T.C.
ISTANBUL OKAN UNIVERSITY
INSTITUTE OF GRADUATE SCIENCES

THESIS

FOR THE DEGREE OF

MASTER

OF POWER ELECTRONICS AND CLEAN ENERGY SYSTEMS

HASANAIN MOHAMMED HASAN HASAN

213008012

DEVELOP A CATHODIC PROTECTION SYSTEM (CP) USING A MIX OF GREEN ENERGY SOURCES

THESIS ADVISOR

Assoc. Prof. Elif Altürk

ISTANBUL, February 2025

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ABSTRACT

Develop a Cathodic Protection System (CP) using a mix of green energy sources

The Karbala Oil Refinery of Iraq Understood as one of the largest networks of subterranean pipelines for heavy fuel oil, gas, and crude oil in the whole country. The vulnerable pipelines can undergo hazardous damages from extensive corrosion as well as rusting if not properly protected. The paper outlines scientific investigations for rust. Mechanisms, impacts, and worldwide impacts of corrosion are researched through the improvement of the design based on climatic variables, cathodic protection variables, and resistivity of the soil by simulating those factors. Perform such simulation using COMSOL Multiphysics. A technology was discussed here that smartly protects underground pipelines without needing any conventional AC power. It was created in MATLAB, and the cathodic protection system is powered by a mix of solar panels and wind turbines, the usage of which is meant to reduce the possibility of corrosion and, subsequently, damage that might lead to huge financial losses. For the system to have a long life and work well in all kinds of weather, we should consider the worst situations. Results from tests using the HOMER are also looked at, and the project's lifetime cost is checked.

Keywords: Cathodic Protection, Hybrid Renewable Energy, COMSOL, MATLAB, HOMER

KISA ÖZET

Irak'taki Kerbela Petrol Rafinerisi, ham petrol, gaz ve ağır yakıt yağı taşıyan devasa bir yeraltı boru sistemine sahiptir. Bu sistem, yeşil enerji kaynaklarının bir karışımını kullanarak bir Katodik Koruma Sistemi (CP) oluşturmak için kullanılabilir. Bu borular, uygun koruma yöntemleri kullanılmadığı takdirde paslanma ve paslanmadan çok fazla hasar görebilir. Bu çalışma, pasla ilgili bilimsel araştırmaları ele alır ve korozyonun nasıl işlediğini, dünya üzerindeki etkilerini inceler. Tasarımın anlaşılması ve optimize edilmesi için COMSOL Multiphysics kullanılarak çevresel faktörler, katodik koruma değişkenleri ve toprak direnci için simülasyon yapılır. Yeraltı borularını koruyan akıllı bir sistem hakkında konuştuk. MATLAB, rüzgar türbinlerinden ve güneş panellerinden gelen yeşil enerjinin bir karışımını kullanarak katodik koruma sistemine güç sağlar. Bu, geleneksel bir AC güç kaynağı kullanmak yerine yapılır. Amaç, önemli mali kayıplara yol açabilecek hasarı azaltmaktır. Sistemin ömrünü uzatmak ve farklı hava koşullarında iyi çalışmasını sağlamak için en zor koşulları dikkate alacağız. Ayrıca HOMER'ı kullanarak projenin ömrü boyunca maliyet etkinliğini değerlendireceğiz.

Anahtar Kelimeler: Katodik Koruma, Yenilenebilir Hibrit Enerji, COMSOL, MATLAB ve HOMER

ACKNOWLEDGMENT

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ABBREVIATIONS

“CP: Cathodic Protection

HRES: Hybrid Renewable Energy Source

PV: Photovoltaic

WT: Wind Turbine

BES: Battery Energy System

SRB: Sulfate Reducing Bacteria

ICCP: Impressed Current Cathodic Protection

PID: Proportional Integral Derivative Controller

NPC: Net Price Cost

O&M: Operation and Maintenance

COE: Cost Of Energy “

I. INTRODUCTION

1.1. Overview

"Corrosion is the reaction between metal and its surroundings that changes the metal's properties, turning it into more stable forms like oxides or hydroxides. This process can have economic, environmental, and technical impacts." (ISO 8044-1986).

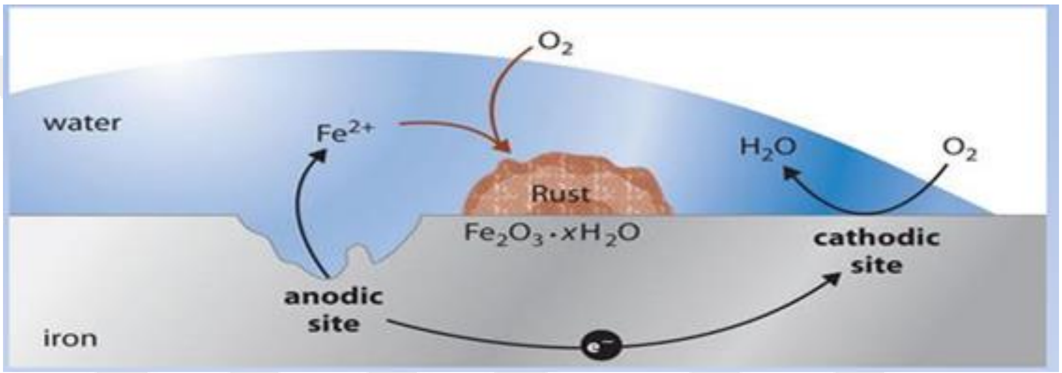


Figure 0.01Anodic & Cathodic Area.

From **Hata! Başvuru kaynağı bulunamadı.**

Anode: Where corrosion occurs (Oxidation-Lost electron)

$Fe \rightarrow Fe^{+2} + 2e^-$,

$Fe^{2+} + 2HO^- \rightarrow Fe(OH)_2$

Cathode: Where gain ions (Reduction – Gain electron)

$2e^- + 2H^- \rightarrow 2H_2$

Corrosion can happen in **two** main ways: general corrosion, which is caused by chemicals, and electrical corrosion.

A-Basic Corrosion General rust is caused by chemical reactions. The general rusting process is extremely slow and is based on the ion content of the solution to which the structure is exposed. It is a light type of rust that usually spreads evenly across the surface of the uncovered metal. In general rusting, lines and tanks usually don't fail fast because there are no holes or damage to the structure. Instead, it only causes rust on the surface. General rust usually only becomes a major issue in very harsh conditions, like in acidic environments. The metal is not perfectly even, and the solution is not completely the same throughout, this leads to electrochemical corrosion cells, which are much more significant than regular rusting.

B-Electrochemical corrosion occurs when a corrosion cell forms due to an electrical process between two metals or parts of the same metal. This cell occurs when there is a change in electrical potential between the metals, often caused by the use of different metals. To prevent anodic reactions, electrons must be stopped from leaving the metal by linking it to a more negative source. Common methods to avoid corrosion include anodic and cathodic inhibitors, shield coverings, and sacrificial anodic methods. However, it has been proven quite widely in different research studies that the most efficient of these rust avoidance methods is (Impressed Current Cathodic Protection). This method includes applying electricity to the cathode of the corrosion cell, which sends a flow of electrons over the metal surface.

Numerous variables may influence the cathodic protection system and the requisite current levels. This includes earth resistance, how well coatings work, pH level, and the amount of Sulfate Reducing Bacteria (SRB) in the electrolyte environment. The oil and gas industry consistently confronts corrosion in pipelines transporting oil and gas, which are vital to the nation's energy infrastructure. A multitude of industrial pipelines transport hazardous chemicals, including toxic, combustible, and detrimental elements. Consequently, it is imperative to implement robust safety protocols to ensure the security of these pipelines and safeguard our national energy security [43], [44], [45]. The anodes in this impressed current cathodic protection system are powered by energy from solar cells and wind turbines, among other renewable sources. This energy also charges a DC battery. This facilitates a continuous current flow to the iron pipes, which serve as the cathode. Corrosion has evolved from a relatively obscure subject to a critical domain of engineering that requires emphasis and scrutiny. Amid the present energy crisis, renewable sources such as wind and solar power may address several challenges, particularly when integrated with existing safety protocols [46]. Renewable energy sources provide some of the most optimal and dependable alternatives for sustainable energy. This article examines the operational dynamics of a hybrid wind and solar PV system with battery storage over time, using MATLAB/Simulink for modeling and simulation purposes. We are modeling cathodic protection using COMSOL Multiphysics. The rising need for sustainable energy has resulted in significant advancements in green energy technology, particularly in wind and solar power systems. Both systems provide clean energy; nevertheless, they encounter challenges due to inconsistent performance. This raises concerns over the reliability and consistency of their energy supply. Hybrid renewable energy systems (HRES) that integrate various sources such as wind and solar provide a viable solution to these challenges. The integration of solar and wind energy may mitigate the fluctuations inherent to each source, resulting in a more dependable and efficient energy supply [47].

1.2. Background

1.2.1. Importance of Hybrid Systems for DC Loads

1.2.2. Wind Turbine Types

Wind turbines are an important part of hybrid systems, which convert wind energy into electrical power. There are two main types of wind turbines based on the axis of their rotation:

•Horizontal Axis Wind Turbines (HAWTs): Mostly a type of wind turbine seen every day, it has one rotor mounted on a horizontal axis. Usually it is large and works in wind farms, both onshore and offshore. The blades turn at right angles to the wind, and these turbines are very good at making power when the wind is fast. They also need a way to move the rotor to follow the wind direction

•Vertical Axis Wind Turbines (VAWTs): A type of turbine wherein the rotor is installed on a vertical axis. This generally constitutes a smaller fraction of HAWTs and is repeated on an urban site or a site with variation within the wind direction. Its yaw mechanisms do not require these types of turbines, and they can collect wind from any direction. As described, two subtypes can be identified with regard to VAWTs: the Savonius, Darrieus turbines. Even though they are less efficient than those in the category of HAWTs, they prove helpful in certain applications due to their flexibility in wind orientation [9].

1.3. Benefits of Wind Turbines

Wind turbines are key to providing major benefits for a hybrid system. Among them is the fact that:

• Sustainability: Wind, being a renewable resource, runs without producing emissions; thus, reducing the dependency on fossil fuels-very effective in fighting climate change and general environmental decay [6].

• Energy Cost Savings: After being put in place, wind turbines entail very minimal operational and maintenance costs. Much less subject to price variations as opposed to traditional fuels, wind energy proves to be economically stable in the long run as an energy source [7].

• Scalability: Wind turbines can be installed in decentralized as well as centralized generation, from a single windmill for meeting a residence's energy requirement to large wind farms for feeding electricity to the whole community. This versatility allows the energy source to be highly specific for demand patterns and geographical condition [8].

• Energy Security: Wind turbines produce energy locally, reducing fuel import dependence and hence adding energy independence and security for the regions with constant wind resources [9].

• Complementarity with Solar Power: Typically, wind turbines are more productive at night and in cloudy weather. These characteristics perfectly complement a solar PV system in a hybrid renewable energy setup that allows the user to have relatively more consistent and reliable generation of electricity through/over different times of the day and weather [,10].

• Job Creation: Wind energy has rapidly advanced as a technology that creates both domestic and global jobs. These jobs are created in the manufacturing process, installation, maintenance, and related services [11].

• State and federal finances benefit from the wind energy industry's ability to generate manufacturing, installation, and maintenance jobs [15].

1.4. Types of Solar Panels

Solar panels are another critical component in hybrid renewable energy systems, that is, capturing energy from the sun. There are several kinds of solar panels, each having its benefits and applications:

- Monocrystalline Solar Panels: These panels are cut from one large crystal and are known for high efficiency coupled with long life. Monocrystalline panels offer the highest power output per square meter out of all types of panels, so they are generally preferred for applications where space is limited. Though they are more costly, their performance in low-light conditions and energy conversion rate are usually better than others [12].

- Polycrystalline Solar Panels: These panels are cut from silicon crystals which are formed by melting, resulting in a lower cost of manufacturing compared to monocrystalline panels. They are less efficient and slightly bulkier than monocrystalline panels but they are cheaper, and mostly used when it comes to the installation of solar power for homes and businesses. Their efficiency falls slightly below that of monocrystalline panels; therefore, they are more suitable for applications with abundant space [13].

• Thin-Film Solar Panels: These panels are formed by depositing thin films of photovoltaic material on a substrate. Lighter and more flexible than crystalline panels, thin-film panels are generally well-suited for portable applications and large-scale installations on irregular surfaces. They are, though, less efficient than crystalline panels; therefore, much more roof space is necessary for such a system to have the same output. Typically, they are more cost-effective for large installations, like solar farms [14].

• Bifacial Solar Panels: Bifacial solar cells can collect light from the front and rear surfaces, and so their total power output is more than that possible with unifacial cells. Usually, unifacial cells of either monocrystalline or polycrystalline type are mounted in such a way that both the front and back sides of the cell are exposed to sunlight. Particularly, bifacial modules are advantageous when the albedo is high, such as in regions covered by snow or sand. The levelized cost of energy is reduced further by the higher efficiency possible with such dual-sided modules as compared to standard single-sided modules [15].

1.5. Benefits in Solar Panels

Many beneficial things about solar panels make them famous in green energy systems. They work especially well with wind machines. Some of these benefits are:

• Clean Energy Generation: Electricity is simply generated by solar photovoltaic panels from sunlight without any harmful emissions. This thus goes a long way in reducing greenhouse gas emissions and fighting climate change, making solar energy the most favorable source of electricity [16].

• Independence Comes First: With solar panels, it's easy to produce energy far from the cities; this helps homes and offices depend less on main electricity. It lowers the risk of price changes and boosts security in energy [17].

• Low Operating Costs: After you have set up solar panels, you do not need to do much to maintain them, and because they do not use any fuel, you save money in the long run. Normally, the period over which solar panels work well is between 25 and 30 years, during which time they keep generating power with little loss [18].

• Scalability and Flexibility: Solar panels can be implemented as very small applications like rooftop installation or large solar farm installation. These show flexibility, being able to adjust and cater to a very broad range of energy needs- from a home to an industry [19].

• Peak Energy Generation Plan: The solar panels produce energy maximally at midday, which is typically the time of peak energy demand for most people. This agreement with peak demand reduces the dependence on fossil fuel-based peaker facilities and also reduces the expensive adjustments that would have to be made to the infrastructure of the grid [20].

• Modularity: This is another befit as solar panel systems are expandable; this implies that they can be increased with time as more energy is required and space is available. Solar power is highly advantageous for both small and large projects in the sense of providing so much freedom [21].

• Minimal Impact on the Environment: Compared to other energy sources, solar cells are much friendlier to the environment. Traditional power plants require much more land and water than these do. Once operational, they neither pollute the air as other power plants do, nor create noise [22].

1.6. Issue Description

There are many barriers to the successful implementation of hybrid renewable energy systems despite the benefits that are promised. These include the unpredictable nature of the sources of renewable energy with regard to power generation, problems associated with control in handling the flow of electricity from the different sources, and need to manage energy storage systems effectively.. In addition, engineering systems that are designed to directly supply a DC load would require very sophisticated control algorithms to ensure correct distribution of power and to ensure that there are not too many energy conversion losses. All hybrid systems must, therefore, ensure that the fluctuations in both the load and the environment are controlled efficiently to make the stability of the system priority [23] & [24].

1.7. Aims of the Research

The main aim of this research is to model and simulate a hybrid wind-solar system for DC energy supply for the underground piping protection, considering the contribution of the systems' components developed: modeling of realistic solar cell and wind turbine models as well as contributing to a control system that will help in energy management and maximization of efficiency in distribution. Emphasis is on the impact of weather elements on the energy management system and efficiency and the reliable and effective functioning of the system.

1.8. Benefits in Reducing Rust in Crude Oil Pipelines

Reduced corrosion in crude oil pipelines is a major benefit of hybrid renewable energy systems. Oil and gas pipelines, in particular, are vulnerable to corrosion, which is a big problem in the sector as a whole. Figure I.2 shows that conventional approaches to corrosion management, such as impressed current systems and sacrificial anodes, are power hungry and often consume fossil fuels. Hybrid renewable energy systems use both solar and wind power to charge cathodic protection systems. This means less traditional power is needed [16].

Using green energy to power cathodic protection systems in mixed systems can provide these benefits:

- Energy self-sufficiency: Hybrid systems enable constant access to clean energy at remote sites with minimal or no grid power availability.
- Costs of operations reduced: Over time, the use of renewable energy to power cathodic protection systems results in significantly lower energy costs.
- Environmental impact reduced: Such systems lower the carbon footprint in corrosion protection, thus moving toward a more sustainable approach in the oil and gas sector.
- Improved corrosion protection: With continuous energy supply from solar and wind sources, the hybrid system ensures current for cathodic protection can always be made available and consequently will reduce drastically the rate of corrosion of the pipeline surface..

1.9. Research Area

To minimize corrosion in crude oil pipelines, this research models a hybrid renewable energy system comprising wind and solar electricity that drives a DC load which is to be applied for cathodic protection. Power electronic components, including DC-DC converters, and energy management techniques will be concentrated on in creating models and simulations of the system in COMSOL-MATLAB/Simulink. The performance of the system will then be tested under different variations. to evaluate the total efficiency of the system and its cathodic protection ability in matters concerning pipe corrosion with regard to the availability of wind speed, sun irradiation, and load demand. Find out how hybrid renewable energy systems could be used to minimize pipeline corrosion by extending the life of the crude oil pipelines, it is a research study that will reveal.

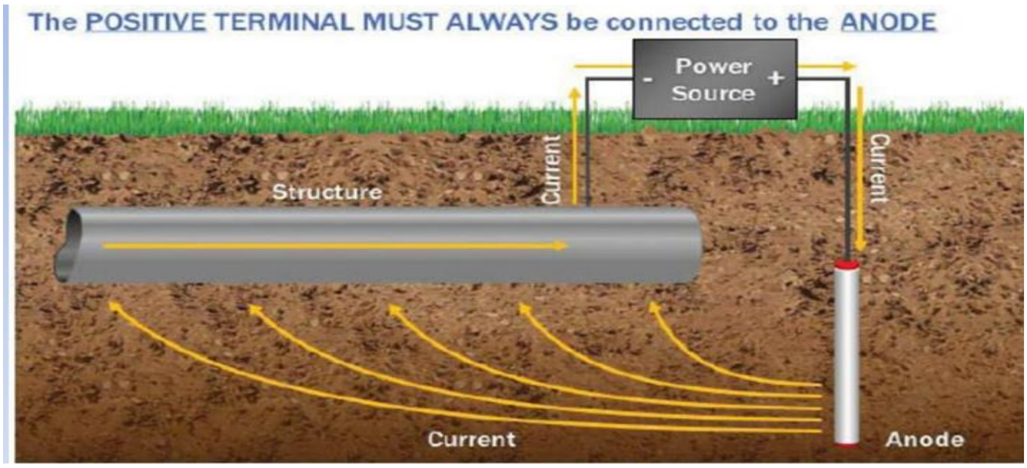


Figure 2.Cathodic Protection System (CP).

1.10. Thesis Organization

The subsequent chapters of this thesis are organized as follows:

Chapter 2 offers an extensive analysis of the current literature about hybrid renewable energy systems, focusing on wind and solar photovoltaic technologies, DC-DC converters, and energy storage techniques.

In Chapter 3, the method for modeling and simulating the hybrid system's parts and the full energy management system is explained, along with how it can be used for cathodic protection.

Chapter 4 presents a comprehensive study of the simulation results and evaluates the system's performance across various climatic and operating situations, emphasizing its function in corrosion mitigation.

Chapter 5 closes the study by summarizing key results and providing suggestions for future research and practical applications.

II. REVIEW OF THE LITERATURE

2.1. INTRODUCTION

The transition to renewable energy is a direct result of the growing demand for a reliable supply of electricity. Wind turbines and solar panels are popular for their renewable and environmentally friendly properties. Due to the sporadic nature of some energy sources, energy production fluctuates over short and seasonal intervals. Wind/PV hybrid energy systems are designed to optimize the complementary characteristics of wind and solar energy. Integrating multiple energy sources and energy storage solutions, including battery packs, can improve the reliability and cost-effectiveness of hybrid systems. Many scientists have been looking for ways to improve the performance of stand-alone hybrid wind/PV energy systems, focusing on aspects such as system cost and energy production cost.. These mixed systems rely on power electronics that enable effective energy conversion and management. Maximizing solar and wind energy requires DC-DC converters in photovoltaic systems and AC-DC converters in wind turbines as well as MPPT algorithms. Energy storage systems help enhance the techniques of load balancing and improve management of the whole system.. Renewable energy hybrids demonstrate significant efficiency in the management and control of power systems. The use of alternative hybrid energy sources in oil pipelines facilitates an efficient corrosion reduction strategy by delivering a reliable and sustainable power supply. The integration of wind and solar energy sources with effective power management may mitigate corrosion damage and improve the pipeline integrity. Simulating hybrid renewable sources for DC loads is a good way to make the system more reliable and less harmful to the environment. Hybrid renewable energy systems Improving system design and exploring alternative configurations by using simulation tools such as HOMER Pro can be very useful in many cases. These systems can also benefit from sophisticated control strategies, sources: [11], [18], [20], and [19].

2.2. Converting Wind Power System

2.2.1. Overview for Wind Turbine Components

Wind turbines are the primary means by which renewable energy systems generate electricity from the energy of the air. In order to operate the rotor of a generator that is attached to the wind turbine, the rotor blades are responsible for capturing wind energy. Through the process of electromagnetic induction, this spin generates electrostatic current. The following equation is used to determine the amount of electricity that may be generated by a wind turbine: For the equation PWT = 0.5 ρ A v^3 Cp, where PWT represents power output, ρ represents air density, A represents rotor swept area, v represents wind speed, and Cp gauges the efficiency of energy conversion.In addition to being a source of renewable energy, wind turbines also contribute to energy independence and have minimal operational expenses. Wind turbines offer a number of benefits, including energy independence, low operating costs, and clean energy. Changes in the direction of the wind, as well as how it seems and sounds to the populations that are nearby, are among their concerns. Windmills are still capable of generating power, which is beneficial to both the environment and the economy, despite the obstacles that they face: Wind turbines are able to create a significant amount of power when there is a strong wind. The forecasts of energy production are increased when wind patterns are stable over the long period. Through the use of less fossil fuels, wind power helps to decrease emissions of greenhouse gases and improves energy security.Wind turbines have lower total operating costs than power plants after they have been installed. Weaknesses include the fact that the creation of wind energy is influenced by a number of different elements, such as the fact that it is intermittent, the need that wind speed be high, the possibility that there will be minimal energy output in tranquil locations, and the possibility that local populations would argue against it. In addition, there may be difficulties associated with the use of land, such as enormous tracts of land. In addition, there may be difficulties brought forth by limited resources and varying wind speeds. In addition, maintenance might be difficult, particularly for windmills that are located offshore. Wind energy, in general, is a difficult and possibly contentious alternative to other forms of renewable energy sources since it provides a number of obstacles and possible conflicts. [18] and [2] are the references.

Turbine rated power	**5 KW**	**Installation cost**	**1100/k($)**
Hub height	1 m	O & M cost	15 ＄/kW/year ($)
Turbine rotor diameter	0.15 m	Lifetime	20 years
Cut-in speed	1 m/s	Discount rate	4%
Cut-out speed	20 m/s		

Table1 : Wind plant technical and economic factors. (source: reference [5])

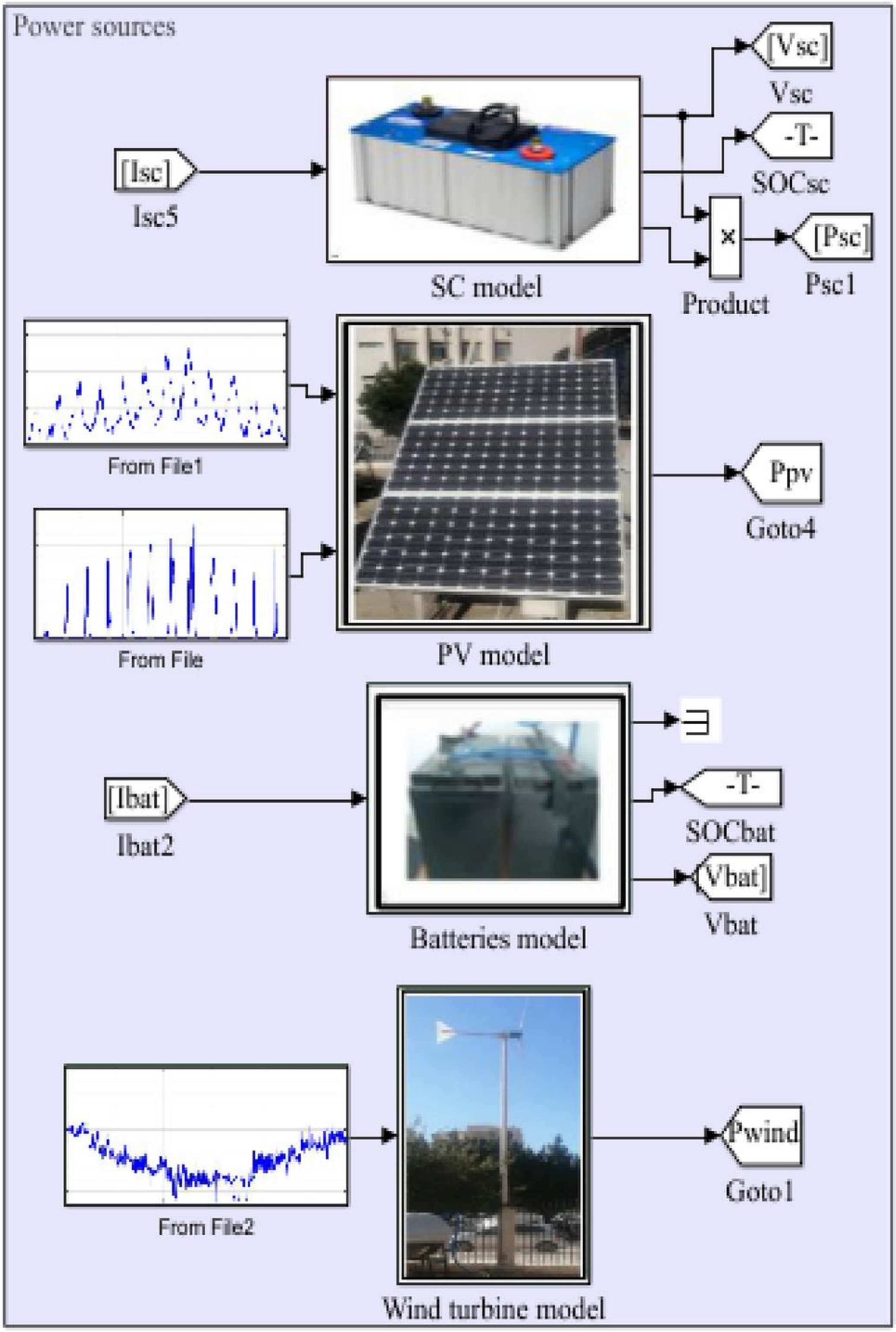


Figure 3.Wind Turbine Simulink modeling of different power components. (source: reference [15])

2.2.2. Wind Speed Variability and Power Output

In order to determine how much electricity wind energy systems can generate, it is crucial to take into account changes in wind speed. The wind speed, which may vary significantly over time, greatly affects the amount of electricity that windmills generate. In alternative energy systems that use solar and wind technologies, it is important to note and control variations in wind speed to enhance the output of energy. Characteristics of the components of the wind turbine should also be put into consideration in the design of a wind energy system. Efficiency in wind power generation is based on the kind of turbine, blade shape as well as the generator performance. Apart from the aforementioned, other very complex mathematical models are used to calculate wind power wherein air density and the area and tip ratio of the blades are all taken into consideration. Variation in wind speed has much greater impact on energy production. The changes in the speed of the wind affect the amount of electricity a wind turbine can produce. These changes make energy production erratic and thus difficult to predict how much power can be availed at any given time. In order to address these problems, advanced control techniques, such as Maximum Power Point Tracking (MPPT) algorithms, have been included in hybrid renewable energy systems. These algorithms improve energy conversion efficiency by adjusting system parameters based on real-time conditions. MPPT algorithms ensure that the system operates at its highest level of performance by constantly monitoring and adapting to changes in wind speed. As per simulation studies, fluctuation control of wind speed and maximization of power generation in hybrid renewable energy systems has been achieved with that management plan. Wind speed and solar irradiance have been compared in different scenarios to see how effective the control systems are under actual conditions.In summary, this feature is important in observation and hence reducing the wind speed variations for better efficiency of the hybrid sustainable electricity plants, as shown in the figure. Such systems could be designed by scientists, utilizing advanced control strategies and carrying out extensive simulation studies, for energy supply to the local load demand sun and wind energy are utilized See sources: [17], [6], and [22].

Figure 4. Annual Resource Wind Speed Data of The Karbala Site

Wind Turbine Tower	Characteristics
Tubular Tower	• - Constructed with rolled steel plates that are bonded jointly from top to bottom and have flanges. • - Internal vertical ladders serve to gain access to the yaw mechanism and power lines.
Lattice Tower	• - Constructed using metal rods that are formed in a precise way and then assembled to create a lattice shape. • - Solid framework • - Fairly priced • - Facilitates straightforward assembly and transportation.
Guyed Wind Tower	• - The wind tower is held aloft by guy wires. • - Additional room is necessary to secure the guy wire. • - Low-cost • - Appropriate for limited capacity HAWTS

Wind Turbine Tower	Characteristics
Tilt Up Wind Tower	• - A securing device for the rotating turbine is necessary for the upkeep of the structure. • - The windmill may be swiftly serviced by dropping it to the bottom. • -Suitable for small capacity HAWTs
Free Standing Tower	• - Typical uses for HAWTs • - Tower diameter depends on HAWT size. • - Requires just only a little of land

Table 2: Wind turbine tower types. (source: reference [16])

Parameter	Rated Values
Rated power	5 kW
Generator KVA	6.5 kW/0.9
Wind velocity (m/s)	12 m/s
Speed(pu)	1
Generator torque	0.882 Nm

Table 3: Wind electricity components. (source: reference [6])

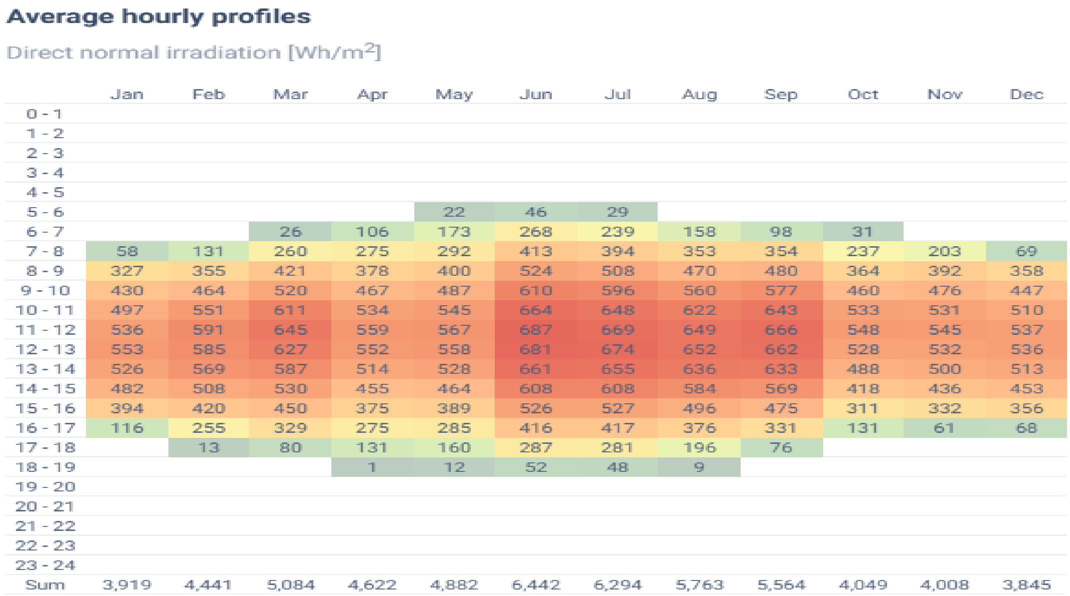
2.3. Solar Photovoltaic System

2.3.1. PV Cell Characteristics

Solar photovoltaic (PV) systems offer a number of benefits as they use the abundant sunshine as a sustainable source of energy. They provide for the feasibility of daily energy use while being easy to improve by simply adding more panels when the demand increases. A type of system that can come afterwards, where low operational costs maintain grid stabilization by producing energy near the place of consumption. Besides, it helps reduce greenhouse gas emissions and air pollution, while also enhancing energy independence and security.

Solar power is variable due to the sun and weather, which must be controlled. A reduction in sunlight diminishes the energy output of solar cells. , so shade can lower efficiency. Shading may diminish energy production efficiency; generation is constrained in low light circumstances. An additional aspect is the seasonal variance that affects the annual energy output and the aesthetic considerations about the panel installations. There is an environmental challenge in the proper disposal and recycling of photovoltaic systems at the end of their life.

In conclusion, comprehending the characteristics of photovoltaic cells is crucial for optimizing solar energy advantages while mitigating the related obstacles. Applying technological innovations such as MPPT optimization algorithms and advanced system architectures integrated with battery storage would make it possible to provide support during low light as a standby, as well as to store surplus energy efficiently, addressing the challenges of a sustainable future. Refer to sources: [11] and [2].


Average hourly profiles

Direct normal irradiation [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6					22	46	29					
6 - 7			26	106	173	268	239	158	98	31		
7 - 8	58	131	260	275	292	413	394	353	354	237	203	69
8 - 9	327	355	421	378	400	524	508	470	480	364	392	358
9 - 10	430	464	520	467	487	610	596	560	577	460	476	447
10 - 11	497	551	611	534	545	664	648	622	643	533	531	510
11 - 12	536	591	645	559	567	687	669	649	666	548	545	537
12 - 13	553	585	627	552	558	681	674	652	662	528	532	536
13 - 14	526	569	587	514	528	661	655	636	633	488	500	513
14 - 15	482	508	530	455	464	608	608	584	569	418	436	453
15 - 16	394	420	450	375	389	526	527	496	475	311	332	356
16 - 17	116	255	329	275	285	416	417	376	331	131	61	68
17 - 18		13	80	131	160	287	281	196	76			
18 - 19				1	12	52	48	9				
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	3,919	4,441	5,084	4,622	4,882	6,442	6,294	5,763	5,564	4,049	4,008	3,845

Figure 5.Total energy supply (TES) in Iraq. (source: reference [11])

Strengths	Weaknesses
1. An environmentally friendly energy source: solar photovoltaic systems use the sun's plentiful rays to generate electricity, which is a reliable and sustainable energy source.	**1. Variability:** in output is caused by irregularity, which is the fact that solar energy production is dependent on brightness and may be influenced by weather conditions.

Strengths	Weaknesses
2. Regular daily pattern: Better energy production projections and grid integration are made possible by the comparatively regular daily patterns of solar energy.	**2. Seasonal fluctuations:** solar energy production might differ due to the altering angle of the sun during the year, impacting total yearly output.
3. Scalability: solar arrays may be augmented by including more panels, hence enhancing energy output to meet escalating load.	3.**Seasonal variations:** the total yearly production may be impacted by variations in solar energy output due to the sun's shifting angle throughout the year.
4. Minimal running expenses: solar photovoltaic systems incur little operating costs post-installation, since they do not need fuel or continuous resource inputs.	4. **Significant initial expenses:** the upfront price for solar panel installation and equipment may be considerable, affecting the initial return on investment.
5. Centralized generation: rooftop solar panels may be affixed to roofs and disseminated over several sites, alleviating pressure on centralized power infrastructure.	5. **The effect of shade:** even minor shadowing on a solar panel may markedly diminish energy output from the whole panel or array.

Strengths	Weaknesses
6. Environmental benefits: generating electricity from sunlight decreases greenhouse gas emissions and air pollutants, helping to clean up the environment and combat climate change.	6**. Generation of electricity is constrained under poor lighting conditions:** energy output diminishes considerably during overcast, rainy, or substantially darkened circumstances.
7. Minimal servicing: solar panels want less upkeep, lacking moving items, hence diminishing operating complications and expenditure.	**7. Technical considerations:** the visual appeal of solar panels may not consistently conform to architectural tastes or community aesthetics.
8. Scientific developments: continuous improvements enhance solar panel efficiency, increasing energy collection and decreasing total prices.	**8. Geographical constraints**: energy from the sun production is contingent upon location, exhibiting greater efficiency in areas with more sunshine exposure.
9. Grid support: solar energy may enhance grid stability by producing electricity near demand centers, hence reducing transmission losses**.**	**9. End-of-life leadership**: the appropriate disposal and recycling of solar panels pose issues in mitigating environmental effect.

Strengths	Weaknesses
10. Energy liberty: solar photovoltaic systems facilitate diversification of the energy portfolio and diminish reliance on fossil fuels, hence enhancing energy security.	**10. Battery backup is a necessity:** the retention of surplus solar energy for use during times of insufficient sunlight necessitates efficient and economical battery technology.

Table 4: Strengths and disadvantages of solar photovoltaic power systems. (source: reference [2])

2.3.2. Solar Irradiance and Power Generation

Solar panels are important in mixed renewable energy systems because they provide a trustworthy and green source of electricity. The biggest benefit of solar PV technology is that it can collect a lot of sunlight, giving us a reliable and clean energy source. Daily solar energy trends are quite consistent, making it easier to plan and integrate into the power grid. Also, solar panels can be expanded, allowing for more panels to be added as energy needs grow. Solar PV systems have low running costs after they are installed because they don’t require ongoing resources.

But solar energy faces challenges too; for example, intermittency or up-front capital costs, not forgetting the need for storage. Solar panels generate power in the presence of sunlight and output variations are dependent on weather conditions. To have energy supply 24/7, there must be some way of storing energy or even a different means of power supply in the night when solar panels cannot work. Seasonal fluctuations and shadowing may affect solar energy output levels annually.

Notwithstanding these limitations, the environmental advantages of solar energy are substantial. Solar photovoltaic systems reduce carbon dioxide emissions and air pollution, fostering a cleaner environment and supporting efforts to mitigate climate change. Furthermore, the extensive deployment of solar panels reduces strain on centralized power systems and promotes energy autonomy by diversifying the energy portfolio.

Continuous technical developments enhance the effectiveness of solar panels, increasing energy collection and reducing prices. Solar PV systems, devoid of moving components, need less maintenance, hence streamlining operations and lowering costs.

In summary, solar radiation is one of the most vital sources for electricity production in hybrid renewable energy systems. The use of the vast sunshine supplied by solar PV systems would build up a sustainable and environmentally friendly power supply, while effectively dealing with challenges related to intermittency as well as initial investment outlay. Refer to sources [33], [39], [32], [38], and [5].

Module rated power	**330 Watts**	**Installation cost**	**800 $ /kW (USD)**
DC-AC ratio	1.2	O & M cost	9 $ /kW/year (USD)
Module tilt angle	29°	Lifetime	25 years
Inverter rated power DC	3.17 MW	Discount rate	9%

Tracking	1-axis (Azimuth)		

Table 5: Technical and financial features for a solar photovoltaic plant. (source: reference [5])

The output power of photovoltaic systems is dependent upon solar irradiation and cell temperature. Solar irradiation significantly influences the photovoltaic (PV) current, however the PV voltage decreases when the cell

Temperature exceeds the standard testing criteria for solar cells. The Code of Conduct Test Settings stipulate a cell temperature of 25°C, and sun irradiation. The photovoltaic output may be determined using the below equation:

$$P_{pv}=P_{pv.rated} \times G/(G_{ref}) \; [1+\beta_{ref}(T_c-T_{ref})] \qquad (1)$$

Where PPV.rated is the solar panel rated power in KW , G is the hourly global insolation in kW/m2

Gref denotes the standard test conditions irradiance, whereas βref represents the Celsius coefficient., TC is the cell temperature can be found by formula :

$$T_C = T_a + (NOCT-20)/800 \times G \qquad (2)$$

Ta represents the natural temperature of the chosen location, whereas NOCT denotes the ordinary operating cell temperature, often provided in the data sheets of photovoltaic modules. The dynamic model of the DC wire of the photovoltaic array is available in [12]:

$$V_{pv}=V_{dc}+L_{dc}(dI_{pv})/dt+I_{pv}R_{DC} \qquad (3)$$

Where V_{pv} and I_{pv} are the voltage and current of the PV array respectively. R_{DC} and L_{DC} are the DC cable's resistance and inductance respectively.

This information helps the decision-maker when choosing to build a wind machine or set up a solar farm to produce electricity. However, the long-term costs of using green energy are much lower than those of traditional energy sources. The hybrid system includes a DC load, a wind rotor, solar panels, and batteries for storage. The choice of system design depends on the load needs. ICCP is mainly the application of DC power to the circuit. This implies that the system should solely utilize direct current (DC) to avoid power conversion losses. Secondly, a mixed system is used instead of a single-source system. This helps to maintain a steady power supply. During the day, solar panels create electricity, and wind turbines produce power whenever the wind is strong enough. Also, because the device won't produce power consistently, a battery is added to store energy when it generates more than is being used.

2.4. Power Electronics for Hybrid Integration

2.4.1. DC-DC Converters for PV System

An important part of adding solar systems into mixed renewable energy mixes uses DC-DC converters. To increase the amount of power given by the PV array, such converters are needed. This happens by using algorithms that follow the Maximum Power Point. Those converters are very key in hybrid systems because they help give efficient transmission and use of electricity from the photovoltaic system to other parts for the whole system. The PV array and its DC-DC converters form an important part of the entire hybrid system. These are key in getting the best out of solar radiation because they change the direct current electricity that is produced by the PV cells into something that the rest of the system can use. It includes MPPT algorithms, which optimize power extraction in different environmental conditions by monitoring and adjusting the operating point of the PV array.Further, DC-DC converters allow easy fit and working together in the hybrid system when linked with more parts like energy storage systems or wind turbines. Good power handling and control ways are enabled by these converters, which check voltage levels and make sure that different energy sources and loads are correctly lined up. Depending less on power provided by the grid, this smooth integration enhances the general dependability and effectiveness of the system.allow you to check these converters' adjustability to variations in temperature, sun irradiation, and other such environmental factors. The DC-DC converters' control settings can be optimized to always get the best power from the PV array.DC-DC converters are used by PV systems as a crucial part of hybrid renewable designs meant for efficient solar energy harvesting. They can be used to reduce losses, maximize power generation using algorithms for maximum power point tracking, and initiate straightforward communication with different components, which makes them important to system performance improvement. The cited works are [23], [41], and [15].

2.4.2. AC-DC Conversion for Wind Turbine

Using wind turbine systems in mixed green energy options depends a lot on AC-DC conversion technology. From a scientific and economic standpoint, the converter component works as both an inverter and a rectifier, allowing for reversible energy flow between AC and DC lines. The converter's efficiency is important for effective power transfer. Its capacity, lifespan, and efficiency are key factors in how well the system performs. The converter's ability to handle power coming in and going out is important for keeping the hybrid system stable and reliable.

In a system that uses wind, solar, and storage together, energy is sent from these green sources to a common DC bus by converting AC power into DC power. Control methods for DC-DC converters in wind and solar devices used maximum power point tracking, so this would be used here to help make energy transfer more efficient. Energy management using supervisory control can effectively control the flow of energy from different sources and the allocation between the battery storage system and other loads. From the simulation results, it can be inferred that the proposed control strategies are effective in energy optimization while keeping the system stable.

The DC/AC inverters can be utilized within a microgrid application to transform the DC power from such sources as photovoltaic systems and wind energy installations into AC power so that it may be synchronized with the grid. LCL filters assure noise-free operation and improved power quality. These maximum power, DC voltage, grid voltage, and filter components impose very critical performance of inverters and filters in the system and, hence, are required to be built and optimized very carefully for efficient AC-DC conversion and smooth connection to the grid.

AC-DC conversion is done because the mixed green energy system requires combining different energy sources into one power supply. Coordinated power flow control methods with well-tuned converter settings will ensure better handling of power flow and, thus, better utilization of the energy while maintaining the system stable and reliable. See references: [21], [13] and [12].

2.4.3. MPPT Algorithms for Wind and Solar

The improvement of power generation in hybrid renewable energy systems greatly relies on the application of Maximum Power Point Tracking algorithms. Wind and solar sources must work at their maximum power points, so energy extraction is maximized, too.

A common algorithm used is INC (Incremental Conductance), with which the zero slope of the photovoltaic module's power-voltage curve at the Maximum Power Point (MPP) is considered. It compares incremental conductance with array conductance and pinpoints quite accurately the MPP. The most important equation that drives this algorithm is $dP/dV = I + VdI/dV$ where dP/dV stands for incremental conductance allowing efficient tracking of MPP under variable environmental conditions.

In hybrid systems, which combine wind and solar sources with energy storage — batteries — two converters are applied in the system to control power flow and extract the maximum amount of energy from the renewables. The implementation of MPPT algorithms in these configurations ensures a continuous and steady electrical supply to the loads, "even in periods when there is no renewable source.

Research indicates that the use of a cocktail of clean energy sources may increase system efficiency and performance. Adapting MPPT algorithms to some specific characteristics of each source, for example, the use of the P&O algorithm for optoelectronic panels and the Tip Speed Ratio (TSR) algorithm designed for wind turbines, enables the HRES to optimize its power output for the diversity of operating conditions while keeping an optimal point of output for the power delivered by the source. Additionally, effective energy management strategies facilitate surplus power utilization by either storing it in battery systems or feeding it back to the grid as needed.

In summary, MPPT algorithms play a crucial role in improving the efficiency of HRES by optimizing power extraction from both wind and solar energy sources. By employing sophisticated control strategies and incorporating energy storage systems, HRES might offer a reliable and stable power supply while reducing the reliance on regular fossil fuel sources. Refer to sources [11], [37], and [17].

2.5. . Power Retention Device

2.5.1. Battery Storage Model

Battery backup is very important for hybrid renewable energy systems. These are systems in standalone DC microgrids, where stability and reliability are very essential. In a photovoltaic system, the battery stress-related issues maintain constant supply. This was tested in Sarawak, Malaysia in a standalone photovoltaic system wherein it was combined with a battery-supercapacitor hybrid energy storage system (HESS). This was to supply electricity to a rural community.

The key factors of this setup included a sun-to-electricity area strength level of 5 kilowatts, everyday power use of 27.4 kilowatt-hours, a power source’s basic voltage level of 48 volts, its size of 1000 ampere-hours, its inside opposition of 0.005 ohms, a supercapacitor's ability of 1000 farads, and a supercapacitor's equal line opposition of 0.001 ohms. The importance of these factors is that they help make sure things work as well as possible and as smartly as they can in the mix system..

Battery storage facilitates the collection of surplus energy produced by the photovoltaic system during optimal sunlight conditions, enabling its utilization at times when sunlight is absent.For the purpose of satisfying the community's day-to-day energy requirements, this will be a power source that is both steady and dependable. The mixture makes the system more resistant to variations of sunlight and minimizes the amount of instances in which it is used. Moreover, it results in an improvement in the overall performance and efficiency of the storage system. Using a linear filter power allocation plan in tests improves the optimization of battery and supercapacitor use for superior management of energy.

In summary, battery storage forms the basis for the provision of backup power in an HRES when there is low or no generation taking place and also contributes toward the improvement of stability and reliability of a standalone DC microgrid. The work presented in this thesis highlights how the integration of battery and supercapacitor storage within PV systems can utilize different components to enhance performance and reduce stress. Refer to source [24].

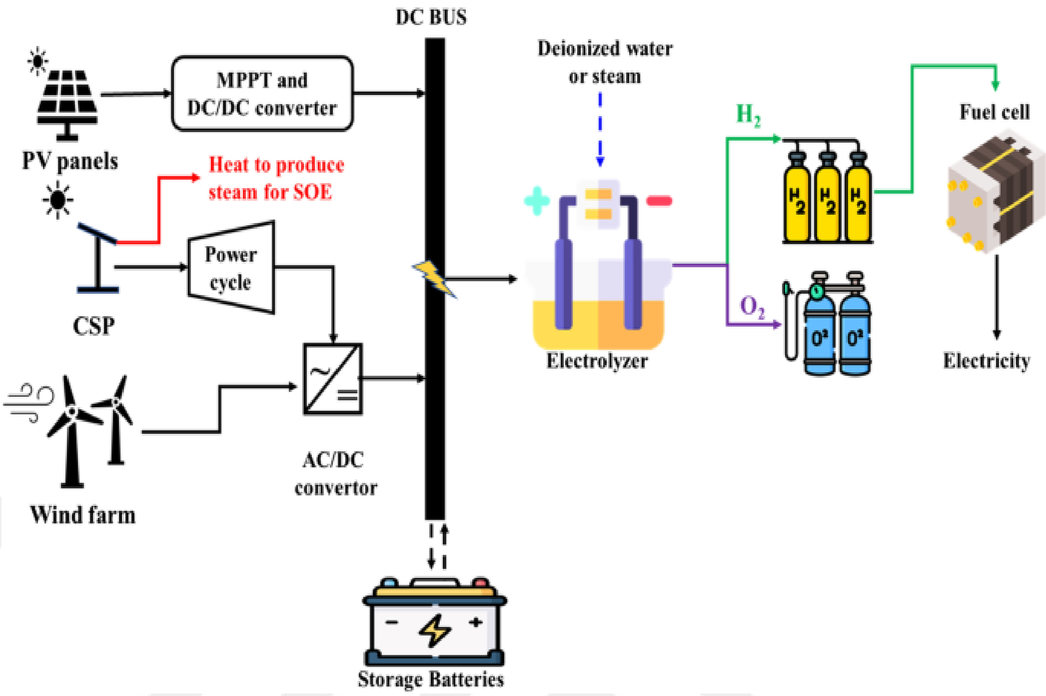


Figure 6.AThe schematic diagram for solar/wind hydrogen production systems Full size image (source: reference [28])

2.5.2. Charge/Discharge Algorithms

Employing charge/discharge strategies is key for dual backup energy sources. The control of energy exchange between varied parts, especially solar panels, windmills, and batteries, is mainly supported by those strategies. The system can maintain DC loads powered steadily and efficiently by smartly fueling and using up these parts at optimal times.System stability and battery life in a battery-supercapacitor combined energy storage system depend explicitly on the charge/discharge algorithms. As enabled to perform synchronized operation, such algorithmic operations would facilitate energy exchange among various storage entities, including batteries and supercapacitors.The same algorithms of charge/discharge take their significance for hybrid optimization in PV/wind turbine applications with hybrid storage aimed at controlling power imbalances and energy production variations.Charge/discharge algorithms also play an important part in the optimization of hybrids in PV/wind turbine applications with hybrid storage to control power imbalances and energy production variations. The algorithms allow the system to adjust its charging and discharging rates of storage components according to the demand for power. These algorithms ensure proper functioning of the system in all conditions by keeping a vigilant eye on parameters such as load power, renewable contributions of electricity, and the states of charge of the battery and supercapacitor. At last, charge/discharge algorithms are most important in restoring efficiency through the combination of renewable energy. This type of algorithm offers constant power supply to DC loads, increases energy utilization, and protects elements from damage by governing energy flow in the system. Look at the cited works: [4] and [15].

Parameter	**Rated Values**
Rated of battery	50 (Ah)
Voltage	379 V
Available Voltage	355 (Va)
Charging current (A)	21.05 (A)
Charging Voltage	405 (Vch)

Table 6: Battery parameters. (source: reference [6])

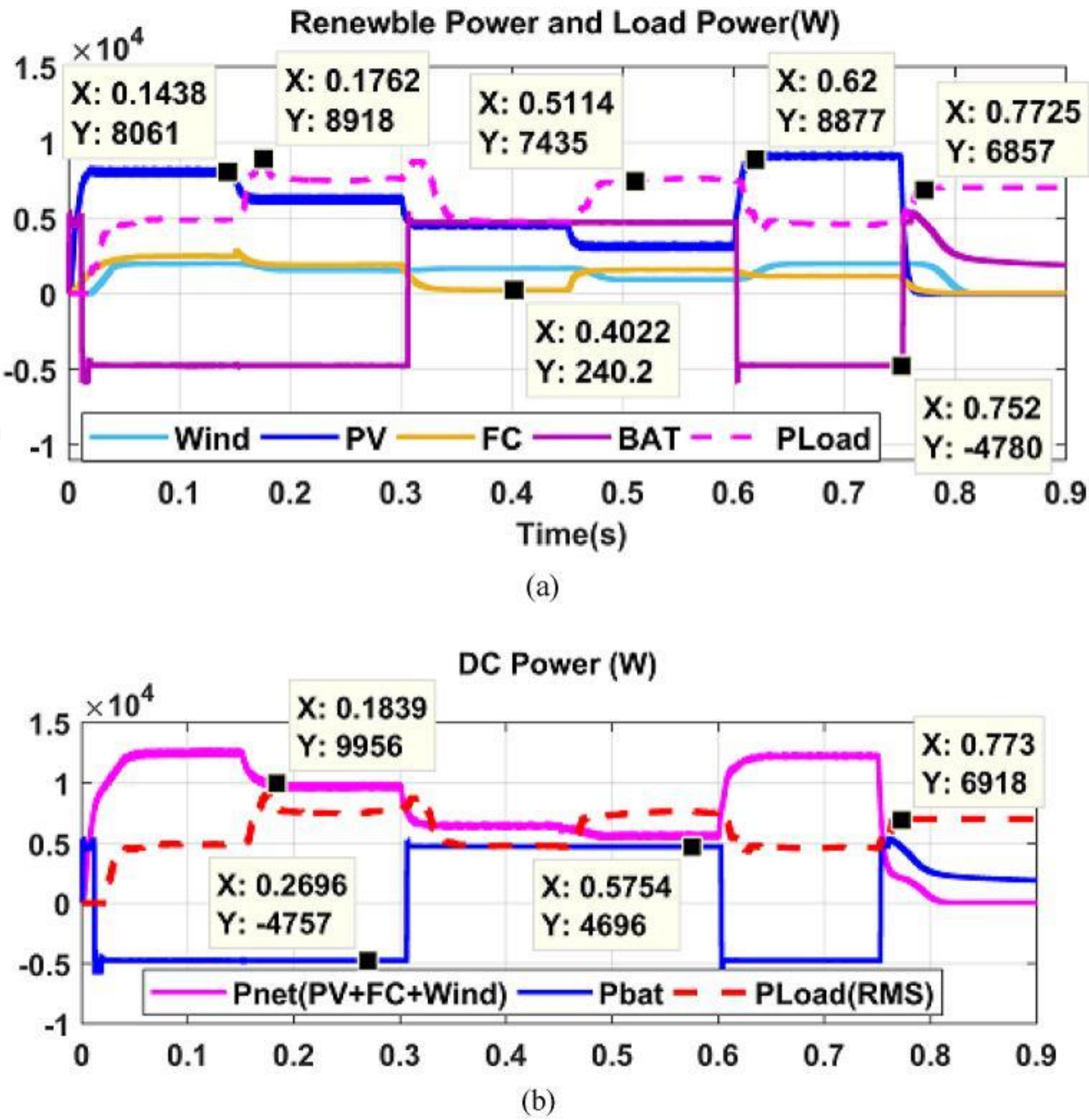
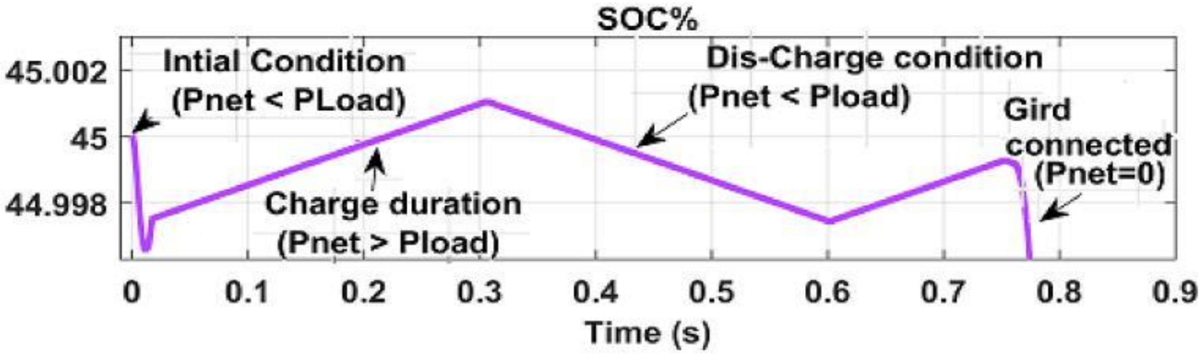
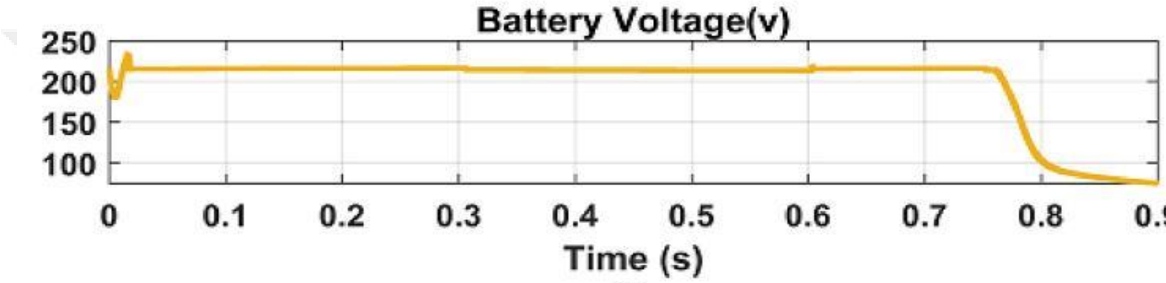


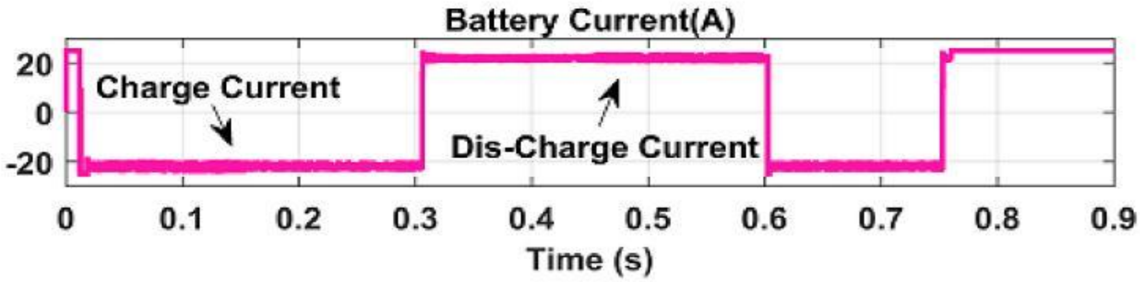
Figure 7.A sustainable energy option Energy production (a) from wind, photovoltaics, fuel cells, batteries, and loads (b) from net energy production, batteries, and loads. (source: reference [24])



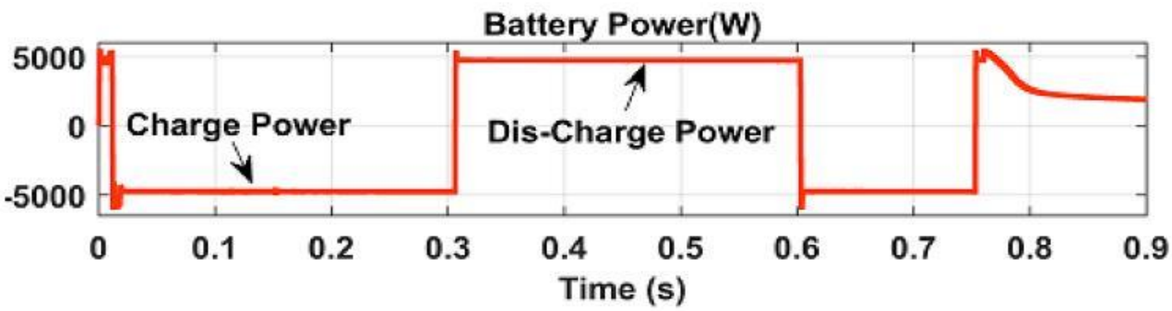
(a)



(b)



(c)



(d)

Figure 8.a)-(d) depicts the reaction of the backup source battery's properties, including state of charge percentage, charge and discharge voltage (213V-220V) Vdc, current (20A-22A), and power 4474W-4700W.

2.6. Power Management and Control

2.6.1. Load Balancing Strategy

The optimal load balancing is key to the successful management of the hybrid smart energy system for DC loads. An electricity management system is vital for the efficient use of power from different sources to meet the fluctuating demand for loads. For a system with mixed renewable energies comprising photovoltaic solar cells, wind energy conversion systems, power electronics, and maybe an energy storage system, the load balancing method is key. The best way to do load balancing is to use the power that gets created from green sources such as solar photovoltaic systems and wind turbines to meet the loads. This covers monitoring the output of these sources and using parameters associated with variations in the speed of the wind, level of irradiation from the sun, and how temperature affects the efficiency of the photovoltaic. With reference to windy and sunny systems, the implementation of MPPT algorithms supports maximum power production via these sources. Also, the mix of power parts, like DC-DC changers for solar cell systems and AC-DC changers for wind turbines, is key for making the best use of power change and sharing. These parts help to change the changing DC output from green sources into a steady form right for powering DC needs. Also, an energy storage system can keep extra energy made during times of high supply for later use when there is not enough being made. The primary goal of the load balancing strategy is the continuous and stable electric power supply to DC loads with maximum exploitation of renewable energy sources. Effectively managing power distribution from different origins considering the load demand, weather circumstances, and energy storage availability would be an approach towards balancing generation with consumption. Incorporating a strong strategy for load balancing within a mixed renewable energy grid for DC loads requires a concerted effort for components including PV systems, wind turbines, power electronics, and perhaps an energy storage system. Optimization of the use of renewable sources of energy and ensuring a stable supply to meet demand for loads will be able to greatly enhance the efficacy and dependability of these systems. Refer to sources: [8] and [6].

2.6.2. Hybrid System Integration Control System

Control system Solar power Windmills electricity storage control system energy conversion management control algorithms vastly improved efficiency systems maximum power point tracking methods used bidirectional dc converter used battery vector control direct power control are used machine side grid side converters advanced energy management strategies enhance efficiency electrical energy transfer simulation studies tested effectiveness control systems throughout a variety of operating conditions including factors such as wind speeds solar irradiance levels and local loads. The results obtained can be applied to the operating conditions, the choice of components, and energy management in a system of hybrid renewable energy. Without doubt, control of the integration is an essential asset in the effective working condition of the renewable sources of energy and thus promotes high output of energy with minimum impact on the environment. see [17] and [15].

System	PV(kW)	WT(kW)	AC/DC(kW)	COE($/kWh)	NPC($)	RF(%)	Prod.(kWh/y)	Cons.(kWh/y)	CO_2(kg/y)
Grid/PV	60	0	45	0.0702	262,927	56.7	194,994	190,575	52,183
Grid/WT	0	144	60	0.124	487,863	37.7	210,832	199,747	78,597
Grid/PV/WT	62	12	43	0.0735	276,775	59.9	199,450	191,646	48,534

Table 7: Find out how the University of Jeddah adjusted its grid-connected HRES systems. (source: reference [9])

2.7. Application in Corrosion Process of Crude Oil Pipelines

A sustainable way to prevent crude oil pipelines from corrosion while both improving operating efficiency and minimizing environmental effect is to employ hybrid renewable energy sources. Integrating solar photovoltaic systems with wind energy conversion systems ensures a steady supply of electricity for DC loads, which are essential for pipeline infrastructure.

To provide electricity for the DC consumption, wind turbines—which are sturdy and can harness wind energy—are necessary. If you want your wind energy conversion system to work as efficiently as possible, you need to think about things like power output and wind speed variations. Similarly, solar photovoltaic systems may supplement the DC load's power supply by reforming sunlight into electrical energy applying the properties of PV cells.

Hybrid power electronics, such as alternating current to direct current converters for wind turbines and solar systems, provide for efficient energy transmission from renewable sources to the load. In addition, MPPT algorithms make sure that the DC load gets a constant supply of power from wind and solar by maximizing their power generation capabilities.

These main renewable sources may be supplemented with an optional energy storage device to put any surplus power produced during peak production hours to good use. Charge and discharge algorithms integrated into battery storage models allow for efficient management of excess energy and the assurance of a continuous power supply even when renewable output is low.

The DC load's stability and dependability may be enhanced by the use of effective power management and control techniques, such as load balancing and control systems that integrate hybrid systems. Reducing the likelihood of operational disturbances is possible via careful management of the distribution of power from different renewable sources.

Combination renewable energy technologies may safeguard crude oil pipelines from oxidation, diminish carbon dioxide emissions, and raise operating efficiency. Integrating sources of clean energy such as sunlight and windmills with sophisticated electrical components and oversight systems enhances efficiency and environmental sustainability while fulfilling the energy requirements of essential infrastructure.

Prevalent techniques for corrosion mitigation include anodic and cathodic inhibitors, protective coatings, and sacrificial anode approaches. The most effective technique is Impressed Current Cathodic Protection, which entails providing electricity to the cathode of the corrosion cell, therefore transmitting electrons over the metal surface. This strategy may aid in environmental preservation and fulfill the energy requirements of essential infrastructure [14] and [16].

2.8. Benefits of Reducing Corrosion with Renewable Energy

Reducing the corrosion rate in the crude oil pipeline is one of the most significant benefits of using sustainable hybrid energy. Apart from decreasing the greenhouse gas emissions, it provides an opportunity to use renewable energy, such as solar and wind power, which come from outside the grid. Environmental benefits resulting from hybrid renewable energy systems can be viewed through gained reliability and reduced CO_2 due to the grid/PV/WT combination. Previous studies showed that NPC, COE, and CO_2 emissions can be minimized with the installation of PV systems in addition to the main grid. Aiming at helping to integrate the PV systems, the optimal design reduces COE and NPC with a constraint that the yearly load demand shortfall should not exceed 0.1%. Hybrid renewable energy systems are a benefit to the economy and the environment as well, as this compares with grid-only systems. Grid/PV systems dramatically reduce carbon dioxide emissions compared to grid-only systems, as shown by environmental assessments carried out in various universities. In comparison with the use of only the grid, it was found that the Al Baha University Grid/PV system reduced CO_2 emission by 54.3%. Many schools are already enjoying the green environment resulting from the installation of hybrid renewable energy sources.

Sustainable reductions in pipeline corrosion and greenhouse gas emissions can be achieved through the integration of renewable energy sources into conventional power networks. The hybrid systems usher in enhanced efficiency and life of business due to the utilization of wind and solar power. Review the cited works [10] and [9].

Investigators-year	Location	System studied	Technique	COE ($/kWh)	RF (%)	CO_2 (kg/y)
Ref. [24]-2019	Uni. of Sharjah, UAE	PV/FC/Battery/Diesel/Grid	Techno-economic	0.092	66.1	24,000
Ref. [25]-2019	Uni. of Sharjah, UAE	PV/FC/Grid	Economic-environment	0.071	40.4	133,000
Ref. [26]-2017	Islamic Azad Uni., Iran	PV/WT/Battery/Diesel	Techno-economic	0.319	100	1,034
Current-2020	Al Baha Uni., KSA	Grid/PV	Feasibility-Sensitivity	0.069	59.1	50,588

Table 8: Brief comparison of related studies. (source: reference [9])

System	PV(kW)	WT(kW)	AC/DC(kW)	COE($/kWh)	NPC($)	RF(%)	Prod.(kWh/y)	Cons.(kWh/y)	CO_2(kg/y)
Grid/PV	62	0	47	0.0688	260,812	59.1	197,315	192,865	50,588
Grid/WT	0	96	60	0.107	406,997	30.2	199,027	194,559	80,055
Grid/PV/WT	65	21	54	0.0707	280,935	66.2	206,421	202,101	43,627

Table 9: Evaluation outcomes of grid-connected hybrid renewable energy systems for Al Baha University. (source: reference [9])

System	**PV(kW)**	**WT(kW)**	**AC/DC(kW)**	**COE($/kWh)**	**NPC($)**	**RF(%)**	**Prod.(kWh/y)**	**Cons.(kWh/y)**	**CO_2(kg/y)**
Grid/PV	55	0	40	0.0753	272,352	50.1	187,713	183,988	58,060
Grid/WT	0	162	60	0.120	496,158	45.1	230,660	209,874	72,820
Grid/PV/WT	43	9	32	0.0806	282,062	43.7	181,712	177,919	63,321

Table 10: At Sattam University, we designed grid-connected HRES systems. (source: reference [9])

System	**PV(kW)**	**WT(kW)**	**AC/DC(kW)**	**COE($/kWh)**	**NPC($)**	**RF(%)**	**Prod.(kWh/y)**	**Cons.(kWh/y)**	**CO_2(kg/y)**
Grid/PV	58	0	44	0.0714	265,273	54.8	192,943	188,984	53,981
Grid/WT	0	162	90	0.0989	466,136	56.1	255,285	239,773	66,573
Grid/PV/WT	62	12	43	0.0726	274,310	60.6	200,772	192,143	47,795

Table 11: Tabuk University's grid-connected HRES efficiency improvements findings. (source: reference [9])

Emissions (kg/year)		Al Baha		Jeddah		Sattam		Tabuk	
	Grid-only	Grid/PV	Grid/WT	Grid/PV	Grid/WT	Grid/PV	Grid/WT	Grid/PV	Grid/WT
Carbon dioxide	110,726	50,588	80,975	52,183	78,597	58,060	72,820	53,981	66,573
Carbon monoxide	314	143	229	148	223	164	206	153	189
Unburned hydrocarbon	35	16	25.6	16.5	24.9	18.4	23	17.1	21.1
Particulate matter	23.7	10.8	18.3	11.3	17.4	12.9	16.1	12	14.7
Sulphur dioxide	258	118	188	121	183	135	169	126	155

Emissions (kg/year)									
		Al Baha	**Jeddah**	**Sattam**	**Tabuk**				
	Grid-only	**Grid/PV**	**Grid/WT**	**Grid/PV**	**Grid/WT**	**Grid/PV**	**Grid/WT**	**Grid/PV**	**Grid/WT**
Nitrogen oxides	2,803	1,281	2,050	1,321	1,990	1,470	1,844	1,367	1,685

Table 12: Detailed environmental results for selected universities. (source: reference [9])

Domestic or residential uses Monthly consumption bracket tariffs		
Consumption less than or equal to 110 kWh (low)	Consumption between 111 and 400 kWh (medium)	Consumption between 401 and 800 kWh (high)

Domestic or residential uses **Monthly consumption bracket tariffs**		
$0.1/kWh	$0.14/kWh	$0.17/kWh

Table 13: Tax brackets for monthly consumption. (source: reference [12])

Categories	**Carbon dioxide emission (kg/year)**	**Carbon monoxide emission (kg/year)**
Low-consumer	443	0.0217
Medium-consumer	653	0.226
Large-consumer	3,259	0.182

Table 14: Comparative ecological evaluation for low, medium, and big consumers, respectively. (source: reference [12])

Type of Hydrogen Fuel Cells	**Advantages**	**Disadvantages**
Solid Oxide FC (SOFC)	Able to reduce the electrolye management problems [sub-ref-254] • -High efficiency	• -High operating Temperature [sub-ref-256]

Type of Hydrogen Fuel Cells	Advantages	Disadvantages
	• -Able to operate with a variety of catalysts [sub-ref-254] • -Fuel Flexibility [sub-ref-255]	• -Several requirements on ceramics material such as chemical compatibility, thermal expansion compatibility, and stability in oxidating and reducing conditions [sub-ref-257]
Polymer Electrolyte Membrane FC (PEMFC)	• -Able to reduce electrolyte management problems & corrosion [sub-ref-254] • -Quick start-up with low temperature [sub-ref-258]	• -High cost [sub-ref-259] • -Complex bipolar plate design [sub-ref-259]

Type of Hydrogen Fuel Cells	**Advantages**	**Disadvantages**
Phosphoric Acid FC (PAFC)	• -High tolerance to the impurities in hydrogen [sub-ref-260] • -High efficiency [sub-ref-261]	• -Lesser power produced compared to other FC [sub-ref-262] • -Short lifetimes [sub-ref-262] • -High manufacturing cost [sub-ref-263]
Molten Carbonate FC (MCFC)	• -Able to reduce the electrolyte management problems • -High efficiency [sub-ref-264] • -Able to operate with a variety of catalysts [sub-ref-265]	• -High manufacturing cost [sub-ref-266] • -Short lifetime [sub-ref-264]

Type of Hydrogen Fuel Cells	Advantages	Disadvantages
Alkaline FC (AFC)	• -Able to operate with a variety of catalysts [sub-ref-267] • -Faster cathode reaction in alkaline electrolyte, thus high performance [sub-ref-268]	• -Short lifetime [sub-ref-269] • -Pure oxygen and pure Hydrogen is required to supply continuously [sub-ref-270]

Table 15: Advantages and disadvantages of major FC. (source: reference [16])

III.METHODOLOGY (DESIGN CALCULATION – I.C.C.P (U/G PIPELINE EXTERNAL)

3.1. INRODUCTION

This chapter explains the testing steps for creating (I.C.C.P) that will be done in a scientific research allowed via the authorities for this type of design, the cathodic protection model is used under different conditions, both internal and external, and disturbances. The inputs to the model are usually the pipe length, diameter, and type of product. External factors such as soil resistivity & PH, etc. If the area that needs protection is big and complicated to measure, you can split it into different zones, like underground or flooded areas, and create a thorough plan for each zone. After splitting the zones, plan the anode types and related devices accordingly.

with pressure acting on the fixed anodes while they are in use. Also, when choosing a coating, you should follow the different coating types. This will assist you in determining the necessary amount based on current demand through prevailing rates and the full anode weight required for cathodic protection.

3.2. Estimates for the Design

3.2.1. Surface Area Calculation (NACE SP0169))

Any area must be assessed independently, devoid of any coverings. If any part of the system is changed by something like weather, that part should be measured separately too. If not, the current measurements might not give accurate results.

$$\mathbf{S = \pi \; x \; D \; x \; L \; x \; 1.1} \qquad \textbf{(III.1)}$$

Where, D : Pipe diameter (m)

L : Pipe length (m)

1.1 : Safety factor (Surface area)

3.2.2. Current Requirement

Total current requirements shall be calculated using the following formula:

$$\boldsymbol{IR} = \mathbf{S \; x \; Id \; x \; (Cb)} \qquad \textbf{(III.2)}$$

Id = Icd + Itc

Where, S : Surface Area (m 2)

Icd : Current Density (mA/m2)

Itc : Temperature Compensation (Opr. Temp(℃) – 25(℃))

Cb : Coating breakdown (5 %)

Id : Current Density with Temperature (mA/ m2)

Uf : Utility factor (20%)

3.2.3. M.M.O Tubular Anode Requirement (NACE-SP0169)

$$\mathbf{N} = \frac{\boldsymbol{IR}}{\mathbf{Ia}} \qquad \textbf{(III.3)}$$

Where, IR : Current requirement (A)

Ia : Anode current output (A / EA)

3.2.4. The Anode resistance (Ra)

$$Ra = \frac{\rho}{2 \times \pi \times L}\left(\ln\frac{8L}{d} - 1\right) \quad \textbf{(III.4)}$$

Where, ρ : Resistivity of soil (ohm-cm)

L : Active depth of Deep Well Ground Bed (cm)

d : Diameter of anode & backfill column (cm)

RT =Ra + Rc

Cable resistance (Rc).

The idea of cathodic protection states that reducing the corrosion rate requires making sure that the impressed cathodic current rapidly reduces the amount of dissolved oxygen in the solution as soon as it reaches the surface. Thus, the cathodic potential that has the lowest corrosion rate is the one that is at the limiting diffusion current. The limiting diffusion current with the (CuSo4) reference cell is seen to lie between -850 mV and -1800 mV, determined by the cathodic polarization curve. This means that -850 mV to -1800 mV is an adequate approximation for the cathodic protection potential..

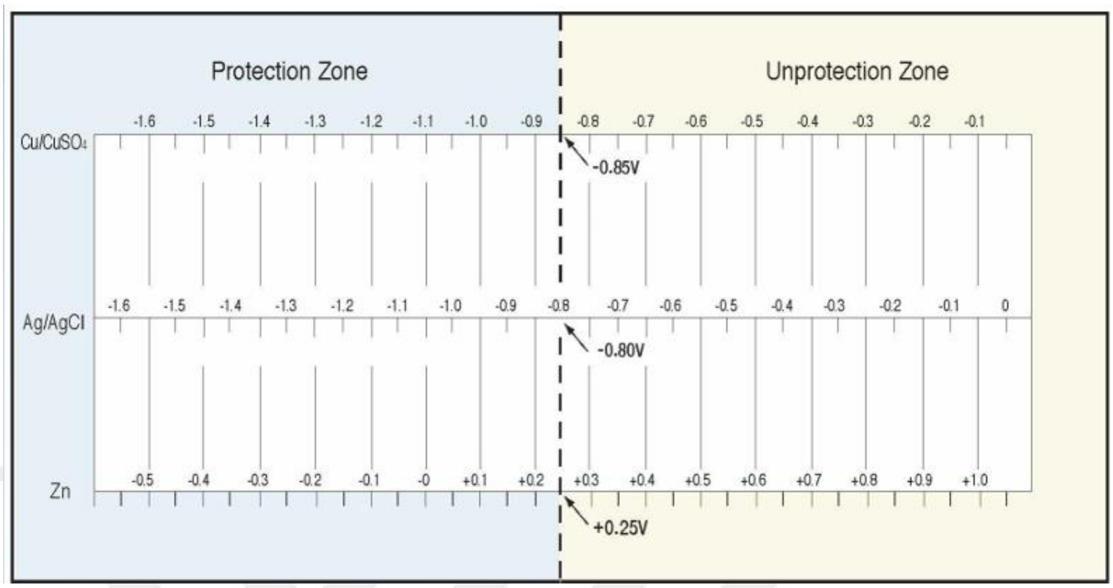


Figure 9.Image is taken from NACE CP2 Manual(range of potential)

In the present investigation, the effect of soil resistivity on substation grounding grid corrosion is assessed. This result indicates the importance of proper adjustment of protective potential in practical situations. In addition, the described research develops a computational approach based on the Boundary Element Method for modeling the distributions of electric potential, current densities, and pipeline protection at different soil sites. This paper will investigate the issue of different soil resistivity effects on pipelines in multi-layered soils. The pipelines in fig. 2. Current density measures the cathodic protection current that is used for each unit of exposed metal surface on a pipeline. The initial and final current levels help determine the number of anodes required and their size.

3.2.5. The Anode Mass Calculation

Once we know the current demand and have chosen an anode, we can calculate the total anode mass. To find the total anode mass (Ma) needed for its duration, you use the following formula:

$$\boldsymbol{Ma} = \frac{\boldsymbol{Icm}\,.\boldsymbol{tf}.\mathbf{8760}}{\boldsymbol{u}.\mathcal{E}} \qquad \textbf{(III.5)}$$

Where;

Ic : Current demand with mean current density

tf: Design life

u: Anode utilization factor

Ƹ : Electrochemical capacity of design.

3.2.6. ANODE NUMBER CALCULATION

“Based on the anode selection, total anode number (N), the mass of anode (Ma) and anode dimension should be obtained in order to meet the conditions for initial and final current (Ici and Icf) outputs and also anode current capacity (Ca).

Concerning to initial and final current outputs, individual current output (Ia) is measured by means of Ohm’s Law:

$$\boldsymbol{Ic = N\ .\ Ia = +\frac{N(Ec^{\circ} - Ea^{\circ})}{Ra} = \frac{N\ .\Delta E^{\circ}}{Ra}} \qquad \textbf{(III.6)}$$

Where;

$\in a$ °: Circuit design potential of anode selected (V)

R : Resistance of anode (Ohm)

I : Individual current output (are to be calculated for initial and final current separately)

$\in c$ °: Potential of protective design

Concerning to anode current capacity, the formula is:

$$Ca\ =\ Ma * \varepsilon *\ u$$

Where;

M : Total anode mass

u: Anode utilization factor

Ƹ: Electrochemical capacity of design

$$Catot = N.Ca\ \geq Icm\ .tf\ .8760$$

$$Iatot\ i = N\ .Iai\ \geq Ici$$

$$Iatot\ f = N\ .Iaf\ \geq Icf$$

Where;

Cato : Total amount of anode current capacity

Icf,cm, Ici : Current demands based on each current densities

Iai and Ia : Individual current outputs for initial and final current densities”

3.2.7. Create Current Density

The cathodic protection current necessary to shield an exposed metal surface is represented by current density (Ic). A number of environmental variables, including atmospheric pressure, pH, oxygen levels, and the presence or absence of saltwater and wave currents, affect the machine's performance. In order to determine the current density, the system is brought to its steady-state protection potential, and its mean design current density is used. The calculations are based on the DNV-B401 standards.

Depth (m)	Design Current Densities (initial/final) in A/m²			
	Tropical (>20°C)	Sub-Tropical (12-20°C)	Temperate (7-12°C)	Arctic (<7°C)
0 - 30	0.150 / 0.090	0.170 / 0.110	0.200 / 0.130	0.250 / 0.170
> 30	0.130 / 0.080	0.150 / 0.090	0.180 / 0.110	0.220 / 0.130

Figure 10,Densities of current for the beginning, middle, and end components as a function of depth and local conditions based on DNV [37]

3.2.8. Coating Degradation Factor (fC)

The coating disintegration factor refers to the degree to which the coating contributes to an increase in the drop in current density (i.e., g). A number of factors, including time, operating circumstances, and coating quality, all have an impact on the coating breakdown factor. Whereas the value of the coating breakdown factor might range anywhere from 0 to 1, it is measured. In the event that the result is zero, it indicates that the coating is capable of providing a hundred percent electrical insulation, while a result of one indicates that the coating is unable to give any electrical insulation at all.

“FC, can be estimated as follows;

$FC = k1 + k2 * t$

Where;

t : lifespan of coating

k1 +k2 : constant values of coating properties

When it comes to dirt, there are four different paint coatings that may be classified according to the impact that E has on the coating system."

3.2.9. Current Drain Design Parameters

In the CP system, it is necessary to incorporate all of the components that are connected by means of electricity into the estimation of the flow of current. It is necessary to take into account both the current density and the layer breakdown factor in order to successfully calculate the flow of current in buildings where CP is not required.

What will happen is contingent upon the portion of the system's exterior that will be covered in sand. Assuming that it utilizes 5 Amps per well, the current draw estimate for a decent covering is based on this assumption. Due to the usage of cement, subsea wells have a greater loss of current compared to platform wells. It is essential to make preparations for 8 Amps per well since there is a possibility that the construction of subsea wells would result in a substantial current drain.

When designing for the current flow of anchor chains, which only includes docking at the top side, it is important to take into account thirty meters of each chain. The design of the mooring system should take into consideration the chain section that is in touch with saltwater when the system is at sea level. Additionally, the design should extend 25 meters from the docking point for each chain.

on the basis of the recommendation of DNV B401.

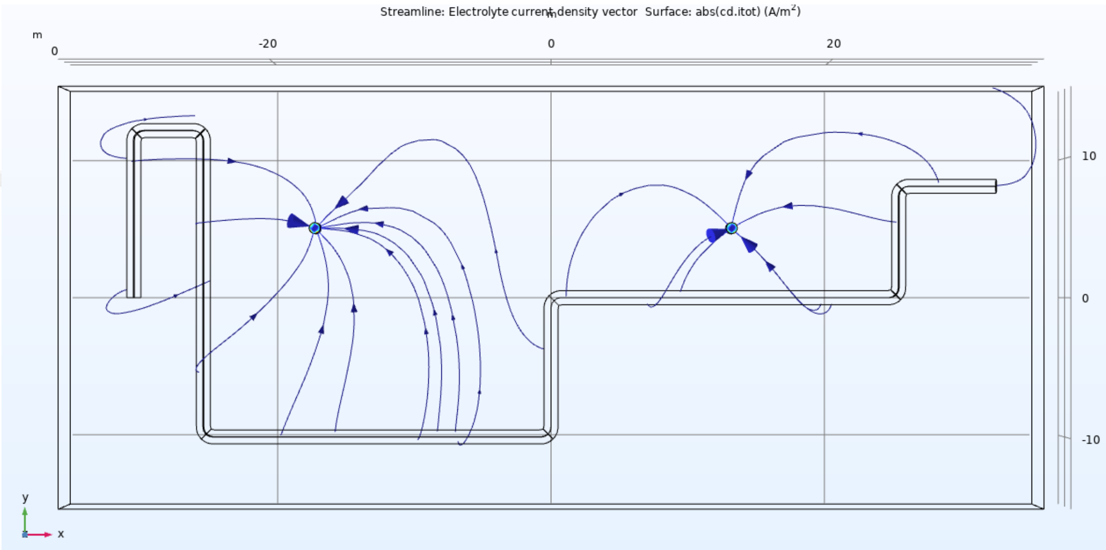


Figure 11.Current Density Distribution

IV. SIMULATION AND RESULTS

4.1. Introduction

The main goal of this thesis is to describe the model of the electrical protection of underground pipeline systems and to carry out design analysis for covered and bare cathodic protection, including the power needs to supply the system with direct current from sources of renewable energy.. The Hybrid System shown in Figure (Iv.1) is modeled using MATLAB program. The photovoltaic and turbines serve as the principal power sources for the Hybrid-RES, while the battery system acts as a backup to provide power when there isn't enough produced by the solar system. The battery energy storage system (ESS) can store and provide power based on the abundance of solar power and energy demand. This helps maintain a balance of power and keeps the system's frequency at normal levels. Three converter controllers are used in this work: the MPPT for the PV system, the battery charging and draining controller, and the MMPT for the wind system.

4.2. Simulation of The CP System

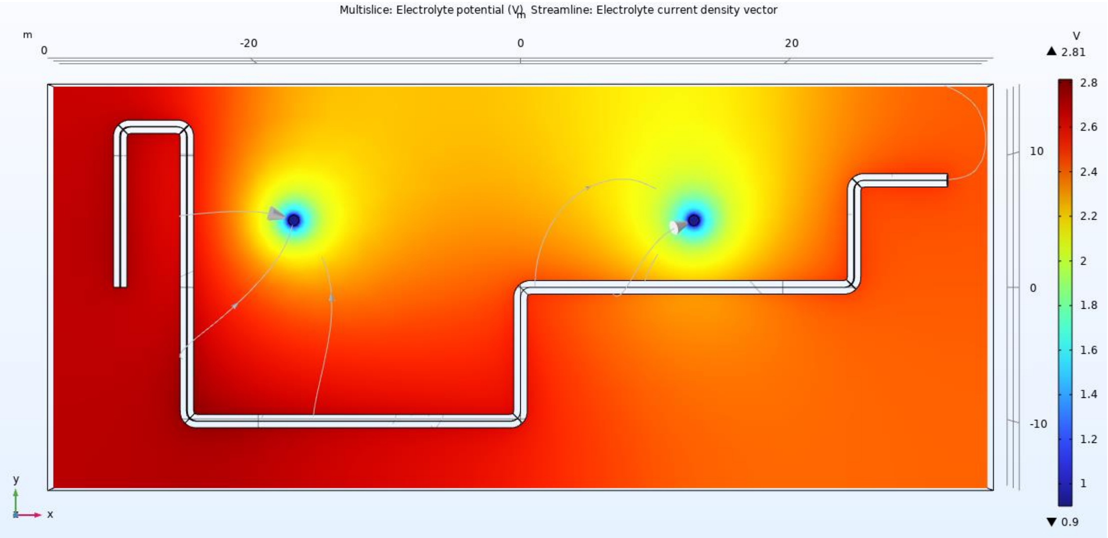


Figure 12.Suggested CP system simulated by COMSOL

The controller module diagram was produced using simulations in the COMSOL/Simulink environment, facilitating the assessment of anode characteristics for a 30-meter subterranean design.

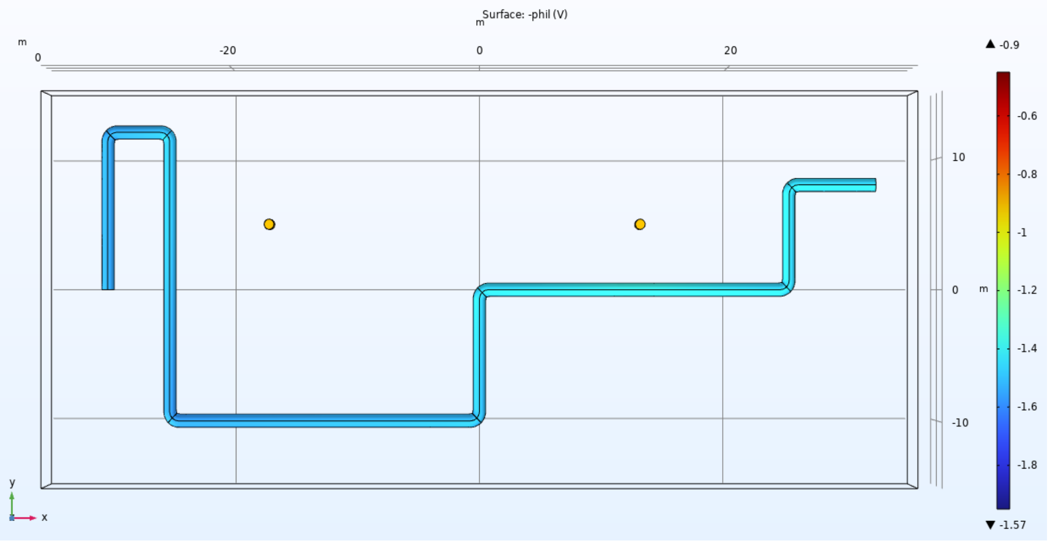


Figure 13,The Pipeline Under Protection System.

From **Hata! Başvuru kaynağı bulunamadı.** the Current density 5 (mA/ m2) pread around the pipeline to The structure was safeguarded against rust using a $Cu/CuSO_4$ reference electrode at pH 7.04, with soil resistivity of 20 (ohm-cm) and a corrosion potential ranging from 1100 to 1600, which falls within the protected range. The primary input parameter is detailed in the table.

Service	Size (inch)	Length (m)	External Surf Area	Operating Temp	Current Density	DC V Out	DC A Out
Crude Oil	32	1,250	3,511.53 m2	25	20 mA/m^2	37.1 V	12A

Table .24: Design For U/G Pipe Line (I.C.C.P)

This calculation sheet defines the requirements of system design, equipment / materials of an impressed current system for underground pipeline for Karbala Refinery Project. And this calculation sheet provides the parameters to develop a suitable impressed current cathodic protection.

4.3. Simulation of The Hybrid Renewable Source System

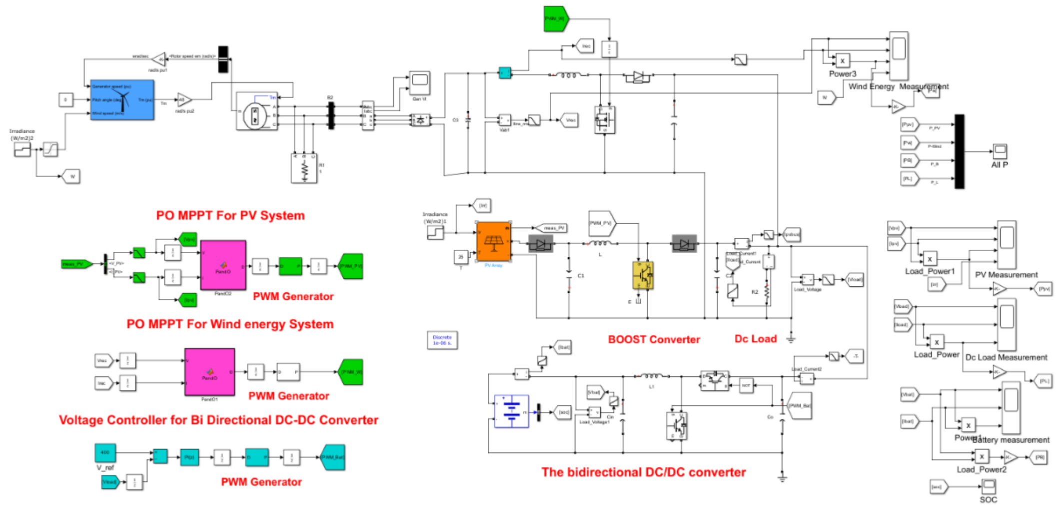
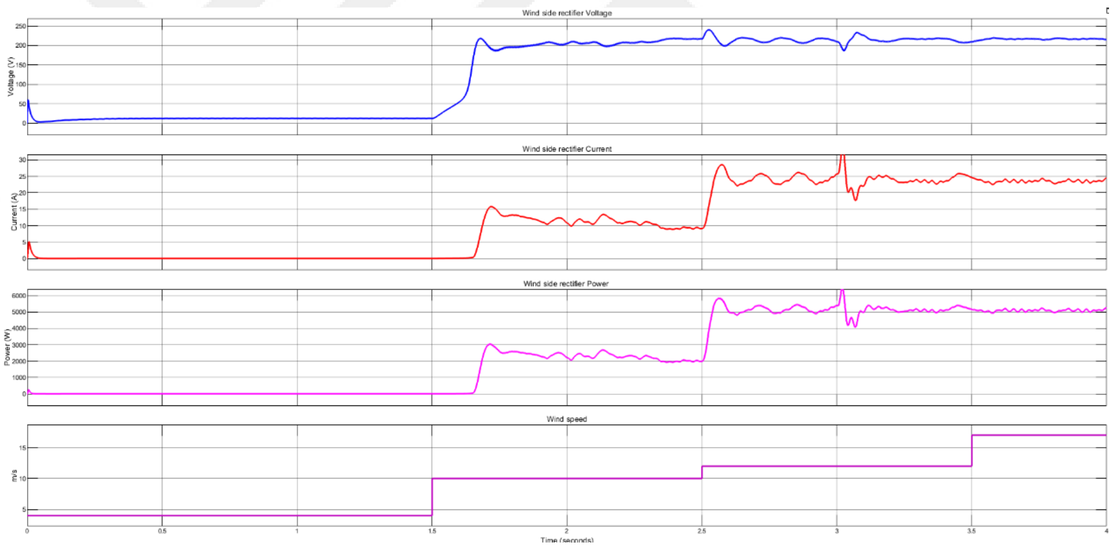
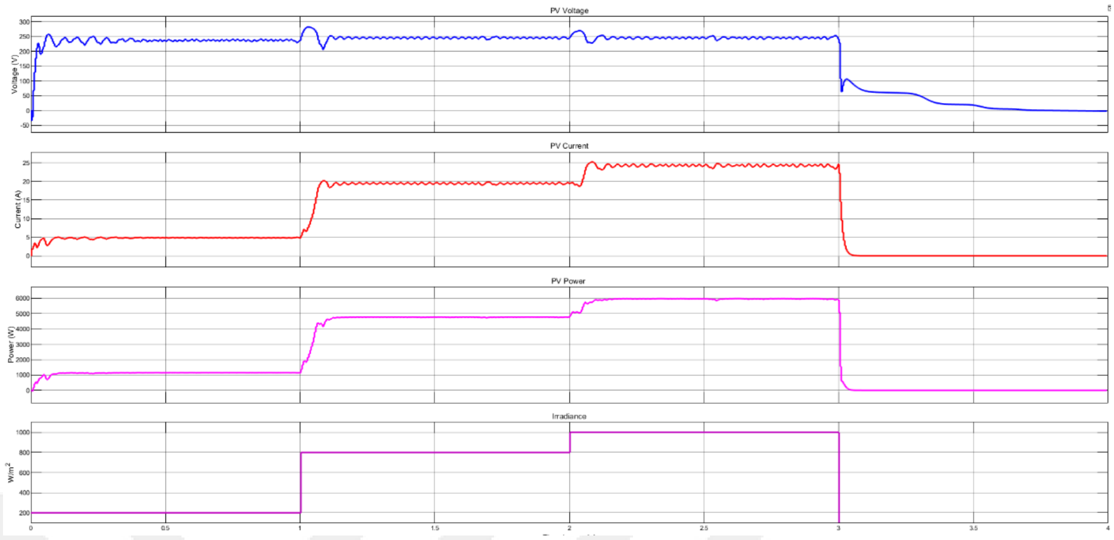


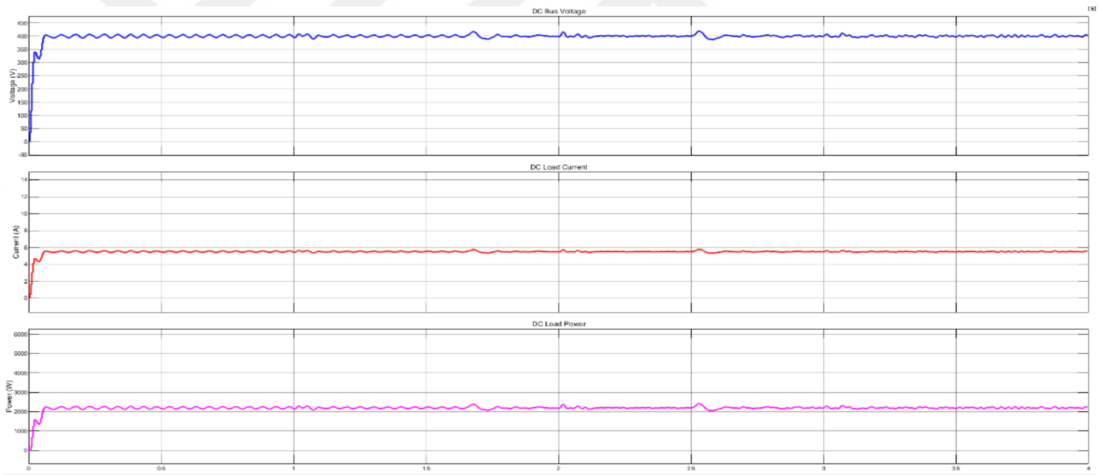
Figure 14.Suggested Hybrid-RES system simulated by MATLAB



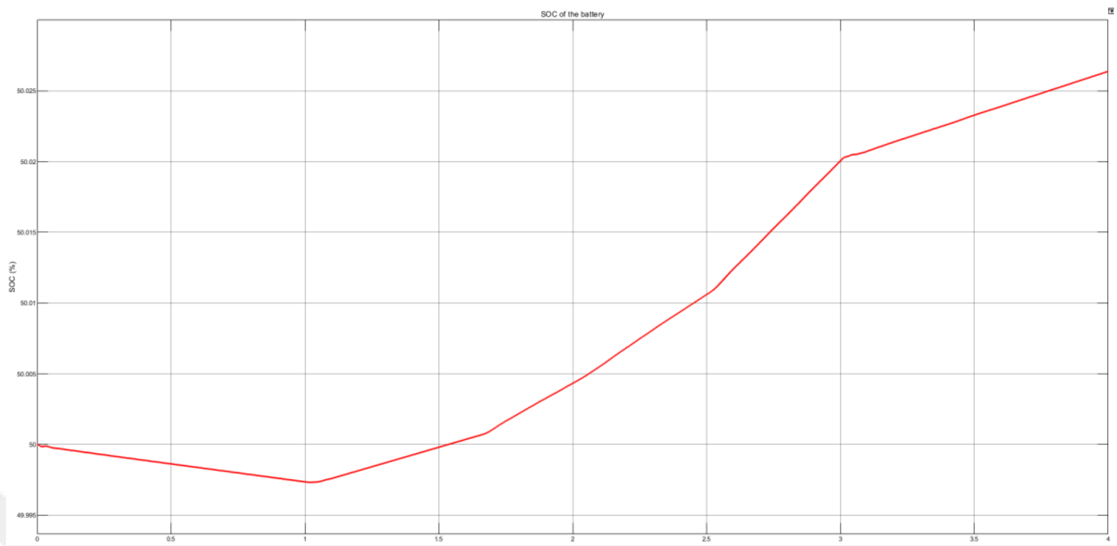
a-Wind Energy



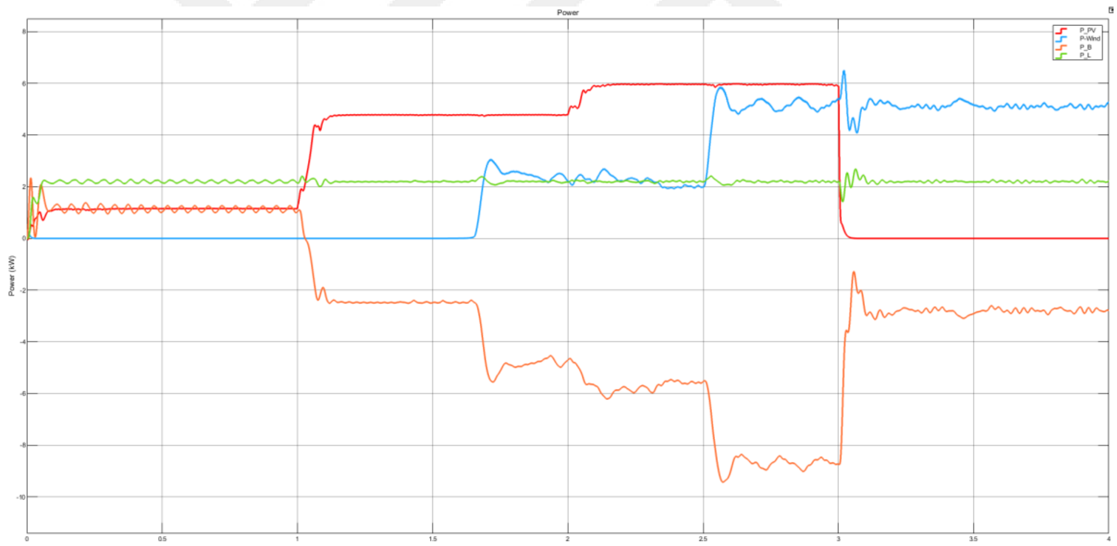
b-PV Energy



c-Dc Bus Load



d-SOC



e-All Power Source

Figure 15. The Result of MATLAB Simulation

At the beginning of the first interval, the light intensity is set to 200 W/m², and the velocity of wind is 4m/s. At the start, the windmills don't produce any power, from the wind. But within a few milliseconds, they start generating about 270 W. The solar panels (Ppv) generate insufficient energy to meet the demand, thereby drawing power from the battery. At this moment, there isn't any extra power available.

In the second case, the solar power is raised to 800 W/m², and the wind is blowing at a velocity of 10 m/s. When the amount of power required decreases relative to the amount of power given, the energy goes into charging the battery until it is completely full. Meanwhile, the solar panels produce 800 W right after the sunlight increases. This power is enough to power everything,

Here we show a third scenario when the PV irradiation is raised to 1000 W/m² & the wind speed is 12 m/s. When the amount of power required decreases relative to the amount of power given, the energy goes into charging the battery until it is completely full.

In the final scenario, we see that the PV array doesn't produce any power at all when the irradiance is set to 0 W/m² and the speed is set to 17 m/s. However, the wind turbine does produce around 5000W, is the same amount of power at speed (12m/s) since the mechanical speed limiter is set at (12m/s)which is an excess of power to extra load, but it will be wasted since the battery is already full.

VI.CONCLUSION

5.1. Conclusion

A-This section presents the results obtained from HOMER, an output stating that the system should have no annual capacity shortages for a period of 20 years. According to the (Table.16. in HOMER), stand-alone system appears to be the best choice as it has good output capacity with low initial costs and also with low running costs; the net price cost (NPC) for the project is [$28,147], and the O&M cost is [$20]; the system comprises the battery storage part, the wind machine part, and the sola cells part. A device that is generally powered by green electricity will need a battery set. Even with one of the two- either the solar panel or the wind turbine-missing, the setup can still operate. Thus a hybrid set with solar panels together with batteries can be realized or a wind machine together with batteries.

To supply affordable energy to CP units in remote areas, the results of this study can help in the setup of an independent integrated wind and solar technology. Sunshine and wind are plentiful and potentially valuable in south and central parts of Iraq. We advise installing the recommended optimal hybrid system in subsequent research to validate its performance

Architecture					Cost				System		PV		T701			Li.ONESS			
PV (kW)	PV-MPPT (kW)	T701	Li.ONESS	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Capital Cost ($)	Production (kWh/yr)	O&M Cost ($)	Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)
5.56	1.00		2	CC	$19,141	$0.609	$330.74	$13,344	100	0	8,344	3,558				44.2	1,138	10.2	9.22
4.80	1.00	1	2	CC	$28,147	$0.881	$339.31	$22,200	100	0	7,200	3,463	10,000	3,828	20.0	44.2	632	10.2	9.22
		2	2	CC	$30,036	$0.952	$287.31	$25,000	100	0			20,000	7,656	40.0	44.2	621	10.2	9.22

Table.16 Cost level list established

B—This study discusses the details of an impressive current cathodic protection device. The test results show that the cathodic protection current goes up when the temperature, conductivity, and oxygen flow rate of the saltwater solution are all raised.

5.2. The Future Operation

Additional investigation of alternating current corrosion interference in subterranean long-distance pipelines and the use of artificial intelligence methods like algorithmic optimization and machine learning to enhance energy management systems are also emphasized in this thesis. It also stresses the need for integrating algorithms for load demand prediction and solar radiation, as well as evaluating the effect of wind turbines on system frequency.

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