,05}{100}\right)\right) = 14,42A \qquad (13)$$

Total DC current for the inverter, k being the number of parallel strings;

$$I_{mpp} = kxI_{mpp_{T_{max}}} = 2x14,42 = 28,84A \qquad (14)$$

This value is appropriate because it is lower than the inverter catalog current value of 48.25A.

Figure 3. Modeling power distribution with Huawei inverter

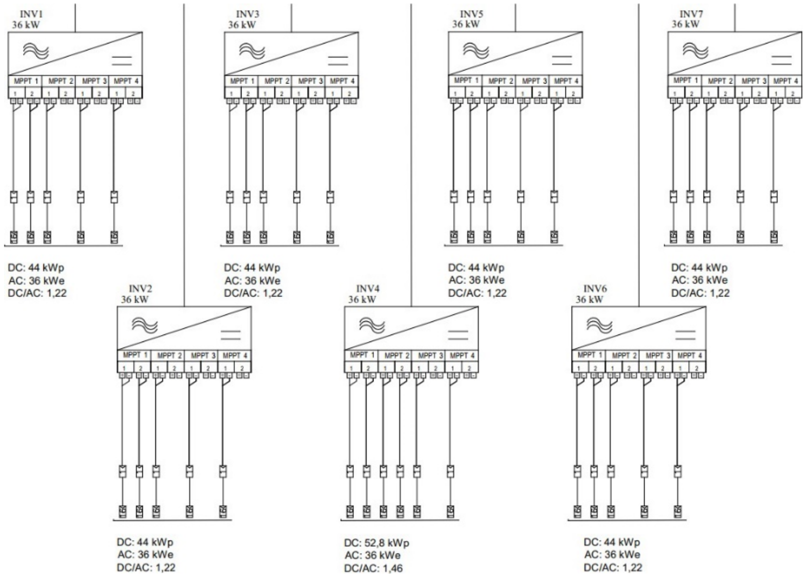
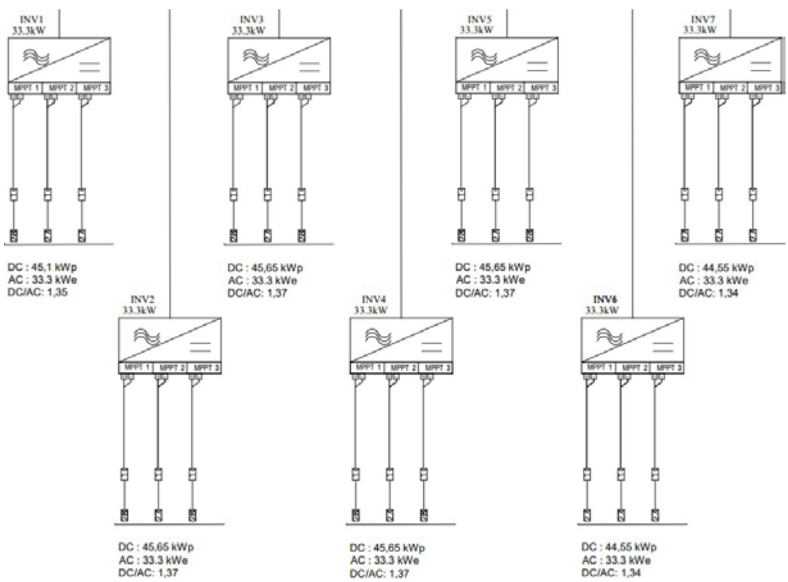


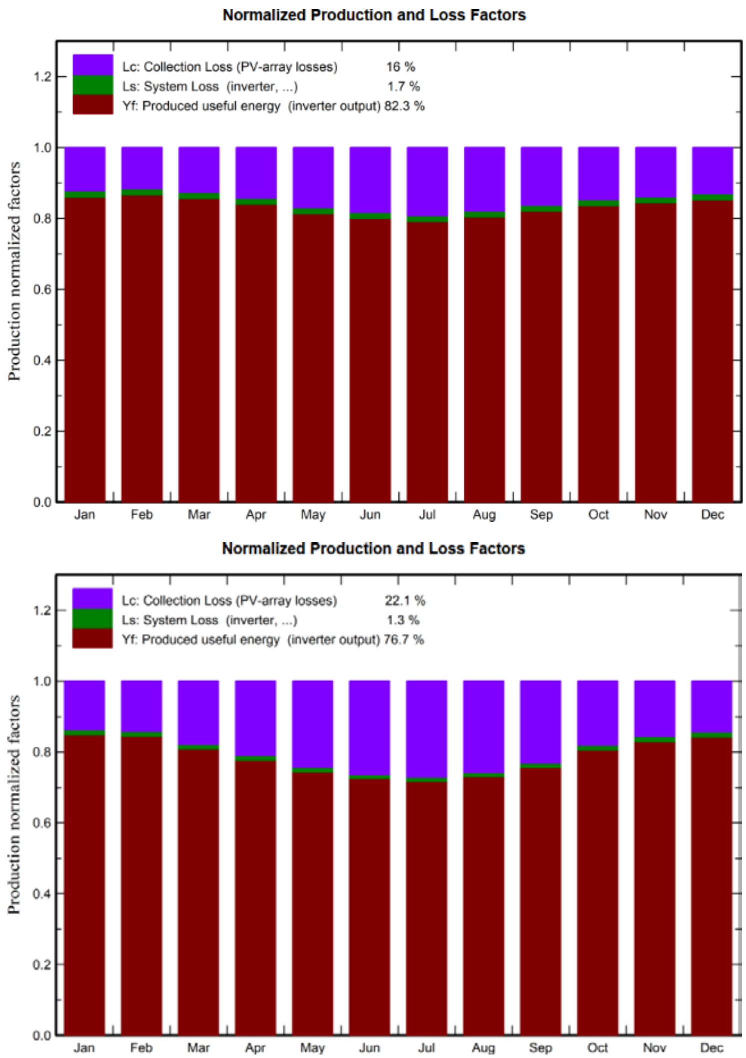
Figure 4. Modeling power distribution with SolarEdge inverter



As a result of the analysis made in the PVSyst program, after deducting the losses, energy can be obtained from the

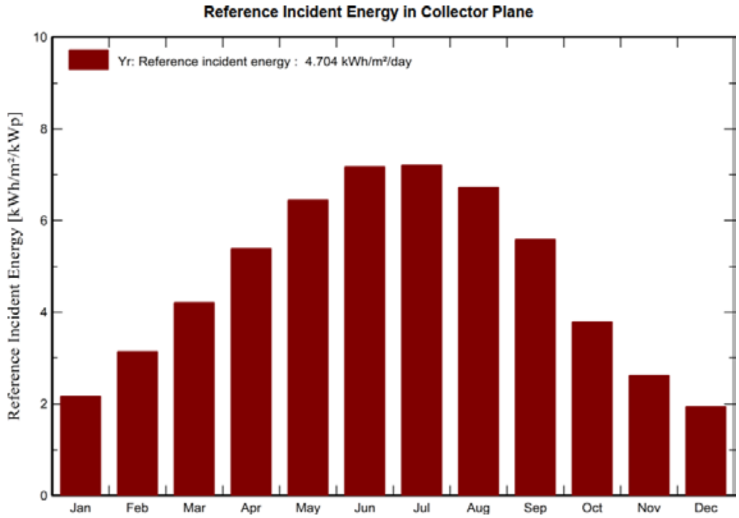
Huawei inverter output with 82.3% efficiency, while this value was 76.7% in the SolarEdge inverter (Figure 5).

Figure 5. a) Huawei inverter system normalized production and loss factors b) SolarEdge inverter system normalized production and loss factors



According to the analysis results, the average daily energy coming to the unit collector plane is 4.704kWh.

Figure 6. Annual distribution of reference incoming energy in the collector plane



According to the simulation results, the specific output of the Huawei inverter system is 1316 kWh/kWp/year, and the specific output of the SolarEdge inverter system is 1414 kWh/kWp/year (Table 2-3). Here, GlobHor indicates Horizontal global irradiation, DiffHor indicates Horizontal diffuse irradiation, T_amb indicates Ambient temperature, GlobInc indicates Incident global irradiation in the collector plane, GlobEff "Effective" global, after all optical losses, EArray Effective energy at the array output. E_user indicates Energy need of the user, E_Solar indicates Energy supplied to the user from solar, E_Grid indicates Energy injected into the grid, EFrGrid indicates the energy drawn from the grid for the internal consumption (when PV is not sufficient), and during night.

Table 2. System with Huawei inverter balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb ºC	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	62.5	25.65	1.68	66.9	60.2	18.31	150	17.97	-0.007	132
February	83.3	32.23	3.26	87.9	80.2	23.91	127	23.52	-0.006	103.5
March	127.1	54.22	7.08	130.5	120.5	33.99	143	33.43	-0.006	109.6
April	159.7	67.4	11.86	161.5	150.1	40.46	122	38.74	1.063	83.3
May	199.9	75.04	16.77	199.9	186.2	47.93	105	41.06	6.103	63.9
June	215.9	70.79	20.98	215	200.3	50.21	242	49.42	-0.005	192.6
July	223.7	68.23	24.86	223.4	208.1	51.57	170	50.76	-0.005	119.2
August	206.4	57.78	25.14	208.4	194.9	49	184	48.21	-0.005	135.8
September	163.4	43.81	19.99	167.6	155.9	40.8	129	39.93	0.214	89.1
October	112.2	40.96	13.86	117.2	107.5	30.45	130	29.92	0.014	100.1
November	73.4	24.69	7.95	78.6	71.1	21.02	150	20.66	-0.007	129.3
December	55.7	24.83	3.09	60.1	53.7	16.33	149	16.03	-0.008	133
Year	**1683.2**	**585.63**	**13.1**	**1717**	**1588.7**	**423.98**	**1801**	**409.63**	**7.345**	**1391.4**

Table 3. System with SolarEdge inverter balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb ºC	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	62.5	25.65	1.68	66.9	60.2	18.61	151	18.23	0	132.8
February	83.3	32.23	3.26	87.9	80.2	24.62	127	24.1	0.03	102.9
March	127.1	54.22	7.08	130.5	120.5	36.14	143	34.69	0.71	108.3
April	159.7	67.4	11.86	161.5	150.1	43.88	122	39.24	3.74	82.8
May	199.9	75.04	16.77	199.9	186.3	52.59	105	41.25	10.26	63.7
June	215.9	70.79	20.98	215	200.4	55.68	242	54.54	0	187.5
July	223.7	68.23	24.86	223.4	208.2	57.22	170	55.9	0.14	114.1
August	206.4	57.78	25.14	208.4	195	54.21	184	53.09	0	130.9
September	163.4	43.81	19.99	167.6	155.9	44.48	129	40.89	2.69	88.1
October	112.2	40.96	13.86	117.2	107.6	31.7	130	30.56	0.5	99.4
November	73.4	24.69	7.95	78.6	71.1	21.45	150	21.02	0	129
December	55.7	24.83	3.09	60.1	53.7	16.56	149	16.22	0	132.8
Year	**1683.2**	**585.63**	**13.1**	**1717**	**1589.1**	**457.14**	**1802**	**429.75**	**18.08**	**1372.3**

Figures 9 and 10 show the change in system performance from year to year due to losses. The losses involved are due to various reasons. The technical expressions used in the figures can be explained as follows;

Global Horizontal Radiation [kWh/m2]: It is the value determined in the light of the meteorological data measured and recorded to date in the simulation program. In current systems, this value is included in the simulation report as 1683 kWh/m2.

Global Radiation to the Solar Panel Surface[kWh/m2]): It refers to the gains or losses to be achieved depending on the mounting angle of the panel. While this value increases in panels placed at an appropriate angle, it may decrease or even be a negative value depending on the lack of slope or the change of direction of the panels.

Close Shading: Radiation loss: It shows the radiation losses due to shading that may occur in the system depending on the angle of the sun. In the report, this value is 0.93% for the Huawei inverter system and 0.90% for the SolarEdge inverter system.

Global IAM factor (Angle Reflection Factor): Not all of the radiation falling on the panel can be used by the cells. While most of the incoming radiation is absorbed by the panel, some of it is reflected. This factor represents the losses due to diffraction reflected from spherical radiation depending on the panel mounting angle.

Contamination Loss Factor (Panel Contamination Factor): It is a loss that can vary depending on environmental factors rather than the plant. Dust, snow, leaves, etc. It shows the energy production loss of the panels during the year as a percentage due to pollution in the panels. In general, this value is taken as 3% in the PVsyst program.

Module Degradation Loss: The output power of a photovoltaic module may decrease over time or its power may decrease due to the failure of a single cell in the module. This will cause productivity to decrease. It is specified in technical documents by panel manufacturers. This value is 0.7.

PV loss depending on radiation level: It shows the losses caused by low radiation in PV panels.

Temperature-dependent PV loss: The voltage produced by PV modules is inversely proportional to temperature. In other words, in arrays consisting of PV panels under the same radiation and at different temperatures, the panels in the cold environment produce more voltage. The starting voltage of each inverter is different. Therefore, the activation time of the system in the morning varies. It shows the loss of electricity production as a percentage due to time differences arising from this value.

Shadings: Electrical Loss acc. to strings (Electrical loss due to shading): It shows the production loss in the PV arrays in the system as a result of the solar panels being exposed to shadow. In current systems, this loss is seen as 0.01%.

Module quality loss: It refers to the losses caused by the decrease in the efficiency of PV modules over time. It is specified in the documentation by the panel manufacturer.

LID (Light Induced Degradation)-Aging Loss: It shows the aging loss rate that will occur in PV modules due to radiation. In the current system, this loss is seen as 2%.

Mismatch loss modules and arrays: It is not possible for all modules to have the same current and voltage values in the PV arrays created. The PV module with the lowest current value connected in series on the array determines the current value in the array. Under these conditions, the module producing more current than the current value will suffer a production loss. The corresponding value indicates this loss.

Ohmic cabling loss: It shows the losses of the cables used in the system. This value may vary depending on the cross-section of the cables, the type of conductor used and their size.

Inverter Loss During Operation: As with every device, there is a certain efficiency in inverters due to losses. These losses show the rate of electrical energy lost according to the efficiency of the inverter. This loss is seen as 1.46% in the Huawei inverter system and 1.92% in the SolarEdge inverter system.

Nominal inv. Inverter loss via Power: When inverters are loaded with DC power above their AC output capacity, the generated energy may be lost at certain times. It shows these losses, which vary depending on the system design. This loss is 6.74% in the Huawei inverter system and 0.86% in the SolarEdge inverter system.

Max. Inverter loss due to input current: Operation above the maximum input current.

Inverter loss above rated inverter voltage: Each inverter has its own operating voltage. TV series can produce below this voltage value. The energy loss that will occur during these periods when the inverter is not working is indicated in this way.

Inverter loss resulting from sold power: These are the losses arising from the operation of the arrays connected to the inverter under minimum power, specified within the scope of the inverter technical specifications.

Inverter loss due to sold voltage: It shows the inverter-related loss caused by arrays producing voltage above the maximum MPTT voltage value.

Night consumption: It shows the production made when the inverter is not working, and the idle losses when it is not working.

Available Energy at Inverter Output: Shows the electrical energy expected to be produced at the output.

Energy Injected into the Grid: It shows the electrical energy that will be injected into the grid after all losses.

Figure 9. System with Huawei inverter loss diagram

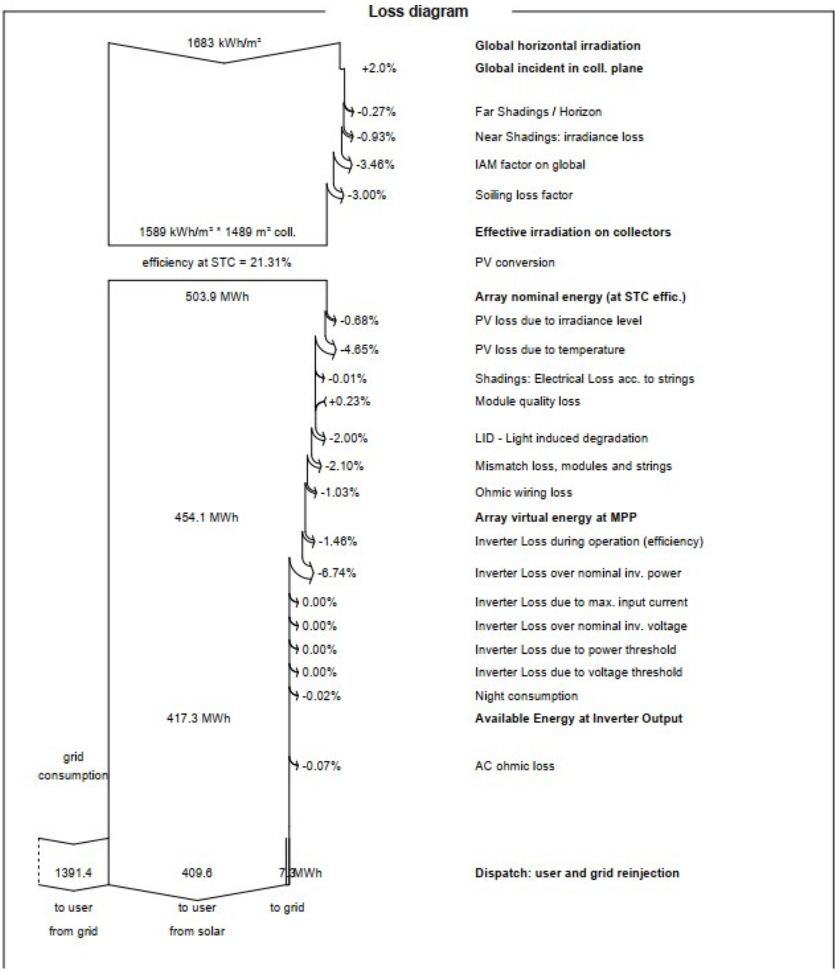
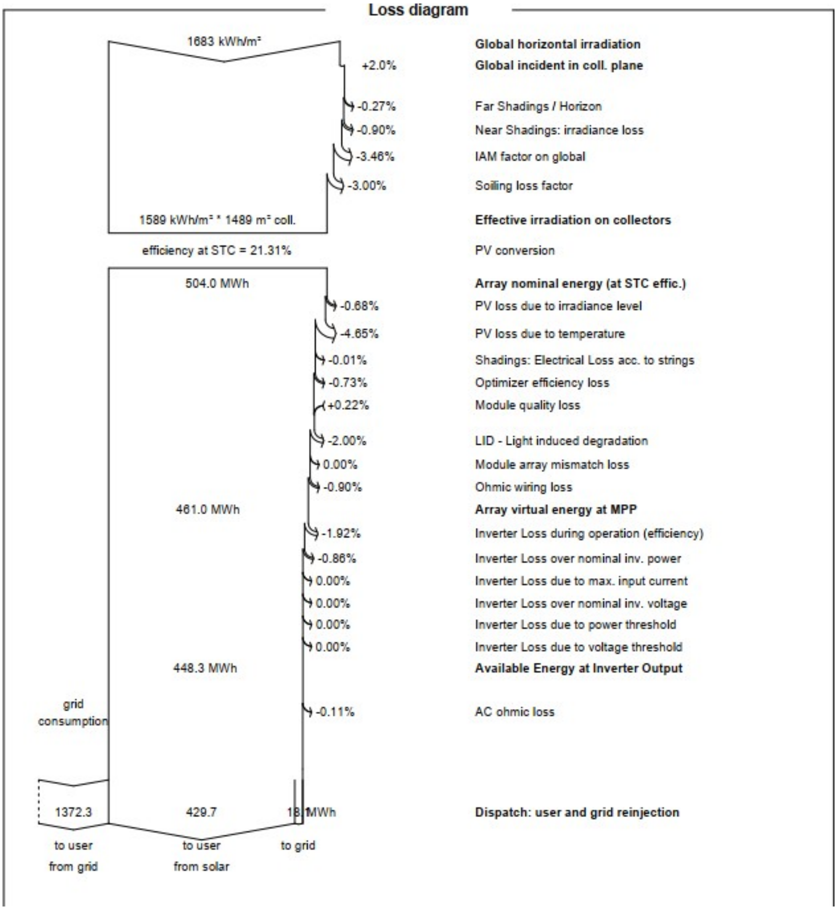


Figure 10. System with SolarEdge inverter loss diagram



In the simulation program, the production value of the photovoltaic power plant with Huawei inverter at the end of the first year was determined as 409.6 MWh, and the production value of the photovoltaic power plant with the SolarEdge inverter at the end of the first year was determined as 429.7 MWh.

In this study, the solar energy system installed on the roofs of Ankara Yıldırım Beyazıt University 15 July Martyrs Campus was evaluated in terms of the results to be obtained when two different inverters were used. PvSyst 7.3 program was used in the study. Using the SolarEdge inverter in the modeled system provides higher energy production and higher efficiency compared to the choice of Huawei inverter. The difference clearly reveals the importance of inverter selection in the installation of PV systems.

REFERENCES

[1] https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik#:~:text=2022%20y%C4%B1l%C4%B1nda%20elektrik%20%C3%BCretimimizin%2C%20%34,g%C3%BCc%C3%BC%20104.136%20MW%27a%20ula%C5%9Fm%C4%B1%C5%9Ft%C4%B1r. Erişim tarihi:20.03.2023

[2] UNFCCC, Conference of the Parties, United Nations Framework Convention on Climate Change, FCCC/CP/2015/L.9/Rev.1, 2015.

[3] https://www.mfa.gov.tr/paris-anlasmasi.tr.mfa Erişim tarihi:20.03.2023

[4] Z. Aktas, A review and comparison of renewable energy strategies or policies of some countries, in: 4th International Conference on Renewable Energy Research and Applications, Palermo, Italy, 2015.

[5] Barker PP, De Mello RW. Determining the impact of distributed generation on power systems. I. Radial distribution systems. IEEE power engineering society summer meeting, 2000, vol. 3; 2000. p. 1645–1656.

[6] Chiradeja P, Ramakumar R. An approach to quantify the technical benefits of distributed generation. IEEE Trans Energy Convers 2004;19:764–73.

[7] Lee, J., Chang, B., Aktas, C., & Gorthala, R. (2016). Economic feasibility of campus-wide photovoltaic systems in New England. Renewable Energy, 99, 452-464.

[8] Šúri M, Huld TA, Dunlop ED, Ossenbrink HA. Potential of solar electricity generation in the European Union member states and candidate countries. Sol Energy 2007;81:1295–305.

[9] Germany's SUN-AREA Research Project. Mapping the solar potential of rooftops, ArcNews Fall; 2009.

[10] Chaves A, Bahill AT. Pilot study uses DEM derived from LiDAR, ArcUser Magazine for the Esri Software Users; 2010. p. 24–27.

[11] Gastli A, Charabi Y. Solar electricity prospects in Oman using GIS-based solar radiation maps. Renew Sustain Energy Rev 2010;14:790–7.

[12] Ludwig D, Lanig S, Klarle M. SUN-AREA towards locations-based analysis for solar panels by high resolution remote sensors (LIDAR). In: Proc. İn international cartographic conference, Santiago de; 2009.

[13] Santos T, Gomes N, Brito M, Freire S, Fonseca A, Tenedorio JA. Solar potential analysis in Lisbon using LiDAR data. In: Proc. in 31st EARSeL symposium and 35th general assembly, Prague; 2011.

[14] Nguyen HT, Pearce JM, Rob H, Barber G. The application of LiDAR to assessment of rooftop solar photovoltaic deployment potential in a municipal district unit. Sensors 2012;12(4):4534–8.

[15] Strzalka A, Alam N, Duminil E, Coors V, Eicker U. Large scale integration of photovoltaics in cities. Appl Energy 2012;93:413–21.

[16] Lukac N, Zlaus D, Seme S, Zalik B, Stumberger G. Rating of roofs' surfaces regarding their solar potential and suitability for PV systems, based on LiDAR data. Appl Energy 2013;102:803–12

[17] Willis HL. Analytical methods and rules of thumb for modeling DGdistribution interaction. IEEE power engineering society summer meeting, 2000, vol. 3; 2000. p. 1643–1644.

[18] Thong VV, Driesen J, Belmans R. Power quality and voltage stability of distribution system with distributed energy resources. Int J Distrib Energy Resour 2005;1:227–40.

[19] Kucuksari, S., Khaleghi, A. M., Hamidi, M., Zhang, Y., Szidarovszky, F., Bayraksan, G., & Son, Y. J. (2014). An Integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments. Applied Energy, 113, 1601-1613.

[20] Kamalinia S, Afsharnia S, Khodayar ME, Rahimikian A, Sharbafi MA. A combination of MADM and genetic algorithm for optimal DG allocation in power systems. Universities power engineering conference, 2007. UPEC 2007. 42nd International; 2007. p. 1031–5.

[21] 1. T.C. Ministy of Energy and Natural Resources, “Solar”, 2022.

[22] Edward J. Coster , Johanna M.A.Myrzik, Bas Kruimer and Wil L. Kling, “ Integration issues of distributed generation in distribution grids” Proceeding of IEEE January 2011.

[23] N.K.Roy, H.R.Pota “Current Status and Issues of Concern for the Integration of Distributed Generation Into Electricity Networks” IEEE systems journal 2014.

[24] IEEE Application Guide for IEEE Standard 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Std 1547.2 -2008, 2009.

[25] H.Alatrash, R A. Amarin and L. Cheung, “Enabling large scale PV integration into the grid” , in Proceedings of IEEE Green Technologies Conference, pp.1-6,19-20 Apr.2012.

[26] R.Hudson and G. Heilscher, “PV grid integration – System management issues and utility concerns,” Energy Procedia, Vol 25, pp 82-92,2012.

[27] M.H.Coddington, B.D. Kroposki and T.S.Basso, “Evaluating future standards and codes with focus on high penetration photovoltaic (HPPV) system deployment,” in Proc IEEE PVSC, Jun 20-25, 2010, pp, 544-549.

[28] Gotekar, P. S., Muley, S. P., Kothari, D. P., & Umre, B. S. (2015, December). Comparison of full bridge bipolar, H5, H6 and HERIC inverter for single phase photovoltaic systems-a review. In 2015 Annual IEEE India Conference (INDICON) (pp. 1-6). IEEE.

[29] Yongheng Yang, Huai Wang and Frede Blaabjerg, “Reactive Power Injection Strategies for Single-Phase Photovoltaic Systems Considering Grid Requirements” IEEE Trans. on Ind. Applications, Vol. 50, No. 6, Nov/Dec 2014, pp 4065-4076.

[30] Mohamed Shawky El Moursi, Weidong Xiao, Jim. L. Kirtley Jr, “Fault ride through capability for grid interfacing largescale PV power plants”, IET Gen, Trans and Distribution 2013.

[31] Yongheng Yang, Prasad Enjeti, Huai Wang and Frede Blaabjerg, “Suggested grid code modifications to ensure wide-scale adoption of photovoltaic energy in Distributed Power Generation Systems” Industry Applications Society Annual Meeting, 2013 IEEE pp 1-8.

[32] Elin Energy, “Sirius – Datasheet – 72M – 550W”, 2022.

[33] Huawei Inverter, “SUN2000-36 kTL, datasheet”, 2022.

[34] SolarEdge Inverter, “SE33.3K, datasheet”, 2022.

[35] SolarEdge Power Optimizer, “P1100 W, datasheet”, 2022.

EXAMINATION OF RENEWABLE ENERGY TECHNOLOGIES AND DETERMINATION OF ISSUES TO BE CONSIDERED WHILE REALIZING BIOFUEL PRODUCTION IN EXPERIMENTAL ENVIRONMENT

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1. INTRODUCTION

Energy is one of the most important parameters shaping life in the world. With global warming and the impact of chemical energy on the environment, the method of obtaining energy and its importance increases many times over. For this reason, the importance of sustainable energy has become a concept of great importance in our lives day by day. There are many effective parameters that guide research in renewable energy sources. If we count a few of them; sustainability, cost, optimization, potential determination, hybrid use of renewable resources and effective development of technologies used in renewable energy

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conversion systems. When the scientific researches conducted in this context are examined, the main ones are; Ying L. emphasized the studies that need to be done in order to abandon conventional energy production systems, which are seen as the source of the climatic threats facing the world. By examining the development trends of investments and incentives for renewable energy sources in the world, he tried to determine the cost of switching to renewable energy technology [1]. Due to the increasing importance of renewable energy sources, technical and economic potential determination studies have been conducted for many countries and new ones are constantly being added to these studies. Within the scope of this study, potential determination studies in the literature for many countries are reviewed [2-9]. In the study conducted by Indulkar, it was revealed that maximum benefit from renewable energy resources can be obtained by using Monte Carlo method. It has been examined that Monte Carlo optimization technique provides useful results in making decisions such as which renewable energy source to choose, which source to use for hybrid systems and at what rate.

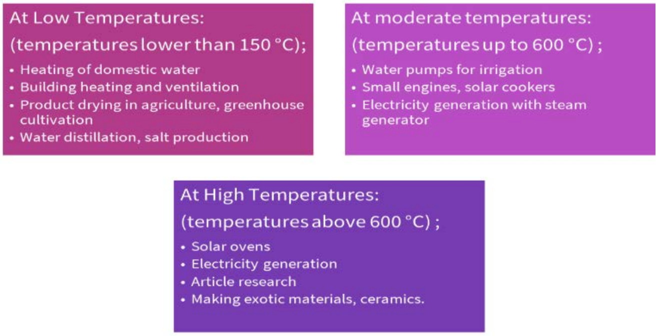
Wind, Hydro, Solar and Cogeneration systems are compared and determined by cost analysis. Thus, it is suggested that maximum efficiency can be obtained from renewable energy sources under minimum cost [10]. In the studies conducted by Kaygusuz A., and Akdeniz F., the necessity of using renewable energy resources comes to the forefront based on the increasing air pollution problem in Turkey, the fact that large hydroelectric power plant projects are highly debated due to the disadvantages they bring in various aspects, and the fact that energy production based on natural gas and oil is not sustainable due to foreign dependence. The importance of hydroelectric, biomass, geothermal, solar thermal, photovoltaic and wind resources for sustainable development is discussed in many studies. It is estimated that hard coal reserves in the country will be depleted in 55 years, lignite in 105 years, oil in 30 years and natural gas in 24 years, and it is emphasized that cogeneration systems should be established especially in power plants using fossil fuels, and it is stated that increasing the efficiency by enriching the coal used will help reduce the amount of emissions. It was concluded that there are many regions in the country where small hydroelectric power plants can be established and that sustainable development can be achieved with the effective use of these resources, especially in terms of wood-fueled biomass [11-13]. In our study, solar energy, nuclear energy, geothermal energy, hydraulic energy and biofuel energy were examined among renewable energy types. It has been seen that biofuels are of great importance among these energy types. For this reason, it has been investigated what factors should be considered during the production of biofuels and what factors should be considered during production in terms of the environment.

2. RENEWABLE ENERGY SOURCES

2.1. Solar Energy

Solar energy is utilized in the form of heat energy and electrical energy through various transformations [14]. Direct electricity generation is also possible by using semiconductors. The areas of utilization by converting to heat are divided into three sections according to temperature limits [15]. These are low temperatures: temperatures lower than 150 °C, medium temperatures: temperatures up to 600 °C and high temperatures: temperatures above 600 °C. The areas of utilization by converting to heat are given in Figure 1 according to temperature limits.

Fig. 1. The areas of utilization by converting to heat, separated according to temperature limits



Solar heating is divided into two main groups as active and passive system heating [15]. In active system heating, a mechanical system other than the known housing elements is used to collect energy in solar energy utilization. The air or water heated in the collectors is circulated in the classical heating system and indoor areas are heated. The collector system replaces the boiler in the normal heating system. The solar energy system can be connected in series or parallel with the normal heating system. Even the heat taken from the sun through the fluid can be circulated through pipes in the wall and concrete structure and stored in the wall and concrete. Passive system heating is a system that provides heating by accepting the sun's rays directly into the dwelling. In the principle of passive heating, the house itself is used as a collector and no mechanical components are used. For this reason, solar energy can only be utilized uncontrolled with passive systems. In utilizing solar energy with passive systems, problems such as the orientation of the house to the sun, its shape and not being shaded by other structures should be taken into consideration and solved during the design and construction of the house. The most common and preferred application of passive systems is the Trombe wall [16] . In this wall, another double glazed wall is made slightly in front of the normal wall. The normal wall is black in color and there is enough space between the glass and the wall to allow air circulation. At the top and bottom of the main wall, the room air is heated by circulation through ducts opening into the room. The ducts are closed when the sun is not shining to provide insulation against the outside. Solar energy usage areas are given in Figure 2.

Fig. 2. Areas of use of solar energy

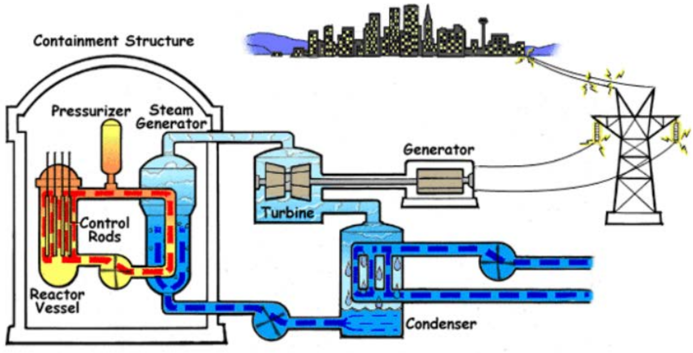
2.2. Nuclear Energy

Nuclear energy is a type of energy derived from the nucleus of the atom. It is related to the formula $E=mc^2$, which expresses the conversion of mass into energy. Nuclear reactors are used to forcibly extract nuclear energy and convert it into other types of energy. Nuclear energy is created by one of three nuclear reactions. Fusion is defined as the fusion reaction of atomic particles. Fission is the forced disintegration of atomic nuclei. Half-life is known as the fission of the nucleus into a more stable state. It can also be defined as natural (slow) fission (nuclear fission) [17] . The areas of use of nuclear energy are given in Figure 3.

Fig. 3. Areas of use of nuclear energy

Nuclear energy is converted into energy through nuclear power plants. When we look at the internal structure of the nuclear power plant, the energy generated by the fission reaction of uranium allows water vapor to be heated to very high temperatures. This high-temperature vapor is given to turbines connected to the electric generator. The high-energy steam hitting the turbine blades turns the turbine shaft in the usual way and the generator generates electricity. The electricity generated in the generator is sent to the place where it will be used with conductive wires called transmission lines. The steam coming out of the turbine, which has dropped in pressure and temperature, goes to the condenser to be used again, and after becoming water, it is heated again with the energy released by the fission and turned into steam and the cycle continues [18]. The working principle of nuclear power plants is given in Figure 4.

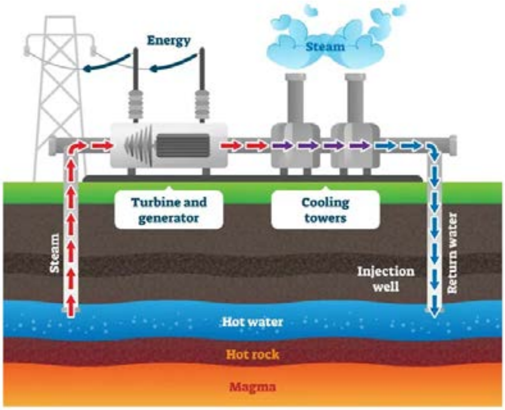
Fig. 4. Working principle of nuclear power plants



2.3. Geothermal Energy

Geothermal energy is a natural type of energy. The heat source used in the formation of this renewable energy is the magma deep in the earth's crust. The temperature of the earth increases towards the inner part of the earth's crust. The depth in meters of the depth to be descended vertically in the earth's crust for a temperature increase of approximately 1 °C is called the geothermal degree. The geothermal degree is usually based on internal temperature steps of 30-35 m. Obtaining geothermal energy is called obtaining geothermal energy by drilling the rainwater loaded with heat energy in the depths of the earth's crust and making it useful to people. There are two main sources of heat in the earth's crust. The first is the heat that has entered the earth's crust and is carried and spread with the magma rising towards the earth's surface. The second is the temperature of the earth itself, called ground temperature or geothermia, which increases as you go deeper into the crust. The value of this is 1100-1200 °C. This energy can be obtained directly from the earth's own heat. The word geothermal is a combination of "geo" meaning earth and "thermal" meaning heat. This energy is formed from the heat of the magma, which is composed of molten rocks kilometers deep in the earth's crust. The heat rising from the magma heats underground pools of water known as geothermal reservoirs. Sometimes the water can even boil to form steam. When these find a place to come to the surface, they come out of geysers as water or boiling water. These are known as hot springs [19] . The working principle of geothermal power plants is given in Figure 5.

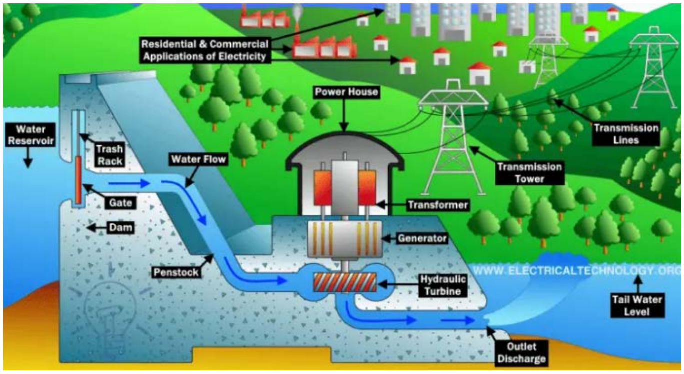
Fig. 5. Working principle of geothermal power plants



2.4. Hydraulic Energy

Hydraulic energy is the most important renewable energy source in certain regions of the world. While large hydroelectric power plant applications are included in the classical renewable energy production in the literature, the energy produced by small hydroelectric power plants is included in the scope of new and renewable energies. The cost of energy produced by hydroelectric power plants is low and pollution-free. They also have high efficiency. Electric energy is transported from power plants, i.e. electricity production factories, to consumption centers through energy transmission lines called high voltage lines. The system of lines connecting all production and consumption centers throughout the country is called interconnected system [20]. The working principle of hydraulic power plants is given in Figure 6.

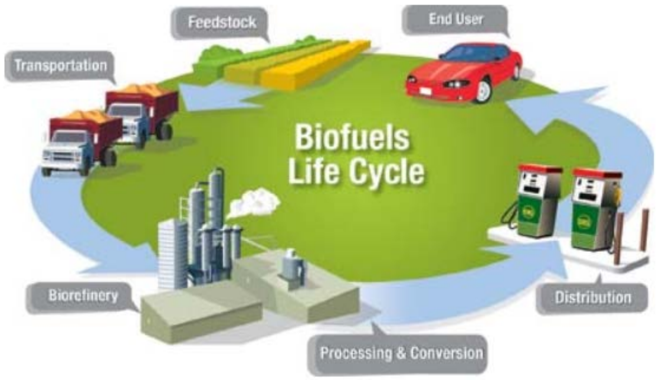
Fig. 6. Working principle of hydraulic power plants



2.5. Biofuel Energy

The limited energy resources known on earth and environmental factors lead to more economical use and better management of these resources. In particular, the search for new, environmentally friendly and renewable energy sources that can replace fossil-based (petroleum and its products) resources has come to the fore. Renewable alternative motor fuels, such as vegetable oils and alcohol, have not been able to compete with petroleum due to the cheaper and more abundant production of petroleum and its products. However, the oil crisis in the mid-1970s led to the withdrawal of petroleum products from the market and a parallel increase in their prices. Due to the concentration of the world's oil reserves in certain regions and political and economic reasons, oil crises have occurred from time to time and continue to occur today. In addition to all these, the fact that oil is a finite resource based on a certain reserve and the development of engine technology dependent on oil has made it necessary to research and reveal new and more environmentally friendly fuels that will be an alternative to diesel fuel without making much change in the existing engine technology. In this regard, especially in countries with high agricultural potential, vegetable oils come to the forefront. Numerous studies have been conducted in various countries, including our country, on the use of vegetable oils and wastes as motor fuel. Research results have shown that vegetable oils and wastes have properties that can be used instead of diesel fuel in internal combustion engines. The main vegetable oils that can be used as engine fuel are rapeseed oil, soybean oil, sunflower oil, corn oil, linseed oil, peanut oil, cottonseed oil, safflower oil and their used forms [21] . The life cycle of biofuel energy is given in Figure 7.

Fig. 7. Biofuel energy life cycle



3. CONSIDERATIONS WHEN REALIZING BIOFUEL PRODUCTION

During the biofuel production, a transesterification reaction was applied. 1000 ml of corn oil was placed in a glass bottle. With the help of a magnetic stirrer placed in the glass bottle, the oil was subjected to preliminary preparation at 600 revolutions per minute and at a constant temperature of 60 °C. In another glass bottle, 400 ml of methanol was mixed with 8 grams of NaOH. When the dissolution of NaOH in methanol was complete, the resulting solution was gradually added to the oil at 60 °C. After 2 hours, the reaction was terminated. At the end of the reaction, the product was transferred to a separatory funnel.

After 24 hours, glycerin with a high concentration was observed in the lower phase. Upon opening the separatory funnel valve, the glycerin in the lower phase was removed from the mixture. With the removal of glycerin, the main product was obtained. The materials used in the reaction are shown in Figure 8.

Fig. 8. Materials used in biofuel reaction

The biofuel obtained when the reaction was successfully completed is shown in Figure 9.

Fig. 9. Biofuel obtained as a result of a successful reaction

Adverse conditions in the reaction may cause the reaction to be unsuccessful during the production of biofuel. These negative effects are the type of oil, free fatty acid, moisture effect, catalyst type, reaction time, effect of alcohol/oil ratio, reaction temperature, stirring intensity and homogeneity of the mixture. As a result of negative effects in the reaction, the desired biofuel cannot be obtained. In this case, the biofuel obtained as a result of a failed reaction is shown in Figure 10.

Fig. 10. Biofuel obtained as a result of a failed reaction

4. CONCLUSIONS

Although there are many sources of renewable energy in the world, the main ones are solar energy, nuclear energy, geothermal energy, hydraulic energy and biofuel energy. As the number of motorized vehicles is increasing day by day, the harmful effect of exhaust emissions on the environment is naturally increasing. Biofuels are important in order to minimize this harmful effect. In our study, it is aimed to find a solution to this problem with biofuels, one of the renewable energy types due to these harmful effects. For this reason, the issues to be considered in order to produce these fuels in the most environmentally friendly way are examined. The use of biofuels on Earth will contribute to the solution of environmental pollution. It will reduce the world's dependence on fossil fuels. It can be said that the use of waste vegetable oils as alternative fuel in the world will be possible and will make a great contribution to national economies and the environment. In this context, Roy et al. (2015) produced biodiesel from canola oil and mixed it with 5%, 10%, 20% and 50% diesel fuel in order to examine the performance and emission values of biodiesel in a diesel vehicle engine. The obtained fuel samples were subjected to performance and emission tests at 1800 rpm and three different loads in a direct injection diesel engine. They compared the results obtained with diesel fuel values and found that there was a decrease in HC, CO, smoke emissions and an increase in specific fuel consumption and NOx values [22]. How et al. (2014) produced biodiesel from coconut oil and experimentally investigated the performance, emission, combustion and vibration parameters at different in-cylinder pressure conditions by creating four different fuel samples as B10, B20, B30 and B50. As a result of the experimental study, it was analyzed that the smoke emission in the B50 fuel sample was reduced by 52.4% and the lowest fuel consumption was in the B10 fuel sample. It was suggested that in-cylinder combustion performance is more suitable for biodiesel use [23]. In this context, by analyzing the studies in the literature, various experimental studies were carried out in our study to determine the issues that should be considered in order to realize an effective and efficient biofuel production. As a result of these experimental studies, the rules that must be considered in production were determined and listed as items. These points are; adverse conditions in the reaction may cause the reaction to be unsuccessful during the production of biofuel. These negative effects are the type of oil, free fatty acid, moisture effect, type of catalyst, reaction time, effect of alcohol/oil ratio, reaction temperature, mixing intensity and homogeneity of the mixture. Care should be taken when using methyl alcohol as it is a very toxic substance. Sodium hydroxide should be stored in a dry environment as it is highly basic and has the ability to retain moisture. Improper use can cause permanent damage. If we look at the cases where waste oil is used in biodiesel production; if these oils thicken and solidify at 20°C, the waste oil must be preheated before adding chemicals. Chemicals used in manufacturing must be resistant to heat and corrosion. CH_3ONa solution (Methanol + NaOH) is highly toxic and corrosive to tank paints. Biofuel should not be placed in tanks with NaOH, Zn, Al and tinned tanks as it will react with these metals. Tanks made of steel should be preferred [68]. Our study will contribute to the literature in general in terms of determining the efficient biofuel production stages to be followed in all studies and the tricks to be considered in production.

REFERENCES

[1] Ying, L., Yin, C., Yuan, R., & Yong, H. (2008, October). Economic incentive mechanism of renewable energy generation. In *2008 International Conference on Electrical Machines and Systems* (pp. 2689-2694). IEEE.

[2] Gubina, A. F., Xiangyang, X., & Zhengmin, S. (2006, October). Analysis and support policy recommendation of renewable energy sources in Western China. In *2006 International Conference on Power System Technology* (pp. 1-8). IEEE.

[3] Mwasumbi, H., & Tzoneva, R. (2007, September). Power sector in Tanzania: Performance, trends and reforms. In *AFRICON 2007* (pp. 1-7). IEEE.

[4] Akinbami, J. F. K. (2001). Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework. *Mitigation and adaptation strategies for global change*, *6*, 155-182.

[5] Mustafa Omer, A. (2002). Energy supply potentials and needs, and the environmental impact of their use in Sudan. *Environmentalist*, *22*, 353-365.

[6] Nguyen, K. Q. (2007). Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam. *Energy Policy*, *35*(4), 2579-2589.

[7] Cherni, J. A., & Kentish, J. (2007). Renewable energy policy and electricity market reforms in China. *Energy Policy*, *35*(7), 3616-3629.

[8] Schneider, D. R., Duić, N., & Bogdan, Ž. (2007). Mapping the potential for decentralized energy generation based on

renewable energy sources in the Republic of Croatia. *Energy*, *32*(9), 1731-1744.

[9] Alnatheer, O. (2005). The potential contribution of renewable energy to electricity supply in Saudi Arabia. *Energy policy*, *33*(18), 2298-2312.

[10] Indulkar, C. S. (2008, October). Monte Carlo planning technique for renewable energy sources. In *2008 Joint International Conference on Power System Technology and IEEE Power India Conference* (pp. 1-7). IEEE.

[11] Kaygusuz, K. (2002). Renewable and sustainable energy use in Turkey: a review. *Renewable and sustainable energy reviews*, *6*(4), 339-366.

[12] Akdeniz, F., Çağlar, A., & Güllü, D. (2002). Recent energy investigations on fossil and alternative nonfossil resources in Turkey. *Energy Conversion and Management*, *43*(4), 575-589.

[13] Kaygusuz, K., & Kaygusuz, A. (2002). Renewable energy and sustainable development in Turkey. *Renewable energy*, *25*(3), 431-453.

[14] Karaca, C. (2012). Design of an electric power generation system from solar and wind energy.

[15] Kendirli, B., & Çakmak, B. (2010). Use of Renewable Energy Sources in Greenhouse Heating. Ankara University Journal of Environmental Sciences, 2(1), 95-103.

[16] Ersayın, E. (2023). Comparison of Energy, Economic and Environmental Analysis Results of Different Types of Trombe Walls for Manisa. Bilecik Şeyh Edebali University Journal of Science and Technology, 10(1), 108-120.

[17] Kaya, İ. S. (2012). Environment and human in the world of nuclear energy. Bolu Abant İzzet Baysal University Journal of Institute of Social Sciences, 12(1), 71-90.

[18] Özer, S., & Güngör, Ö. (2020). Examination of Nuclear Power Plants in Terms of National Security Elements and Law Enforcement Practices in Nuclear Power Plants. Anemon Muş Alparslan University Journal of Social Sciences, 8(5), 1447-1453.

[19] Özçalık, A. G. D. M., & Tezsürücü, A. G. D. From Energy Dependence To Green Entrepreneurshıp: The Use Of Renewable Energy Resources In Turkey's Economy.

[20] Şekkeli, M., & fatih Keçecioğlu, Ö. (2011). Development of hydroelectric power plants in Turkey and case study of Kahramanmaraş region. Kahramanmaraş Sütçü İmam University Journal of Engineering Sciences, 14(2), 19-26.

[21] Demirpolat, A. B., Uyar, M. M., & Arslanoğlu, H. (2022). Biodiesel Fuels Produced from Poppy and Canola Oils, Experimental Investigation of the Performance and Emission Values of the Samples Obtained by Adding New Types of Nanoparticles. *Petroleum Chemistry*, *62*(4), 433-443.

[22] Roy, M.M., Wang, W. and Alawi, M., 2015. Performance and emissions of a diesel engine fueled by biodiesel – diesel, biodiesel – diesel-additive and kerosene–biodiesel blends, Energy Conversion and Management, 84, 164-173.

[23] How, H.G., Masjuki, H.H., Kalam, M.A. and Teoh,Y.H., 2014. An investigation of the engine performance, emissions and combustion characteristics of coconut biodiesel in a high-pressure common-rail diesel engine, Energy, 69, 749–759.

[24] Https://www.tobb.org.tr/SanayiMudurlugu/Documents/KapasiteKriterleri/3529-5.pdf. Union of Chambers and Commodity Exchanges of Turkey 2023 data, [Visit Date: October 20, 2023].

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