



Development Framework for Renewable Energy Systems

Mehdiyeva Almaz¹, Toshmamatov Bobir², Uzakov Gulom³, Rahimov Rahim⁴,
Bakhshaliyeva Sevinc⁵

^{1,4,5}Azerbaijan State Oil and Industry University, Electronics and automation, Baku,
Azerbaijan

^{2,3}Karshi State Technical University, Energy Engineering, Mustakillik, 225, Karshi,
Uzbekistan

Abstract

Environmental solutions in energy, the development of energy projects based on renewable energy sources and the impact of energy infrastructure on the environment are explored. It is noted that modern energy is rapidly developing in the direction of environmental sustainability. One of the key vectors is the introduction of advanced environmental solutions, such as smart grids, carbon capture technologies and the use of green hydrogen. Particular attention is paid to the development of projects based on renewable energy sources - solar, wind, hydro and geothermal. These technologies help reduce greenhouse gas emissions and strengthen energy security. Using new system, simulation studies were conducted taking into account the needs of consumers in the region under study and the results obtained were calculated. The results obtained using the HOMER Pro software used to simulate the system showed that the proposed system has largely justified itself. It was shown that the system allows for complete elimination of dependence on fossil fuels, does not emit carbon dioxide, is environmentally friendly, provides clean energy generation, does not create harmonics and distortions, and eliminates the need for electronic power devices such as inverters. The use of this system can be of great importance for countries that do not have fossil fuel reserves and import energy from abroad. As a result of the use of these systems, it is possible to create conditions for eliminating environmental problems, primarily global warming, as well as dependence on fossil fuels.

Keywords: Renewable Energy, Advanced Technologies, Clean Energy, Environmental Problems, Global Warming, Natural Fuels

I. Introduction

Solar energy is the radiant energy released as a result of the fusion process (the conversion of hydrogen gas into helium) in the core of the sun. The intensity of solar energy outside the Earth's atmosphere is approximately 1370 W/m^2 , but the amount reaching the ground due to the atmosphere varies between $0-1100 \text{ W/m}^2$ [1-5]. Even a small part of this energy reaching the Earth is many times greater than the current energy consumption of humanity. Research on the use of solar energy has become widespread, especially after the 1970s, solar energy systems



have shown technological progress and a decrease in cost, and have established themselves as an environmentally friendly energy source.

The multicrystalline method is more widely used in photovoltaic cell production, as polycrystalline production can be processed more easily. The casting method is more commonly used in polycrystalline silicon production. In polycrystalline silicon, the starting material is prepared in the same way as in monocrystalline silicon. The purity of the silicon must also be the same. Molten semiconductor silicon is poured into molds, allowed to cool, and then the resulting blocks are cut into square shapes. The production costs, which are a disadvantage of single-crystalline photovoltaic cells, can be significantly reduced with this technology. However, the energy conversion efficiency of solar cells obtained from the materials produced is lower (Ojanpera, 2015).

Second Generation Photovoltaic Batteries. Materials such as amorphous silicon (a-Si), cadmium sulfide/cadmium telluride (CdS/CdTe), cadmium selenium (CdSe), copper indium gallium diselenide (CIGS), and thin film Si are attracting attention as important materials used in thin second-generation photovoltaic batteries. These materials are primarily prepared by physical or chemical methods using thin film techniques on a front substrate (glass, etc.) coated with a transparent oxide conductive layer. These include ion beam sputtering, physical vapor deposition, and plasma-assisted chemical vapor deposition. These methods have reduced production costs compared to 1st generation photovoltaic panels [6]. Although the energy conversion efficiency of second-generation photovoltaic cells is not as high as that of single-crystal silicon cells, the efficiency of copper indium gallium diselenide cells has significantly reduced the difference to 19.6% (Ojanperä, 2015).

Solid Dye Sensitized Solar Panels. Solid-state dye sensitized solar panels belong to the 3rd Generation solar cell design and were introduced by O'Regan and Grätzel in 1991 with a nanocrystalline titanium film coated with a molecular dye. Since dye sensitized solar cells have a low manufacturing cost, they have been considered as a potential alternative to traditional inorganic silicon-based solar cells. However, a disadvantage of these solar cells is the occurrence of leakage problems due to the presence of a liquid electrolyte. In research conducted in 1998, the liquid electrolyte was replaced by a solid vacancy carrier material and they were called solid-state dye sensitized solar cells (Shi, 2015). In dye sensitized solar cells, nanostructured TiO₂ and a mesoporous layer are used as the electron carrier layer on top of a transparent conductive oxide material coated on glass or plastic. In addition, zinc oxide or tin oxide can also be used as an electron-carrying layer. The significant dependence of solar panel efficiency on regional climate has been thoroughly studied. It is known that solar panels exhibit different efficiency on sunny days than on cloudy days. In other words, solar panels are more energy-efficient and more effective on sunny days. In comparison, their efficiency on cloudy days is significantly lower.



Batteries play a very important role in energy conservation. They store excess energy unused during the day for later use. If your daily electricity needs are high, batteries alone may not be sufficient in winter when sunlight is limited, especially in areas with limited daylight. As a result, many photovoltaic system users maintain a connection to the main power grid as a backup for such situations.

Solar panel maintenance is infrequent. In fact, it is minimal, requiring only periodic cleaning with mild soap and water. There are exceptions: after a storm, branches can fall onto solar panels, reducing their efficiency. Similarly, if the air contains a layer of smog, dust, or pollution, this can lead to a similar decrease in efficiency [7-11]. Despite existing limitations, the photovoltaic industry is expected to address these issues in the near future. Furthermore, photovoltaic systems are unrivaled in their renewable energy potential and are one of the safest and most environmentally friendly energy sources. Producing surplus electricity using solar panel technology offers a unique opportunity to generate additional income. By selling surplus energy back to the grid, people can increase their income and contribute to a more sustainable future (Fig. 1). A dye used as a light absorber is coated on top of the electron-conducting layer. The next layer is a liquid redox electrolyte for the regeneration of the dye. In solid-state dye-sensitized solar cells, this layer is coated with a solid vacancy-carrying material. The top layer is the electrode used to collect electrons. (Haqfeldt 2010, Kazım 2014). Fig. 2 shows the structure of solid-state dye-sensitized solar cells. The function of a solid dye-sensitized solar cell is different from that of a p-n junction solar cell. Its working principle is based on the principle of photosynthesis. Photons are absorbed and excited by molecules and shared at the interface of electron and hole layers. Electrons are injected into the conduction band of the inorganic semiconductor and transferred to the working electrode.

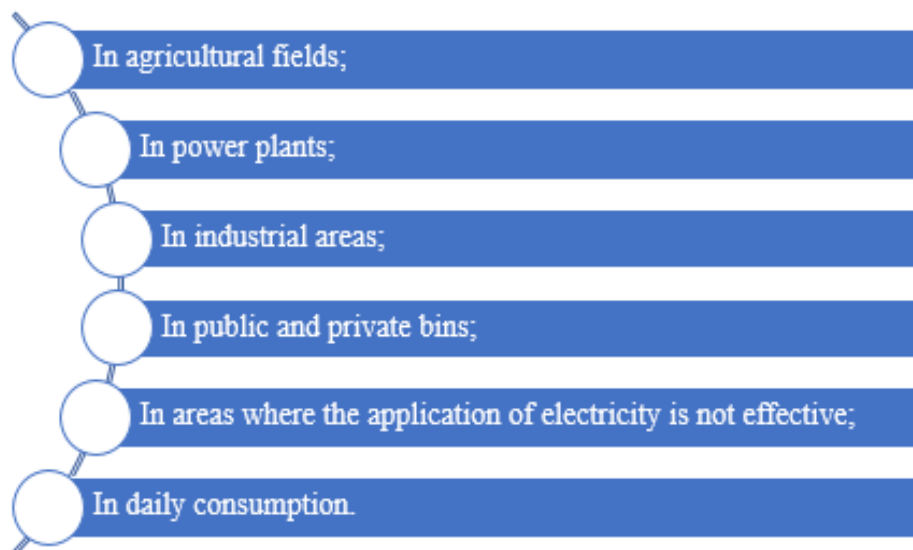


Fig. 1 Application areas of solar panels.



As explained in this paragraph, solar cells have survived from their initial discovery to the present day with significant contributions. Fig. 2 summarizes the development process by type of solar cells and energy conversion efficiency (Fig. 3-4).

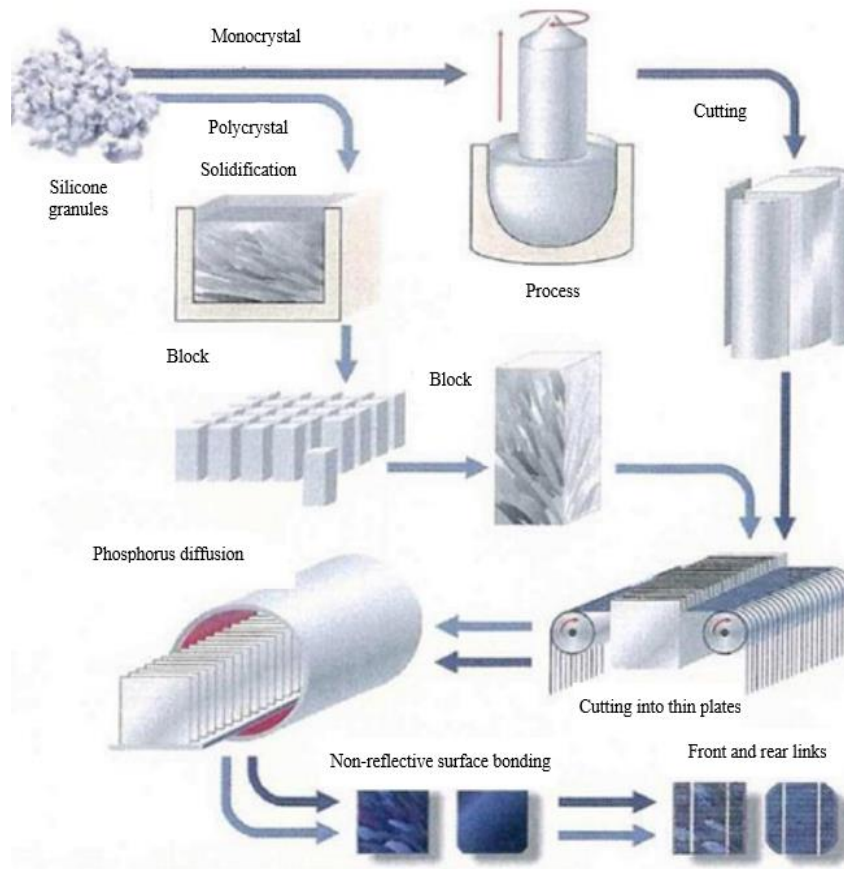


Fig. 2 Single and polycrystalline silicon production methods, such as drawing and cutting.

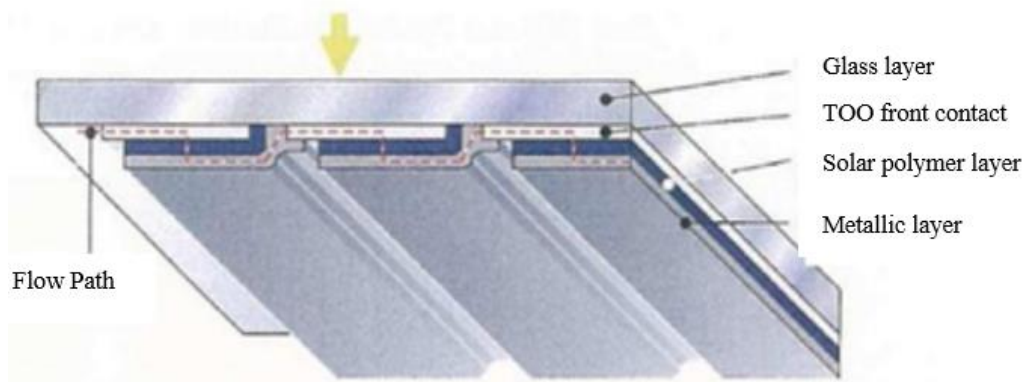


Fig. 3 Panel structure of a thin film solar cell.

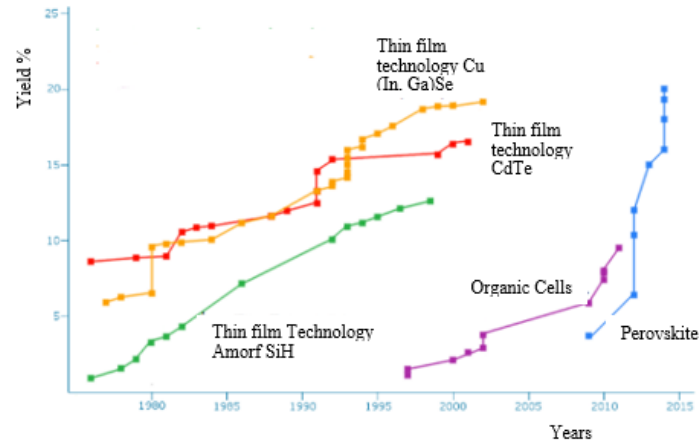


Fig. 4 The development process of solar cells (Green, 2015).

II. Structure of hybrid renewable energy systems

The unconverted state of energy found in nature is referred to as primary energy, and the resources obtained as a result of the conversion of primary energies are referred to as secondary energy. In another classification, if the types of energy remain the same at the end of use, they are called renewable energy sources, and resources that do not renew themselves at the end of use are called non-renewable energy sources. Resources such as solar, wind, geothermal, hydraulic and biomass are examples of renewable energy sources, while resources such as coal, oil and natural gas are examples of non-renewable energy sources. From the past to the present, one of the most important problems of the world is energy. The world population is expected to be about 9 billion in 2040. The increasing population and technological developments require more energy. According to the International Energy Agency report, the current primary energy demand in the world is 14 million tons of oil equivalent (TOE), and it is expected to reach 20.3 billion TOE in the next 20 years, with an increase of 45%..

Due to the depletion of fossil-based energy resources, environmental damage, and global warming, the search for new sources has begun in the world. Developing countries in particular are interested in renewable energy sources to reduce their dependence on foreign sources. Compared to fossil resources, renewable energy sources have become attractive due to their environmental friendliness and inexhaustibility [28]. When statistical data is examined, the average annual growth rate of renewable energy demand in the last fifty years is approximately five times higher than the growth rate in other sources. According to studies, \$68.2 trillion in energy investment is planned worldwide in the next 20-25 years. Although the energy needs of countries differ to varying degrees, the demand for energy is increasing every year. Figure 5 shows the countries and electricity demand (TWh) worldwide for 2022.

As can be seen from Figure 6, the countries with the highest energy demand in the world are technologically advanced countries such as China and America, while the countries with the



lowest energy demand are countries with low development levels such as Africa [25]. As can be seen from the statistical data, the demand and interest in energy has been increasing over the years, and efforts to use energy efficiently have become important [18]. Recently, hybrid systems using renewable energy sources have been developed [29]. Some studies on hybrid systems are explained below.

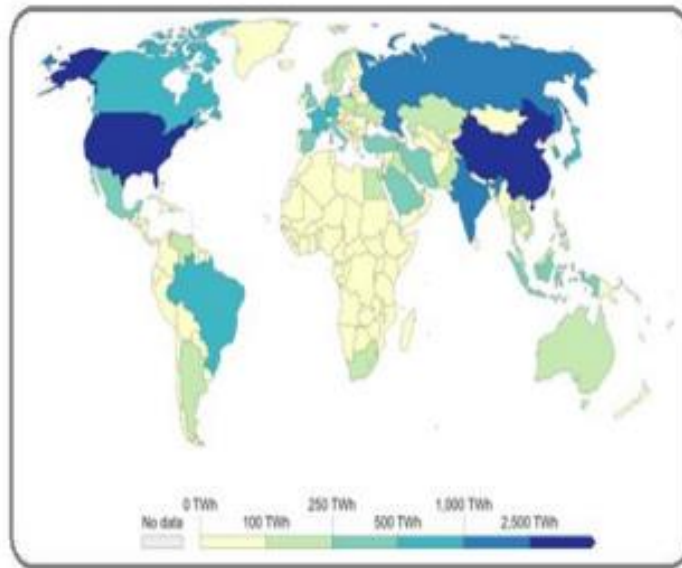


Fig. 5 World electricity demand 2022 (TWh).

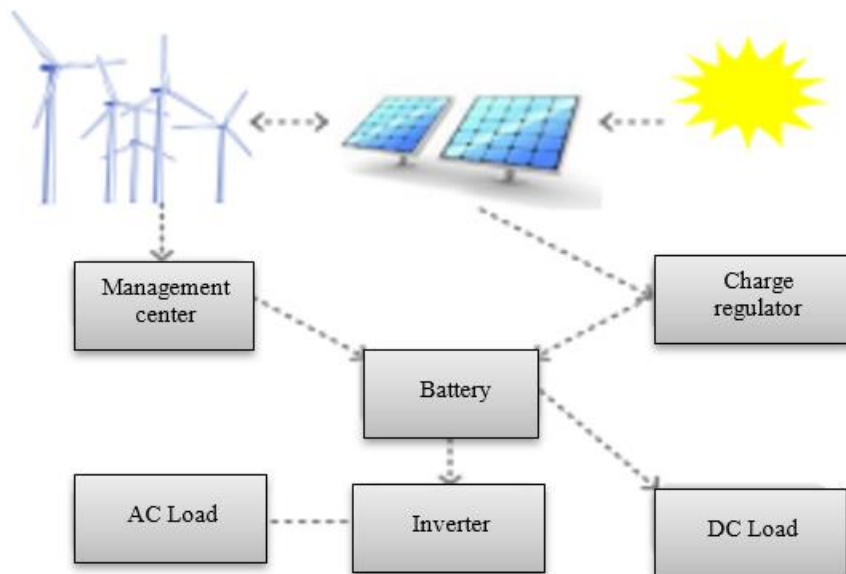


Fig. 6 Diagram of a solar-wind hybrid power system.



Elhadidy and Shahahid designed a wind-solar-diesel hybrid system that will produce 41500 KWh of electricity per year in Dhahran, Saudi Arabia. He made the number and calculations of all the equipment required in the hybrid system design [10]. Engin designed a solar and wind hybrid system in his study to meet the energy needs for the night lighting of the Izmir Solar Energy Institute building [2]. Nelson and colleagues in the Pacific Northwest investigated the lowest cost of solar/fuel cell or wind-solar/battery systems for off-grid power needs. In their study, they found that wind-solar battery systems were more cost-effective than wind-solar fuel cell and electrolysis systems [11]. In the work of Marano et al., the cost analysis and optimization of a power system that includes a photovoltaic power plant and a wind farm, combining compressed air with on-site energy storage, was performed. The optimization process took into account the electrical load on the campus of the University of Salerno in Italy and the renewable energy in the surrounding areas [12].

In his study, Ismail developed a Matlab-based software for the analysis of hybrid systems using a genetic algorithm. He aimed to minimize the cost analysis by considering the types of photovoltaic panels, microturbines and batteries, and the inclination angle of the panels. For this study, it was determined that it would be better to use a microturbine instead of a diesel generator as an additional power source [13]. Sasidhar and Jagadish Kumar used heuristic optimization technique and minimized the cost of the system by optimizing the size of the hybrid energy system. The total cost of the system was calculated by taking into account the operation, maintenance and initial investment costs. The hybrid system they developed included wind turbines, solar panels and batteries. It was concluded that the algorithm developed using Matlab software was efficient. The costs were reduced with this technique [14]. Sangeetha and Suja in their study modeled a hybrid energy system consisting of wind turbines, solar panels and batteries using Simulink software and the optimization predictions made in the software using Matlab software. The purpose of the dimensional analysis of the hybrid energy system is to ensure that the production cost and the reliability of the power supply are high. For this work, the dimensional analysis genetic algorithm and the flower pollination algorithm were used and the results were compared. It was found that the genetic algorithm gives good results, but when the energy cost and efficiency corresponding to the installed power of the flower pollination algorithm are taken into account, it is seen that it gives much better results than the algorithm [15]. Demirtash designed a hybrid system in his work. The energy produced in the system can be stored in battery groups. In addition, the system was implemented in a grid-connected manner. The efficiency values of the system were investigated [1]. Diaf and colleagues conducted a study on the design and optimization of an off-grid hybrid system.

The study was conducted in the Corsican region of France [16]. Dong Chen and colleagues conducted a study on the design phase, benefits, costs and risks in creating wind-solar hybrid systems [17]. Resources produced from more than one energy source are called hybrid energy



systems. Various hybrid system designs such as solar-wind, solar-wind-hydrogen, solar-wind-hydroelectric, solar-hydrogen can be prepared. With a solar-wind hybrid system, the demand for electricity can be met twelve months a year by using renewable energy sources. While the wind speed is low in the summer months when the sun's rays are very bright and strong, the wind speed is high in the summer months when the sun's energy is low. The efficient energy production in wind and solar energy systems varies from year to year and day to day. That is, solar energy can be used on days when the wind speed is not sufficient. Thus, the continuity of energy production is ensured in these systems [18, 19]. The hybrid energy system works in the same way as the wind or solar energy operating system. Only additions need to be made to the system [20]. It can be designed as grid-connected, off-grid or with grid support according to the project requirements. A solar-wind hybrid energy design was prepared in the study. The diagram of the solar-wind hybrid energy system is given in Figure 7. This system generates solar power or wind turbines. The power generated by the wind turbine can be converted to 24 or 48 Volts DC by means of a power regulation system. The DC power is then fed to a charge controller and a DC switch allows the battery to be charged, so a method is required to disconnect the DC portion of the electrical system [21]. When the DC portion is disconnected, the battery powers the power inverter. The power inverter receives the DC signal from the battery and produces 110V AC power [22]. Photovoltaic cells have low operating costs and high reliability. Solar panels are manufactured and sold in a variety of sizes.

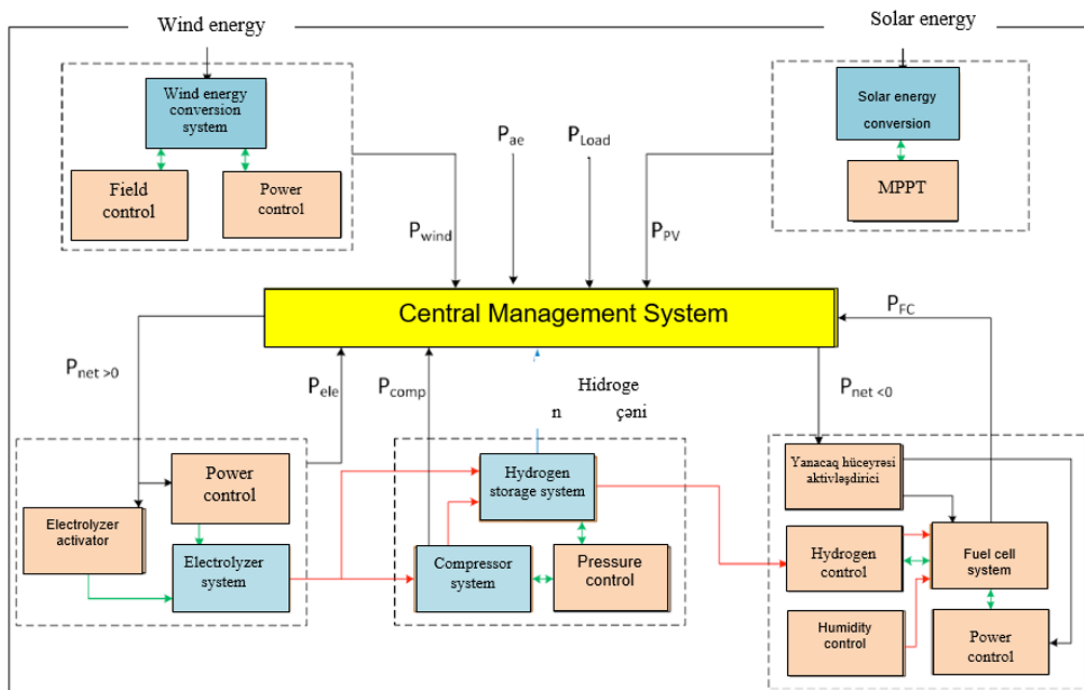


Fig. 7. Power management in a hybrid energy system



The initial investment cost of solar panels is high. Solar cells provide an economical alternative for off-grid powering small to medium-sized loads. The lifespan of a solar cell varies from 10 to 20 years, depending on the application and construction material [23, 24].

Solar panels consist of multiple photovoltaic cells connected in series. The capacity of the panels is determined by the power values obtained in the test environment. It is generally accepted that the maximum power (W_p) value for solar panels is obtained at a temperature of 25 degrees Celsius, a wind speed of 1 m/s and a solar radiation of 1000 W/m². In order to obtain maximum power from the control panel, the operating point must be selected correctly. Because the operating point varies during the day due to the variation of radiation or possible changes in the load. PV panels are not connected directly to the battery, since a charge controller must be used to ensure the long life of the battery. This is done with the controller, in particular to protect it from overcharging and overdischarging [25].

When information about the wind speed is received, it is necessary to arrange wind turbines and measuring stations in order to obtain good results and produce energy more efficiently. When designing and calculating the cost of a wind power plant, it should first be produced according to the amount of energy produced from the selected power plant location. For this reason, the structure of the selected land should be checked and measurements should be taken and then a Wind Monitoring Station (WMS) should be installed. The WMS installation site should be in the wind direction and should be selected in places where there are no obstacles that will affect the wind. Because the wind speed may decrease depending on the area of concern.

In hybrid systems, a panel stand is used to carry solar panels. Many companies in the energy sector prefer galvanized steel structure racks that are resistant to environmental conditions, economical and maintenance-free when choosing panel stands.

In a grid-connected system, the electricity produced is not stored in a battery, but is transmitted to the grid. This generated energy can also be connected to the city's central grid with high-power inverters that can be connected to the central grid. The most important reason for choosing this system is that it is easy to install and does not require maintenance costs. It has durable, practical and portable features. Since the energy produced is directly connected to the grid, when the generated energy is not enough, the grid enters directly and provides the amount of energy supplied to the load. Since there is no obligation to include the entire load in the system design, the design can be prepared for any amount or area.

Off-grid systems are systems that provide the necessary energy from the system in cases where there is no electricity or where transportation is difficult and the main line is frequently cut off. Since it operates independently of the grid, it is designed to have enough battery capacity to meet the needs of the installation even if sufficient energy cannot be produced throughout the



year. It has only an initial investment cost. It is very efficient and has very little energy loss. Easy installation is available.

In the installation of a hybrid energy system, electricity is obtained from wind turbines and solar panels in 10 different scenarios. System components such as inverters, charge controllers and batteries were also analyzed in 5 scenarios created independently of the grid. For each designed hybrid system, wind, solar and hybrid energy production values were calculated separately for each month. The calculations were performed with the PvSol program, which obtains values close to reality.

When choosing a battery in an off-grid hybrid energy system, the month with the highest combined power is very important, since wind and solar energy will be stored in the battery. Since a grid-connected hybrid power system is connected directly to the grid, energy storage is not considered, so batteries and charge controllers are not used.

III. Necessary factors for the construction of photovoltaic panels and their operational characteristics

Meral and Dincher (2011) have compiled numerous studies on the change in panel temperature and the resulting efficiency. In this study, the relationships that give the panel temperature and efficiency in a simpler way are given as follows:

$$T_c = T_a + (T_{NOCT} - 20) \frac{l}{800}$$

Where T_c is the temperature of the solar cell (o C), T_a is the ambient temperature (o C), T_{NOCT} is the normal temperature of the solar cell and is taken as 45 o C. l is the value of the instantaneous solar radiation (W/m^2). Depending on this expression, the efficiency of the solar cell is given as follows:

$$\mu = -0.05T_c + 12.757.$$

Other relationships given regarding solar cell temperature are as follows (Tripanagnostopoulos et al. 2005):

$$T_c = 30 + 0.9175(l - 300) + 1.14(T_a - 25).$$

Ross (1976) gave the relationship:

$$T_c = T_a - k_{\Delta T} l.$$

Where $k_{\Delta T} = 0,02-0,04 \text{ Km}^2 /W$. Skoplaki et al. (2016) gave the following expression for the temperature of a solar cell in windy regions:

$$T_c = T_a + \omega \left(\frac{0.32}{8.91+2v} \right) l \quad (v > 0).$$



Here, v is the wind speed (m/s) and w is the installation factor. This value can be taken as 1.0 for onshore panels, 1.2 for flat roofs, 1.8 for pitched roofs and 2.4 for facade cladding. When the above equations are examined, two important parameters appear that affect the temperature and efficiency of the panel with temperature. These are the incoming radiation and the ambient temperature. However, it is clear from equation (5) that the wind speed is also a parameter. The issue that needs to be considered in more detail here is the wind direction. For solar power plants consisting of multiple panels, the direction of the wind coming to the panels is also an important parameter.

Photovoltaic batteries literally convert light (photon) energy into electrical energy. This energy conversion is carried out by creating a surface (cell) that can absorb light energy with semiconductor materials. As is known, semiconductor materials are also the building blocks of electronic elements such as diodes, transistors, triacs, thyristors, etc. The difference between photovoltaic batteries and electronic elements is that the surfaces of the so-called p- and n-type materials are kept larger (also called junctions). Photons strike the junctions and use their energy to activate free electrons in the semiconductor materials, thereby generating an electric current.

IV. Structure of hybrid renewable energy systems

The unconverted state of energy found in nature is referred to as primary energy, and the resources obtained as a result of the conversion of primary energies are referred to as secondary energy. In another classification, if the types of energy remain the same at the end of use, they are called renewable energy sources, and resources that do not renew themselves at the end of use are called non-renewable energy sources. Resources such as solar, wind, geothermal, hydraulic and biomass are examples of renewable energy sources, while resources such as coal, oil and natural gas are examples of non-renewable energy sources. From the past to the present, one of the most important problems of the world is energy. The world population is expected to be about 9 billion in 2040. The increasing population and technological developments require more energy. According to the International Energy Agency report, the current primary energy demand in the world is 14 million tons of oil equivalent (TOE), and it is expected to reach 20.3 billion TOE in the next 20 years, with an increase of 45%. Due to the depletion of fossil-based energy resources, environmental damage, and global warming, the search for new sources has begun in the world. Developing countries in particular are interested in renewable energy sources to reduce their dependence on foreign sources. Compared to fossil resources, renewable energy sources have become attractive due to their environmental friendliness and inexhaustibility. When statistical data is examined, the average annual growth rate of renewable energy demand in the last fifty years is approximately five times higher than the growth rate in other sources. According to studies, \$68.2 trillion in energy investment is



planned worldwide in the next 20-25 years. Although the energy needs of countries differ to varying degrees, the demand for energy is increasing every year.

As can be seen from the statistical data, the demand and interest in energy has been increasing over the years, and efforts to use energy efficiently have become important. Recently, hybrid systems using renewable energy sources have been developed. Some studies on hybrid systems are explained below.

That is, solar energy can be used on days when the wind speed is not sufficient. Thus, the continuity of energy production is ensured in these systems. The hybrid energy system works in the same way as the wind or solar energy operating system. Only additions need to be made to the system. It can be designed as grid-connected, off-grid or with grid support according to the project requirements. A solar-wind hybrid energy design was prepared in the study. This system generates solar power or wind turbines. The power generated by the wind turbine can be converted to 24 or 48 Volts DC by means of a power regulation system. The DC power is then fed to a charge controller and a DC switch allows the battery to be charged, so a method is required to disconnect the DC portion of the electrical system. When the DC portion is disconnected, the battery powers the power inverter. The power inverter receives the DC signal from the battery and produces 110V AC power. Photovoltaic cells have low operating costs and high reliability. Solar panels are manufactured and sold in a variety of sizes. The initial investment cost of solar panels is high]. Solar cells provide an economical alternative for off-grid powering small to medium-sized loads. The lifespan of a solar cell varies from 10 to 20 years, depending on the application and construction material. Solar panels consist of multiple photovoltaic cells connected in series. The capacity of the panels is determined by the power values obtained in the test environment. It is generally accepted that the maximum power (W_p) value for solar panels is obtained at a temperature of 25 degrees Celsius, a wind speed of 1 m/s and a solar radiation of 1000 W/m^2 . In order to obtain maximum power from the control panel, the operating point must be selected correctly. Because the operating point varies during the day due to the variation of radiation or possible changes in the load. PV panels are not connected directly to the battery, since a charge controller must be used to ensure the long life of the battery. This is done with the controller, in particular to protect it from overcharging and overdischarging. When information about the wind speed is received, it is necessary to arrange wind turbines and measuring stations in order to obtain good results and produce energy more efficiently. When designing and calculating the cost of a wind power plant, it should first be produced according to the amount of energy produced from the selected power plant location. For this reason, the structure of the selected land should be checked and measurements should be taken and then a Wind Monitoring Station (WMS) should be installed. The WMS installation site should be in the wind direction and should be selected in places where there are no obstacles that will affect the wind. Because the wind speed may decrease depending on the area of concern.



In hybrid systems, a panel stand is used to carry solar panels. Many companies in the energy sector prefer galvanized steel structure racks that are resistant to environmental conditions, economical and maintenance-free when choosing panel stands. In a grid-connected system, the electricity produced is not stored in a battery, but is transmitted to the grid. This generated energy can also be connected to the city's central grid with high-power inverters that can be connected to the central grid. The most important reason for choosing this system is that it is easy to install and does not require maintenance costs. It has durable, practical and portable features. Since the energy produced is directly connected to the grid, when the generated energy is not enough, the grid enters directly and provides the amount of energy supplied to the load. Since there is no obligation to include the entire load in the system design, the design can be prepared for any amount or are. Off-grid systems are systems that provide the necessary energy from the system in cases where there is no electricity or where transportation is difficult and the main line is frequently cut off. Since it operates independently of the grid, it is designed to have enough battery capacity to meet the needs of the installation even if sufficient energy cannot be produced throughout the year. It has only an initial investment cost. It is very efficient and has very little energy loss. Easy installation is available.

In the installation of a hybrid energy system, electricity is obtained from wind turbines and solar panels in 10 different scenarios. System components such as inverters, charge controllers and batteries were also analyzed in 5 scenarios created independently of the grid. For each designed hybrid system, wind, solar and hybrid energy production values were calculated separately for each month. The calculations were performed with the PvSol program, which obtains values close to reality. When choosing a battery in an off-grid hybrid energy system, the month with the highest combined power is very important, since wind and solar energy will be stored in the battery. Since a grid-connected hybrid power system is connected directly to the grid, energy storage is not considered, so batteries and charge controllers are not used.

V. Proposed Hybrid Energy Model

Our proposed hybrid energy model consists of the following components.

Wind turbine: Electrical energy from wind is obtained by converting the kinetic energy of the wind into mechanical energy (mechanical energy of the turbines). When the wind flow enters the blades of the turbine, it rotates and converts the mechanical energy into electrical energy. According to calculations, a wind turbine can convert up to 59% of wind energy into electrical energy. A variable speed wind turbine with a doubly fed induction generator has been proposed in the wind conversion system. A wind turbine consists of 3 main components: turbine rotor, engine and generator. The power produced in the wind by the turbine is determined by the following expression:

$$P_w = \frac{1}{2} \rho A v^3 c_p (\lambda, \beta) \quad (1)$$



Where P_w is the energy produced by the wind, ρ is the air density, A is the area covered by the wind turbine blades, v is the wind speed, and c_p is the power factor. The power factor of any wind turbine is 0.59.

The engine transfers the power received from the turbine rotor to the generator. The basic modeling equations of the engine are as follows:

$$\frac{d\omega_M}{dt} = \frac{1}{2H_M} (T_M - K \cdot \theta_{MG} - D_M \cdot \omega_M) \quad (2)$$

$$T_M = \frac{P_w}{\omega_M} \quad (3)$$

Here T_M is the accelerating torque, K is the shaft rigidity effect, ω_M is the rigidity in the shaft system, θ_{MG} is the wind turbine speed, and $D_M \cdot \omega_M$ is the turbine stall torque. This approach model is often used to simulate an induction generator. The stator of the generator is directly connected to the grid and the stator voltage (v_s) is used by the grid. The rotor voltage V_r is controlled by the inverter and is used to control the motor. This model can be described as follows:

$$\vec{v}_s = R_s \cdot \vec{i}_s + \frac{d}{dt} \vec{\Psi}_s \quad (4)$$

$$\vec{v}_r = R_r \cdot \vec{i}_r + \frac{d}{dt} \vec{\Psi}_r - j\omega_r \vec{\Psi}_r \quad (5)$$

Here \vec{i} is the space vector (direction) of the current, $\vec{\Psi}_s$, $\vec{\Psi}_r$ are the internal resistances of the stator and rotor, R_s , R_r are the resistances of the stator and rotor. PV solar panels: The photovoltaic process that occurs in these panels, which constitute the PV photovoltaic conversion system, is a physical process in which solar energy is directly converted into electrical energy. As we know, when solar radiation falls on the panels, electrons in the PV cells leave the atoms and diffuse as free electrons. Thus, an electric current I is produced in the panels. The PV module converts only 40% of the sunlight radiation into electrical energy and their output is a DC-constant current. The relationship between the PV output voltage V and the PV cell load current I can be expressed as follows:

$$I_{PV} = I_{SC} - I_D - \frac{V_D}{R_p} \quad (6)$$

$$V_{PV} = V_D - R_s I_{PV} \quad (7)$$

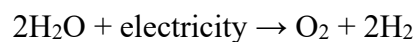
$$I_D = I_0 (e^{V_D/V_T} - 1) \quad (8)$$

Here, I_{SC} is the short-circuit current of the PV cell, I_0 is the saturation current, I_{PV} is the load current, V_{PV} is the output voltage of the PV panel, R_s is the series resistance of the PV cell, V_D is the diode voltage, and I_D is the diode current. In this model, the effect of temperature on the PV panel is not taken into account.



PEM electrolyzer: If the energy produced from the BOE is greater than the energy required by the load, hydrogen is produced from water in the electrolyzer using the excess energy. For this, a PEM electrolyzer is used. The electrolysis of water is the decomposition of water into hydrogen and oxygen gases when an electric current is passed through it. The dynamic model of the PEM electrolyzer consists of four components: anode, cathode, membrane, and additional voltage. The chemical process of electrolysis is given below:

Reaction at the cathode:



Reaction at the anode:



Overall reaction:



The reduction of Na ($E = -2.7 \text{ V}$) is more energetic than the reduction of water (-1.23 V). The voltage required in the electrolyzer can be written as follows:

$$V_{\text{ele}} = E - V_{\text{act}} - V_{\text{ohm}} - V_{\text{conc}} \quad (9)$$

Here E is the equilibrium voltage, V_{ohm} is the ohmic over-potential, V_{act} is the activation over-potential, and V_{conc} is the concentration over-potential. The equilibrium voltage can be expressed by the Nernst equation as follows:

$$E = E_o + \frac{RT_{\text{ele}}}{2F} \left[\ln \left(\frac{P_{\text{H}_2} P_{\text{O}_2}^{0.5}}{P_{\text{H}_2\text{O}}} \right) \right] \quad (10)$$

In addition to these, the gas turbine generator and inverter are also components of the system. These components are the main parts that generate, deliver, convert or store electricity in a hybrid energy system. While PV solar panels generate direct current (DC), wind turbines generate direct current (DC) or alternating current (AC). Since some consumers require direct current, we can directly transmit the energy received from the output of the PV panels (if wind turbines generate DC, their output as well) to consumers. However, most consumers and household appliances require alternating current (AC). Therefore, an inverter is required in the system to convert the received DC to AC. We know that solar radiation and wind speed are not the same at all times of the year or at all hours of the day. Therefore, if the energy generated in the system is more than the energy required by consumers, we must store this energy to meet the energy demand at other times or during peak demand. Although batteries are offered to store energy, they do not store energy for a very long time and losses are high. Therefore, it would be more effective to store this energy in the form of a "fuel". So, by electrolysis of



water, we split it into hydrogen (H₂) and oxygen (O₂). For this, a PEM electrolyzer has been proposed in the system. The electrolyzer converts the already produced AC or DC into hydrogen by electrolysis of water. We store the obtained hydrogen in hydrogen storage tanks for a long time in any volume, and when the energy demand increases, we generate energy by burning it in gas turbine generators.

The control system consists of a main controller for controlling the entire power and a low-level controller that controls various parameters for individual components. The energy received from the BOEM can be simultaneously transmitted to both consumers and to the electrolyzer for hydrogen production.

The decision process is defined by the following expression:

$$P_{net} = (P_{k\u00fcl\u00f6k} + P_{pv}) - (P_{y\u00fck} + P_{ka}) \quad (11)$$

Here, P_{wind} and P_{pv} are the energy received from the wind and the sun, P is the energy required by the heavy consumers, P_{ka} is the power required by auxiliary equipment such as compressor, controller, safety devices. P_{net} is the remaining power (can have a positive or negative value).

To control the process, we write and load a program into the controller in advance and the system will operate based on it. According to the controller's comparison, if the remaining power in the system is greater than the nominal power of the electrolyzer ($P_{net} > P_{ele}$), the electrolyzer will be activated and start producing hydrogen and the obtained gas will be transferred to the hydrogen storage tank via the compressor. On the other hand, if $P_{net} < 0$, that is, if there is a lack of energy in the system, the gas turbine generator will start and produce energy by burning the hydrogen stored in the tank. For the fuel cell to be activated, there must be enough hydrogen in the tank. Otherwise, the system will enter the "hydrogen starvation" mode. This happens when the BOEM is very low for a long time (especially in the winter months) or when the load demand is very high. However, we can overcome this problem by taking a sufficiently large capacity tank.

Another problem that may arise is that without local control, the electrolyzer or fuel cell operates at its full capacity. That is, the cost of the power required for the operation of the electrolyzer depends on its capacity, and if it operates at nominal power, at a certain point $P_{net} > 0$, the power required for electrolysis may exceed the power produced by the BOEM. To overcome this problem, we need to place a local controller next to the electrolyzer and fuel cell. The main goal here is to increase the efficiency of the electrolyzer and fuel cell in order to use the excess energy and stored hydrogen more efficiently. As mentioned earlier, the electrolyzer and fuel cell are used at their maximum capacity, and this can seriously reduce the overall efficiency of the system. For control and management, the nonlinear models of the electrolyzer and fuel cell will be linearized around the selected operating points in the following form:



$$\begin{cases} \dot{x} = Ax + Bu + B'w \\ y = Cx \end{cases} \quad (12)$$

x, u, w, and y are the state, control, excitatory effects, and output variables of the model, respectively.

The proposed off-grid hybrid conversion and storage system was simulated using Matlab and Simulink software. The presented simulation results were calculated considering the load demand based on the average weather conditions in the Absheron region during winter days. The total wind and solar power generated, along with the local wind and PV controller, are shown in Fig. 8a. Fig. 8b shows the generator power, the power required by the loads, and the difference between them (Pnet). As shown in Fig. 8c, when the wind speed is too high, the local controller regulates the turbine operation and keeps the generated energy price constant. The Pnet value given in Fig. 8b is designed to activate or deactivate the components of the hydrogen system. Fig. 8d depicts the state of the electrolyzer and fuel cell during the simulation.

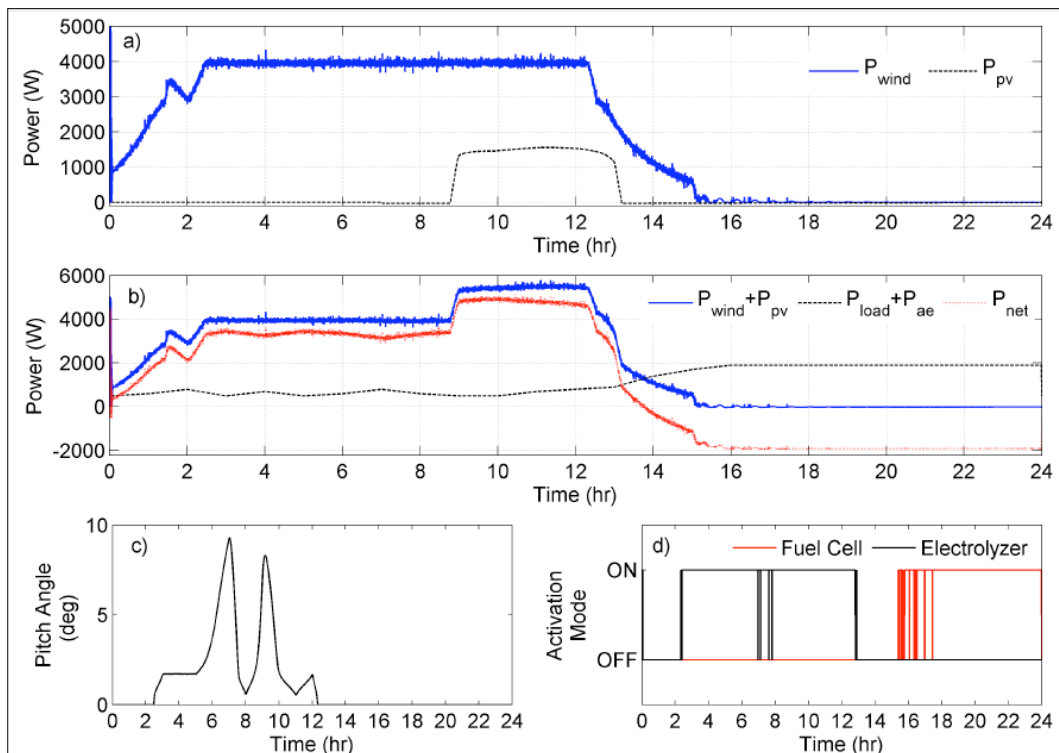


Fig. 8. a) Generated, required and net power, b) Power generated by PV and wind turbine, c) Throttling angle, d) Fuel cell and electrolyzer



A hybrid power system model is proposed. HOMER Pro (Hybrid Optimization Model for Electric Renewables) software was used to simulate this system. HOMER Pro, a micro power optimization model, is a computer program developed by the US National BOE Laboratory to facilitate the comparison of power generation technologies in a wide range of applications and to assist in the design of micro power systems.

HOMER Pro models the physical variations of the power system and the costs of its construction, life-cycle operating costs and revenues, while offering designers a variety of options within the framework of technical and economic values. In addition, HOMER allows for the understanding and measurement of the effects of changes and uncertainties in the power system. HOMER Pro software can model a grid-connected or off-grid micro power system that provides electricity or heat demand, reflecting any combination of PV panels, wind turbines, small hydroelectric plants, biomass, geothermal plants, batteries and hydrogen tanks.

HOMER Pro performs three main functions: simulation, optimization, and sensitivity analysis. In the simulation process, HOMER models the performance of a given micro energy system for each hour of the year to determine the technical design and life cycle cost of the system. In the optimization process, HOMER simulates many different system configurations to achieve the system configuration that meets the technical constraints in terms of the lowest life cycle cost.

In the sensitivity analysis process, HOMER performs a series of optimization operations under input assumptions to measure the effects of changes or uncertainties in the model inputs. The proposed system components consist of two BOE (solar, wind) sources, a hydrogen storage tank, a gas turbine generator and seawater, which is used to obtain hydrogen in the electrolyzer. Considering the solar radiation and the number of windy days in the Absheron region, we have investigated the application of this system in the Absheron region. In addition, we must also consider the demand of the loads in the zone where the project will be implemented. The energy demand curve of the consumers in this region is shown in Fig. 9.

When opening the HOMER Pro software, in the opening window of the program, we first add the name of the system and the author's name (if any) and select the zone proposed for the system to be built. The system will be located approximately at 40 degrees 27.8 minutes North and 49 degrees 57.5 minutes East latitude. The average in this region. The average solar radiation and wind speed in this region were retrieved online from NASA's database using HOMER Pro software, and the resulting window is depicted in Fig. 10.

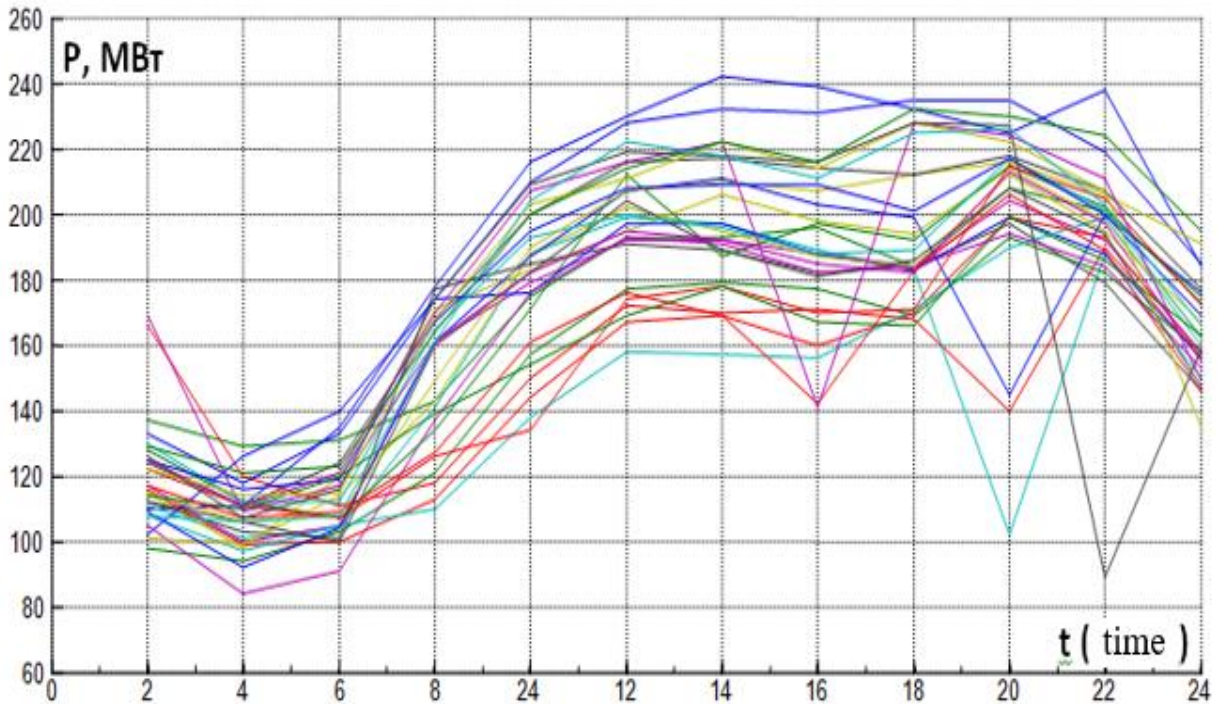


Fig. 9 Daily load graph from the model we propose.

Table 1 shows the components required to build this system.

Table 1. Components required to build a hybrid energy system

Components	Model name	Capacity
PV panel	Generic flat plate PV	2.2 MW
Wind turbine generator	XL-500	4 MW
Gas turbine generator	3 MVt Geneset	3 MW
Electrolytic generator	PEM elektrolizer	3 MW
Hydrogen storage tank	Hydrogen storage tank	50 000 kg
Project duration		25 years

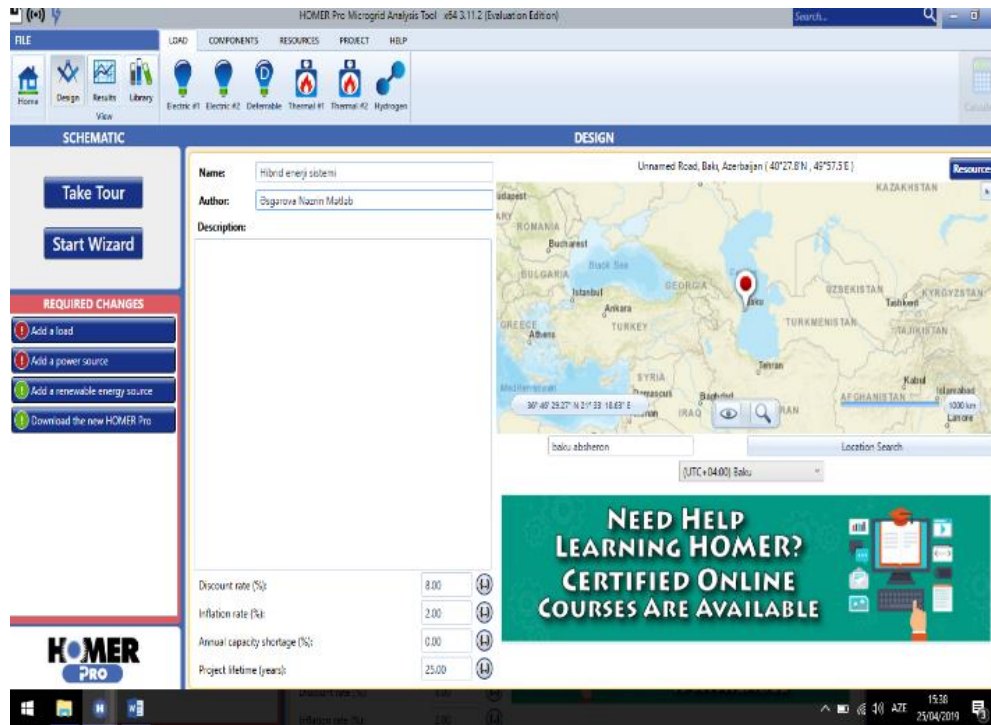


Fig. 10 The window that opens when you enter the initial data in the HOMER Pro program.

Research was conducted on the annual growth rate of electricity production and investment in renewable energy sources globally, as well as the level of development of advanced energy production technologies from these sources with the goal of maximizing the use of renewable energy. In this regard, the research substantiates the need for significant efforts to develop renewable energy through increased investment in our country.

Conclusion

In this work, the application of smart grid technologies that can solve the problem of delivering energy from renewable energy sources to consumers with minimal losses and in efficient ways has been proposed. Thanks to the equipment used in the proposed technologies, it will be possible to reduce the cost of the energy produced in addition to the above, and significantly reduce the number of accidents in the system. A hybrid energy system has been proposed to further increase the use of renewable energy and eliminate dependence on traditional power plants and natural fuels. Using this system, simulation studies were carried out taking into account the needs of consumers in the studied region and the results obtained were calculated. The results obtained from the HOMER Pro software used for the simulation of the system have shown that the proposed system is largely justified. It has been shown that the system allows for complete elimination of dependence on natural fuels, does not emit carbon dioxide, is environmentally friendly, provides clean energy, does not create harmonics and distortions,



and also eliminates the need for electronic power devices such as inverters. The application of this system can be of great importance for countries that do not have natural fuel resources and import energy from abroad. As a result of the application of these systems, it is possible to create conditions for eliminating environmental problems, and most importantly, global warming, and dependence on natural fuels.

References

1. Liu P., Song F., Ouyang J. Spatial frequency-dependent polarization holography in TI/PMMA photopolymers for high-density storage. *Optics Express*, 33(11), pp. 23926–23938
2. Song, F., Wang, P., Ouyang, J., Liu, P. Orthogonal polarization interference with vertical S and horizontal P waves in TI/PMMA cationic photopolymers. *Optics Express*, 33(6), pp. 12809–12824
3. Ma Z., Huang X., Wang Z., Wang X., Ma, J. FedGhost: Data-Free Model Poisoning Enhancement in Federated Learning *IEEE Transactions on Information Forensics and Security*, 20, pp. 2096–2108
4. Chun, K.A.: A review on development of renewable energy sector in Turkey in light of public policies and evaluation of YEKDEM mechanism effectiveness. Bahcesehir University Social Sciences Institute, Istanbul (2019).
5. Jiang, H., Lu, L., Sun, K.: Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. *Atmospheric Environment* 45, 4299–4304 (2011). DOI: 10.1016/j.atmosenv.2011.04.084
6. State Agency for ABOEM of the Republic of Azerbaijan / Use of Alternative and Renewable Energy Sources / [Scientific journal] / Baku: AREA / 2014, 50 p.
7. Abdeen, E., Orabi, M., Haseneen, E. (2017). Optimum tilt angle for photovoltaic system in desert environment, *Solar Energy*, 155, 267–280. doi: 10.1016/j.solener.2017.06.031
8. Fedorov, A. (2015). Photovoltaic System Design for a Contaminated Area in Falun – Comparison of South and East-West Layout, Yuksek Lisans Tezi, European Solar Engineering School.
9. Gholami, A., Khazaei, I., Eslami, S., Zandi, M., Akrami, E. (2018). Experimental investigation of dust deposition effects on photovoltaic output performance, *Solar Energy*, 159, 346–352. doi: 10.1016/j.solener.2017.11.010
10. Gokmen, N., Hu, W., Hou, P., Chen, Z., Sera, D., Spataru, S. (2016). Investigation of wind speed cooling effect on PV panels in windy locations, *Renewable Energy*, 90, 283–290. doi: 10.1016/j.renene.2016.01.017
11. Hafez, A.Z., Soliman, A., El-Metwally, K.A., Ismail, I.M. (2017). Tilt and azimuth angles in solar energy applications – A review, *Renewable and Sustainable Energy Reviews*, 77, 147–168. doi: 10.1016/j.rser.2017.03.131



12. Hammad, B., Al-Abed, M., Al-Ghandoor, A., Al-Sradeah, A., Al-Bashir, A. (2018). Modeling and analysis of dust and temperature effects on photovoltaic systems' performance and optimal cleaning frequency: Jordan case study, *Renewable and Sustainable Energy Reviews*, 82, 2218–2234. doi: 10.1016/j.rser.2017.08.070
13. Jiang, H., Lu, L., Sun, K. (2011). Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules, *Atmospheric Environment*, 45, 4299-4304. doi: 10.1016/j.atmosenv.2011.04.084
14. Agayev F.H., Mehdiyeva A.M., Gafarov G.A., Bakhshaliyeva S.V., Shirinzade N.V. Development of the functional safety system in primary oil refining Nafta-Gaz. Oil and Gas Institute - National Research Institute. Poland. ISSN 0867-8871.
15. Kaldellis, J.K., Kapsali, M., Kavadias, K.A. (2014). Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece, *Renewable Energy*, 66, 612-624.
16. Kaplani, E., Kaplanis, S. (2014). Thermal modeling and experimental assessment of the dependence of PV module temperature on wind velocity and direction, module orientation and inclination, *Solar Energy*, 107, 443–460. doi: 10.1016/j.solener.2014.05.037
17. Kazem, H. A., Chaichan, M. T. (2015). Effect of humidity on photovoltaic performance based on experimental study, *International Journal of Applied Engineering Research (IJAER)*, 10(23), 43572-43577.
18. Mahboub, C., Moumami, N., Moumami, A., Youcef-Ali, S. (2011). Effect of the angle of attack on the wind convection coefficient, *Solar Energy*, 85, 776–780.
19. Mekhilef, S., Saidur, R., & Kamalisarvestani, M. (2012). Effect of dust, humidity and air velocity on efficiency of photovoltaic cells, *Renewable and sustainable energy reviews*, 16, 2920-2925. doi: 10.1016/j.rser.2012.02.012
20. Meral, M.E. and Dinçer, F. (2011). A review of the factors affecting operation and efficiency of photovoltaic based electricity generation systems, *Renewable and Sustainable Energy Reviews*, 15, 2176–2184. doi: 10.1016/j.rser.2011.01.010
21. Ma, Z., Huang, X., Wang, Z., Wang, X., Ma, J. FedGhost: Data-Free Model Poisoning Enhancement in Federated Learning. *IEEE Transactions on Information Forensics and Security* 20, pp. 2096-2108.
22. Song, F., Wang, P., Ouyang, J., Liu, P. Orthogonal polarization interference with vertical S and horizontal P waves in TI/PMMA cationic photopolymers. *Optics Express*. 33(6), pp. 12809-12824
23. Grigorenko I.V. Multi-parametric control of the quality of the functioning of information-measurement systems for various purposes, taking into account factor influences. Specialization 05.11.13 – devices and methods of control and determination of the composition of substances. 15 – Automation and instrumentation. Kharkiv - 2024



24. Ozsabuncuoglu, I. and Ugur A. (2005). Natural resources economy, management and politics. Ankara: Imaj Publishing House.
25. Paudyal, B.R., Shakya, S.R. (2016). Dust accumulation effects on efficiency of solar PV modules for off grid purpose: A case
26. Babak, V., Babak, S., Eremenko, V., Kuts, Y., Zaporozhets, A. Information-Measuring Systems: Theory and Application. Studies in Systems Decision and Control, 592, pp. 1–496
27. Urniezius, R., Petrauskas, R., Vaitkus, V., ... Dargiene, J., Ezerskis, D. Enhancing Prediction by Incorporating Entropy Loss in Volatility Forecasting. EntropyOpen source preview, 2025, 27(8), 806.
28. Ulgen, K., Hepbasli, A. (2003). Comparison of the diffuse fraction of Daily and monthly global radiation for Izmir, Turkey, Energy Sources, 25, 637–49. doi: 10.1080/00908310390212444
29. Vassel, A., Lakovidis, F. (2017). The effect of wind direction on the performance of solar PV plants. Energy Conversion and Management, 153, 455–461. doi: 10.1016/j.enconman.2017.09.077.