cigre Turkey

TEPES
TURKISH JOURNAL OF
ELECTRICAL POWER
AND ENERGY SYSTEMS

TEPES, Vol. 4, Issue. 1, 26-39, 2024 **DOI:** 10.5152/tepes.2024.24002

RESEARCH ARTICLE

# Design of a Stand-Alone Hybrid Solar/Wind/Battery/Diesel Microgrid for a Wastewater Treatment Plant in İzmir Using HOMER Pro Software

**Sude Erdal, Esra Aydın, Cenk Andiç**

Department of Electrical Engineering, İstanbul Technical University, İstanbul, Turkey

**Cite this article as:** S. Erdal, E. Aydın and C. Andiç, "Design of a stand-alone hybrid solar/wind/battery/diesel microgrid for A wastewater treatment plant in izmir using HOMER pro software," *Turk J Electr Power Energy Syst.*, 2024; 4(1), 26-39.

**ABSTRACT**

The significance and rapid rise of distributed power generation utilizing alternative energy sources have been receiving a lot of attention today. Due to the high worldwide demand for clean and sustainable energy, microgrid systems have emerged as a promising solution to improve energy reliability while promoting the grid's insertion of renewable energy sources. To maximize energy production, storage, and distribution, the thesis revolves around the design and simulation of a solar–wind–battery–diesel generator hybrid microgrid system for the Havza Waste Water Treatment Plant located in Izmir, Turkey. HOMER Pro program is used in this report, which is a sophisticated tool commonly used for microgrid analysis and optimization. The economic analysis and emission rates are obtained for the system.

**Index Terms—**Energy optimization, hybrid renewable energy systems, microgrid design, stand-alone microgrid, system modeling and simulation

## I. INTRODUCTION

Due to the growing world population "and the increasing needs of people, the energy demand is increasing every day. Carbon-based sources have been used for years to generate power to meet this demand. However, their environmental damage and lack of sustainability have led people to look for new solutions. Today, carbon fossil-based energy systems are steadily being replaced by renewable energies such as solar, wind, hydroelectric, geothermal, and biomass. The use of these systems has significantly increased in energy production, dependence on fossil fuels, and gas emissions are reduced, and a big step has been taken for sustainable development. In addition to the generation of energy, the transmission, and distribution of energy with minimum losses have also gained importance. An electrical power system is a network of electrical components that are responsible for supplying, transferring, and consuming electrical energy. Power systems of this kind are designed to ensure that customers have access to energy whenever they demand it. An electrical grid that supplies power to homes and industries can be given as an example of a power system. Nevertheless, high demand for energy, especially in crowded cities or regions, may lead to interruptions or disruptions in the grid. Moreover, because of possible transmission line errors, power outages may occur in regions that are far from the power distribution center. Recent grid systems, such as microgrids, are coming to the fore as a common solution to these energy problems.

## II. METHODOLOGY

The study aims to design and analyze a microgrid system fed by solar energy and wind energy for the Havza Waste Water Treatment Plant attached to the General Directorate of Izmir Water Works located in Izmir, Turkey. By accessing the data on consumed electricity by the plant in 2022, it will be ensured that this energy will be met by the specially designed microgrid through HOMER Pro software. The economic analysis of the microgrid is going to be done, and emission rates are going to be obtained.

## III. LITERATURE REVIEW

The incorporation of solar and wind power into microgrid systems is a possible approach for improving energy stability, power system resilience, and minimizing carbon emissions. This literature review examines the available research and expertise on the design and modeling of solar-wind hybrid microgrid systems.

In a case study of Eskişehir Osmangazi University (ESOGU) students, a hybrid microgrid, which includes a photovoltaic (PV) power system

**Received:** February 8, 2024
**Revision Requested:** February 11, 2024
**Last Revision Received:** February 14, 2024
**Accepted:** February 15, 2024
**Publication Date:** March 4, 2024

**Corresponding author:** Sude Erdal, f.suderdal@gmail.com

and an energy storage unit, was intended to power a portion of the hospital complex on the ESOGU campus. The HOMER software was used to design, model, and last but not least optimize the microgrid. The program found the optimal PV power source and energy storage unit capacity for the hospital's demanded load. The net present, energy, and operation costs are examined according to the simulation [1].

In the case study of Islam, Zeyad, Akanto, and Ahmed, a standalone microgrid that includes wind power, solar power, and diesel generators was designed to investigate the efficiency of the microgrid. The proposed model was created and tested in HOMER Pro using solar irradiance and wind speed data from Cumilla, Bangladesh. In addition, three case studies were carried out. According to the modeling findings, the lowest levelized energy and net present costs were found as $1.01 and $791 531, respectively [2].

In the study by Boqtob, Moussaoui, Markhi, and Lamhamdi, a grid-connected microgrid, which consists of a wind turbine generator, photovoltaic panels, battery pack, and generators sourced on diesel fuel, was designed. Data on Tahla, Morocco's sunlight, and the velocity of wind were considered while using HOMER Pro software. According to the simulation, the highest initial capital cost and the highest operation costs were calculated [3].

The study of Raji and Luta [4] investigated the technical and economic viability of housing estate microgrid component sizes through modeling and optimization by using HOMER Pro software. The off-grid cost of electricity for the community-based microgrid is predicted to be $0.509. The community-based microgrid system's grid-forming mode was contrasted to an optional backup energy mode which would connect to the utility in the event of insufficient demand. The comparison of both systems demonstrated that, from an economic standpoint, the viability of the microgrid working as an off-grid is dependent on the distance of breakeven.

In the study of Çetinkaya et al [5], a microgrid was designed for the Faculty of Electrical and Electronics Engineering of ITU. Using the data of 2021 electricity consumption of the faculty, performance analysis was made with the PVsyst program, and economical, performance, and system analyses were made using HOMER Pro software.

A grid-connected microgrid was designed in Mahmud et al's [6] work using meteorological information for a nearby community in Dhaka, Bangladesh. Using HOMER Pro, this study illustrated a potential system design that offers the lowest emissions and production costs for energy. By utilizing real-time data, four different potential microgrids' net present costs (NPCs), energy costs, operational costs, and environmental pollution are compared and evaluated. The goal of the study was to considerably increase the town's supply of affordable renewable energy. Additionally, it was hoped that this design would enable the additional energy to be sold to the grid to reduce the frequency of power outages.

In the study of Madtharad and Chinabut [7], the microgrid design for one rural island of Thailand, where investing in submarine wiring is not financially feasible, was examined. HOMER Pro was employed to calculate the optimal sizing of PV arrays and battery systems. The report aimed to highlight an approach for calculating the optimal electricity tariff for microgrids.

Management at MUET Jamshoro Pakistan developed designs for both off-grid and on-grid microgrid systems using PV power, and they used HOMER Pro to determine the demand for energy, system optimization, and financial sustainability of the system. The study's findings demonstrated that on-grid microgrid systems were more economically feasible than off-grid systems since off-grid systems required additional backup batteries [8].

In the study of Munir et al [9], Electrical engineering students at the University of Azad Jammu and Kashmir witnessed load estimate and expense evaluation for the development of an ideal hybrid model of renewable energies. Three scenarios were developed on the HOMER Pro program to assess demand and predict costs. As a result, it was shown that a scenario which consists of five batteries, 20kW wind power, converter and 20kW PV power was the most cost-effective one.

In the article written by Strunz et al [10], operational controls were designed for a direct current (DC) microgrid which includes wind and solar energy. A paired model for predicting the generation of renewable wind and solar power was offered to measure operational reserve for both real-time and day-ahead scheduling. The simulation was used to demonstrate how the power-electronics-based voltage-power droop control and operational optimization worked.

In the paper of Chishti et al [11] and other members of IEEE, a three-phase utility that supplies a non-linear load was built to be connected to an alternating current (AC) microgrid that is integrated with wind and solar electricity and includes battery storage. Power Quality performance for the local nonlinear load was enhanced by momentum based least mean square (MLMS) adaptive control. As a consequence, the system was able to function effectively in all dynamic situations. IEEE standards were also used to find the grid current THD.

**Main Points**

- High battery prices are identified as the primary factor leading to excess electricity generation in the context of energy systems optimized by HOMER Pro.
- HOMER Pro's optimization algorithm prioritizes minimizing system costs, which inclines it towards favoring electricity production over storing excess energy in batteries due to the cost-effectiveness consideration.
- Introduction of microgrids to wastewater treatment plants results in a remarkable decrease in emission rates, showcasing the potential of this technology in environmental mitigation efforts.
- The integration of microgrids with high renewable fractions led to the avoidance of emitting 770,039 kilograms of hazardous gases, underscoring the significant environmental benefits associated with this approach.

According to Yan and Hou [12], optimizing microgrid configuration today places a high price on lowering setup costs and raising the power system's reliability in operation. The intended purpose of the wind-light storage system was examined in their study along with a methodology for controlling microgrid capacity appropriately. All critical data were entered into the HOMER Pro tool, which runs simulation computations to determine the configuration that maximizes efficiency and effectiveness.

In the paper of Dash et al [13], a grid-connected hybrid microgrid with solar and wind electricity was created for a distant Indian community. By using renewable energy sources to meet load requirements, it was intended to create a cleaner, more ecologically friendly environment. The HOMER Pro application was employed to assess the data that was provided as well as the viability of the suggested hybrid power system economically. For comparison, on and off-grid models were created and fine-tuned. A sensitivity study was conducted for each model to determine the impact that changes in grid energy pricing would have on the model's total cost. The grid-connected hybrid (PV and wind turbine) power system that was suggested was the most practical and economical choice for the town, according to the simulation results.

Yasin and Alsayed [14] designed a microgrid for residential households by using HOMER Pro. The simulation showed that the most appropriate solution includes PV, battery, and a generator. The economic analysis is done, and Levelized Cost of Energy (LCOE) is found to be approximately $0.44/kWh. They found that the system produces nearly 11% of excess energy. To reduce this surplus, a deferrable load is added, and excess power is reduced to 7%.

On the other hand, it is found that other optimization methods can also be also used for choosing the optimal size of a microgrid. For instance, an article focusing on the optimal size selection for hybrid solar, wind, and battery-based off-grid systems showed that mixed-integer linear programming can be used. In consequence, it is found that wind turbines are cost-effective options for various climates in Iran, considering O&M costs [15].

Moreover, in an article, a discrete version of the harmony search is used for optimal sizing. Thanks to that method, the amount of solar panels, wind turbines, and batteries are optimized cost-effectively [16]. This method is also used in another article. For wind and solar hybrid microgrid systems, the discrete harmony search algorithm is used to choose the most efficient number of components for the system. It is claimed that determining the optimal size is a discrete optimization problem. In this article, it is stated that four types of methods are frequently being used for size optimization in microgrids. These are probabilistic, analytical, heuristic, and hybrid methods. Consequently, this algorithm finds the best solution in a very short time which is less than a second [17].

A solution to increase the effectiveness of a microgrid is to increase the performance of the controllers. Research shows that with the unpredictable nature of the load, unmodeled dynamics may occur. Moreover, with the increased number of distributed generations connected to microgrids, controlling may become difficult. Hence, this dynamic affects the performance of the microgrid. Different scenarios are investigated in the research. In addition, by utilizing different converters, the voltage of the microgrid tried to be kept stable. The performance of controllers is observed in MATLAB Simulink. As a result, it has been found that ILGQ controllers may overcome many problems in the microgrid [18].

For the energy management of a microgrid, another optimal sizing survey is studied for a hybrid solar, wind, battery, diesel, and biomass microgrid. It is aimed to meet the energy demand of Basra, Iran with the microgrid. For the decision of the size of the components, a meta-heuristic optimization algorithm is applied and compared with other optimization algorithm results. As a result, it is found that this algorithm method is better than the other algorithms such as PSO, GA, GWO, CSO, and ALO in terms of economic concerns, having the lowest value of levelized cost of energy and annual cost [19].

Türkay and Ayan [20] investigated on and off-grid hybrid microgrids in different regions of Turkey through HOMER Pro software. The result showed that the cost of the off-grid system is much higher than the on-grid system. The locations are selected from seven regions of the country to see the climatic effects. In addition, the average consumption of a household consisting of four people is determined as approximately 13 kWh/day. It is obtained that the lowest cost is achieved in the Marmara region. Additionally, it is found that capital costs of solar panels and wind turbines are important factors in on-grid applications.

Türkay et al [21] used swarm optimization and genetic algorithm to optimize the microgrid, which achieves the best economic solution while providing the requirements of the power system. Fuel-based generation systems and microgrid systems that include solar power units are used in the system. The best economic configuration is achieved with the swarm optimization method. When microgrids are introduced to the system, results show that the cost is lower.

## IV. TRADITIONAL POWER GRIDS

According to Boztepe [22], a traditional power grid has three stages: the generation, transmission, and distribution of power. The traditional power grid maintains the structure of the 1900s, with centralized control and one-way power flow. Furthermore, it is vulnerable during natural calamities, where even a pole overturning can disrupt the power supply of a vast area. On the other hand, since it comprises very long transmission lines, the system is not very secure and is open to assault [22]. Considering this information, it can be said that traditional power systems have a low level of power resilience, which refers to an electrical power system's capacity to endure and recover from interruptions like cyberattacks, natural catastrophes, equipment malfunctions, or other unforeseen incidents. In addition, traditional power grids are more common with the usage of carbon-based power sources. Some challenges are faced when renewable energy sources are integrated into traditional power grids. The balance between production and consumption has to be maintained in the grid for a stable frequency. Because of the unpredictable and fluctuating nature of renewable energy systems such as PV (very reliant on sun exposure), keeping the frequency in the needed range may become difficult. Boztepe [23] adds that since renewable energy sources are generating power on the grid, the power flow becomes bidirectional, which makes controlling the power system harder. Therefore, whether the traditional power grid can effectively control a grid with multiple distributed generators should be questioned. The traditional grid requires minimal load changes relative to the overall grid power to maintain stable operation. However, renewable distributed generators generate highly variable and unpredictable energy, which causes stability problems in the traditional grid framework. Boztepe claims that distributed generation offers several advantages over traditional centralized power generation and transmission systems. First, they reduce transmission losses by producing power close to the load, thus reducing the amount of energy transported over long distances. Second, distributed generation systems have higher reliability as their failure impacts only a smaller portion of the grid. Last, they reduce the load on transmission lines by meeting the energy demand of nearby loads, thereby decreasing the need for additional transmission lines. The application of distributed generators is expanding along with the employment of renewable energy systems [24].

## V. MICROGRID SYSTEMS

A microgrid is a localized power plant or small power system that possesses all the features of a larger utility. A microgrid, according to Shahgholian, is a small power system with dispersed energy resources [25]. A microgrid mostly uses renewable energy systems such as solar and wind power, which minimizes the environmental footprint. Storage devices can be also integrated into the system. The microgrid has the flexibility to either connect with the primary power grid or function independently as a self-sustaining power source. When the microgrid is connected to the main grid, it requires less work done for frequency regulation than connecting renewable energy resources directly to the main grid. Yokoyama [26] states that microgrids can be used as a system framework for minimizing the negative consequences of power fluctuations in traditional power systems and adds that microgrids are designed to operate independently. Still, controlling them may become difficult when multiple renewable energy sources are introduced to the system. To maintain a balance between energy generation and consumption, microgrids can be connected to the external power system. This connection allows microgrid operators to purchase electricity from the utility, and sell excess power generated back to the grid. This interaction helps regulate frequency and voltage within the microgrid while ensuring a reliable energy supply. A microgrid framework comprises five key components: points of common connection, dispersed generators, flexible loads, energy storage devices, and control systems [27]. During instances of power outages or when the main grid is unavailable, the microgrid can operate autonomously, ensuring continued electricity supply. Thus, it minimizes the effects of grid blackouts. The microgrid system provides local and reliable power for regional communities that are dependent on the long transmission lines of the main grid, which are exposed to environmental factors. Consequently, it can minimize transmission losses and increase efficiency. Since the system has energy storage devices, the operation can continue without interruption. Adefarati and Bansal [28] claim that microgrid systems improve the local delivery of energy, increase efficiency, provide grid safety by reducing grid congestion, achieve cost savings, make the grid more resilient, and help the economic growth of rural areas. In light of this information, it can be said that by connecting renewable energy sources to the microgrid rather than connecting them to the main grid, various problems in the main grid can be prevented.

Microgrids can be classified by various factors. However, the most frequent classification is made according to their size, source, operation mode, power type, usage area, and control type. First, they can be categorized by their size: small scale, medium scale, or large scale. Then they can be categorized by their operation mode: island mode (off-grid) or grid-connected (on-grid). Also, they can be divided into DC microgrids, AC microgrids, or hybrid microgrids by their power type. Moreover, they can be categorized by their sources: diesel sources, hybrid sources, or the most preferred one, renewable energy resources. They may have centralized control or decentralized control. Last, they can be categorized according to their residential, industrial, or commercial usage areas.

## VI. SOLAR AND WIND POWER POTENTIAL OF TURKEY

Turkey's geographic location offers substantial potential for solar energy. The average total radiation value is calculated to be 1527.46 kWh/m$^2$ and the average total sunlight length is determined as 2741 hours annually, according to the Solar Energy Potential Atlas of Turkey. Furthermore, it is estimated that the highest values of sunshine time and solar energy are achieved in July, while the lowest values are in December [29].

The wind capacity in Turkey is 11 GW currently. Furthermore, it has a potential of approximately 48 GW of wind capacity if a 5 MW wind power plant could be established per square kilometer, assuming the wind speed is around 8 m/s. Besides, this potential would only correspond to approximately 2% of the surface area of the country [30].

Based on Figs. 1 and 2, it can be said that Izmir has effective potential in both wind and solar power. Therefore, simulation studies have been conducted in the Havza Waste Water Treatment Plant which is attached to the General Directorate of Izmir Water Works.

## VII. PHOTOVOLTAIC POWER SYSTEMS

A PV power system is a technology that captures sunlight and directly converts it into useful electrical energy by using solar panels comprised of PV cells. According to Messenger and Abtahi, the PV cell, which is a specially designed PN junction semiconductor device, is a crucial factor in the design of PV systems. PV cells generate DC electricity by using the photovoltaic effect. A single PV cell can produce only 5W at 0.5 $V_{dc}$. To improve the output power, a high amount of PV cells must be connected in parallel or series, which compose PV modules. Therefore, the output power can reach up to 400W. Also,

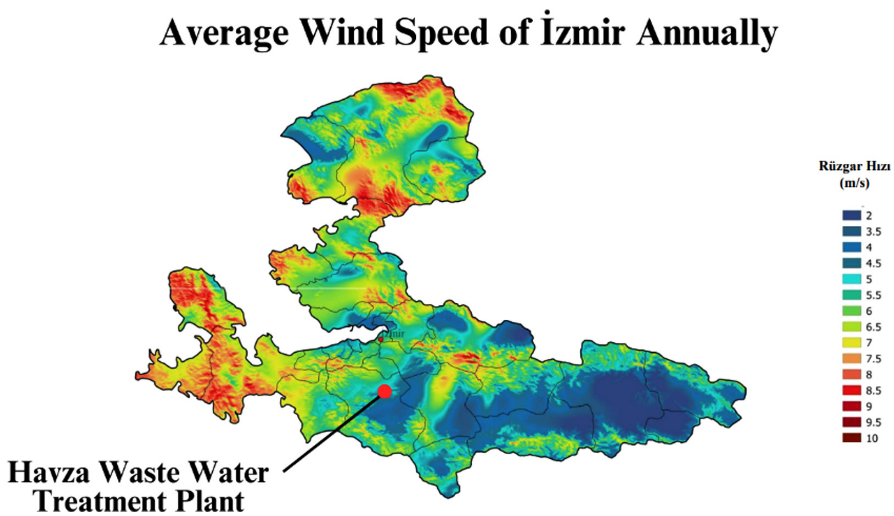


**Fig. 1.** Average wind speed of İzmir [31].

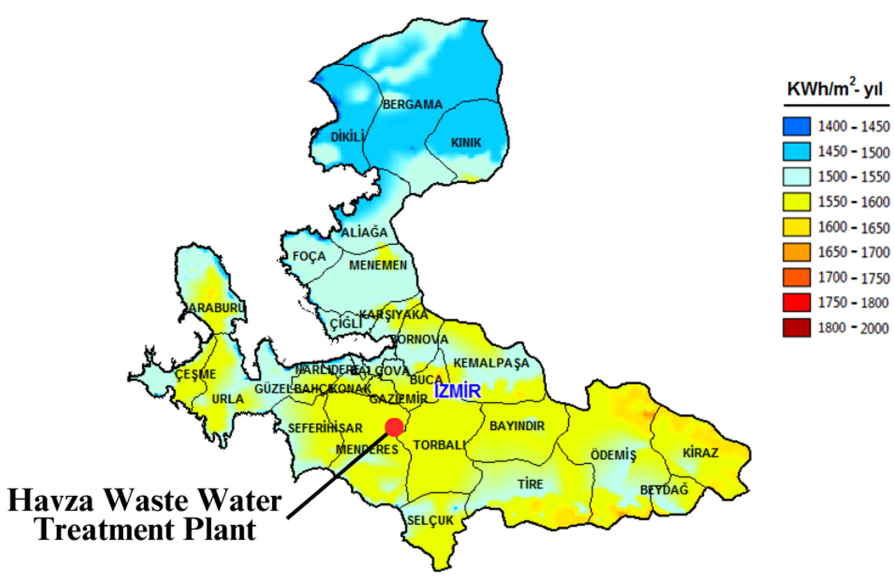


**Fig. 2.** Solar map of İzmir [32].

there exist PV arrays, which are made up of many modules that are linked together [33].

### A. Photovoltaic Power System Types

There are several varieties of PV power systems, each with its unique set of characteristics and applications. The most common categorization is into three: off-grid, on-grid, and hybrid PV systems.

#### 1) Off-Grid Photovoltaic Systems

They are also known as standalone systems and they are not connected to the utility. These systems are mostly implemented in distant areas where the grid connection is restricted or costly. Since they are not connected to the grid, off-grid systems include battery storage to store surplus power generated during the day for usage during low-light or night time durations. Atalay claims that off-grid PV systems have four key components: solar panels, battery packs, inverters, and charge controllers. The charge controller regulates and stores the electrical energy generated by the solar panel in the batteries. With the use of inverters, this stored energy is turned into electrical energy for consumption. For off-grid PV systems, battery quality is critical. Batteries with high efficiency, high-temperature resistance, and extended service life should be desired. However, it should be noted that the cost would be increased with these qualifications [34].

#### 2) On-Grid Photovoltaic Systems

They are also known as grid-connected PV systems. The system enables bidirectional power flow between the photovoltaic system and the electricity grid. These systems do not require storage devices. Hussin claims that during the day, the system is mostly dependent on the PV panel. The grid is needed to satisfy load needs at night or when solar radiation is low [35].

**3) Hybrid Photovoltaic Systems**

To provide more steady and continuous electricity, hybrid PV systems can combine solar power with other renewable energy sources such as wind turbines or diesel engines.

**B. Photovoltaic Power System Components**

A PV system is comprised of many major components that operate in tandem to convert solar radiation into usable electrical energy. Solar panels, charge controllers, batteries, battery banks, and inverters are examples of these components.

**1) Inverters**

Inverters are circuits that convert direct current to alternating current. According to Dr. Franklin, direct current energy is generated by a PV array or a battery bank. Lighting, fans, pumps, motors, and specialty equipment will all be supported. However, to use the energy to power alternating current loads, the current must be transformed. Inverters are available in various sizes to suit a wide range of loads [36].

**2) Charge Controllers**

According to Dr. Franklin, it is utilized to adjust the amount of charge entering into the battery from the module to prevent overcharging. The amperage that charge controllers can control varies [37]. Atalay says that since the voltage and current generated by PV are not constant, a charge controller is required for effective battery charging. Moreover, it prevents reverse currents from flowing from the battery to the panels. In addition, when the battery is full, the charge controller cuts the power coming from the solar panels [38]. It is mostly included in off-grid PV systems since these systems require batteries.

**3) Batteries**

Energy storage devices like batteries are used to store surplus power generated during the day for usage during low light, night time, or during periods of high demand. Battery quality is critical for off-grid PV systems. Batteries with high efficiency, high-temperature resistance, and extended service life are desired for PV systems. Various battery types are used in PV systems. The most common ones are lead-acid batteries, lithium-ion batteries, and nickel–cadmium batteries. Battery selection for a PV system is influenced by a variety of criteria, including energy storage needs, system size, budget, maintenance concerns, and the PV system owner's unique goals.

**4) Battery Banks**

Dr. Franklin [39] states that if the overall voltage need exceeds what a single battery can provide, several batteries are connected to create a battery bank. To illustrate, a battery bank with two 12-volt batteries connected in series can generate up to 24 volts of DC energy, and a battery bank with four batteries connected in series can produce 48 volts. It should be noted that batteries have a short life span, and they are expensive. That's why the cycle of the battery is important. A battery's life cycle can be extended if it is not discharged to 0% charge. A good design would be to discharge the batteries to 50% capacity and then recharge them to full capacity. This method, however, may need to have extra batteries in the bank. Deep-cycle batteries, which may be depleted to 80% of their storage capacity, are also used in solar systems.

**5) Solar Panels**

A PV system's major component is solar panels. They comprise numerous photovoltaic cells that use the photovoltaic effect to turn sunlight into electricity. Ceyran [40] states that they have a lifespan of 25 to 30 years and they have an average efficiency of 15%. Solar panels are classified into various categories, each utilizing specific materials and technology to convert sunlight into power. Monocrystalline silicon, polycrystalline silicon, and thin-film panels are the most common forms of solar panels. Depending on the manufacturer and product design, there may be variances in efficiency, power output, and other performance characteristics within each type of solar panel. Cost, efficiency, available space, installation requirements, and climatic variables should all be addressed when selecting solar panels for a specific project.

## VIII. WIND POWER SYSTEMS

A wind power system [Fig. 3], also known as a wind energy system or wind turbine system, is a renewable energy system that generates electricity by harnessing the power of the wind. Onshore and offshore wind power systems are the two primary types. In this study, only onshore wind power systems will be explained due to the simulation area being on land. Proper site selection, wind assessment, and wind turbine design are all critical components of a wind power system's effective implementation.

**A. Wind Power System Components**

To transform wind energy into useful electrical energy, a wind power system consists of several key parts. The components can be listed as wind turbines, which include a rotor and a tower, gearbox, generator, converter, and control system.

**1) Wind Turbine**

The major component of a wind power system is the wind turbine. Its components include a tower and a rotor with two or three blades. When the wind blows, the rotor rotates, turning the wind's kinetic energy into rotational energy. There are four types of wind turbines: type 1, 2, 3, and 4 wind turbines.

**2) Generator**

The wind turbine's rotating rotor is linked to a generator, which turns rotational energy into electrical energy. The generator generates an alternating current. Synchronous generators such as PMG and WRIG; and asynchronous generators such as SCIG and DFIG are widely used in wind power systems.

**3) Gearbox**

A gearbox is a mechanical component that accelerates the transmission of rotational energy from the wind turbine rotor to the generator. It is mounted in the nacelle and functions as a speed increaser, allowing the generator to revolve at the needed speed to produce effective power. The gearbox is essential in wind turbine systems because it optimizes the generator's rotating speed to meet the needed speed for optimal power generation. The gearbox, by raising the speed, enables the use of smaller and lighter generators, lowering costs and enhancing the overall efficiency of the wind turbine system. When PMG is used in type-4 turbines, there is no need to use a gearbox.

**4) Control System**

A control system monitors and manages the functioning of a wind turbine. It guarantees that the turbine works within safe limits and maximizes its performance. The control system changes the angle and pitch of the blades to harvest maximum wind energy and safeguard the turbine under high wind conditions.

**5) Converter**

A power converter is used in certain wind power systems to convert the AC electricity generated by the wind turbine into the proper voltage and frequency for connection to the electrical utility or direct usage.

**B. Wind Power**

Wind power is dependent on the air density, the wind speed, and the swept area. The equation is given here.

$$\text{Power of Wind} = \frac{1}{2}\rho A V^3$$

$$\rho = \text{air density}\left(\frac{kg}{m^3}\right)$$

$$V = \text{wind speed}\left(\frac{m}{s^2}\right)$$

$$A = \text{swept area}\left(m^2\right)$$

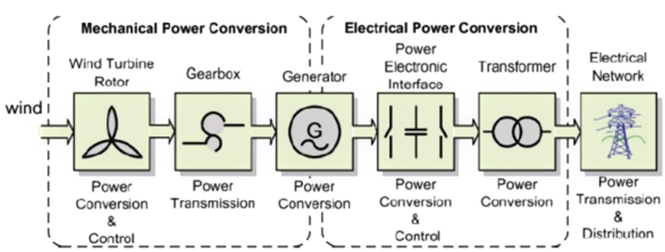


**Fig. 3.** Scheme of wind power system [41].

However, Ackermann [42] claims that the maximum power that can be received by wind is obtained by multiplying the wind power with the Betz constant, which is 0.59.

$$P_{max} = \frac{1}{2}\rho A V^3 \times 0.59$$

It can be said that, even if no losses in power extraction were achievable, only 59% of the energy generated by wind can be used by a wind turbine.

**1) Wind Power Curve**

It can be seen on Fig. 4 that the turbine starts to rotate and generate power at the cut-in wind speed, which is around 3 m/s. Moreover, it can be claimed that the turbine reaches its full capacity at approximately 12 m/s. Then, it continues to generate the maximum power output until the speed reaches the cut-out wind speed, which is 25

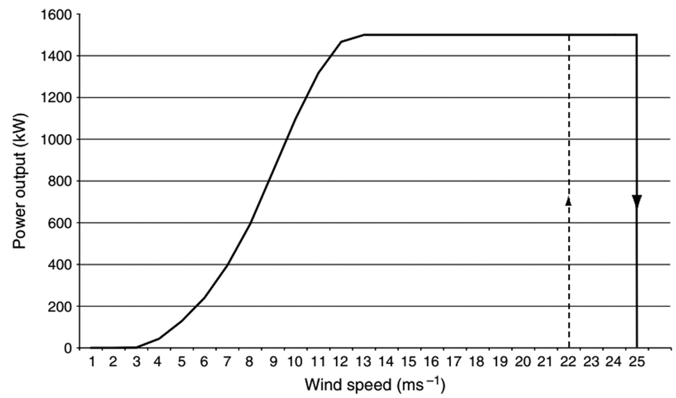


**Fig. 4.** Wind power curve [43].

m/s in this graph, and stops generating power. In light of this graph, it can be said that wind turbines do not work at every wind speed. It has a special interval of speed to operate. Ackerman states that when the velocity falls below the cut-out wind speed and to the functioning interval again, the turbines do not instantly restart. There may be a delay which is known as a hysteresis loop, which requires a 34 m/s reduction in wind speed [44].

**2) The Effect of the Number of Wind Turbines on Power**

Considering that storms do not impact all wind turbines simultaneously, an increasing amount of wind turbines minimizes the effects of turbulence. The percentage variance of power output decreases with a rate of $n^{-1/2}$ , with $n$ representing the number of generators. Furthermore, a broad distribution area of wind turbines is preferable since the weather does not influence all wind turbines simultaneously. However, a powerful transmission infrastructure is required for big areas with many wind turbines [45].

As seen in the Fig. 5, power is more stable with a larger number of wind turbines. However, there is not much difference between 150 and 300 wind turbines. This is due to the formula. The variability of output decreases with more wind turbines.

**IX. MICROGRID DESIGN**

The planned microgrid for the plant will include an AC bus, DC bus, converters, battery storage system, wind turbines, and PV solar panels. The system will feed the electric motors and pumps in the plant. The microgrid will be designed as an AC microgrid considering the power type. In addition, it will be a hybrid microgrid considering its source; as it combines two different sources: wind and solar power.

Electrical consumption data obtained from the General Directorate of İzmir Water Works shows that the plant consumed a total of 1275 MWh of electricity in 2022. The electrical consumption of the Havza Waste Water Treatment Plant is given in kWh per month in Table I.

**A. HOMER Pro Software**

The software is utilized for the design and analysis of the planned microgrid system for the treatment plant. The National Renewable Energy Laboratory developed HOMER, which is presently updated and offered by UL Solutions. It allows users to model and optimize

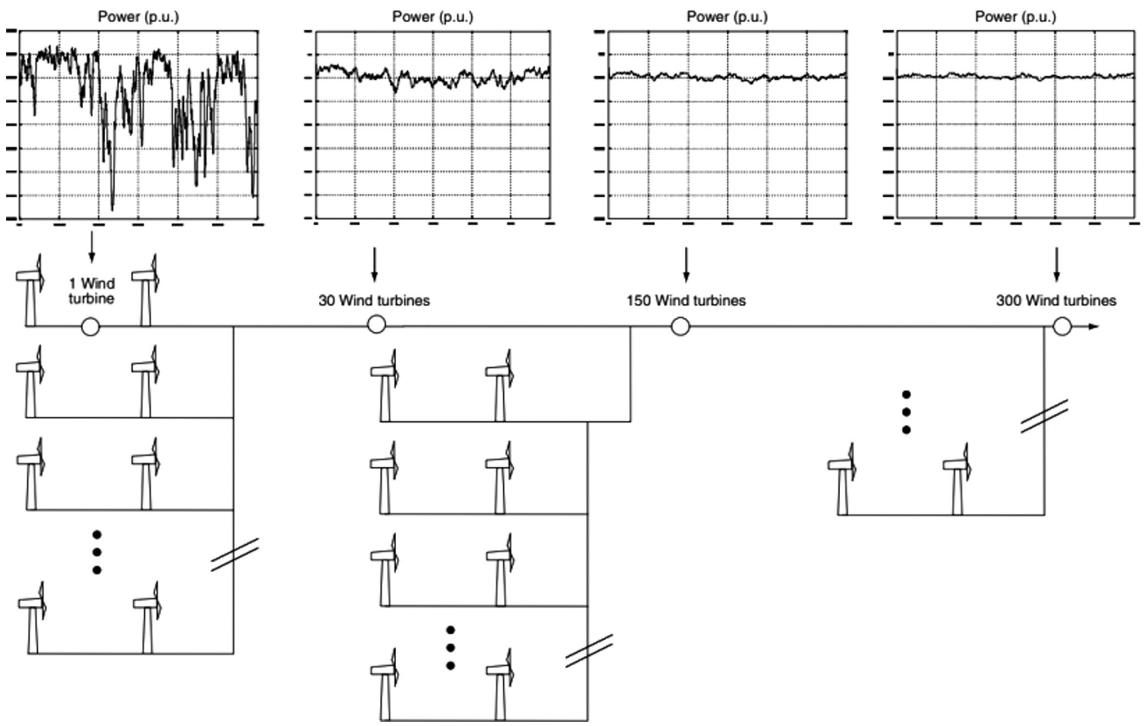


**Fig. 5.** Power production variability relation with the number of wind turbines [46].

an endless number of systems that employ solar PV, wind turbines, batteries, diesel engines, basic grid connections, and other components. The program provides access to meteorological data for the simulation region. The application replicates the operation of a hybrid microgrid in one-minute to one-hour time increments for a whole year [47].

**TABLE I.**
ENERGY CONSUMPTION OF THE PLANT

| Month | kWh |
|---|---|
| January | 114 342.67 |
| February | 99 843.34 |
| March | 107 037.63 |
| April | 107 939.11 |
| May | 113 446.35 |
| June | 101 321.33 |
| July | 105 242.92 |
| August | 112 669.08 |
| September | 106 735.41 |
| October | 109 691.40 |
| November | 98 023.78 |
| December | 99 051.43 |

Through the program interface that is shown in Fig. 6, the location of the Havza Waste Water Treatment Plant is selected, and the wind speed and solar radiation values of this location are accessed.

**1) Meteorological Data**
Based on NASA's meteorological data from 1983 to 2005, the program provided the necessary weather data for the region as seen in Tables II and III.

**2) Load Parameters**
The data given in Table I was the consumption values given in kWh/month. Data are converted to kWh/day and entered into the "Deferrable Load" section of the program as can be seen in Table IV.

In the load section, scaled annual average, storage capacity, peak load, and minimum load ratio values are required. Scaled annual average is calculated as 3494.93 kWh/day. The maximum energy in 2022 was consumed in January, which was 3688.473 kWh/day. The parameters are obtained according to the calculations given below. The peak load is determined as 153.686 kW.

$$Average\ Load = \frac{3494.93}{24h} = 145.633kW$$

$$Load\ Ratio = \frac{Average\ Load}{Maximum\ Load} = \frac{145.633kW}{153.686kW} * 100 = 94.76\%$$

To decide on the storage capacity, 10 different storage capacity values are analyzed and compared with each other. It is found that the lowest cost is obtained at 800 kWh.

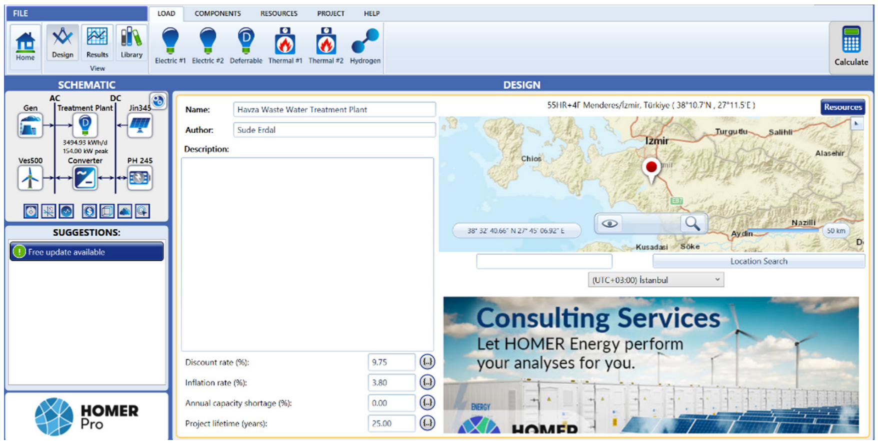


**Fig. 6.** Software interface.

The inflation rate is taken as 4.3%. In addition, the discount rate of Turkey is found as 9.75 [48]. The project lifetime is chosen as 25 years. Moreover, the annual capacity shortage is considered zero since the system is an off-grid microgrid which is required to meet all the load demand.

### 3) Components

The system consists of wind turbines, photovoltaic panels, battery systems, converters, generators, AC buses, and DC buses. While choosing the components, the lowest costs and adequate capacities are taken into account.

**a) Converter:** The system converter of the software is selected. The parameters that are recommended by the program are preferred. According to the software, its cost is determined as $300 per kW. Also, the replacement cost is chosen as $300 and its efficiency is 95%. Its lifetime is obtained as 15 years.

**b) The Storage System:** The storage system is chosen as a generic 100 kWh lithium-ion battery [Table V]. The capital cost of a storage system is determined as $151 per kWh [49]. With this information, the capital cost and replacement cost are found to be $15 100. The operation and maintenance costs are taken as $10 per year, and the lifetime of the battery is chosen as 15 years. In addition, its maximum discharge power is 300 kW.

**c) Wind Turbine:** Wind turbines of Electriawind Garbi 150/28 are utilized in the system. Its capital and replacement cost are determined as $105,000. Its O&M cost is estimated at $3000 per year. Moreover, its hub height is found as 35 m from the datasheet of the turbine. In

**TABLE II.**
MONTHLY AVERAGE SOLAR GLOBAL HORIZONTAL IRRADIATION DATA

| Month | Clearness Index | Daily Radiation (kWh/m²/day) |
|---|---|---|
| January | 0.475 | 2.160 |
| February | 0.485 | 2.870 |
| March | 0.534 | 4.190 |
| April | 0.533 | 5.200 |
| May | 0.595 | 6.580 |
| June | 0.655 | 7.580 |
| July | 0.671 | 7.580 |
| August | 0.656 | 6.700 |
| September | 0.638 | 5.410 |
| October | 0.576 | 3.730 |
| November | 0.491 | 2.380 |
| December | 0.434 | 1.790 |

**TABLE III.**
MONTHLY AVERAGE WIND SPEED DATA

| Month | Average (m/s) |
|---|---|
| January | 5.700 |
| February | 6.000 |
| March | 5.500 |
| April | 4.910 |
| May | 4.630 |
| June | 5.380 |
| July | 6.430 |
| August | 6.040 |
| September | 5.220 |
| October | 5.110 |
| November | 5.320 |
| December | 5.740 |

**TABLE IV.**
MONTHLY AVERAGE LOAD

| Month | Average Load (kWh/day) |
|---|---|
| January | 3688.473 |
| February | 3565.834 |
| March | 3452.827 |
| April | 3597.970 |
| May | 3659.559 |
| June | 3377.378 |
| July | 3394.933 |
| August | 3634.486 |
| September | 3557.847 |
| October | 3547.142 |
| November | 3267.459 |
| December | 3195.207 |

**TABLE V.**
LI-ION BATTERY PARAMETERS

| Nominal Voltage | 600V |
|---|---|
| Nominal Capacity | 167 Ah |
| Efficiency | 90% |
| Maximum Discharge Current | 500A |

addition, the lifetime is chosen as 25 years and the ambient temperature effects are considered. The amount of wind turbines is limited to 4 [Fig. 7].

**d) Photovoltaic Panels:** Jinko Solar345JKM345M-72 panels which use monocrystalline modules with an efficiency of 13%. It is one of the common solar panel brands that is used widely in Turkey. Its capital cost and replacement cost are determined as $180 per kW. Also, the O&M cost is found as $10. The lifetime is estimated at 25 years. The maximum capacity is limited to 600 kW.

e) Diesel Generator: A diesel generator is used as a backup source in case of an energy shortage. An autosized generator is utilized, which can adjust its production according to the need. The system tries to minimize the capacity of the generator. The software presents the economic parameters as $500 of initial and replacement cost, $0.030/operation hours of O&M cost, and $1/L of fuel price.

**B. Simulation Results**

**1) Case I**
In the first case, the battery and converter's capacities are not restricted, and their capacity is determined by the software [Fig. 8].

**a) Cost Summary:** The software creates different scenarios with different combinations of the components and displays costs in many categories including NPC ($), LCOE ($/kWh), initial capital ($), and operating cost ($/year) [Fig. 9]. The capacity or the quantity of the components is given in Table VI, which shows the best result in terms of costs, and the costs of this system are illustrated in Table VII.

The software defines the NPC of the system as the current worth of all the expenses minus gains over the system's lifetime. On the other hand, COE shows the price of the useful energy per kWh. The operating cost is calculated by subtracting the annualized capital cost from

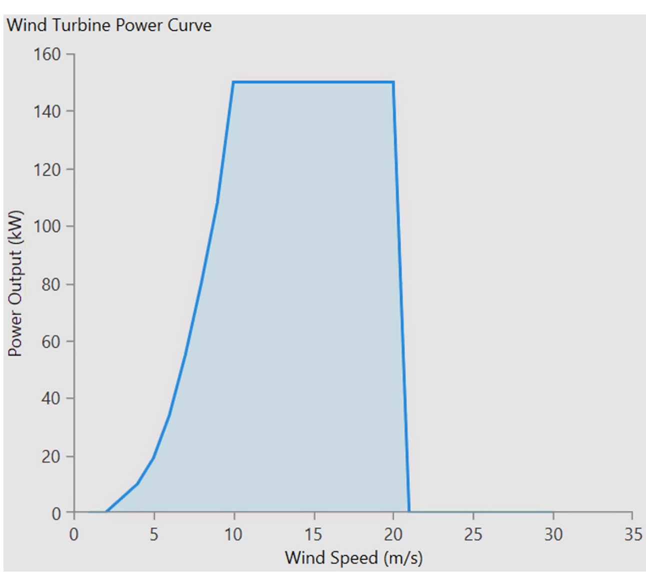


**Fig. 7.** Wind turbine power curve.

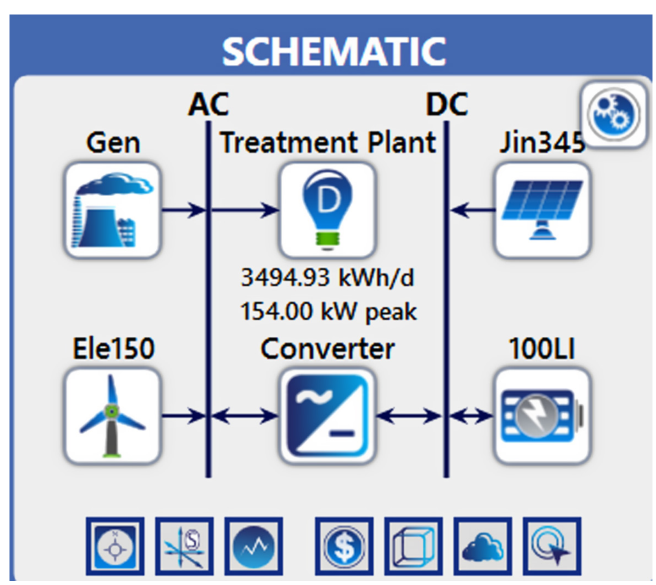


**Fig. 8.** The schematic of case I.

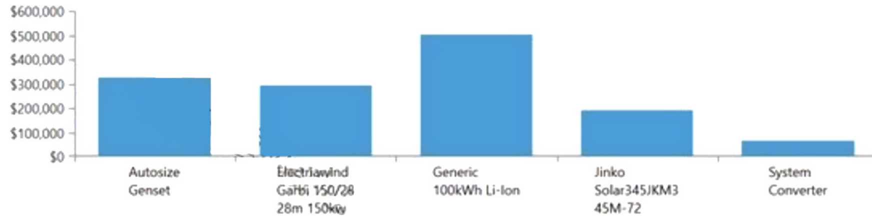


**Fig. 9.** Cost comparison by component.

the total yearly cost. Lastly, initial capital is the entire installed cost at the beginning of the project [Fig. 10].

**b) Detailed Component Results:** First, it is estimated that the diesel generator worked for 526 hours in a single year and produced 54 887 kWh of energy. It used 15 410 liters of fuel, which costs $15 410 annually. The operation and maintenance costs are equal to $2525 annually. Second, the Jinko 345W Solar Panel is analyzed. It is found that it produced 910 246 kWh annually and its capital cost is equal to $108 000. Since solar panels have a capacity factor of 17.3%, the mean output is calculated as 104 kW. Moreover, the panels are operated for 4389 hours in a year. Their levelized cost is estimated at $0.0152.

Thirdly, Electriawind Garbi 28/150 wind turbines are analyzed. The two turbines produced a total of 980 494 kWh of power annually. The total capacity is 300 kW; however, due to the effect of the 37.3% capacity factor, the mean output is calculated as 112 kW. The capital cost is calculated as $210 000 and the O&M cost is calculated as $6000. It was found that turbines worked for 8166 hours in a single year. Furthermore, the levelized cost is determined as $0.0217. It is seen that the LCOE of wind power is larger than solar power in this project.

Finally, the 100 kWh Li-Ion Batteries are analyzed. They worked for 13.2 hours annually, and their annual throughput was 394 281 kWh. In their lifetime, their total throughput is calculated as 5 914 221 kWh. The total nominal capacity is calculated as 2400 kWh. Although, the usable nominal capacity is 1920 kWh. The lifetime is calculated as 15 years.

In light of this information, solar panels, generators, and wind turbines met 46.8%, 2.82%, and 50.4% of the total load demand respectively. Moreover, the renewable fraction is 95.7%. In this case, 30.7% of excess electricity occurs, which corresponds to 597 342 kWh.

The emission rates are measured as well. A total of 40 338 kg of carbon dioxide, 254 kg of carbon monoxide, 11.1 kg of unburned hydrocarbons, 1.54 kg of particulate matter, 98.9 kg of sulfur dioxide, and 239 kg of nitrogen oxides are produced annually because of the utility of a diesel generator.

**c) Comparison With Non-renewables:** The grid is integrated into the system to compare the carbon emissions with and without the renewable integration. When the system is fed with only utility, it is found that 805 779 kg of carbon dioxide, 3493 kg of sulfur dioxide, and 1708 kg of nitrogen oxide are emitted in a year. Compared to the microgrid, it is calculated that carbon dioxide, sulfur dioxide,

**TABLE VI.**
WINNING SYSTEM ARCHITECTURE

| Component | Total Capacity or Amount |
|---|---|
| Solar panel | 600 kW |
| Wind turbine | 2 Turbines (each 150 kW) |
| Diesel generator | 160 kW |
| Li-Ion battery | 24 kW |
| Converter | 154 kW |

**TABLE VII.**
COST ANALYSIS

| | |
|---|---|
| NPC ($) | $1.37M |
| COE ($) | $0.0782 |
| Operating cost ($/year) | $41 020 |
| Initial capital ($) | $806 655 |

COE, cost of energy; NPC, Net present cost.

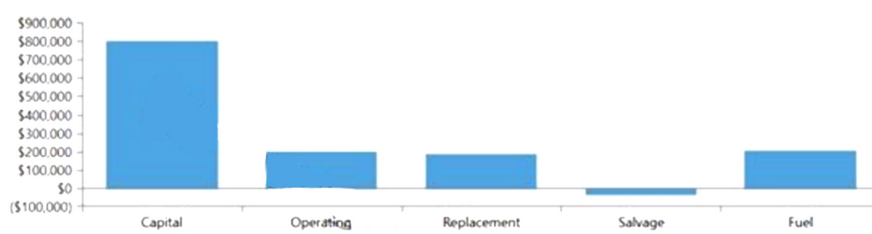


**Fig. 10.** Cost comparison by cost type.

and nitrogen oxide emissions increased to 1897.6%, 3392.5%, and 614.6% respectively. In total, there is a significant rise in emissions, which correlates to 1883.8%.

**2) Case II**

In the second case [Figs. 11, 12, and 13], the battery and converter minimum capacities are limited to 85 kW and 300 kW respectively. Furthermore, the wind turbine is connected to the DC bus, so that the battery is not limited to the capacity of the converter.

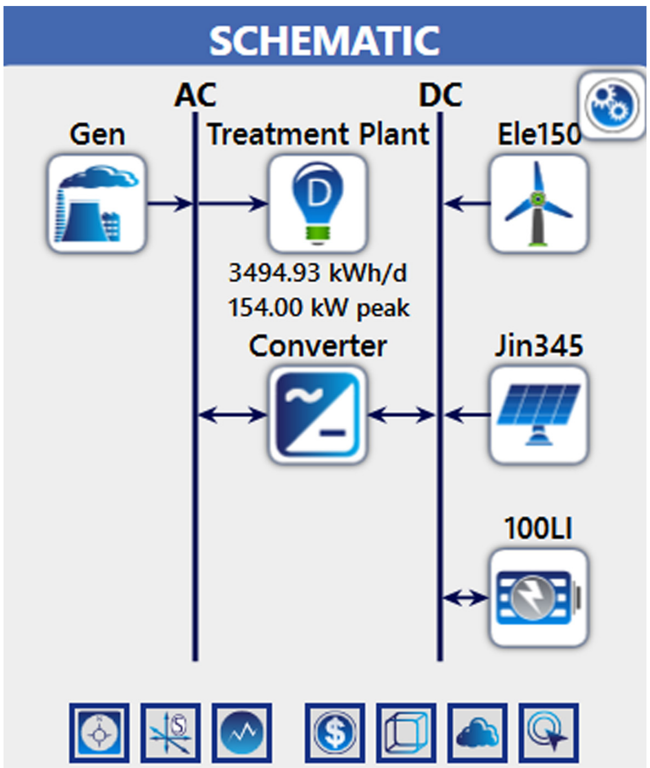


**Fig. 11.** The schematic of case II.

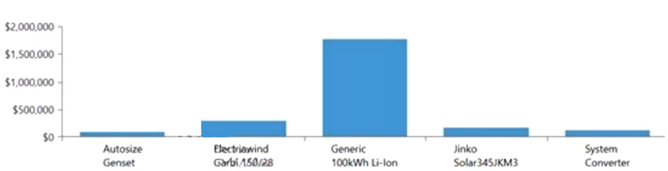


**Fig. 12.** Cost comparison by component for case II.

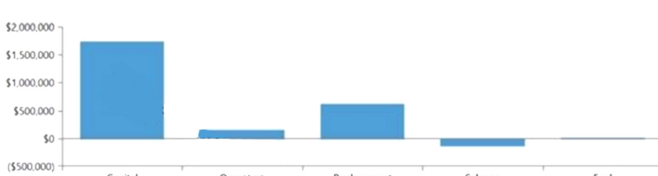


**Fig. 13.** Cost comparison by cost type for case II.

Solar panels, generators, and wind turbines met 44.7%, 0.423%, and 54.8% of the total load demand respectively. Furthermore, the renewable fraction is 99.4%. In this case, the excess power is 22.3%, which corresponds to 399 401 kWh/year.

On the other hand, emission rates are 5536 kg/year of carbon dioxide, 34.9 kg/year of carbon monoxide, 1.52 kg/year of unburned hydrocarbons, 0.211 kg/year of particulate matter, 13.6 kg/year of sulfur dioxide, 32.8 kg/year of nitrogen oxide.

**3) Comparison of Cases I and II**

In case II [Tables VIII and IX], it is seen that the net present cost is almost two times that of case I. In addition, LCOE is increased from $0.0782 to $0.140. This enhancement is mostly due to the high cost of batteries. With the increased battery capacity, more energy is stored, and excess electricity is decreased to 22.3%, while it is 30.7% in case I. On the other hand, due to the lower usage of the generator, the renewable fraction is found to be larger in case II, so the emission rates are decreased significantly. In addition, 35 323.5 kg of less hazardous emissions are released.

## X. CONCLUSIONS AND RECOMMENDATIONS

As a result, the hybrid microgrid including wind/solar/battery/diesel generator is designed for the Havza Waste Water Treatment Plant in İzmir, Turkey. The total energy demand is supplied by the designed microgrid and it even produces excess power, which can be sold to the grid or utilized in the irrigation of the agriculture, since the plant is located between many agricultural fields. In addition, it should be noted that the plant may require more energy as the plant grows in years.

**TABLE VIII.**
WINNING SYSTEM ARCHITECTURE FOR CASE II

| Component | Total Capacity or Amount |
|---|---|
| Solar panel | 527 kW |
| Wind turbine | 2 Turbines (each 150 kW) |
| Diesel generator | 160 kW |
| Li-Ion battery | 86 kW |
| Converter | 300 kW |

**TABLE IX.**
COST ANALYSIS FOR CASE II

| | Cost |
|---|---|
| NPC ($) | $2.45M |
| COE ($) | $0.140 |
| Operating cost ($/year) | $50,272 |
| Initial capital ($) | $1.76M |

COE, cost of energy; NPC, Net present cost.

In terms of cost, it is acquired that batteries are the highest-price components in the system. Moreover, the capital cost is estimated as the most expensive cost type. The main reason for the excess electricity is the high prices of batteries. Since HOMER Pro optimizes the system to have the lowest cost, it tends to produce more electricity rather than storing it in batteries. It can be claimed that the high costs of batteries are a crucial problem in microgrid design. Although it should be noted that battery prices are expected to decrease significantly in the following years, That is why it is right to say that the total cost will decrease remarkably in the project lifetime, so that microgrid applications will be more feasible and common in the future.

Moreover, it is found that emission rates decrease in a striking way when microgrids are introduced to the wastewater treatment plant. For the plant, the emission rate decreased to 1883.8% with the designed system, and 770 039 kg of hazardous gases were not emitted thanks to the microgrid. It can be said that the emissions can be reduced significantly by the integration of microgrids with high renewable fractions.

For the next step, the grid-connected system can be analyzed and compared with the off-grid results. It should be noted that, although off-grid capital costs are high, grid integration which includes establishing overhead lines and purchasing a distribution transformer could be high for a rural area like Havza Waste Water Treatment Plant. In addition, more renewable resources can be added for a more reliable operation. Depending on multi-renewable sources would be useful since the system is an off-grid design, which does not affect the main utility significantly. Moreover, the recycling process of the designed systems and the transportation can be taken into account for a sustainable solution.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept – S.E.; Design – S.E.; Supervision – E.A., C.A.; Resources – S.E.; Materials – S.E.; Data Collection and/or Processing – S.E.; Analysis and/or Interpretation – S.E.; Literature Search – S.E.; Writing – S.E.; Critical Review – S.E.

**Declaration of Interests:** The authors have no conflicts of interest to declare.

**Funding:** This study received no funding.

## REFERENCES

1. İ. Çetinbaş, B. Tamyürek, and M. Demirtaş, "Design, analysis and optimization of a hybrid microgrid system using Homer software: Eskişehir Osmangazi university example," *Int. J. Renew. Energy Dev.*, vol. 8, no. 1, pp. 65–79, 2019. [CrossRef]
2. M. K. Islam, J. M. Akanto, M. Zeyad, and S. M. M. Ahmed, *Optimization of Microgrid System for Community Elecrtication by Using Homer Pro*, 2021. [CrossRef]
3. O. Boqtob, H. El Moussaoui, H. El Markhi, and T. Lamhamdi, "Optimal sizing of grid-connected microgrid in morocco using Homer Pro." International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), vol. 2019, 2019, pp. 1–6. [CrossRef]
4. A. K. Raji, and D. N. Luta, "Modelling and optimization of a community microgrid components," *Energy Procedia*, vol. 156, pp. 406–411, 2019. [CrossRef]
5. O. Çetinkaya, M. Pürlü, and B. T. Emre, *PVsyst ve Homer Kullanılarak Şebekeye Bağlı Mikro Şebeke Tasarımı*, 2022. [CrossRef]
6. D. M. Mahmud, S. M. M. Ahmed, S. Hasan, and M. Zeyad, "Grid-connected microgrid: Design and feasibility analysis for a Local Community in Bangladesh," *Clean Energy*, vol. 6, no. 3, 447–459, 2022. [CrossRef]
7. C. Madtharad, and T. Chinabut, "Microgrid design for rural island in PEA area." 53rd International Universities Power Engineering Conference (UPEC), Glasgow, UK, vol. 2018, 2018, pp. 1–5. [CrossRef]
8. I. Panhwar, A. R. Sahito, and Ş. Dursun, "Designing off-grid and on-grid renewable energy systems using Homer pro software," *J. Int. Environ. Appl. Sci.*, vol. 12, no. 4, pp. 270–276, 2017.
9. S. Munir, A. Naveed, R. T. Iqbal, and M. Usman, "'A Case Study on Cost Analysis and Load Estimation of Hybrid Renewable Energy System using HOMER Pro', *Eurasian J. Sci*," *Eng. Tech.*, vol. 3, no. 2, pp. 103–108, 2022.
10. K. Strunz, E. Abbasi, and D. N. Huu, "DC microgrid for Wind and solar power integration," *IEEE J. Emerg. Sel. Top. Power Electron.*, vol. 2, no. 1, pp. 115–126, 2014. [CrossRef]
11. F. Chisthi, S. Murshid, and B. Singh, "Development of Wind and solar based AC microgrid with power quality improvement for local nonlinear load using MLMS," *IEEE Trans. Ind. Appl.*, vol. 55, no. 6, pp. 7134–7145, 2019. [CrossRef]
12. Y. Hou, and Y. Yan, "Optimized wind-light-storage configuration based on homer Pro," *J. Phys. Conf. Ser.*, vol. 2303, no. 1, p. 012037, 2022. [CrossRef]
13. R. L. Dash, L. Behera, B. Mohanty, and P. K. Hota, "Cost and sensitivity analysis of a microgrid using Homer-Pro sofware in both grid-connected and standalone mode." International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering (ICRIEECE), Bhubaneswar, India, Vol. 2018, 2018, pp. 3444–3449. [CrossRef]
14. A. Yasin, and M. Alsayed, "Optimization with excess electricity management of a PV, energy storage and diesel generator hybrid system using Homer Pro software," *Int. J. Appl. (IJAPE)*, vol. 9, no. 3, pp. 267–283, 2020. [CrossRef]
15. Y. Cao, M. S. Taslimi, S. M. Dastjerdi, P. Ahmadi, and M. Ashjaee, "Design, dynamic simulation, and optimal size selection of a hybrid solar/Wind and battery-based system for off-grid energy Supply," *Renewable Energy*, vol. 187, 1082–1099, 2022. [CrossRef]
16. A. Maleki, and A. Askarzadeh, "Optimal sizing of a PV/Wind/Diesel system with battery storage for electrification to an off-grid remote region: A case study of Rafsanjan, Iran," *Sustain. Energy Technol. Assess.*, vol. 7, pp. 147–153, 2014. [CrossRef]
17. A. Askarzadeh, "Developing a discrete harmony search algorithm for size optimization of wind-photovoltaic hybrid energy system," *Sol. Energy*, vol. 98, pp. 190–195, 2013. [CrossRef]
18. F. R. Badal, P. Das, S. K. Sarker, and S. K. Das, "A survey on control issues in renewable energy integration and microgrid," *Prot. Control Mod. Power Syst.*, vol. 4, no. 1, 2019. [CrossRef]
19. A. M. Jasim, B. H. Jasim, F. C. Baiceanu, and B. C. Neagu, "Optimized sizing of energy management system for off-grid hybrid solar/Wind/batt ery/biogasifier/diesel microgrid system," *Mathematics*, vol. 11, no. 5, p. 1248, 2023. [CrossRef]
20. O. Ayan, and B. E. Turkay, "Techno-economic comparative analysis of grid-connected and islanded hybrid renewable energy systems in 7 climate regions, turkey," *IEEE Access*, vol. 11, pp. 48797–48825, 2023. [CrossRef]
21. E. Aydın, M. Pürlü, and B. E. Türkay, "'Heuristic Algorithms on Economic Dispatch of Multi-Microgrids wih Photovoltaics', *TEPES*," *TEPES*, vol. 2, no. 2, pp. 147–157, 2022. [CrossRef]
22. M. Boztepe, *Enerji Sistemlerinde Güç Elektroniğinin Yükselen Önemi ve Son Gelişmeler*, 2019, p. 8.
23. M. Boztepe, *Enerji Sistemlerinde Güç Elektroniğinin Yükselen Önemi ve Son Gelişmeler*, 2019, p. 10.

24. M. Boztepe, *Enerji Sistemlerinde Güç Elektroniğinin Yükselen Önemi ve Son Gelişmeler*, 2019, pp. 12–15.
25. G. Shahgholian, “A brief review on microgrids: Operation, applications, modeling, and control,” *Int. Trans. Electr. Energy Syst.*, vol. 31, no. 6, 2021. [CrossRef]
26. R. Yokoyama, T. Niimura, and N. Saito, “Modeling and Evaluation of Supply Reliability of Microgrids including PV and Wind Power.” IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, Pittsburgh, PA, USA, 2008, 2008, pp. 1–5. [CrossRef]
27. G. Shahgholian, “A brief review on microgrids: Operation, applications, modeling, and control,” *Int. Trans. Electr. Energy Syst.*, vol. 31, no. 6, 2021. [CrossRef]
28. T. Adefarati, and R. C. Bansal, “Reliability, economic and environmental analysis of a microgrid system in the presence of renewable energy resources,” *Appl. Energy*, vol. 236, pp. 1089–1114, 2019. [CrossRef]
29. Url-1. Available: https://enerji.gov.tr/bilgi-merkezi-enerji-gunes
30. Url-2. Available: https://enerji.gov.tr/bilgi-merkezi-enerji-ruzgar
31. Url-3. Available: https://repa.enerji.gov.tr/REPA/A
32. Url-4. Available: https://gepa.enerji.gov.tr/MyCalculator/pages/35.aspx
33. A. Abtahi, and R. Messenger, “Introduction to PV systems,” *Photovoltaic Systems Engineering*, 4th ed., p. 49, 2017.
34. Ö. Atalay, B. Yorgun, and R. Erdem, *Fotovoltaik (PV) Güneş Enerjisi Sistemler ve Çatı Uygulamaları*.
35. N. Hussin, N. Amin, M. Safar, R. Zulkafli, M. Majid, and M. Zaman, “Performance factors of the photovoltaic system: A review,” *Hybrid PV Syst.*, 2018.
36. E. Franklin, *Solar Photovoltaic (PV) System Components*, 2018.
37. E. Franklin, *Solar Photovoltaic (PV) System Components*, 2018.
38. Ö. Atalay, B. Yorgun, and R. Erdem, *Fotovoltaik (PV) Güneş Enerjisi Sistemler ve Çatı Uygulamaları*.
39. E. Franklin, *Solar Photovoltaic (PV) System Components*, 2018.
40. Z. Ceyran, *Fotovoltaik Güneş Enerji Sistemleri*.
41. Aselsan, *Rüzgar Türbinlerinde Tam Ölçek Güç Dönüştürücü Uygulaması*.
42. T. Ackermann, “Wind Power in power systems: An introduction,” *Wind Power Power Syst.*, p. 55, 2012.
43. T. Ackermann, “Wind Power in power systems: An introduction,” *Wind Power Power Syst.*, p. 55, 2012.
44. T. Ackermann, “Wind Power in power systems: An introduction,” *Wind Power Power Syst.*, pp. 56–57, 2012.
45. T. Ackermann, “Wind Power in power systems: An introduction,” *Wind Power Power Syst.*, p. 58, 2012.
46. T. Ackermann, “Wind Power in power systems: An introduction,” *Wind Power Power Syst.*, p. 55, 2012.
47. Url-8. Available: https://www.homerenergy.com/products/pro/index.html
48. Url-7. Available: https://www.ceicdata.com/en/turkey/saving-discount-rate-and-interbank-rate/central-bank-discount-rate#:~:text=Turkey%20Central%20Bank%20Discount%20Rate%20data%20was%20reported%20at%209.750
49. Url-8. Available: https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/