Çeşitli Elektrikli Araç Şarj Stratejilerinin Uygulandığı Hibrit bir Mikroşebekenin Tasarımı ve Optimizasyonu

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Design and Optimization of a Hybrid Microgrid that Employs Various Electric Vehicle Charging Strategies

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ETHICAL STATEMENT

I hereby declare that this thesis study entitled "Design and Optimization of a Hybrid Microgrid that Employs Various Electric Vehicle Charging Strategies" has been prepared in accordance with the thesis writing rules of Eskisehir Osmangazi University Graduate School of Natural and Applied Sciences under academic consultancy of my supervisor Prof. Dr. H. Hüseyin Erkaya. I hereby declare that the work presented in this thesis is original. I also declare that, I have respected scientific ethical principle and rules in all stages of my thesis study, all information and data presented in this thesis have been obtained within the scope of scientific and academic ethical principles and rules, all materials used in this thesis which are not original to this work have been fully cited and referenced, and all knowledge, documents and results have been presented in accordance with scientific ethical principles and rules.

14/06/2021

Farhia Abdullahi Mohamud

ÖZET

Bu çalışmada, çeşitli elektrikli araç şarj stratejilerine hizmet eden bir hibrit mikro şebekenin tasarımı ve optimizasyonu sunulmuştur. Bu çalışmada kullanılan hibrit kombinasyon, şebekeye bağlı güneş ve rüzgar üretimidir. Bu optimizasyonun amacı, Eskişehir Osmangazi Üniversitesi kampüsünün elektrik ihtiyacını karşılamak ve çeşitli elektrikli araç şarj modlarına izin veren şarj istasyonları kurmaktır. Elektrikli araçları şarj etmek için hibrit mikro şebekenin seçilmesinin nedeni, yenilenebilir kaynaklardan yararlanmak ve elektriğin en düşük maliyetli olduğu zamanlarda şarj etmektir. Önerilen sistemin modellenmesi ve optimizasyonu, HOMER Grid optimizasyon yazılımı ile gerçekleştirilmiştir. Bu sistemlerin ekonomik, çevresel etkileri ve güvenilirliğine dayalı olarak birkaç sistemin karşılaştırması yapılmıştır. Seçilen optimum hibrit mikro şebeke tasarımı, bir PV sistemi, batarya enerji depolama, rüzgar sistemi, şebeke ve elektrikli araçlardan oluşur. Bu çalışmada, yönetilebilir ve isteğe bağlı elektrikli araç şarjı olmak üzere iki farklı elektrikli araç şarj modu sunulmuştur. Tasarlanan mikro şebekenin çok yıllık olarak teknik ve ekonomik analizi yapılmış ve proje ömrü boyunca performansı değerlendirilmiştir. Ayrıca farklı elektrikli araç şarj istasyonlarının karşılaştırması yapılmıştır. Hem kullanıcılar hem de şebeke için en etkili şarj moduna karar verilmiş olup şarj verimlilikleri de analiz edilmiştir. Sonuç olarak değerlendirildiğinde; isteğe bağlı şarj yerine yönetilebilir şarj istasyonu tercih edilmesiyle birlikte elektrikli araçların talepleri %3,5'ten %1,5'e düşürülmüştür. Çalışmada sunulan mikro şebeke sistemi kullanılarak elektrik faturası %36 oranında azaltılmıştır.

Anahtar Kelimeler: Hibrit, Mikro şebeke, Optimizasyon, Yenilenebilir enerji, Elektrikli araç, Yönetilebilir EA şarj cihazı, İsteğe bağlı EA şarj cihazı.

SUMMARY

In this study, the design and optimization of a hybrid microgrid serving various electric vehicle charging strategies are presented. The hybrid combination used in this study is grid-connected solar and wind generation. The purpose of this optimization is to meet the electricity needs of the Eskişehir Osmangazi University campus and to establish charging stations that allow various electric vehicle charging modes. The reason for choosing the hybrid microgrid to charge electric vehicles is to utilize renewable resources and to charge when electricity is at the lowest cost. Modeling and optimization of the proposed system were carried out with the HOMER Grid optimization software. Several systems have been compared based on the economic, environmental impact, and reliability of these systems. The optimum hybrid micro-grid design chosen consists of a PV system, battery energy storage, wind system, grid, and electric vehicles. In this study, two different electric vehicle charging modes namely deferrable and on-demand electric vehicle charging are presented. A multi-year technical and economic analysis of the designed microgrid has been made and its performance has been evaluated throughout the life of the project. In addition, different electric vehicle charging stations were compared. The most efficient charging mode has been decided for both users and the grid, and charging efficiencies have also been analyzed. When evaluated as a result; with the preference of deferrable charging station instead of on-demand charging, the demands of electric vehicles were reduced from 3.5% to 1.5%. Using the microgrid system presented in the study, the electricity bill is reduced by 36%.

Keywords: Hybrid, Microgrid, Optimization, Renewable energy, Electric vehicle, Deferrable EV charger, On-demand EV charger

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ABBREVIATIONS

Abbreviation	**Description**
EV	Electric vehicles
BEV	Battery electric vehicles
HEV	Hybrid electric vehicles
PHEV	Plug-in hybrid electric vehicles
AC	Alternating current
DC	Direct current
PV	Photovoltaics
NPC	Net present cost
LCOE	Levelized cost of energy
IRR	Internal rate of return
HOMER	Hybrid optimization of multiple energy resources

1. INTRODUCTION AND PURPOSE

The use of hybrid renewable sources, such as solar photovoltaic and wind energy, to charge batteries like electric vehicle (EV) batteries became a fascinating option that contributes to a huge number of technical and economic opportunities. This is also a solution to the problems related to the greenhouse effect by the combination of emission-free EV and low carbon renewable sources. The main purpose of using these kinds of clean energies is to reduce the environmental impacts and at the same time to minimize the cost of EV charging.

These days the investment activities toward EVs are increasing rapidly while big companies are taking their opportunity for longer-term investments expecting positive results in the future. Also, energy companies are among the biggest customers for vehicle manufacturers, and they are doing the best to take advantage of this evolution by designing charge stations that are compatible with every EV model and consumer desire. Since EVs are energy-consuming technologies, they bring again the need for reliable electricity and clean energy that we can only find from renewable sources. To charge the EV battery, a charge station that is connected to the electric grid or some renewable energy sources must be found.

To obtain such a great charging system, we will consider a microgrid that contains hybrid renewable energy systems (solar PV and wind energy), grid, and EVs. However, with all these different sources, the complexity of microgrid will increase, which is why optimization of energy is necessary.

This work provides a system design of hybrid microgrids in the presence of renewable energy sources and various EV battery charging strategies. In this study, we are going to establish charging stations in one of the Eskisehir Osmangazi University parking lots using the hybrid microgrid that will provide electric energy for the university campus.

First, a microgrid suitable for this criteria will be designed by determining the structure and defining the evaluation criteria followed by the two battery charging modes deferrable and on-demand charging. The optimal design of the microgrid and these charging modes will be focused in this study.

The strict emission requirements in the last decades of the 20th century forced car manufacturers to produce EVs. Early EVs relied on batteries only. These cars had a limited distance to travel before their batteries drained. To increase the travel distance, hybrid electric vehicles (HEV) were developed. That was followed by the plug-in hybrid electric vehicles (PHEV). As the number of EVs increased, the demand for charging stations climbed up. The charging station should simply be connected to the utility grid. However, concerns for alternative and clean electric energy sources suggested microgrids to feed the charging stations. Microgrids are also considered for sustainable electric energy supply (Atmaja and Mirdanies, 2015).

To operate a reliable charging setup, strong coordination between the charging infrastructure and the distribution grid must be established starting from the design of a suitable grid for the charging strategy. A microgrid is one of the best solutions for smarter, reliable, and more efficient energy operations (Aljohani, T.M. et al., 2020). Currently, most of the power distribution sectors use microgrids to distribute their power efficiently without difficulties.

A microgrid is a power distribution system, and it contains one or more distributed generation units. It can operate in parallel with the electric grid giving higher flexibility and reliability of operation (Hatipoglu, 2013). This system simplifies the use of various renewable energy sources, provides constant power from such sources, and reduces external energy dependency in seasonal changes.

An EV is a general name for vehicles that use electricity as a form of energy to do their work, EVs can be electric cars, buses, scooters/motorcycles, or bicycles and all these vehicles need electricity to charge their batteries.

EVs have a long history that dates back to 1828 when innovators in Hungary, the Netherland, and the U.S created some of the small-scale electric cars while at that time horses and buggies were the only mode of transportation. After that, the first crude EV is developed by Robert Anderson in 1832, but these electric cars became practical after the 1870s. Later, in 1891 William Morrison created the first successful EV in the U.S., and afterward, electric cars gained popularity as people understood the simplicity of electric cars and their low impact on the environment, so they became popular in urban residences.

Some of the innovators took the opportunity to explore ways of improving EV technology by building a better battery for them. While innovators are trying to improve the technology of electric cars, hybrid electric cars came out in 1901. Ferdinand Porsche invented the first hybrid electric car which contained a battery and a gasoline engine.

While the invention of electric cars going fast, suddenly it started declining between 1920 and 1935. The decline was due to the lowering of the cost of crude oil that people saw as a better alternative way when compared to electricity. Later, they totally disappeared. But when gasoline prices became very high and the air pollution produced by vehicles became very dangerous, electric cars attracted attention again. Many automakers began to develop popular vehicle models into EVs which enabled a great achievement in the EV market.

> "According to the International Energy Agency, the number of EVs globally exceeded two million in 2016. More than 750,000 EVs were sold worldwide in 2016, with Norway leading the way in expanding the share of EVs in total car sales" (Nakhle, 2017).

The estimated global EV fleet size in 2020 is 8.5 million units and it is expected that it will be 115 million units in 2030 (I. Wagner, 2021). These include battery electric vehicles (BEVs), such as the Tesla Model S, which runs entirely on electricity through onboard batteries charged from an outlet or charging station, as well as PHEVs like the Chevy Volt, which comprises both an electric motor and a conventional engine (Nakhle, 2017).

Figure 1.1 shows the global BEV and PHEV sales increases rapidly in recent years and continues to increase in the future (Irle, 2020).

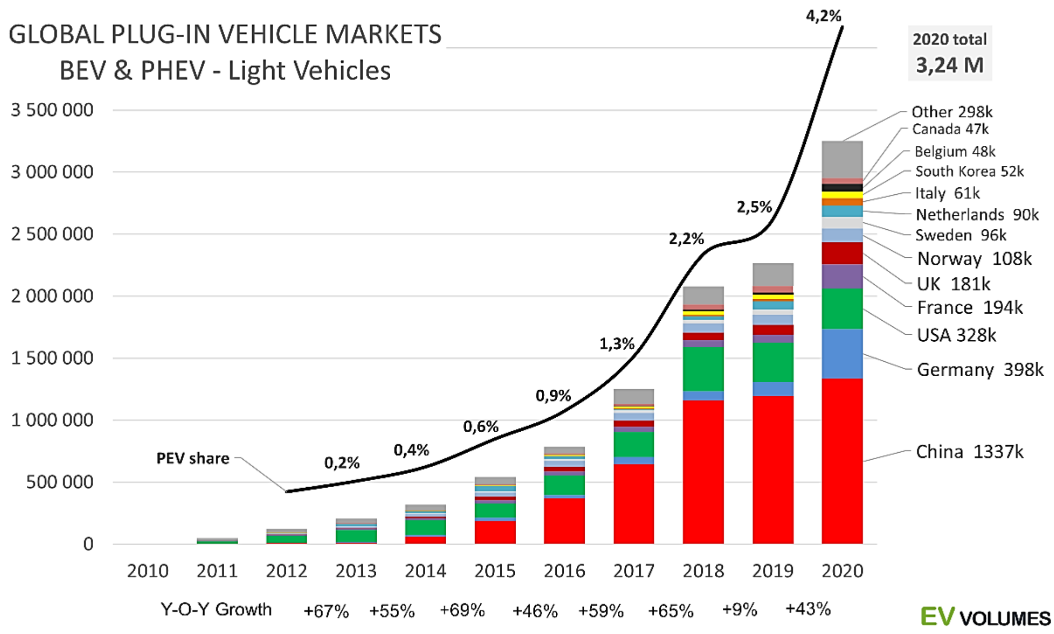

Figure 1.1. Global annual EV sales (Irle, 2020)

With Turkey's rich history as a manufacturing economy, Turkey shows real growth potential for the EV market with its first all-electric, locally produced vehicle (Cevrioğlu, 2020).

Electric car sales are on the rise in Turkey. A study carried out by SHURA Energy Transformation Centre the "High Growth" states that the total number of passenger EVs in Turkey's total stock will be more than 2.5 million in 2030, which represents 10% of the total vehicle stock in the same year, while the sales of battery and plug-in hybrid EVs will be 55% of all vehicle sales in the same year (Saygın et al., 2019).

In recent years, many EVs have been on the roads that increased the demand for charge stations along the roads or at workplaces. That's why some projects related to this sector are undertaken. Not only charge stations but also reliable and sustainable electricity are more significant for this sector.

EVs have different charging modes and levels. This is related to the interaction between the vehicle and the charging point. The charging level is also known as the charging speed.

EV charging mode relates to the communication between the vehicle and the power of the charging point. EVs have an inlet for charging the built-in battery. The charging points have plugs that are designed for the EV inlet. Plugs contain pins that carry power. They have also pins for grounding and communication. The communication between the vehicle and the charging point ensures safety and protects vehicles from overcharging. There are 4 modes of charging as follows:

- **Mode 1:** It is a simple way of charging EVs by using the mains supply. This type has no communication line. Therefore, it is no longer recommended because of safety.
- **Mode 2:** This mode of charging is used by the EVs that requires a Mode 3 charging but cannot access the charging point. A charging cable with an in-line box of electronics is used to create a communication between the charging point and the vehicle by using the regular household plug. Its safety is not perfect as the normal charging station.
- **Mode 3:** This mode of charging is used by the smart charging points. It has a regular and active communication protocol for EVs and the charging point. This mode requires a charge station.
- **Mode 4:** This mode provides DC fast charging to the vehicle. A charging interface is required to convert the direct current.

Table 1.1 presents the 3 EV charging levels as the Society of Automotive Engineers defines.

Table 1.1 EV charging levels (Chon, 2018)

Charging level	Power supply	Charge power	Charging time
Level 1 AC	120 VAC 12 A to 16A	1.44 – 1.94 kW	≈ 17hrs
Level 2 AC	208 – 240 VAC 15 A to 80 A	3.1 – 22 kW	≈ 7hsr–3.5hrs
Level 3 DC	200 – 920 VDC Max. 500 A	From 120 – 350 kW	≈30–10 min

When it comes to energy consumption in large building complexes, whether it is commercial or non-commercial places including educational campuses, the cost of electricity is a huge problem, and lowering that cost is one of the energy goals that companies work on in their lifetime. Most of the energy consumption in commercial buildings is used to provide the primary services including lighting, heating, cooling, or ventilation. Therefore, using only conventional power generation or utility grid to fulfill these necessary requirements will be costly and also environmentally unfriendly since some of these sources of energy produce greenhouse emissions where the cost of fuel is also a factor that needs management.

Eskisehir Osmangazi University campus, which is the area of interest in this thesis, consumes close to 20 million kWh of electricity each year and spends close to 2 million dollars on utility bills per year. The cost of electricity can be reduced if the University itself generates a percentage of campus' total power usage, and this can be done by using renewable energy generation which is cost-effective and a better alternative way of managing the cost of electricity while reducing greenhouse emissions by shifting to the clean energy.

In this thesis, a hybrid microgrid that contains solar and wind power generations are added to the utility grid which will reduce the annual utility bill to a good percentage. The aim of this study is not only to reduce the cost of electricity consumption but also to establish EV charging stations that will be served by the microgrid. The reason for choosing the microgrid to charge the EVs is to take advantage of renewable sources and charge when electricity is at its lowest cost. The optimal design of the microgrid with two charging stations, their technical and economic analysis will be presented.

This study is carried at Eskisehir Osmangazi University, the electricity consumption data of the campus is used for the design and optimization of the hybrid microgrid. The designed microgrid contains solar, battery storage, wind, grid, and EVs.

The optimization in this study is performed by using HOMER optimization software, the technical and economic analysis of the proposed method is done via HOMER. Deferrable and on-demand EV charging modes are designed; their advantages and effectiveness are described.

The main purpose of this research is to design a hybrid microgrid that supplies electricity to the university campus and serves various EV battery charging strategies. Also, to present the simulation of these different charging modes. A comparison of the proposed methods will be done. The microgrid has PV and wind energy units and is connected to utility grid.

The main objectives of the research are as follows:

- To evaluate the renewable energy sources by measuring their efficiency and performance,
- To establish the structure of the microgrid and determine the sizing methods,
- To design a hybrid microgrid that capable of doing various charging activities,
- To examine various battery charging modes such as on-demand charging and deferrable charging, and to realize the most efficient charging method,
- To do a multi-year economic analysis of the designed microgrid system.

This study contains seven main parts: Introduction, literature review, an overview of microgrids, design methodology of the proposed system, structure and components of the proposed system, result and discussion, and the last part is conclusion and recommendation.

In the introduction part, a general review of renewable energy sources and EVs is presented. Then, the background and the evolution of EVs, research objectives, problem statement and the scope of the research are presented.

In the second part, the literature of the related studies are summarized. In the third part, the hybrid microgrids and their components are defined. Classification of microgrids and renewable energy technologies such as solar PV and wind turbines are reviewed.

In the fourth part, the design, evaluation criteria, and optimization method of the hybrid microgrid are determined. The optimization tool that is used in this study is presented in this part.

In the fifth part, the structure and components of the proposed system are presented in detail. The information of components used in the microgrid design are given in this part.

In the sixth part, the results are discussed, and the comparison of the proposed systems followed by various EV charging modes are shown.

Lastly, a conclusion on what is performed during the study is reached.

2. LITERATURE REVIEW

Alternative and sustainable energy source continue to be in demand. Incorporation of renewable energy sources into the electric grid and hybrid microgrids are attracting significant attention. As the number of EVs increases, charging stations and strategies are taking their space in hybrid microgrid research and design.

Savio, D.A et al. (2019) modified a design of a hybrid microgrid-powered charging station and its energy management. Various modes of charging station and energy management have been developed in their study. In another study, an optimal-technical sizing method based on the Simulink Design Optimization of a stand-alone microgrid with renewable energy sources and energy storage has been proposed by Sánchez-Sáinz et al. (2019). The study shows that the system can provide energy for the charging of EVs along the motorway and produce the hydrogen consumed by the fuel cell-buses plus a certain tank reserve.

G.R. Mouli et al. (2016) designed a solar-powered EV charging station for workplaces. The study investigates the possibility of charging battery EVs at workplaces. Maximizing the use of solar PV energy for EV charging with minimal energy exchange with the grid has been focused during the design.

Erdogan et al. (2017) developed EV charging strategies in microgrids containing solar PV. The impact of various PEVs charging strategies in a grid-connected microgrid that contain a PV generation system has been investigated in the study. The utilization of PV generation has increased efficiency, and the dependency on the power grid has also decreased according to the study.

Can (2016) used a meta-heuristic method to schedule the optimal power of a renewable microgrid. The aim was to find the minimal operation cost in a microgrid system that contains low power turbine, solar panels, and diesel generator through optimal power scheduling by genetic algorithms. The daily load, charge-discharge, excess power, and diesel generator power on hourly basis curves have been plotted. Also, daily average, maximum and minimum cost were obtained for selected case scenarios. An interesting study about the evaluation of theoretical and numerical aspects related to an original DC microgrid power architecture for efficient charging of PEVs is proposed by Locment et al. (2015).

Tribioli et al. (2014) developed a real-time energy management strategy for PHEVs based on optimal control theory. In another work, the EV mobile charging station dispatch algorithms are presented by Atmaja et al. (2015). Xiaolong et al. (2016) developed hierarchical management for building microgrids considering virtual storage systems and PHEVs.

To provide reliable and continuous electrical energy to the load, Çetinbaş (2020) used five different meta-heuristic algorithms for sizing and optimization of autonomous microgrids that can afford such characteristics. Mwasil et al. (2014) performed a study about EVs and smart grid interaction. The latest research and improvement of EV integration with the smart grid are reviewed. Also, the strategy for integrating the EVs into the grid and various smart charging technologies was presented in the study.

It can be observed that most researchers use different kinds of algorithms and optimization techniques to solve their problems. When it comes to problem-solving, everyone chooses the most suitable and easiest way to reach the goal. Various optimization algorithms are so far available today. For example, Diab et.al (2019), used novel optimization algorithms of Whale Optimization Algorithm (WOA), Water Cycle Algorithm (WCA), Moth-Flame Optimizer (MFO), and Hybrid Particle Swarm-Gravitational Search Algorithm (PSOGSA) to design and optimize a microgrid operation. Singh and Khan (2017) applied the artificial shark optimization (ASO) method to remove the limitation of existing algorithms for solving the economical operation problem of a microgrid.

One of the latest nature-inspired metaheuristic optimization algorithm named Grasshopper Optimization Algorithm (GOA) is used by Bukar et al. (2019) in the area of microgrid system sizing design problem, and it is applied on autonomous microgrid system to determine the optimal system configuration that can reliably supply the demanded energy.

Some of the researchers choose a better and a short way of optimization by using software tools instead of the long way of creating algorithms, but some of them may not be efficient or otherwise not suitable for the purpose of certain researches. HOMER is one of these software tools that is used for hybrid renewable energy optimization and analysis, and we will take a look at recent studies that are done using this software.

Çetinbaş et al. (2019) used HOMER software to design and optimize a microgrid system for supplying power to a section of the hospital complex that is located on Eskisehir Osmangazi University campus, the objective of the study was the reduction the cost of electricity by adding renewable energy sources to the system and evaluation of the overall performance and economic feasibility of the system throughout its lifetime.

In another study, Panhwar et al. (2017) designed off-grid and on-grid renewable energy systems by using HOMER. The purpose was the optimization, calculation of the energy demand, and economic viability of both the systems. The results showed that the on-grid system's net present cost is less; therefore, it was more economical than the off-grid system.

For special application on a farm, Frisk, M. (2017) conducted research and designed a hybrid renewable energy system to supply the energy needed in a milk and meat farm located in Cuba. The simulation and the optimization of the system were carried out by using HOMER software, the sources of energy that are used were solar, wind, and biogas. A couple of scenarios were presented during the study and one of them was electrically and financially effective.

A study by Astatike and Chandrasekar (2019) in Adama, Ethiopia focused on the design and performance analysis of hybrid microgrid power supply systems, and the analysis was done using HOMER software. The system contained a wind turbine, solar PV, and diesel generator as a hybrid combination to supply reliable power for the rural village. After their analysis, they showed that the hybrid combination of wind, solar, and diesel is more reliable and cost-effective than the other available hybrid system combinations.

To meet the electrical load demand of residents, numerous studies have been done. In one of the recent studies, Turkdogan (2021) focused on the design of a hybrid renewable energy system that covers the energy needs of a single-family home. Their electric loads and vehicles like fuel cell EVs powered by hydrogen. The system design and optimization are done by using HOMER. It is ensured that the system consumes zero fossil fuels and emits no greenhouse gases since the energy used by electrical loads and fuel cell electric car was generated using only renewable energies.

Finally, as the latest research points, the use of renewable sources of energy to cover the demand for electricity and at the same time protecting the environment from pollutions became a more significant topic in today’s global energy sector. From that perspective, we are also taking this opportunity to promote the green energy application to fulfill the needs of electricity.

3. OVERVIEW OF MICROGRIDS

3.1. History and Definition of Microgrids

The history of microgrids goes back to 1882 when Thomas Edison constructed a power plant station as a microgrid before establishing a centralized grid. Edison's station had what today's microgrid systems have, except that it was a limited distribution network due to the restriction of DC transmission networks. Today's microgrid system surpasses that. The operation imperfections and limitations of conventional grids like generation unbalance, difficult control of stability, lack of flexibility, vulnerability, extensiveness and complexity of the system, and sometimes lack of reliability for some applications, led the researchers to develop a more reliable and cost-effective system to transmit electricity.

In comparison to the traditional grids, microgrids enable easy access to renewable sources, low transmission losses, less dependence on the grid, lower greenhouse gas emission, lower energy bills, and improved reliability and security of the electric grid.

The word 'microgrid' is composed of two words 'micro' which means very small and 'grid' meaning an electrical network of lines. Therefore, microgrids have all the essential components that a power system has but in a small range.

Definition of U.S. Department of Energy Microgrid Exchange Group: A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid (Ton and Smith, 2012).

According to Kwasinski (2014), microgrids are independently controlled electrical networks that are powered by local distributed generations.

One or more kinds of distributed energy like solar panels, wind turbines, and generators with and without storage system that produce its power (Wood, 2020). Microgrids are localized which means they produce energy for nearby customers, they can operate independently without connecting to the main grid.

According to the definition of Hossain et al. (2019), a microgrid is a controlled small-scale power system that can be operated in an islanded and/or grid-connected mode in a defined area to facilitate the provision of supplementary power and/or maintain a standard service.

In general, microgrids can be divided into three categories, namely: remotely-located microgrid, industrial microgrid, and utility microgrid. We will discuss the classification of microgrids in the following section.

3.2. Classification of Microgrids

Microgrids can be classified according to various aspects. Figure 3.1 shows the most commonly used classifications.

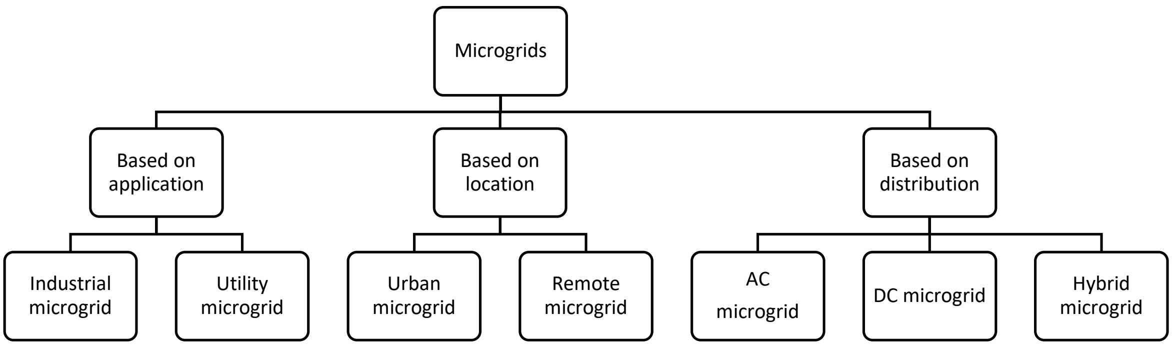

Figure 3.1. Classification of microgrids

Based on the application, we can classify microgrids as industrial and utility microgrids. Industrial microgrids are established near industries for commercial purposes to ensure reliable energy and minimized costs for the site. A utility microgrid is a kind of distribution grid system that supports the main grid during heavy loads. It can be stand-alone or grid-connected. The difference between utility and industrial microgrids is the purpose of application.

On the basis of the place where it is located, microgrids can be classified as urban and remote microgrids. Urban microgrids are those that are located in urban areas and are normally connected to the utility grid. They can be located in both residential and commercial sites such as university campuses, hospitals, data centers, communities, industries, and shopping malls. Remote microgrids are the ones that are constructed in remote areas where the utility grid is not available for geographical reasons. They are used in military, islands, and hilly areas as these microgrids are known as islanded microgrids (Bukar et al., 2019).

According to the system of distribution, microgrids can be classified as AC microgrids, DC microgrids, and Hybrid microgrids.

3.2.1. AC microgrids

AC microgrids use the AC power supply in their distribution network through an AC bus so the energy produced from the AC distribution units can be connected directly to the utility grid without requiring a conversion system, while DC producers require DC/AC inverter for their connection to the AC line. Examples of distribution units that produce AC include wind turbines, hydro, biogas, and tidal. AC distribution system can be sub-classified as single-phase and three-phase with or without neutral point lines (Hossain et al., 2019).

Figure 3.2 shows the configuration of a microgrid using an AC distribution system through an AC bus.

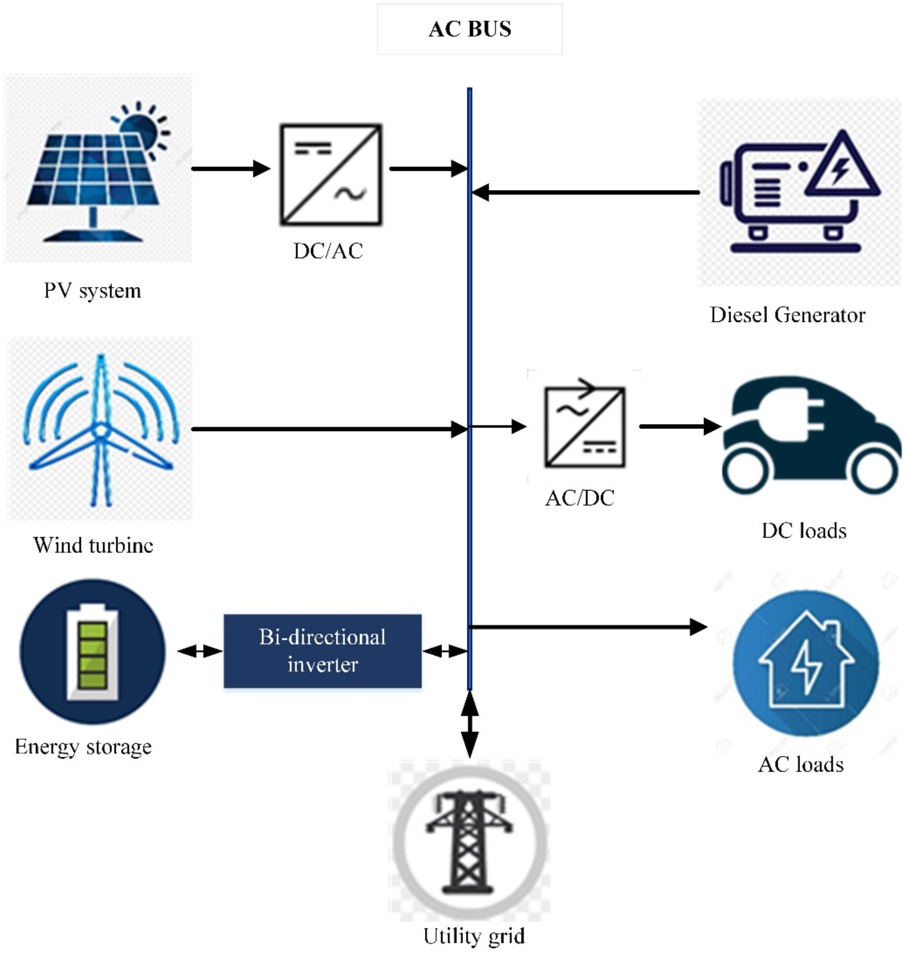

Figure 3.2. AC configuration of microgrids in general

3.2.2. DC microgrids

DC microgrids are those that use the DC power supply in their distribution network via DC bus line so the AC distribution units in the network require AC/DC converter for their connection to the DC network. These kinds of microgrids have higher efficiency and low transmission losses in the application of DC loads. Examples of DC power generators in the microgrid include solar PV and fuel cells. The DC distribution network can be either monopolar, bipolar, or homopolar (Bukar et al., 2019).

Figure 3.3 shows the DC configuration of a microgrid that uses DC distribution through a DC bus.

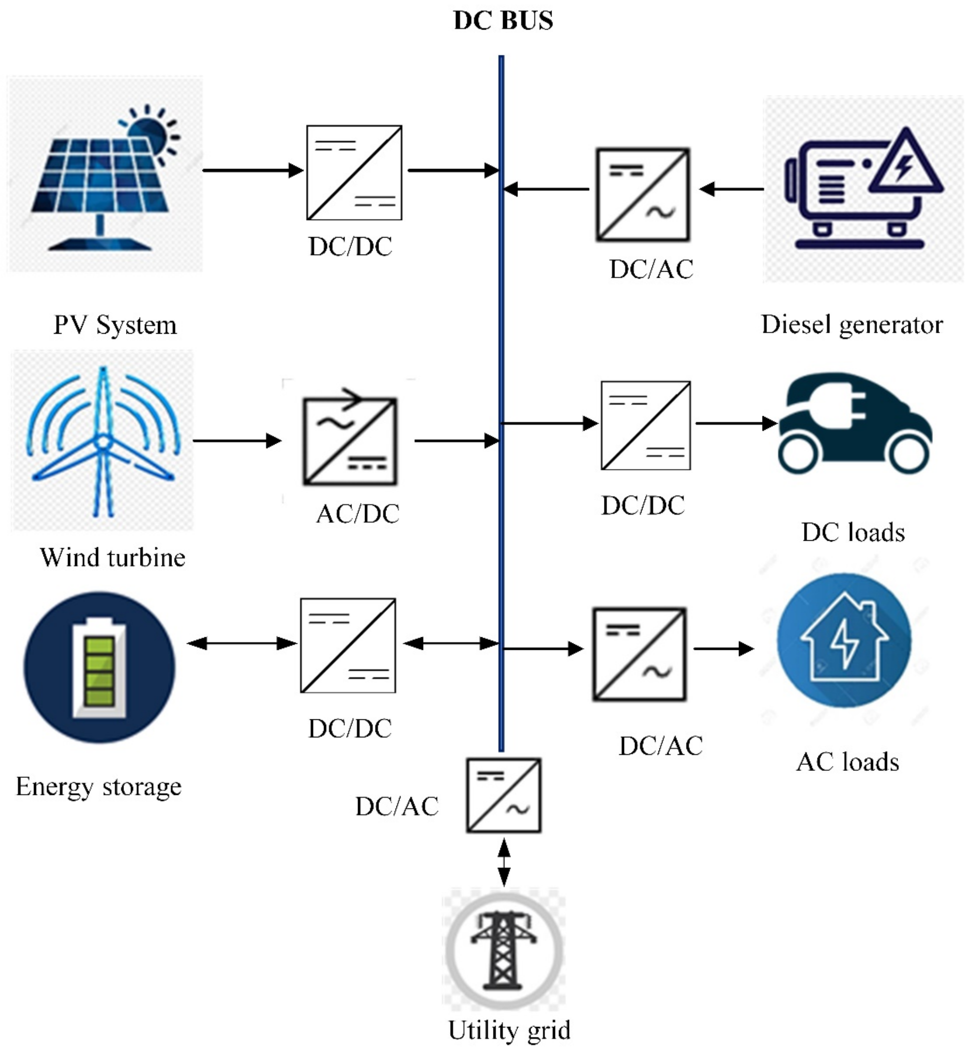

Figure 3.3. DC configuration of microgrids in general

3.2.3. Hybrid microgrids

Hybrid microgrids contain both AC and DC power supply in their distribution networks in the presence of a Microgrid Controller (MC) or what is known as Microgrid Central Controller (MGCC) to control the operation of the microgrid. The purpose of constructing hybrid microgrids is to minimize the number of interface elements, reducing conversion elements and energy losses, therefore, enhancing the overall efficiency of the network (Unamuno and Barrena, 2015). The AC-DC hybrid configuration of microgrids is shown in Figure 3.4.

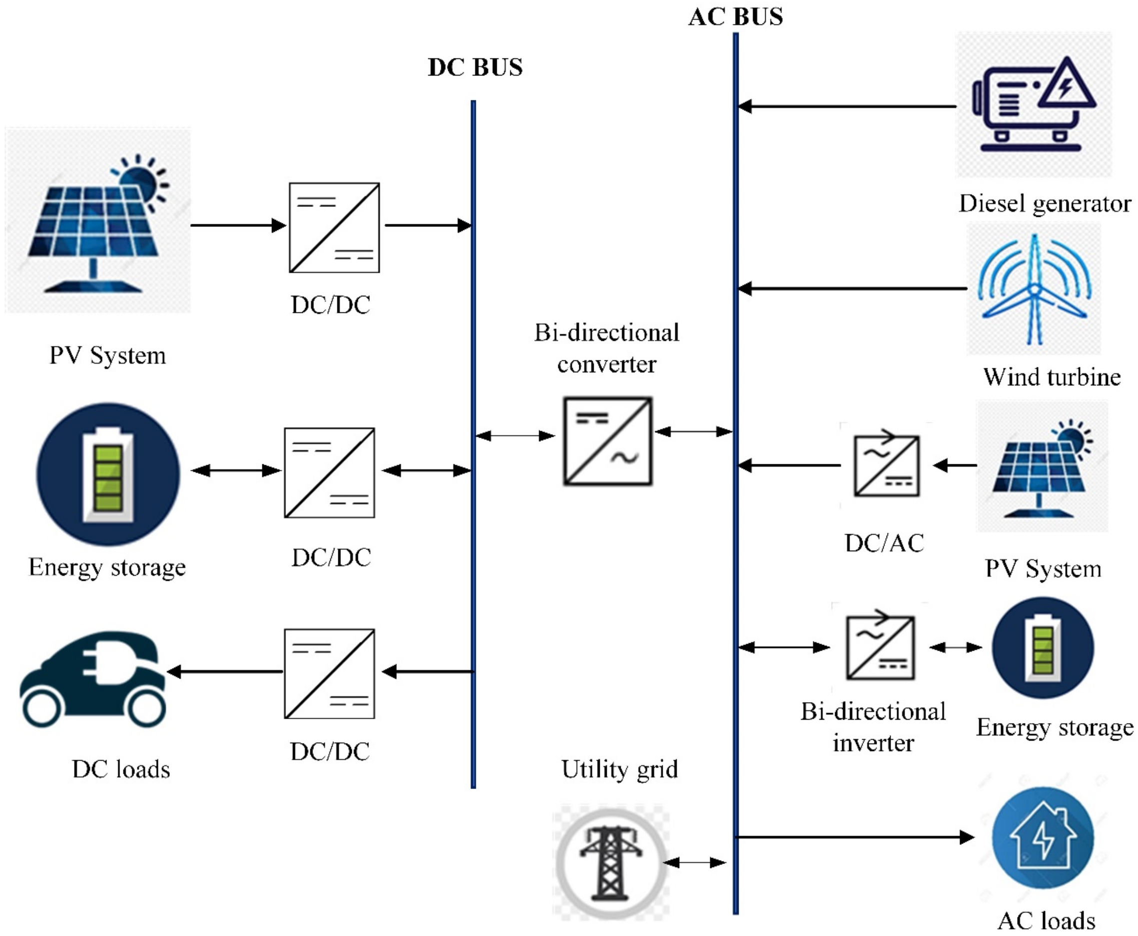

Figure 3.4. AC-DC Hybrid configuration of microgrids in general

3.3. Renewable Energy Sources in Hybrid Microgrids

As their name suggests hybrid microgrids always contain two or more kinds of power generation mixed together with the help of control technology to ensure a proper operation. The idea of using more than one source of energy is to improve the performance and reliability of the system and to fulfill the end-user requirements. Using this system will reduce the impact of time-variation during day and night when dealing with renewable energies.

There are several combinations of energy sources available today to be used as a hybrid system such as wind-solar hybrid, solar-diesel hybrid, wind-hydro hybrid, and wind-diesel hybrid. There are many factors that must be taken into consideration for choosing a proper hybrid technology. The most important ones are the availability of the source and the cost of installation. Also, accessibility to the grid and backup of energy is important for the effective choice of a hybrid system. When using renewable energies as a source of energy, factors like weather and seasonal variations may affect the system efficiency, so calculations and observations related to the preferred system are always necessary.

In this design, solar and wind energy were chosen as renewable sources of energy. Both technologies are becoming popular these days in the electricity production industry. Solar photovoltaics and wind turbines are available widely and less expensive compared to their alternatives. By considering the current location and the resources that we have, we will briefly discuss the renewable sources solar PV and wind.

3.3.1. Solar energy

Energy is one of the most important things in human life. There are numerous sources that we can find energy directly or indirectly. The most prominent source of energy that we have is the sun. The energy we receive from the sun exceeds our demand that we can use it for various purposes like heating and converting to electricity.

Energy from the sun reaches the earth in the form of radiation. The amount of radiation that a given location receives is dependent on the factors like weather, seasonal variation, the scope of the land, and the location itself.

Turkey has a great geographical location suitable for the harvest of solar energy. The annual average solar radiation is 3.6 kWh / (m^2 day) and the total annual insulation period is approximately 2460 hours (Balat, 2005). According to Table 2.1, sunshine and solar energy reach the highest levels in the months of June, July, and August (Yelman, 2018).

Table 3.1. Turkey’s solar energy potential by months (Yelman, 2018)

Months	**Monthly total solar energy (kWh/m^2-month)**	**Hours of sunshine (hour/month)**
January	51.75	103
February	63.27	115
March	96.65	165
April	122.23	197
May	153.86	273
June	168.75	325
July	175.38	365
August	158.4	343
September	123.28	280
October	89.9	214
November	60.82	157
December	46.87	103
Total	1,311	2,640
Average	3.6 kWh/m^2-day	7.2 h/day

3.3.1.1. Photovoltaics (PV)

The technology that is used to convert sunlight directly into electricity is known as photovoltaics. The photovoltaic collector panels contain solar cells which are made from semiconductor material like silicon. There are many types of solar cells used today, and most of them contain silicon wafers.

Recently there is an enhancement towards the efficiency of PV cells as researchers develop new technologies of photovoltaics. They worked both the materials involved in solar cells and device configuration from laboratory scale to commercial-scale devices with cost-efficiency.

Figure 3.3 shows the classification of PV technologies as first generation, second generation, and third-generation based on today’s commercially available photovoltaic solar cells technology.

- The first generation is known as crystalline silicon solar cells since they were made from silicon. Their average efficiency is 20%. Pure silicon is needed to manufacture these cells that may result in a high cost of production. Crystalline silicon solar cells are divided into two subgroups: monocrystalline and multi-crystalline silicon cells.

- Second-generation solar cells are known as thin-film solar cells. Their cost is lower compared to the first generation but their efficiency is lower, too. The advantages of thin-film solar cells over silicon solar cells are low-temperature processing techniques, less material is used, variety of deposition process, and its compatibility with low-cost substrates (Chopra, K.L., et al., 2004). Examples of second-generation PV technologies are Cadmium Telluride solar cells, amorphous solar cells, and Copper Indium Gallium Selenide solar cells.
- Third-generation solar cells are developed to increase the electrical performance of the second generation. The multi-junction cells are hard to produce, so these cells are costly. They are used with concentrator lenses. Their current efficiencies are around 30%. The cells can be compared according to their cost per watt of electricity they produce. In that sense, the multi-junction cells can be the most economical action. The goals of third-generation solar cells are ultra-high efficiency cells and to promote thin-film solar cells that use novel approaches to obtain efficiencies in the range of 30%–60% (Amin et al., 2017).

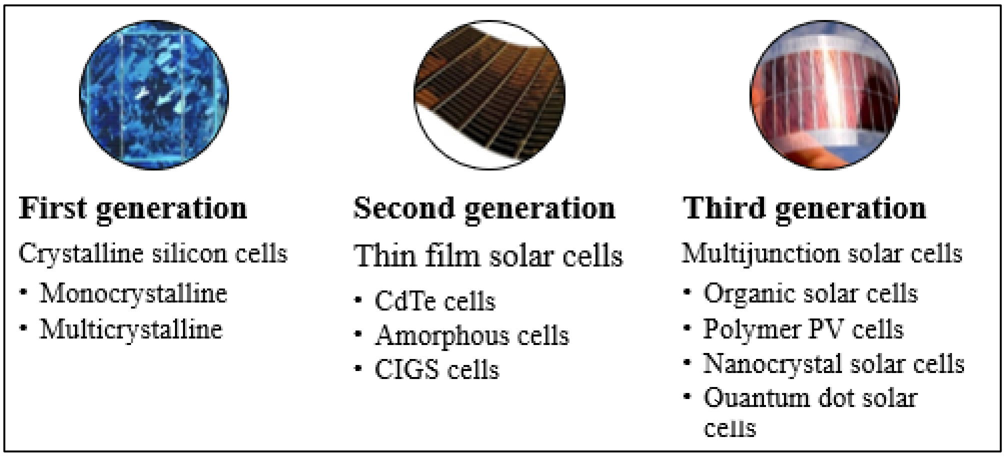

Figure 3.5. Classification of PV technology

To generate electricity, a number of solar cells are connected in series to form a photovoltaic module which can then be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity and can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination

(European communities, 2009). The direct current produced from the PV system is converted into alternating current by using an inverter when grid connection is required.

3.3.2. Wind energy

The energy that is produced when air flows in the atmosphere is called wind energy. It is one of the most important renewable energies that we have. It provides clean energy that can be used as an alternative source of energy. Wind energy resources are available naturally although different geographical regions have different wind energy potential.

Turkey's geographical location offers an extensive wind energy potential which makes the country to be in the first positions in the list of countries having the wind energy potential. Table 3.2 shows the annual average wind speed and the annual average wind energy potential of various regions of Turkey.

Table 3.2 Wind potential at various regions of Turkey (Togrul, I. and Ertekin, C., 2011)

Region	**Annual average wind speed** (m/s)	**Annual average wind density** (m/s)
Marmara	3.3	51.9
Southeast Anatolia	2.7	29.3
Aegean	2.6	23.5
Mediterranean	2.5	21.4
Black Sea	2.4	21.3
Central Anatolia	2.5	20.1
East Anatolia	2.1	13.2
Turkey average	2.5	24.0

According to the table, East Anatolia has the lowest potential wind speed which is 2.1 m/s while Marmara has the highest average wind speed at 3.3 m/s making this region the most attractive region for wind energy application among the regions in Turkey.

3.3.2.1. Wind turbines

A wind turbine converts the kinetic energy of the wind into mechanical energy and then to electricity. The output of the turbine is used as an input of a generator to generate electricity. This overall system is also known as wind energy conversion system and it consists of three parts: aerodynamics, mechanical part, and electrical part.

3.3.2.2. Types of wind turbines

Based on the alignment of the axis of rotation, wind turbines are grouped into two categories Horizontal and Vertical Axis wind turbines. Horizontal Axis Wind Turbines (HAWTs) are more common than the Vertical Axis Wind Turbines (VAWTs) in usage, but VAWTs have also many advantages when compared to HAWTs.

As an advantage of VAWTs over HAWTs, VAWTs don't need a yaw mechanism since they can harness the wind from all directions. Also, VAWTs can be installed very close together inside the wind farms. This allows more in any space. They are quiet, omnidirectional, and they also generate lower forces on the support structure (Saad and Magedi, 2014).

Both of them are used in wind farms for different objectives. Horizontal Axis Wind Turbines are used in places with high wind speeds while Vertical Axis Wind Turbines are used for areas with low wind speeds. Figure 3.6 shows the horizontal and vertical axis of wind turbines.

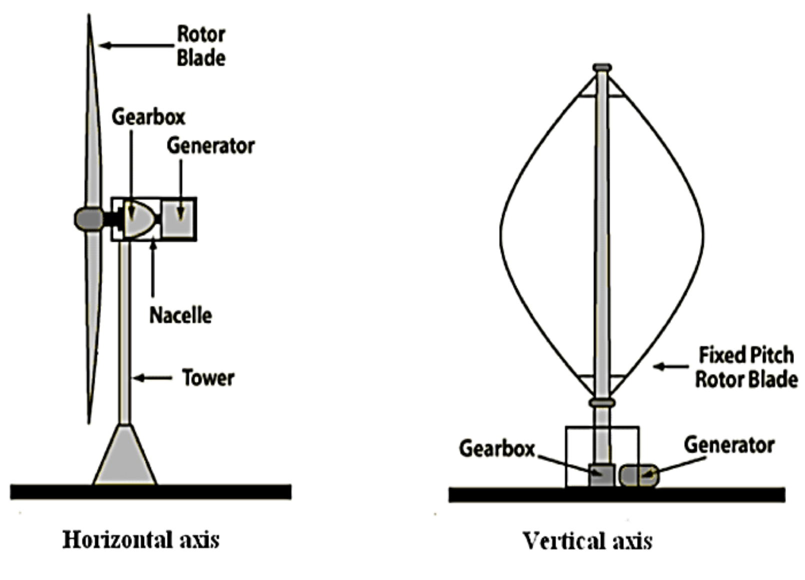

Figure 3.6. Horizontal and vertical axis of wind turbines (Al-Kharbosy, 2012)

3.3.2.3. Components of wind turbines

The following are the main parts of Wind Turbines: The blades rotate when wind occurs over them making the rotor spin. The nacelle includes all the main components of the turbine, like the gearbox and yaw system. The rotor hub transfers the rotational energy to the rotor shaft. The gearbox converts the low-speed, high-torque rotation of the rotor to high-speed rotation with low-torque for input to the generator. The generator converts the mechanical energy from the rotor to electrical energy providing AC. The controller monitors the turbine and collects information. Anemometer and wind vane are also attached to the controller to measure wind speed and wind direction. The tower holds the turbine. The transformers transform the electricity from the generator to meet the requirements of the grid (Schinke, B., et al., 2017)

3.3.2.4. Weibull distribution

To find accurate data and reliable information about the feasibility of wind energy resources, it is necessary to choose a method for calculating wind speed or wind power density. The most common methods that are used to find the wind resource information are probability distribution systems like Weibull distribution and other similar probability distribution functions. Weibull distribution is the most commonly used method, and it uses a frequency distribution function to calculate the wind power density. The Weibull function fits the wind probability distribution more accurately compared to other methods (Ouarda et al., 2015). Figure 3.7 shows an example of a histogram and Weibull distribution of wind speeds.

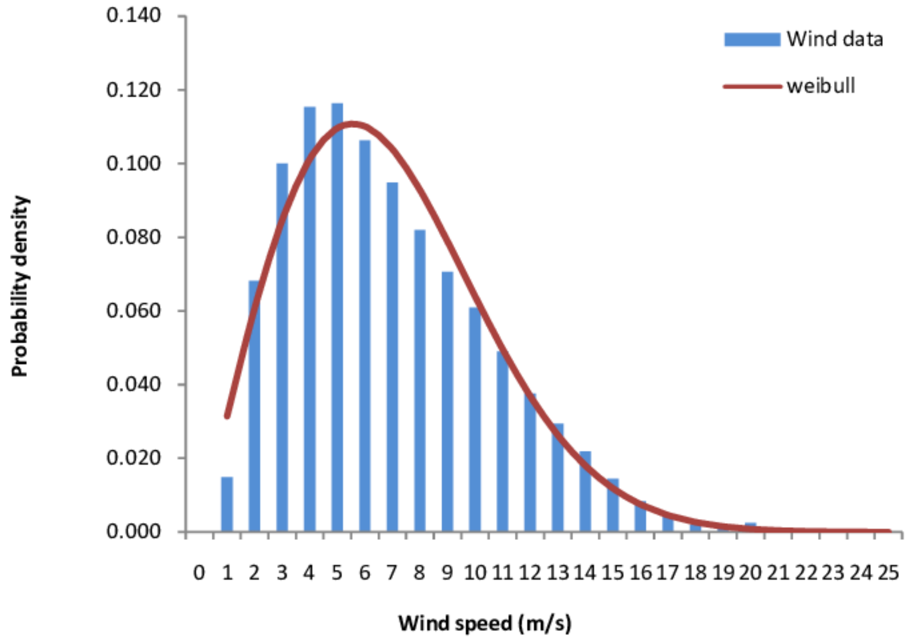

Figure 3.7. Histogram and Weibull distribution of wind speed (Fouad et al., 2015)

4. DESIGN METHODOLOGY OF THE PROPOSED SYSTEM

The design of the hybrid microgrid is complex, and a careful procedure is required for an efficient system. This is due to the different renewable energy sources available in the system and the necessity of both energy conversion and storage. These factors lead to the complexity of the design. Several methodologies and phases are required to obtain an optimal design for the microgrid.

In this section, the design and optimization of the microgrid are presented. The various EV charging strategies are proposed. Also, a software tool for simulation and optimization of the hybrid microgrid is determined.

4.1. Optimal Design of the Hybrid Microgrid

For optimal design of the hybrid microgrid systems, three important phases are included in the design procedure. These are the classification of hybrid renewable energy systems, identifying the evaluation criteria, and selecting the optimization methods (Çetinbaş, 2020). Figure 4.1 shows the design procedure for optimal hybrid microgrid design.

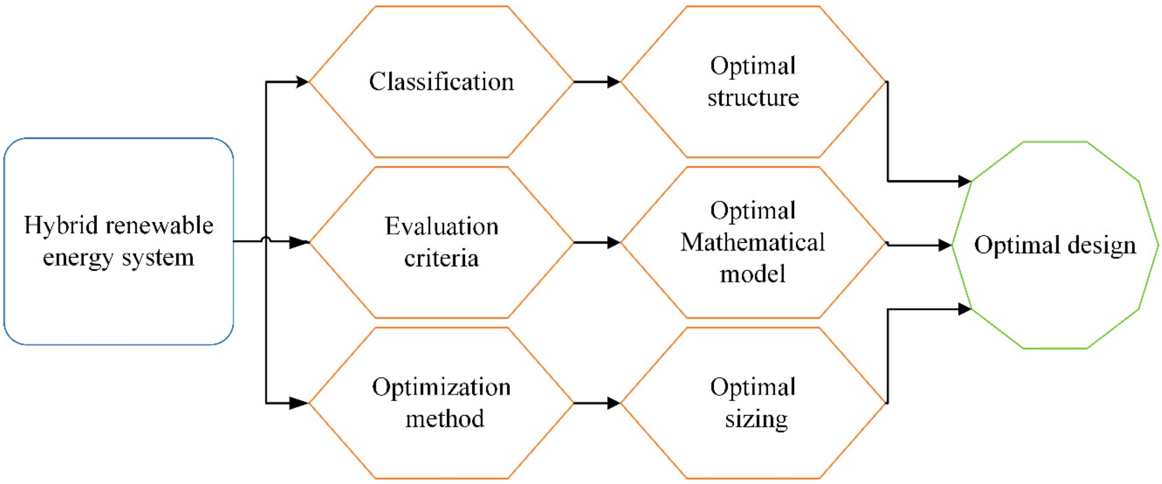

Figure 4.1. Design procedure for optimal hybrid microgrid design

4.2. Evaluation Criteria for Hybrid Microgrid Systems

For optimal design of the system, determining the evaluation criteria is one of the most important phases in the design procedure. In this phase, social, economic, and technical assessment must be done in order to create a relation between optimal response and feasible implementation regarding the reality of the microgrid configuration (Santos et al., 2018).

These factors play an important role in determining the mathematical model of the system to be designed. The social assessment reflects the improvement in the quality of electrification in society, community services, impact on local resources, and clean energy. The economic assessment reflects the initial investment, operation, and maintenance cost. The technical assessment reflects the reliability of the used energy resources and autonomy of the batteries as well as system reliability in the event of failures (Santos et al., 2018).

4.3. Optimization Methods

In every design, a proper optimization method is necessary because optimization provides economic and reliable usage of the resources that are available. Since microgrid systems integrate a large number of distributed generations, proper planning of the design and its optimization techniques must be figured out.

There are so many techniques used in the optimization of microgrids. These may be computational techniques that are based on mathematics and algorithms or other conventional methods. Some of the researchers propose different methodologies that determine the optimum sizing and configuration of hybrid microgrids by ensuring the minimum cost and reliability of the system. They base their analyses on simulation techniques.

Some of these mathematical programming methods used for optimization are nowadays implemented by software tools. Some of these tools and computational optimization techniques for microgrids are presented in by Gamarra, C. and Guerrero, J. M. (2015).

4.3.1. HOMER software

Hybrid systems are complex in terms of construction and management; they require additional tools to be optimized, analyzed, or managed. HOMER is the abbreviation of Hybrid Optimization of Multiple Energy Resources, and as its name suggests, it is an application software designed for the optimization of hybrid sources. It is used in the design of off-grid and on-grid for remote, stand-alone, and distributed generation power systems as well as their technical and financial evaluation (Kassam, 2010). HOMER was first developed in 1993, and today it is one of the most frequently used optimization software. It converges many different sources of energy whether it is traditional or renewable sources into one place and then automatically analyses by converting it into optimized data that can be used for decision making or investment purposes.

The process of the design in HOMER consists of three stages. The first stage is the simulation of the resources obtained; the second is the optimization; and the third, sensitivity analysis.

4.3.1.1. Simulation

In the simulation stage, the configuration of different components, resources, electrical loads, and constraints of the system is decided; sizing and the combination of the system components are selected so that the energy balance for each hour can be calculated. The electricity and thermal energy demand per hour are compared to the energy the system can provide in that hour. The energy flow from all the elements in the system is calculated, and the system configurations are considered to be feasible if it appropriately meets the electric and thermal load demands and satisfies all technical constraints of the system (Frisk, M., 2017)

The most important thing in this stage is that the technical analysis and the cost of the micro-power systems are evaluated; i.e., the total cost of operation and installation of the system in the lifetime is estimated. That is one of HOMER’s capabilities.

4.3.1.2. Optimization

After simulating all possible combinations of the system configuration, the optimal solution is obtained by choosing the best possible configuration. This is based on the Total Net Present Cost (TNPC). A list is displayed and sorted by considering the Net Present Cost. In the NPC, all costs and revenues of the system's lifetime including initial capital, operation and maintenance cost, component replacement, and fuel cost are calculated. HOMER calculates these values and displays the value in a table from the lowest possible NPC to the highest.

NPC is calculated as follow:

$$NPC = \sum_{t=0}^{T} C_{cap,t} + C_{om,t} + C_{rep,t} + C_{fuel,t} - (R_{s,t} + R_{g,t}) \quad (4.1)$$

In the formula, T represents the lifetime of the system or the project. $C_{cap,\,t}$ is the capital cost of the system in year t. $C_{om,\,t}$ is the cost of maintenance and operation in year t. $C_{rep,\,t}$ is the cost of replacement of components in year t. $C_{fuel,\,t}$ represents the cost of the fuel in year t. While $R_{s,\,t}$ and $R_{g,\,t}$ are revenue from salvage and grid respectively in year t.

These values are simulated in hourly time series and HOMER finds the optimal solution where the system meets all the energy demands with the least value of Net Present Cost.

HOMER also calculates the Levelized Cost of Energy (COE) for each of the optimized systems and gives the opportunity to select one's favorite system based on the cost of energy. CEO is the representation of the average cost of electric production of each kWh of the system, like the net present cost (NPC) the cost of energy (COE) also calculates the overall cost of the system's lifetime.

COE is calculated as follow:

$$COE = \frac{C_{tot}}{E_{tot.load}} \quad (4.2)$$

C_{tot} represents the total cost of the system per year, and $E_{tot. load}$ is the total electrical load served in the year. Therefore, COE is the ratio of the total cost of production to the total load.

4.3.1.3. Sensitivity analysis

HOMER carries out this stage of sensitivity analysis to show the variables and uncertainties that cannot be controlled by the designer in the long run. Sensitivity analysis can be done by entering multiple values for a particular input variable and HOMER shows how the results are affected by repeating its optimization process for each value of the variable (HOMER, 2021).

In the HOMER sensitivity analysis, for each of the uncertain variables, the overall system is simulated. This will give different parameters for technical characteristics and cost. Likewise, for each of the sensitivity variables, the overall system is simulated by giving technical and cost parameters, and a final solution is found where the system can meet the total demand (Frisk, M., 2017).

HOMER grid is used for this design and optimization process, homer grid is a new version of the homer software that enables you to design behind-the-meter, grid-connected, and distributed systems, it also adds the possibility of adding EVs to the system which was not available in the earlier versions of HOMER, so that we can minimize the cost of EV charging.

5. STRUCTURE AND COMPONENTS OF THE PROPOSED SYSTEM

The proposed system contains wind and solar as hybrid sources of energy, a converter, battery energy storage system, EVs, grid, and primary loads. Wind turbines produce AC power, so they are connected to the AC line without using an inverter. PV arrays generate DC power, and it is connected to the DC line by using a controller. When the energy produced from the renewable sources is not enough or the demand is higher than the supply, an energy storage system is used as a backup to provide the rest of the needed energy, and it is connected to the DC line through a converter to feed the line or take from it. A bi-directional converter is also used to implement a power conversion between the AC and the DC lines. The extra power after the battery is fully charged will be sold to the grid. EVs are also part of the system and it will be considered as a load. Power supplied from the AC line will be used to charge the EVs. Not only EVs but also primary loads will be fed from the AC line.

Figure 5.1 shows the schematic of the proposed method and the components used in the design.

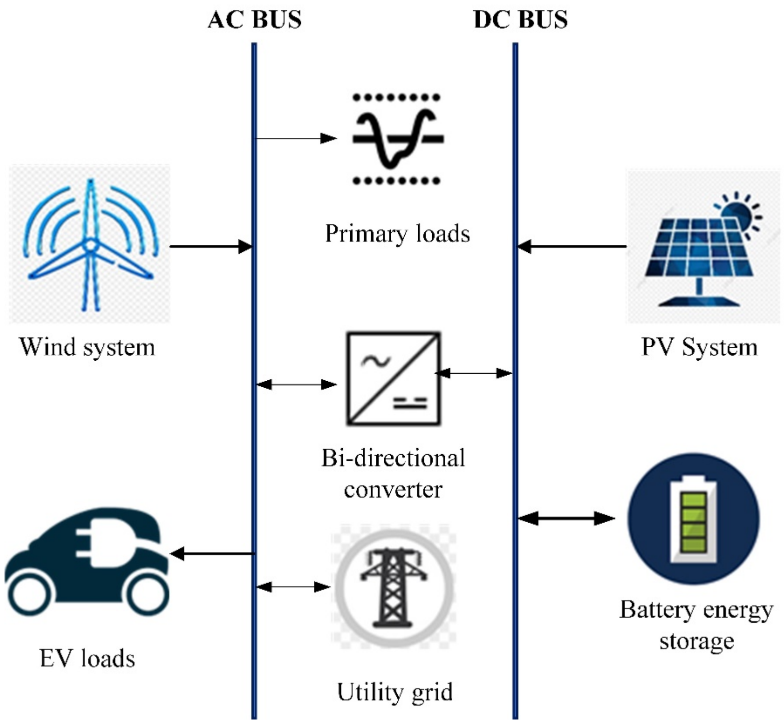

Figure 5.1. Structure of the proposed microgrid system

5.1. The Primary Load

The load profile of the primary load is illustrated in Figure 5.2. The input data is the average load of one-year electric consumption presented as the hourly load average of each month. The data used in this thesis belongs to the Eskisehir Osmangazi University campus, and it is a total load of one-year electric consumption of the campus in one hour range of the daily electric usage. HOMER provides a different pattern of a load profile: daily profile which is an hourly pattern of daily electric usage, yearly profile which is presented as hourly load average for each month of the year, and seasonal profile which provides the seasonal electric demand as monthly.

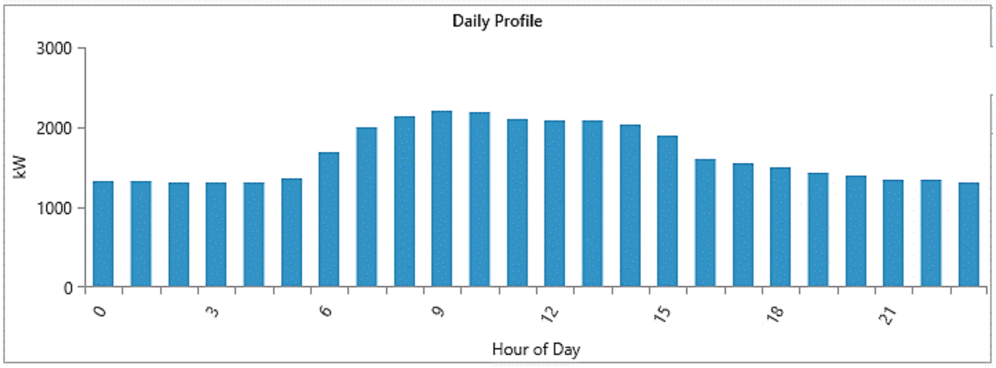

Figure 5.2. Daily electrical load profile

The annual average energy consumption per day is 49,286 kWh and the average power is 2,053.6 kW. The peak power is 4,552.2 kW and the load factor is 0.45. To deeply understand the load profile, also the seasonal profile is presented in Figure 5.3 so that the average electric demand of each month and the peak ones can be seen clearly.

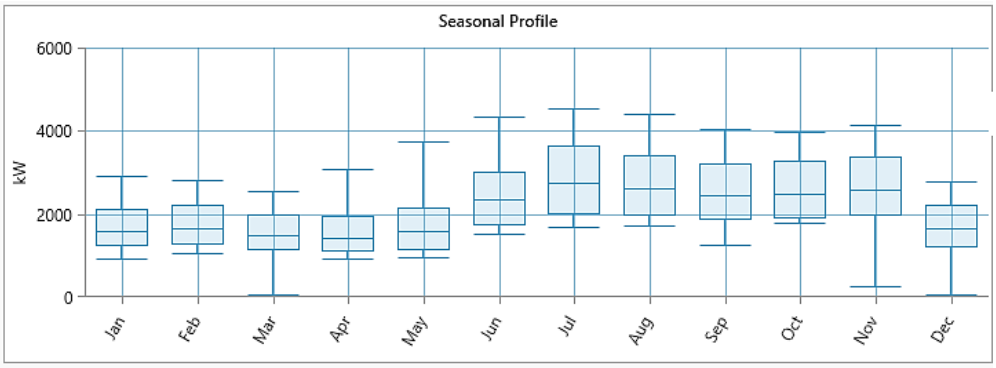

Figure 5.3. Seasonal load profile

5.2. PV System

HOMER needs some necessary variables when modeling or sizing a certain component. These variables include the number of components, their capacity (usually kilowatts or quantity), capital cost, operation, and maintenance cost, and replacement cost. There may be other variables or factors that must be taken into consideration like efficiency, component lifetime, or the effect that some variables may have on each other.

In this model, the size of the PV array is important. Once the peak demand of the load is known, the next step is deciding the PV size. This depends on the fraction of the solar production in our system since hybrid sources are available in the design. Availability and the capital cost of generation units in the system are what make that part have more percentage than others in the production of the energy. Solar generation is one of the best alternatives of renewable sources of energy in terms of cost and availability; therefore, approximately 32% of the production in our system will be from the PV.

There is an approximate installation cost of 500,000-550,000 USD for a 1 MW solar system in Turkey. A 1 MW system generates an annual average of 1,400,000 kWh of electrical energy (Canbul, 2021). From that perspective, installing a 5MW solar system will cost approximately 2,500,000 USD to 2,750,000 USD. The operation and maintenance cost will also around 6,000 USD to 7,500 USD. The panel life is set to be 25 years with an efficiency of 13%. If we consider the Generic flat plate type PV, a de-rating factor of 80% is also applied to the PV power output to account for reduced output in real-world operating conditions which may not exactly equal the panel ratings. The economic inputs of the PV array are presented in Table 5.1.

Table 5.1. PV array cost inputs

Capacity (kW)	**Capital cost** ($)	**Replacement cost** ($)	**O&M cost** ($)	**Lifetime** (Years)
5,000	2,750,000	2,750,000	7,500	25

5.2.1. Solar resource

Solar resources are the solar global horizontal irradiance of the location of interest. Via HOMER it is possible to download the desired resource data from the NASA prediction of the worldwide energy resource database. NASA provides monthly averaged data for solar global horizontal radiation over a 22-year period for the given location. The resource data that is used belongs to the Eskisehir Osmangazi University located in Eskisehir city of Turkey, the information of the resource data location is as follow:

Latitude: 39°45.1' N

Longitude: 30°29.0' E

Time Zone: GMT/UTC+3:00

In Table 5.2 the Solar Global Horizontal Irradiance (GHI) data of the studied area is presented.

Table 5.2. Monthly average global horizontal radiation data of one year for Eskisehir

Month	**Clearness index**	**Daily radiation** ($Kwh/m^2/day$)
Jan	0.441	1.890
Feb	0.465	2.640
Mar	0.499	3.820
Apr	0.479	4.620
May	0.536	5.910
Jun	0.587	6.800
Jul	0.626	7.060
Aug	0.619	6.270
Sep	0.605	5.030
Oct	0.538	3.360
Nov	0.480	2.200
Dec	0.404	1.560

The scaled annual average (kWh/m^2 /day) of the studied area is found to be 4.26. Figure 5.4 illustrates the daily insolation of solar irradiance as well as the clearness index of one year.

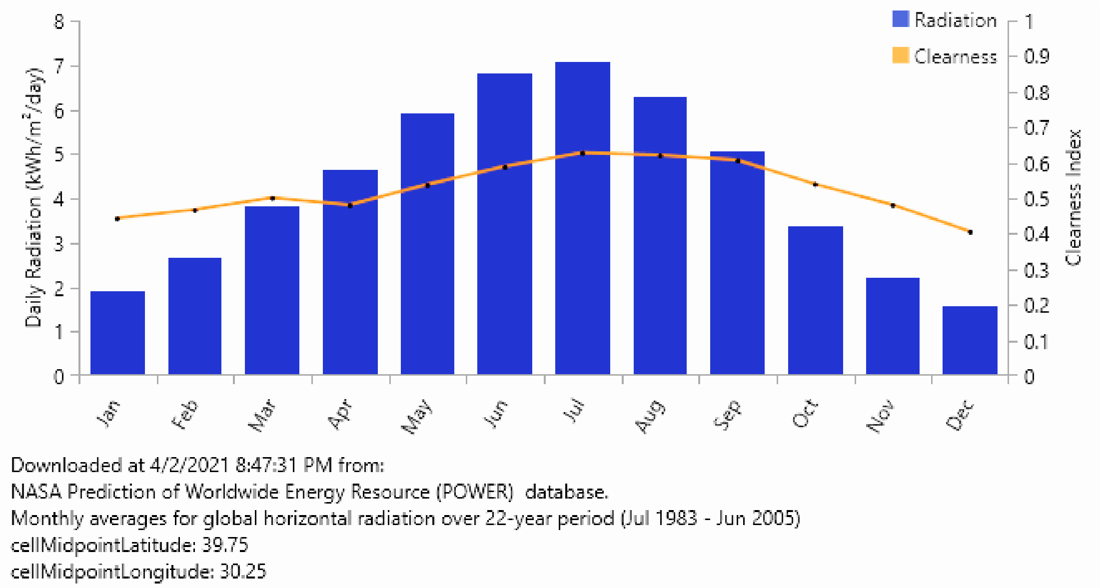

Figure 5.4. Solar daily radiation and clearness of the studied area

There are also advanced options that HOMER allows which can be applied to the PV array. Temperature effects can also be considered as a factor. PV array production can be increased using the Maximum Power Point Tracking System also the converter load capacity can be sized by deciding the PV/converter ratio, in our system the PV/converter ratio is 1.

The panel orientations like panel slope and azimuth are decided by HOMER as a default, the ground reflectance is 22%. If we consider the temperature effect by using ambient temperature defined in the temperature resource the following information is found:

Temperature effects on power (%/°C): -0.5

Nominal operating cell temperature (°C): 47 °C

Efficiency at Standard Test Condition (%): 13%

5.3. Wind System

As part of power hybrid resources, the wind turbine will also take an important role in the generation of electricity in the modeled system. Wind turbines are also available in a wide variety like solar panels but a little bit expensive than solar; therefore, we limited the percentage of the wind generation approximately to 20% in our production system.

In Turkey, a 1MW wind energy system costs approximately a 1.2 million Euro which is around 1.4 million USD (Güngör, 2017). Globally, it's $2.6 – $4 million per average-sized commercial wind turbine. The typical cost is $1.3 million per megawatt (MW) of electricity-producing capacity (Blewett, 2020). In this design, Enercon E-82 E2 2MW wind turbine is used. The hub height is 85 m, and the rotor diameter is 82 m. The cost is presented in Table 5.3.

Table 5.3. Wind turbine cost inputs

Capacity (kW)	**Capital cost** ($)	**Replacement cost** ($)	**O&M cost** ($)	**Lifetime** (Years)
2,000	3,000,000	3,000,000	30,000	20

5.3.1. Wind resource

The wind resource data that HOMER provides is also a NASA prediction of the worldwide energy resource database. After downloading the resources, HOMER displays a monthly averaged daily wind speed (m/s) based on the location of the project. The data given by NASA is a monthly average wind speed at 50m above the surface of the earth over a thirty-year period. In Table 5.4 the monthly average wind speed data of the studied area is presented.

Table 5.4. Monthly average wind speed data of one year for Eskisehir

Month	**Average** (m/s)
Jan	4.960
Feb	5.290
Mar	5.000
Apr	4.570
May	4.040
Jun	4.130
Jul	4.450
Aug	4.240
Sep	3.950
Oct	4.150
Nov	4.690
Dec	5.040

The annual average speed (m/s) of the studied area is found to be 4.54 m/s, the other parameters like altitude above sea level and anemometer height are given as 0 m and 10 m respectively. Some of the advanced parameters are also given as follow: Weibull k: 2

1hr. autocorrelation factor: 0.85

Diurnal pattern strength: 0.25

Hour of peak wind speed: 15

Figure 5.5 illustrates the average wind speed (m/s) of one year based on the longitude (30.25 $^{\circ}$E) degree E and the latitude (39.75 $^{\circ}$N) degree N of the studied area.

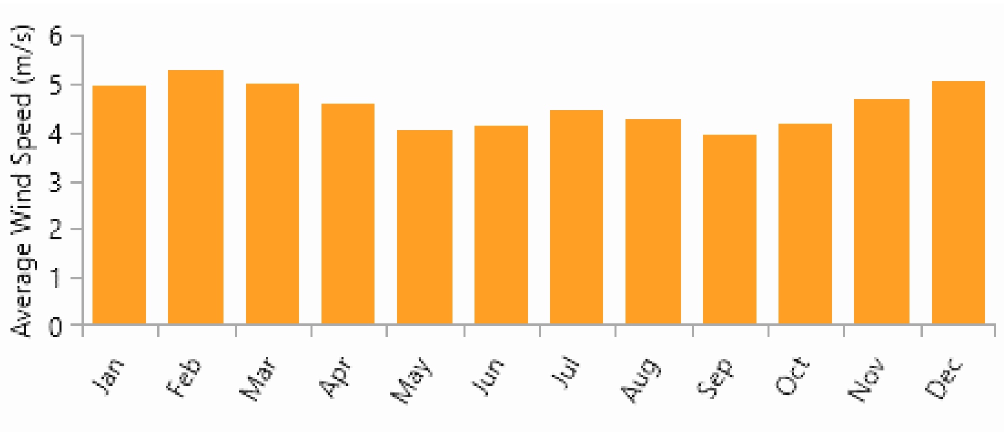

Figure 5.5. Average wind speed of the studied area

The wind turbine power curve is presented in Figure 5.6. In the figure, the relation between the wind power output and the wind speed is plotted.

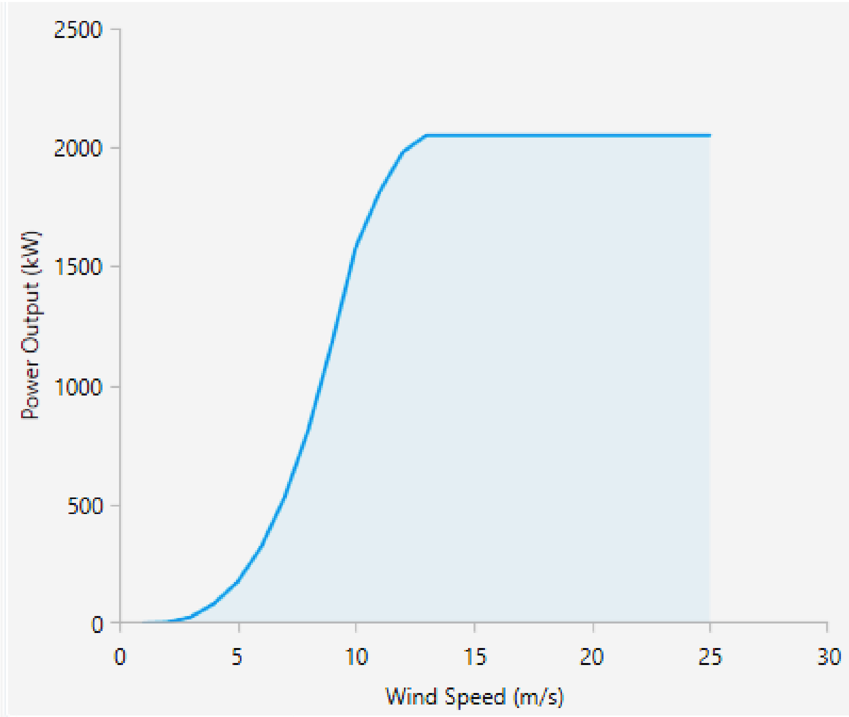

Figure 5.6. Wind power curve

5.4. Battery Energy Storage System

Battery Energy Storage System is necessary for such complicated energy generation systems. In this model, the type and the size of the battery are needed. The software that is used provides various battery types as well as a range of battery capacities. The one with the suitable characteristics for this system will be chosen. HOMER optimizes the battery after choosing which kind of battery is needed, the designer can also size its own battery by giving a search space from the dropdown menu. In our design, we will let HOMER optimize the orientation and the string number for us after choosing the battery type and its capacity.

The type of battery that is chosen is a Generic 1MWh Li-ion with a nominal voltage of 600V and a capacity of 1,670Ah, the efficiency is 90% and the maximum charge current is 1,670A. The economics of the battery that is chosen for the system is presented in Table 5.5.

Table 5.5. Battery cost inputs

Component	**Capital cost** ($)	**Replacement cost** ($)	**O&M cost** ($)	**Lifetime** (Years)
Generic 1MWh Li-ion	700,000	700,000	10,000	15

5.5. EV Loads and Charging Stations

EVs are also part of our system design, and we are aiming to attract EV users and give them an opportunity to charge their vehicles with our grid. To let that happen, we tried to find the most comfortable charging options that can be attractive to the customers in the interest area and provide them different alternative charging methods.

HOMER provides various EV charging options, and one can choose the most suitable form of charging according to its capability. It will also let modeling the desired EV models as well as their charge power inputs. The model also includes the number of chargers and charge sessions which can be sized as desired. The EV charging options that we would like to add to our design are also allowed by HOMER. These options are an on-demand EV charger and a deferrable EV charger. These two options will give more chances to our potential users. It can also become an interesting and modern way of charging their devices at a low price.

The estimated EV load on the campus is 1,089 kWh/day avg. for on-demand EV charger and 868 kWh/day avg. for deferrable or Smart EV charger. This may not be the actual load of total EVs on the campus. It is the estimated daily profile load of EV models that are uploaded to the HOMER. After sizing the charge station, HOMER automatically calculates the load of the given models and gives a daily or annual chart of these loads. Figure 5.7 and Figure 5.8 shows the EV loads.

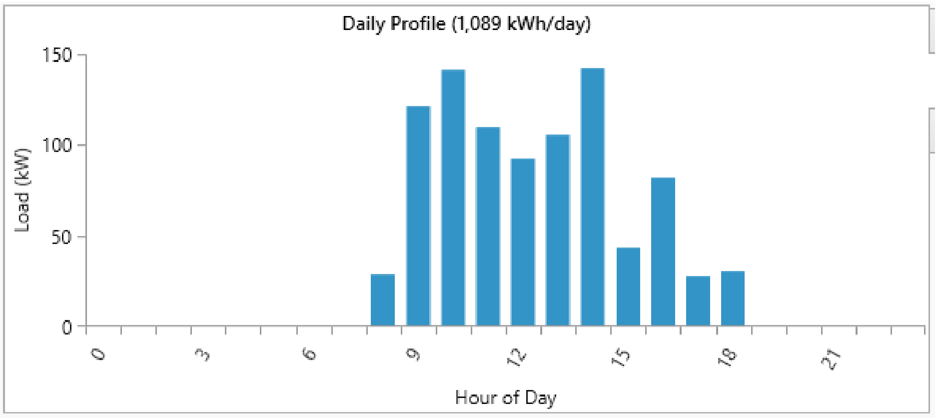

Figure 5.7. On-demand EV load

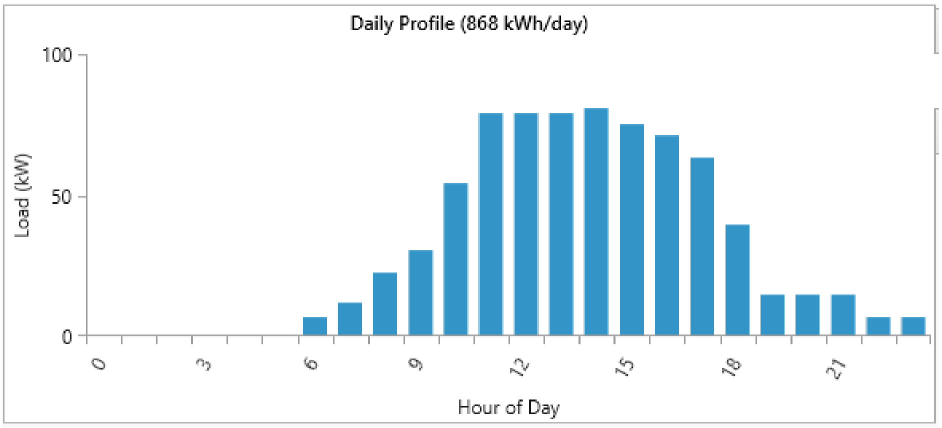

Figure 5.8. Deferrable EV load

5.5.1. EV charge station modeling

In this thesis, two different EV battery charging strategies are applied. These are deferrable EV charging and on-demand EV charging. Using these two charging strategies, a scenario is created by picking some of the most frequently used EV models in the studied area. 5 different models were used in this study. A total of 500 vehicles were used and each of the selected vehicles represents 20% of the total population. After that, an hourly profile of each month is created by typing the number of visits per charge station during hours of the day. HOMER allows specifying some features when modeling charging stations. Table 5.6 shows Specifications of deferrable and on-demand EV chargers from HOMER

Table 5.6. On-demand and deferrable EV chargers specification

Variable	Description
Charger output power (kW)	The output of kW per charger
Meantime connected (hr.)	The mean amount of time in hours the vehicle is connected to the charging station
Number of chargers	The number of chargers at the charging station
Scaled Avg. Session/day	The average number of vehicle charging sessions per day

5.5.1.1. Deferrable EV charger

The deferrable EV Charging strategy allows users to optimize their charging stations and have some flexibility when the EV load is served (HOMER Energy, 2017). As its name suggests, deferrable means to postpone or delay something to a later time. It allows users to prioritize the use of renewable power by scheduling charging to take advantage of grid electricity when it is at its lowest cost. It is also known as the smart station mode since it models the intelligent charging of cars to minimize cost. The maximum allowed charging power for the smart charger in the HOMER Grid is 22 kW per charging station. Smart charging is a way of optimizing the charging process conferring to the distribution grid constraints availability of renewable energy source and customer preferences (IRENA, 2019).

Table 5.7 presents the input data of the deferrable EV charger. The charger output power is 22 kW with 10 chargers. The mean time connected is 8 hr., and the average sessions/day is 20.

Table 5.7. Deferrable charger input data

Name	Percentage of EV Population	Maximum Charging Power per EV	Average Charging Duration	Average Required Energy
Jaguar I-Pace	20.0 %	16.5 kW	10 hrs	90.0 kWh
Renault Zoe	20.0 %	22.0 kW	3 hrs	52.0 kWh
BMW i3	20.0 %	11.0 kW	4.5 hrs	43.0 kWh
Mercedes EQC 400 4MATIC	20.0 %	11.0 kW	8.5 hrs	85.0 kWh
Hyundai Kona	20.0 %	11.0 kW	7 hrs	64.0kWh

5.5.1.2. On-demand EV charger

An on-demand EV charger is a fast way of charging EVs for a more efficient charging solution. It allows customers to charge their EVs in minutes instead of hours. That’s what makes fast chargers more convenient and attractive to the users.

HOMER grid allows a maximum on-demand EV charging power of 150kw per charging station. We can also customize the EV models that we desire in the vehicle table by creating a list of EV models with different properties of charging and their duration times. Table 5.8 presents the input data for the on-demand EV charger. The charger output power of the station is 150 kW. The number of chargers is 6, and the average sessions/day is 20.

Table 5.8. On-demand charger input data

Name	**Percentage of EV Population**	**Maximum Charging Power per EV**	**Average Required Energy**	**Average Charging Duration**
Jaguar I-Pace	20.0 %	104 kW	90.0 kWh	44.0 min
Renault Zoe	20.0 %	46.0 kW	52.0 kWh	56.0 min
BMW i3	20.0 %	49.0 kW	43.0 kWh	36.0 min
Mercedes EQC 400 4MATIC	20.0 %	112 kW	85.0 kWh	35.0 min
Hyundai Kona	20.0 %	77.0 kW	64.0 kWh	44.0 min

After specifying the vehicle models and their charging characteristics, a monthly profile of the number of vehicles that visits the charging stations during hours of the day is created. According to the working hours and the availability of charging stations of the studied area, a monthly profile of EV charging visits per hour is created randomly as presented in Table 5.9.

Table 5.9. Monthly profile of EV charging visits per hour

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
06:00	50	50	50	50	50	50	50	50	50	50	50	50
07:00	100	100	100	100	100	100	100	100	100	100	100	100
08:00	150	150	150	150	150	150	150	150	150	150	150	150
09:00	200	200	200	200	200	200	200	200	200	200	200	200
10:00	300	300	300	300	300	300	300	300	300	300	300	300
11:00	300	300	300	300	300	300	300	300	300	300	300	300
12:00	300	300	300	300	300	300	300	300	300	300	300	300
13:00	300	300	300	300	300	300	300	300	300	300	300	300
14:00	250	250	250	250	250	250	250	250	250	250	250	250
15:00	200	200	200	200	200	200	200	200	200	200	200	200
16:00	200	200	200	200	200	200	200	200	200	200	200	200
17:00	150	150	150	150	150	150	150	150	150	150	150	150
18:00	100	100	100	100	100	100	100	100	100	100	100	100
19:00	50	50	50	50	50	50	50	50	50	50	50	50

In Table 5.9, the number of EV visitors in each month of the year during specific hour of the day is written. The number of visits per hour are assumed similarly in all months.

5.6. Bi-Directional Converter

Since our system is a mixture of AC and DC powers, a converter is required between the AC and the DC lines for conversion of the generated power in both forms. To fulfill that need a bi-directional converter is used in this system. We will let HOMER optimize the capacity of the converter for us. As input, we choose a system converter type from the catalog, and we will observe how much capacity we need after optimization. The cost of the converter that we chose is 300$ per kilowatt-hour and has an efficiency of 95% in both the inverter and the rectifier inputs. Table 5.10 summarizes converter economics.

Table 5.10 Converter cost inputs

Component	**Capital cost** ($)/kWh	**Replacement cost** ($)/kWh	**O&M cost** ($)/kWh	**Lifetime** (Years)
System Convertor	300	300	0	15

5.7. Utility Grid

From the utility menu in the HOMER, a simple tariff was chosen. The selected tariff has a demand charge of $0.098697 and a sell-back rate of $0.098697. The cost was calculated according to the EPDK energy sell rates.

6. RESULTS AND DISCUSSION

In this section, an analysis of the optimization results and a comparison between the recommended systems have been made. The comparison is based on various aspects like economics, reliability, and the wellbeing of the environment. The system that meets all or most of these properties is declared as the winning system.

Overall system analysis are done according to the winning system. Also, the analysis and the comparison of EV charging stations are made after deciding the proper hybrid system.

Before we proceed in the comparison of the systems, the average electric energy consumption and the annual peak electric demand that must be covered by the system are presented as follow.

Average electric energy consumption is given in Table 6.1.

Table 6.1. Average energy consumption

Daily	**Monthly**	**Annual**
55,552.8 kWh/day	1,689.7 MWh/month	20,276.8 MWh

The annual peak electric demand is 4,811.62 Kw, and it occurs on 29th July as illustrated in Figure 6.1

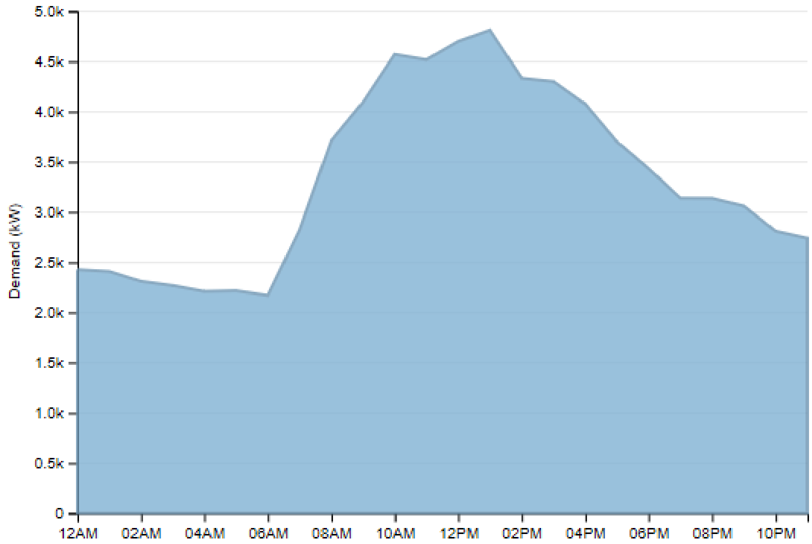

Figure 6.1. Load profile for the day on which the largest demand occurs (July 29)

6.1. The Base System

The system that has the lowest initial capital cost is known as the base case system, but it doesn't mean that it is the best system. HOMER shows the system that contains the simplest combination with the least initial cost as a base system and compares the other systems that meet the required combination of the desired model.

In this optimization result, the base case contains a grid and solar PV system. Therefore, the electric needs of the studied area are met with a grid connection and a 5 MW PV. Currently, $1.25M is spent on utility bills per year. The base case electric bill for 12 months of the year is presented in Tables 6.2 and 6.3.

Table 6.2. The base case electric bill of one year (January-June)

Variables	Jan.	Feb.	Mar.	Apr.	May	June
Energy Charges ($)	88,083	76,256	65,099	59,238	63,219	112,327
Consumption (kWh)	947,458	823,233	744,887	666,546	712,634	1,163,228
Sales (kWh)	54,996	50,604	85,299	66,350	72,097	25,124
Demand Charges ($)	0	0	0	0	0	0
Peak Demand (kW)	2,826	2,744	2,376	2,528	2,758	3,966
Monthly Total ($)	88,083	76,256	65,099	59,238	63,219	112,327

Table 6.3. The base case electric bill of one year (July-December)

Variables	July	Aug.	Sep.	Oct.	Nov.	Dec.
Energy charges ($)	144,808	136,450	121,012	138,427	153,149	96,067
Consumption (kWh)	1,470,171	1,390,506	1,239,805	1,415,454	1,571,938	1,006,598
Sales (kWh)	2,970	7,995	13,711	12,909	20,227	33,249
De-charges ($)	0	0	0	0	0	0
Peak demand (kW)	3,550	3,763	3,973	3,888	4,194	2,844
Monthly total ($)	144,808	136,450	121,012	138,427	153,149	96,067
Annual total ($)	1,254,131					

The monthly electric bill breakdown chart of the base case system is also presented in Figure 6.2.

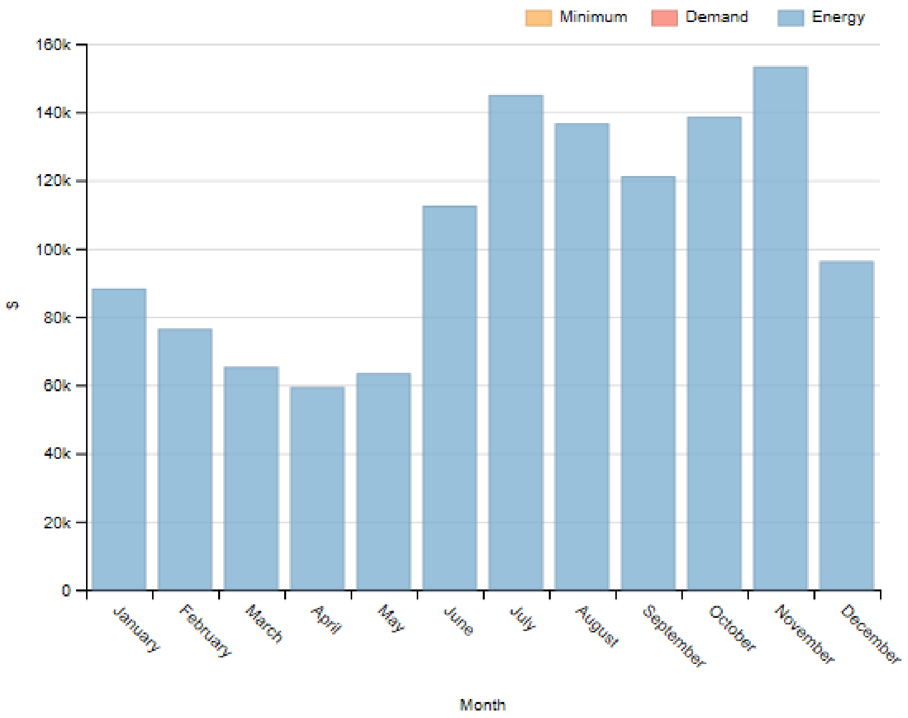

Figure 6.2. Monthly electric breakdown of the base-case

6.1.1. Carbon dioxide emissions

The annual total (metric tons) carbon dioxide emissions of the base case system are 8,312 t/yr. It has a huge carbon dioxide emission when compared to other systems. Such a big amount of emission will cause bad pollution to the environment, as well as to the humans that live in that surroundings. Besides, this system has no bill saving.

6.2. System 1

In this system, the hybrid combination of wind and solar with a grid connection is used to meet the electric demand of the campus. Using this combination, the annual utility bill will be reduced to $799,831 and there will be an average annual energy bill saving of $452,300.

The installation recommendation of system 1 is presented in Table 6.4. Component size, cost of installation, and expenses are shown in the table.

Table 6.4. System1 installation

Component	Price	Installation Size	Total Installed Cost	Annual Expenses
Generic flat plate PV	$0.55/watt	5MW	$2,750,000	$7,500/yr
Enercon E-82 E2 [2MW]	$3,000,000	2MW	$3,000,000	$30,000/yr

6.2.1. System 1 savings: According to the base case system

Table 6.5 presents the annual savings, capital expenses, and project lifetime savings of System 1. According to the base case system, this system has more savings and a simple payback time of 7 years. That means using solar, wind, and the grid is better when compared to the base one.

Table 6.5. System 1 savings overview

Costs, Savings, and Economic metrics	Value
Average annual energy bill savings ($)	452,301.10
Capital Expenses ($)	6,667,377.00
Payback time (simple/discounted) (years)	7.1/9.5
Internal Rate of Return (IRR) (%)	12.68
Project lifetime savings over 25 years ($)	11,307,508

The predicted one-year electric bill of system 1 (Solar + Wind + Grid) is listed in Tables 6.6 and 6.7.

Table 6.6. Predicted electric bill of system1 (January-June)

Variables	Jan.	Feb.	Mar.	Apr.	May	June
Energy Charges ($)	41,841	29,055	18,127	21,514	34,028	82,519
Consumption (kWh)	610,467	482,377	483,481	447,940	536,149	917,522
Sales (kWh)	186,532	187,994	299,813	229,956	191,380	81,439
Demand Charges ($)	0	0	0	0	0	0
Peak Demand (kW)	2,642	2,302	2,043	2,307	2,757	3,732
Monthly Total ($)	41,841	29,055	18,127	21,514	34,028	82,519

Table 6.7. Predicted electric bill of system1 (July-December)

Variables	July	Aug.	Sep.	Oct.	Nov.	Dec.
Energy Charges ($)	108,041	103,658	94,300	107,258	113,225	48,269
Consumption (kWh)	1,123,496	1,104,647	1,005,679	1,146,460	1,193,596	641,064
Sales (kWh)	28,826	54,382	50,225	59,724	46,397	152,000
Demand charges ($)	0	0	0	0	0	0
Peak Demand (kW)	3,483	3,316	3,864	3,681	3,799	2,596
Monthly Total ($)	108,041	103,658	94,300	107,258	113,225	48,269
Annual Total ($)	799,831					

6.2.2. System 1 cash flow summary

The cash flow summary of system 1 over the project life is illustrated in Figure 6.3. The green bars stand for the operating cost, the orange one is for initial capital, the pink is for replacement costs, and the blue stands for salvage.

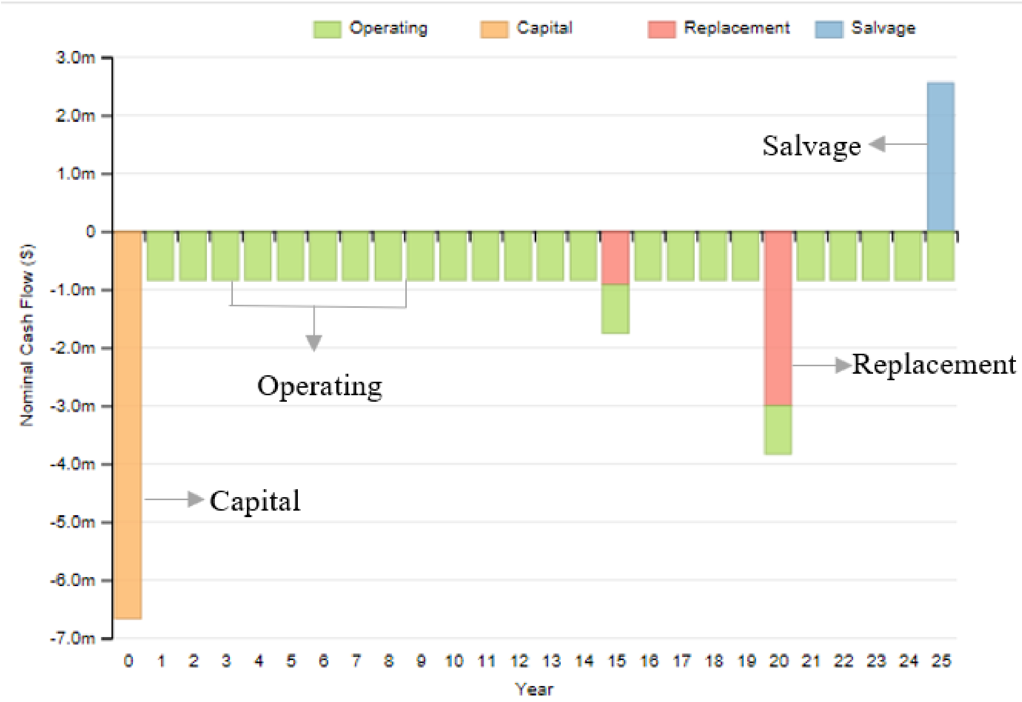

Figure 6.3. System 1 cash flow summary

6.3. System 2

In this system, the hybrid combination of wind and solar with a battery storage system and grid connection is used to meet the electric demand of the campus including the EV charging. The production of electricity in this system is the same as the previous system. The difference is that there is a backup in this system. A battery energy storage system is added in case of interruption. The use of energy storage will increase the reliability of the system thereby encouraging the use of renewables instead of purchasing from the grid.

By using this combination, the annual utility bill will be reduced to $801,393 and there will be an average annual energy bill saving of $450,738.10.

The installation recommendation of system 2 is presented in Table 6.8. Component size, cost of installation, and expenses are shown in the table.

Table 6.8. System 2 installation

Component	Price	Installation Size	Total Installed Cost	Annual Expenses
Generic flat plate PV	$0.55/watt	5MW	$2,750,000	$7,500/yr
Enercon E-82 E2 [2MW]	$3,000,000	2MW	$3,000,000	$30,000/yr
Generic 1MWh Li-Ion	$700,000	1 MW	$700,000	$10,000/yr

6.3.1. System 2 savings: In comparison to the base case system

Table 6.9 presents the annual savings, capital expenses, and project lifetime savings of System 2. According to the base case system, this system has also more savings and a simple payback time of 9 years. That means using solar, storage, wind, and the grid is better when compared to the base one.

Table 6.9. System 2 savings overview

Costs, Savings, and Economic metrics	Value
Average annual energy bill savings ($)	450,738.10
Capital Expenses ($)	7,354,081.00
Payback time (simple/discounted) (years)	9.0/15.1
Internal Rate of Return (IRR) (%)	8.30
Project lifetime savings over 25 years ($)	11,268,460

The predicted one-year electric bill of system 2 (Solar + Storage +Wind + Grid) is in Tables 6.10 and 6.11.

Table 6.10. Predicted electric bill of system 2 (January-June)

Variables	Jan.	Feb.	Mar.	Apr.	May	June
Energy Charges ($)	42,164	29,323	18,488	21,904	34,361	82,652
Consumption (kWh)	588,101	459,350	460,604	422,143	515,325	904,667
Sales (kWh)	160,896	162,247	273,282	200,207	167,178	67,237
Demand Charges ($)	0	0	0	0	0	0
Peak Demand (kW)	2,642	2,302	2,043	2,307	2,757	3,732
Monthly Total ($)	42,164	29,323	18,488	21,904	34,361	82,652

Table 6.11. Predicted electric bill of system 2 (July-December)

Variables	July	Aug.	Sep.	Oct.	Nov.	Dec.
Energy Charges ($)	107,978	103,533	94,050	107,089	113,258	48,594
Consumption (kWh)	1,113,713	1,091,627	989,511	1,133,030	1,181,888	620,955
Sales (kWh)	19,678	42,625	36,592	48,002	34,356	128,600
Demand charges ($)	0	0	0	0	0	0
Peak Demand (kW)	3,341	3,281	3,864	3,681	3,799	2,575
Monthly Total ($)	107,978	103,533	94,050	107,089	113,258	48,594
Annual Total ($)	801,393					

6.3.2. System 2 cash flow summary

The cash flow summary of system 2 over the project lifetime is illustrated in Figure 6.4. The green bars stand for the operating cost, the orange one is for initial capital, the pink is for replacement costs, and the blue stands for salvage.

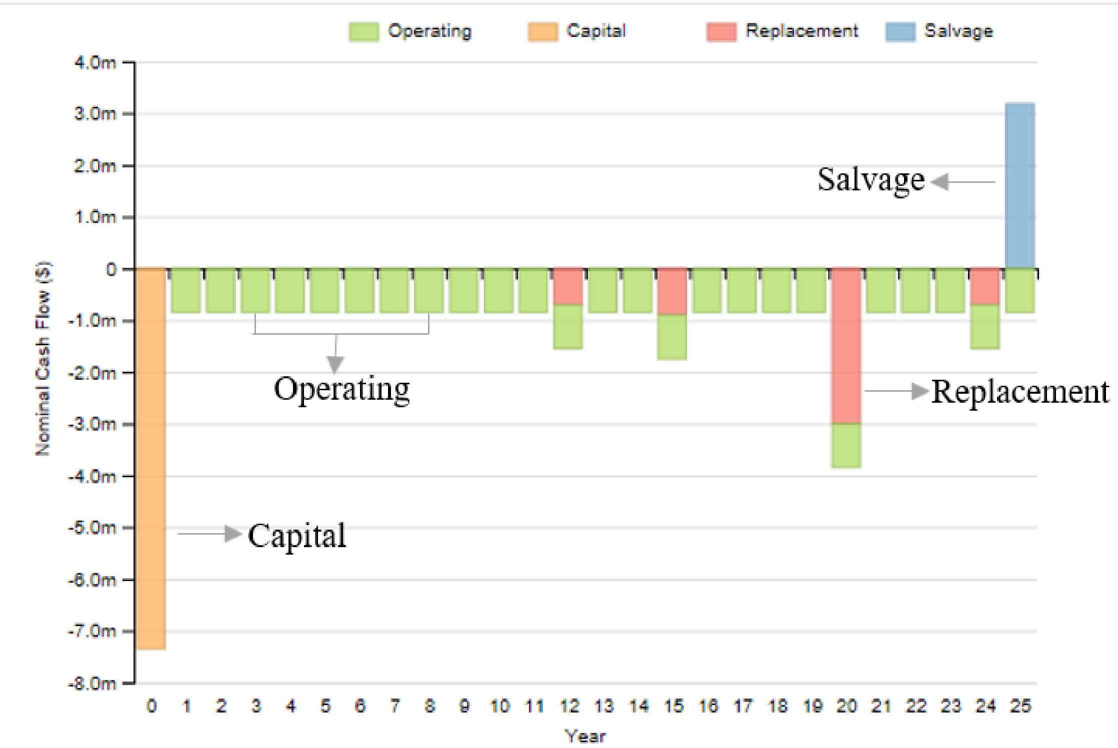

Figure 6.4. System 2 cash flow summary

6.4. Comparison of System 1 and System 2

As mentioned before, the comparison will be based on three important aspects: the economic, the reliability, and the environmental perspectives. So, let us compare and see which of the systems is more effective to be considered as the winning system, and proceed to the rest of our design.

6.4.1. Comparison of the systems based on the economics

In Table 6.12, the total costs, savings, and economic metrics of the project's lifetime for both system 1 and System 2 are presented. From the table, we can see that system 1 is more economical than system 2 although they are very close to each other.

Table 6.12. Economic comparison of System 1 and System 2

Costs, Savings, and Economic metrics	**System 1**	**System 2**
Capital Expenses ($)	$6,667,377	$7,354,081
Operation Expenses ($)	$894,061	$935,351
Annual Total Savings ($)	$390,012	$348,722
Annual Utility Bill Savings ($)	$452,300	$450,738
Annual Demand Charges ($/yr)	$0/yr	$0/yr
Annual Energy Charges ($/yr)	$799,831/yr	$801,393/yr
Discounted payback time (yrs.)	9.5	15.1
Simple payback time (yrs.)	7.1	9.0
LCOE ($/kWh)	$0.070/kWh	$0.075/kWh
IRR %	12.68%	8.30%
Net Present Cost ($)	$18,225,360	$19,445,850

In Figure 6.5, the projected annual savings on the utility bill for both system 1 and system 2 is also shown. We can see clearly that there is a little bit of difference that is not detectable. But if we consider this comparison only from the economic perspective, the winning system is the one that contains solar, wind, and the grid. So, we will proceed to the comparison to see if the other points of view will change this decision or it will be the same.

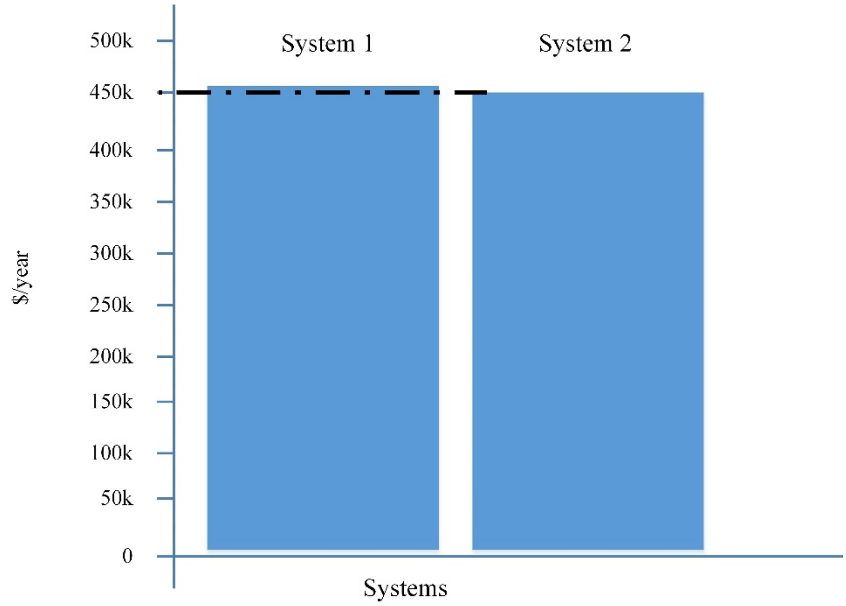

Figure 6.5. Projected annual savings on the utility bill for system 1 and system 2

6.4.2. Comparison of the systems based on the environmental impact

In Table 6.13, the carbon dioxide emissions and annual fuel consumption of both systems are presented. From the table, we can observe that system 2 has lower carbon dioxide emissions than system 1. The carbon dioxide emissions of system 2 and system 1 are 5,991.9t/yr and 6,125.9t/yr respectively. This clearly shows that system 2 is more-friendly to the environment.

Table 6.13. Environmental impact comparison of system 1 and system 2

Environmental impacts	**System 1**	**System 2**
CO_2 Emissions (metric ton/yr)	6,125.9 t/yr	5,991.9 t/yr
Annual Fuel Consumption (L/yr)	0	0

Therefore, using solar, storage, wind, and grid together is safer and better for the environment. The percentage of renewable energy in this combination is more when compared to system 1. So, according to the environmental impact perspective, the winning system is the one that contains solar, storage, wind, and the grid.

6.4.3. Comparison of the systems according to the reliability

In Table 6.14, the degree of reliability for both system 1 and system 2 is presented. From the hybrid combination that each system contains, we can observe that system 2 which contains solar, storage, wind, and grid is more reliable than the solar, wind, and grid combination. The reason is that the storage system that is available in system 2 can be used as backup energy source when all generation units are not available or sudden failures occur.

Table 6.14. Reliability comparison of system 1 and system 2

Reliability	**System 1**	**System 2**
Hybrid combination	Solar + wind + Grid	Solar + storage + wind + Grid
Degree of reliability	Reliable	More reliable

The battery that is added to this system is not for the fulfillment of all electrical demands of the system. It is intended to cover the EV station needs without relying on the generation sources. This way customers could charge their vehicles even when there is no electricity in the microgrid system.

One of the stations that are proposed in this study is the deferrable EV charger. It works as a smart charger and harvests energy from renewable sources for users that prefer lower-cost electricity. By considering this station, the importance of the battery system can be seen clearly. That is why system reliability is considered a significant factor of comparison.

By using the combination solar, storage, wind and the grid, the technical and economic analysis of the load and EV chargers are presented in the following sections of this chapter. Firstly, the characteristics of the load served using this system are analyzed. Then, the renewable fraction and the EV charging stations are discussed in detail.

6.5. The Total Load Served

The AC primary load that is served is 17,989,554 kWh/yr, according to the electric consumption data obtained from the campus. The predicted grid sales are 1,340,899 kWh/yr. The EV charger served is 714,639 kWh/yr. The peak load is 4811 kW. Figure 6.6 shows an hourly time series plot of the total load served. A 3.5% of the total generation is served to the EV chargers.

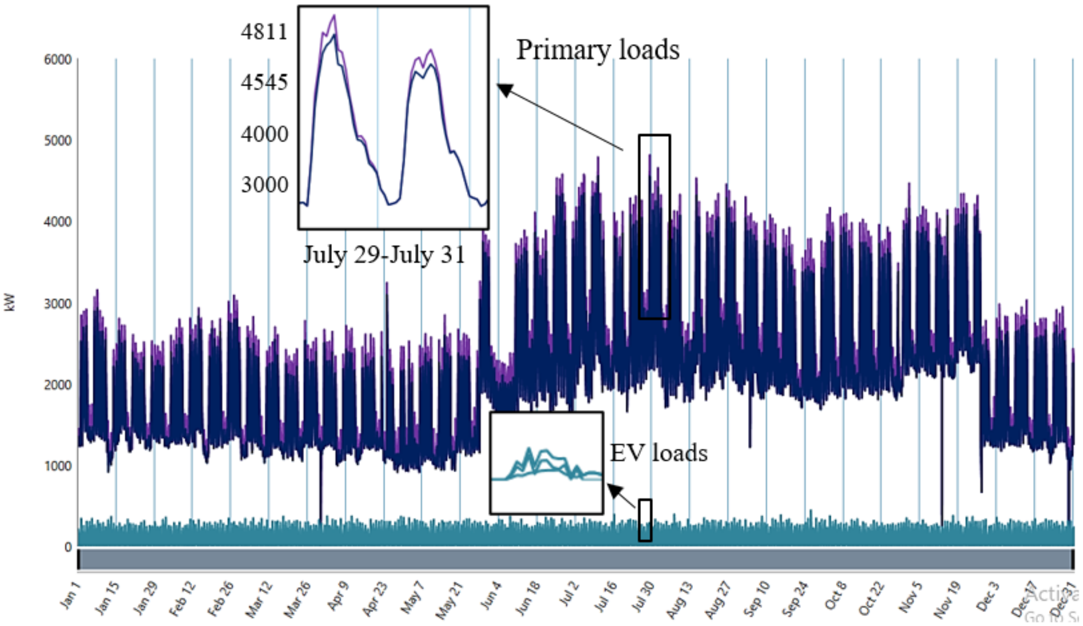

Figure 6.6. Hourly electrical load served for one year

In Figure 6.6, the total electrical load served is highlighted with a purple color. The dark blue is for AC primary load and the light blue is the total EV charger served in one year.

6.6. The Electrical Production by Component

The electrical production of the overall system, the amount, and the percentage of each component is presented in the following section.

6.6.1. PV production

The PV system has a capacity of 5MW. It produces approximately 32% of the total electrical production in this system. Based on the available resource, the production details of the Generic flat-plate PV used in this system are given in Table 6.15.

Table 6.15. The PV output data

Variable	Value	Unit
Rated Capacity	5,000	kW
Mean Output power	736	kW
Mean Output energy	17,667	kWh/d
Capacity Factor	14.7	%
Total Production	6,448,371	kWh/yr
Dedicated converter	5,000	kW

Figure 6.7 presents an hourly PV output power map of one-year production. The annual PV production is 6,448,371 kWh/yr. The maximum output power during the day is 4,463 kW.

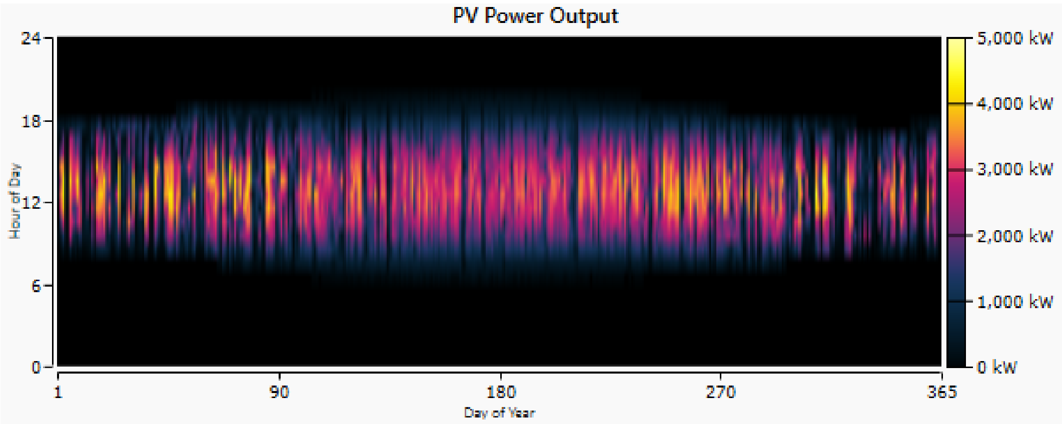

Figure 6.7. PV output power of one year

6.6.2. Storage system

The storage system used in this system is a Generic 1MWh Li-ion battery with a nominal capacity of 1,000 kWh. In Table 6.15 and Table 6.16, the working and installation details of the battery are presented.

Table 6.16. Battery quantity and orientation details

Variable	**Size**	**Unit**
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	600	V

Table 6.17. Battery working details

Variable	**Value**	**Unit**
Autonomy	0.390	hr.
Storage Wear Cost	0.246	$/kWh
Nominal Capacity	1,000	kWh
Usable Nominal Capacity	800	kWh
Lifetime Throughput	2,861,063	kWh
Expected Life	11.8	yr

Figure 6.8 shows an hourly state of charge of the battery storage system. The input energy is 254,985 kWh/yr and the output is 229,486 kWh/yr. The annual throughput is 241,900 kWh/yr.

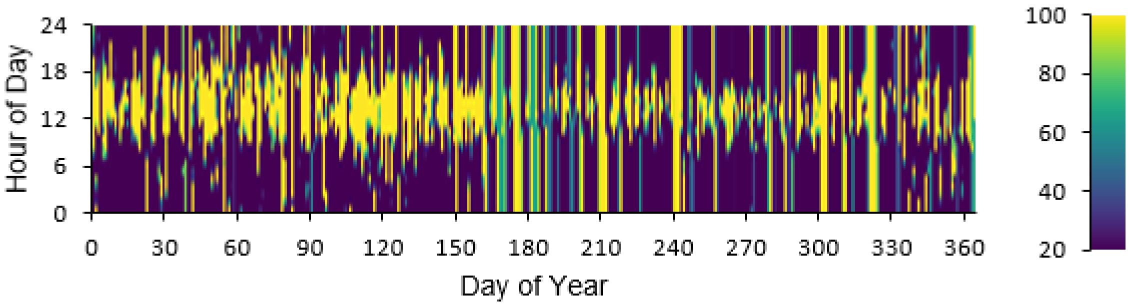

Figure 6.8. Battery state of charge

6.6.3. Wind turbine production

The wind turbine system has a capacity of 2MW. It produces approximately 22% of the total electrical production in this system. Based on the available resource, the production details of the Enercon wind turbine used in this system are given in Table 6.18.

Table 6.18. Wind production details

Production details	Value	Unit
Total Rated Capacity	2,000	kW
Mean Output	523	kW
Capacity Factor	26.2	%
Total Production	4,582,721	kWh/yr

Figure 6.9 presents an hourly wind turbine power output of one year. The total production of the wind turbine is 4,582,721 kWh/yr. The maximum output power during the day is 2,050 kW.

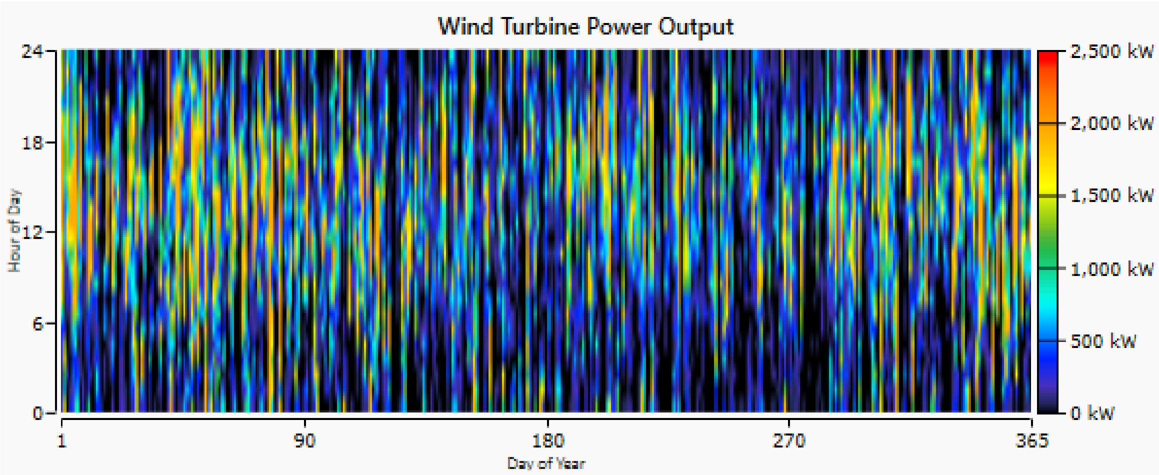

Figure 6.9. Wind output power

6.6.4. System converter

The system converter has a capacity of 3,014 kW. The inverter and the rectifier details of the system converter are presented in Table 6.19.

Table 6.19. System converter details

Variable	Inverter	Rectifier	Units
Capacity	3,014	3,014	kW
Mean Output	690	4.57	kW
Minimum Output	0	0	kW
Maximum Output	3,014	843	kW
Capacity Factor	22.9	0.152	%

Figure 6.10 shows the inverter and the rectifier outputs of the converter. The output energy of the inverter is 6,043,560 kWh/yr whereas the output energy of the rectifier is 39,997 kWh/yr.

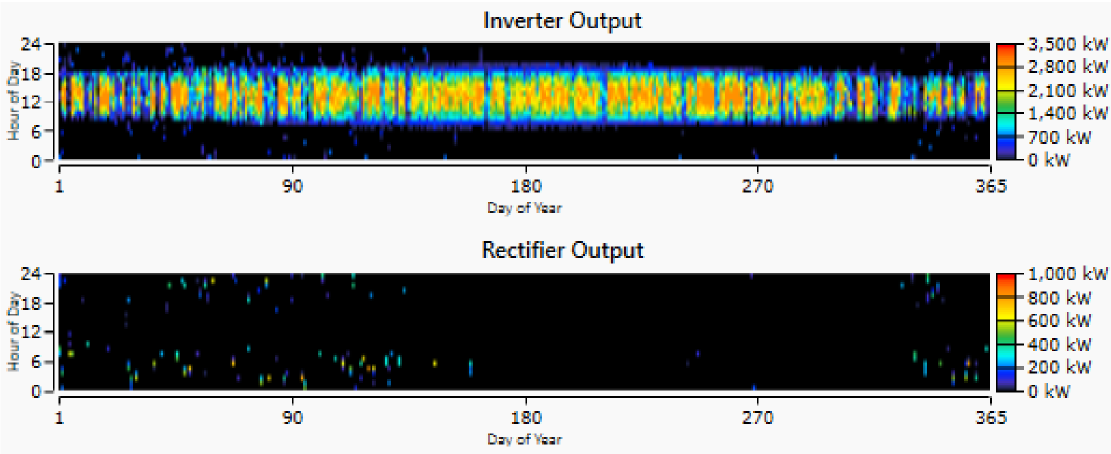

Figure 6.10. Inverter and rectifier output power

6.7. Total Electrical Production

This microgrid system produces total energy of 20,512,005 kWh/yr. The energy produced is optimized to its minimum. The excess electricity is 0.5% which means 99.5% of the energy produced is used by the facility.

The facility uses 20,048,763 kWh/yr. The generation sources analyzed above serves the load and each component has a significant position in the production.

Table 6.19 summarizes how each of the generation sources serves the load. The percentage of each component is also shown in the table.

Table 6.20 Total electrical production

Generation source	**Size** (kWh/yr)	**Percentage** %
Generic flat-plate PV	6,448,371	31.4
Enercon E-82 E2 [2MW]	4,582,721	22.3
Grid Purchases	9,480,913	46.2
Total	20,512,005	100

Figure 6.11 shows the electric production of the generation sources and how they serve the load. The light blue represents the utility grid, the green represents PV production and the dark blue represents wind production.

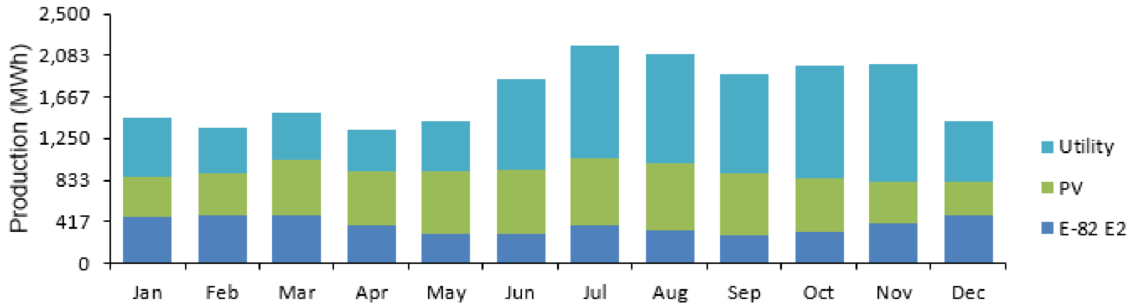

Figure 6.11. Monthly electric production of generation sources

6.7.1. Renewable fraction

The total renewable fraction in this system is 52.7% with a maximum renewable penetration of 1,467% as calculated in the HOMER. Table 6.21 summarizes the total renewable production.

Table 6.21. Renewable fraction of the total production

Energy-based metrics	**Value**	**Units**
Total renewable production divided by load	55.0	%
Total renewable production divided by generation	53.8	%
One minus total nonrenewable production divided by the load	100	%

6.7.2. System cost summary

This system has a total Net Present Cost of 19,445,848 USD. This was obtained after deduction of salvage from the summation of all expenses incurred over the project lifetime. Table 6.22 shows the overall system cost summary and it's Net Present Cost.

Table 6.22. System cost summary

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel	Salvage ($)	Total NPC ($)
Enercon turbine	$3,000,000	$956,422	$387,826	$0.00	($539,005)	$3,805,242
1MWh Li-ion	$700,000	$537,351	$129,275	$0.00	($148,459)	$1,218,168
Generic flat PV	$2,750,000	$0.00	$96,956	$0.00	$0.00	$2,846,956
Grid	$0.00	$0.00	$10,360,015	$0.00	$0.00	$10,360,015
Converter	$904,081	$383,578	$0.00	$0.00	($72,193)	$1,215,466
Overall system	$7,354,081	$1,877,352	$10,974,072	$0.00	($759,657)	$19,445,848

6.8. EV Charger Loads

6.8.1. On-demand EV charger load served

The annual energy consumption of this EV charger is 397,399 kWh. The peak load is 304 kW. With the on-demand EV charger mode, 20 charging sessions per day are supplied through 6 chargers. Each capable of providing 150 kW maximum power output. There is no missed session in this mode. Since it is a fast charger, the average session duration is less than an hour.

By using this charging mode, the impact of the total EV loads on the microgrid is decreased from 3.5% to 2%. This means, the impact of EV loads on the microgrid when used the on-demand mode is 2% of the total electrical loads served. Table 6.23 shows the total energy served to the on-demand EV charger and the number of sessions.

Table 6.23 On-demand EV charger load served

On-demand EV charger	Load served
Annual Energy Served	397 MWh
Peak Load	304 kW
Energy per Session	54.4 kWh
Charging Sessions per Day	20.0
Charging Sessions per Year	7,308
Average Missed Sessions per Day	0
Utilization Factor	9.98 %

6.8.2. Deferrable EV charger load served

The annual energy consumption of this EV charger is 317,240 kWh. The peak is 160 kW. With this EV charging mode, 13 charging sessions per day are supplied through 10 chargers. Each capable of providing 22 kW maximum power output. An average of 7.0 potential users left per day without charging their EVs because all chargers were occupied when they arrived.

By using this charging mode, the impact of EV loads on the microgrid is decreased from 3.5% to 1.5%. This means, the impact of EV loads on the grid when used the deferrable mode is only 1.5% of the total load. Table 6.24. shows the total energy served to the deferrable EV charger and the number of sessions.

Table 6.24. Deferrable EV charger load served

Deferrable EV charger	**Load served**
Annual Energy Served	317, 240 kWh
Peak Load	160 kW
Energy per Session	66.6 kWh
Charging Sessions per Day	13.0
Charging Sessions per Year	4,756
Average Missed Sessions per Day	7
Utilization Factor	43.4 %
Average Session Duration	8.00 hr.

6.9. Comparison of EV Charging Modes

The charging modes presented in this study are deferrable/smart and on-demand/fast EV charging modes. Both of them are today's most preferred charging modes. To identify the effectiveness of each mode, 5 models were applied to the deferrable mode. Another 5 vehicles with similar models were also applied to the on-demand mode to see the difference between them.

Table 6.25 shows the comparison of the two modes of charging in terms of energy consumption when connected to the grid.

Table 6.25. Comparison of charging modes in terms of consumption

Station details	Deferrable EV Charger	On-demand EV Charger
Max. charger output power (kW)	22 kW	150 kW
Average charge duration (hr.) per EV	8 hrs.	1hr
Annual energy served (kWh)	317,240	397,399
Peak power (kW)	160	304
Sessions per day	13	20
Sessions per year	4756	7308
Missed sessions per day	7	0
Impact on the microgrid	1.5%	2%

6.10. Discussion

From Table 6.22, it can be observed that the electricity demand of the on-demand type is more than the deferrable type. Although, the same models were used and the required energy per EV remains the same. The load served increases directly with the charger output power and the speed of charging.

For example, in the on-demand EV charging mode, 6 chargers with 150 kW output power were used to charge 5 different EV models. The required energy per EV model is achieved with an average daily profile of 1,089 kWh/day, and the charge duration per EV was less than an hour. Which means high demand with high-speed charging. On the other hand, in the deferrable EV charging mode, 10 chargers with 22 kW output power were used to charge the same EV models. The required energy per EV was achieved with an average daily profile of 868 kWh/day. The average charge duration per EV was 8 hrs with managed sessions. In this mode, the demand is not very high, but the charging speed is not as fast as the on-demand mode. Also, it’s cost-effective since this mode works as smart charging and charges only when electricity is at its lowest cost.

Each mode has its own characteristics and charge efficiency. Therefore, the EV users prefer which type is suitable for them. But the question is, which one is more effective to both users and the charge station owners or the grid? The answer is that the deferrable mode is more cost effective to the users. Also, the electrical demand of the deferrable mode is less than the on-demand mode since it consumes only 1.5% of the total consumption. In addition, the long-term use of fast charging will have a negative impact on the EV battery capacity.

At the same time, fast charging is a threat to the grid stability and it creates load imbalance. For that reason, deferrable EV charging have seen to be more effective than the on-demand charging mode.

According to the changing world, smart systems always win over others. That's why the smart charger is being preferred by many EV owners and charge suppliers. The growing technology and the complexity of microgrids recall the need for control and smart systems. This will simplify the coordination of both sides.

6.11. Benefits of Deferrable EV Charging Mode

Table 6.26 presents the benefits of the deferrable EV charging mode to both users and grid owners. Smart EV charging mode has several advantages in both user and the grid sides. Some of the most important advantages of this mode is as follow:

Table 6.26. Benefits of deferrable EV charger

Deferrable/smart charger	**EV owners**	**Charge suppliers/grid**
Charging safety	Automatic test connection between the vehicle and the device	
Cost and environment	Saving money and protecting the environment by optimizing charging time and charging when it is cheaper	Protecting the environment by providing renewable energy to the users.
Billing system	Easily automatic payments, avoiding billing disputes	Automatic billing based on the prices that have been set
Electricity consumption	Controlled charging sessions	Controlled charging events, avoiding excess capacities
Grid stability	Taking part in demand response	Signal based control
Keeping up to date	Smart charging services keep both users and suppliers up to date	Smart charging services keep both users and suppliers up to date
Easily station management		Easily creating device groups, model pricing, and packages for customers

6.12. Advantages of HOMER Grid

- It enables powerful and accurate modeling of grid-connected renewable energy systems.
- It helps commercial and industrial customers reduce demand charges and electrical costs through the design of behind-the-meter projects.
- Accurately models and compares the financial benefits of different distributed energy investments.
- Helps users reduce the financial risk by providing the best mix of resources for the lowest cost.
- Provides a multi-year analysis and tests how the distributed energy projects are likely to perform decades from now.
- It has an improved time-series viewer that allows users to access it easily and include it in their final reports. (Misbrener, 2019).

7. CONCLUSION AND RECOMMENDATIONS

In this study, the optimum design of a hybrid microgrid using various EV battery charging strategies has been carried out. The hybrid sources considered during this study were solar PV and wind. The study was applied to Eskişehir Osmangazi University. The electricity consumption data of the campus were collected and arranged in accordance with the implementation of this work. The obtained data were analyzed using HOMER optimization software. Observation and visualization of data were accessed through this software.

According to the data obtained, it is estimated that the scaled annual average electrical load of the campus is 49.286 kWh / day, with a peak of 4.552 kW. In addition, two different charging stations have been installed. The estimated average annual EV loads randomly generated in HOMER during modeling were approximately 2,000 kWh / day with a peak of 440 kW.

Three different system cases are suggested. Two of the proposed systems were deemed suitable for this model. Comparisons of the proposed methods have been made based on the economic, environmental impact, and reliability of these systems. Economically, the system containing solar PV, wind, and grid connections was better. However, considering environmental impacts and reliability, the system containing solar PV, storage, wind, and grid connection was more effective than the other system. With a small difference in economy, the system which is more reliable than other systems has been chosen to ensure the security of the microgrid. Also, the deferrable/smart EV charging mode has been approved as the efficient charging system for both users and microgrid compared to the on-demand EV charging mode. Finally, the percentage of EV demand is reduced to 1.5%. The performance of the preferred system and how it is likely to be in the future is presented. Technical and economic analyzes throughout the project lifetime were carried out perfectly. Using the microgrid system presented in the study, the electricity bill is reduced by 36%.

In the future, the integration of microgrids and EVs can be taken to higher levels by creating a strong infrastructure for EV charging methods. It's like building a wireless EV charger that will reduce wiring costs and add simplicity to EV charging. Likewise, creating smart metering for both wireless and wired EV charging can provide secure payment and billing for both users and grid owners. This infrastructure will directly reduce the cost of the power supply required for wired charging stations. Building high-level DC microgrids could also support the future of EV fast charging. This will also reduce the stress of EVs on the public grid by shifting their load to DC microgrids.

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