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Design and Optimization of Hybrid Renewable Energy Systems for A Residential House in Babylon, Iraq: Insights From Homer Software Analysis

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Abstract. *The study investigates the development and improvement of hybrid renewable energy systems for a residential residence in Babylon, Iraq, utilising the HOMER programme. The project aims to determine the most efficient and cost-effective energy system design for residential usage, in response to the growing global need for sustainable and renewable energy sources. The process entailed examining different permutations of solar photovoltaic (PV) panels, wind turbines, and battery storage devices. According to the results, an off-grid photovoltaic (PV) and battery system is the most cost-effective option, with the lowest upfront investment and ongoing expenses. Nevertheless, the integration of wind energy, although enhancing the dependability and variety of the system's energy sources, results in higher upfront and ongoing costs. These findings offer vital information for politicians and engineers to implement renewable energy solutions that are customised to Iraq's specific meteorological and economic circumstances.*

Keywords: *Renewable energy, wind turbine, NASA, Homer.*

1. INTRODUCTION

The increasing worldwide need for energy, particularly from environmentally friendly and renewable sources, is gaining momentum, protecting the environment by managing pollution and reducing greenhouse gas emissions has become a critical global priority. While fossil fuels remain widely used and are not likely to be phased out in the near future, the days of abundant and cheap energy from these sources are dwindling. Therefore, there is an urgent need to explore alternative energy sources, with a particular focus on renewable energy. This shift is essential not only to address the environmental impacts associated with traditional energy sources but also to ensure a sustainable and secure energy future. As we transition from fossil fuels, the development and implementation of renewable energy technologies become increasingly important to meet the world's energy demands while minimizing environmental damage.[1] In the European Union, green energy sources will provide 50% of the electricity by 2040. In China and Japan, they will provide about 30%, and in the US and India, they will provide over 25%. Outside of Asia, coal will provide less than 15% of the electricity.[2], Base-load energy is made by traditional power plants that mostly use coal or gas. These plants do, however, pollute the environment and add to the greenhouse effect, which is bad for the environment, because they use the sun as a heat source, Concentrating Solar Power Plants (CSPPs) are a better option. Many mirrors or lenses work together to focus a lot of sunshine on a small area of these plants. The focused light is then used to heat an engine, which works in a way similar to how

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*heat engines are used in fossil fuel power plants to turn heat energy into electricity, along time ago, people started thinking about using sun thermal power. It was shown for the first time in Germany in 1907, after the 1973 oil crisis, there was a lot of interest in solar energy as a way to heat water for power plants in the United States. In California in the late 1980s, the first commercial solar thermal power station was built, as more people switch to green energy, these solar power plants play a big role, they provide a long-term way to make electricity that reduces our reliance on fossil fuels and lessens our impact on the environment. [3] p*resently, Iraq is in need of additional electricity to fulfill the increasing demands of its people. The population of Iraq had a substantial the population rose from 14 million in 1980 to 32 million in 2010, and it is projected to reach over 64 million by 2050.[4] there were 2.75 million more people living in Iraq in 2000 than there were in 1980. The population growth rate rose to 3.23% between 1995 and 2000. In addition, the rate of growth has declined to 2.72% between 2000 and 2005, and it is expected to reach 1.09% between 2045 and 2050. [5], therefore, a greater amount of energy is necessary to facilitate economic growth and address the recurring shortage of power on a daily basis. As per the Ministry of Energy, the highest level of electricity required in 2008 was 12,000 MW, but only 6000 MW was supplied, power systems in Iraq and other countries around the world are having more problems than usual with power outages. As a result, energy policies and rules should be looked at again all over the world. Most of these crises have been directly linked to climate change (more natural and environmental disasters), old infrastructures, changes in the market due to things like money problems, wars, rumors of wars, and terrorist threats; and higher demand for and loads on electricity grids.[6], also, Iraq has a short-age of power, and the effects of wars and terrorist attacks have made everyone work hard to find ways to make power output better. Still, using batteries is thought to be an important part of storing low-energy amounts. Depending on the weather and the fluctuation of green energy sources, batteries need to store energy that isn't being used or that is extra for times when there is extra energy. [7] to make the best system with a link for a hybrid traditional/RE system, HOMER software is used. PV, wind rotor, grid, batteries, and a power converter make up the hybrid system. At first, the system was planned and improved to meet all the standards that were needed, then, all the technical, economic, and environmental details were looked into in great depth and discussed. The figure 1 represent the step to design the hybrid system.

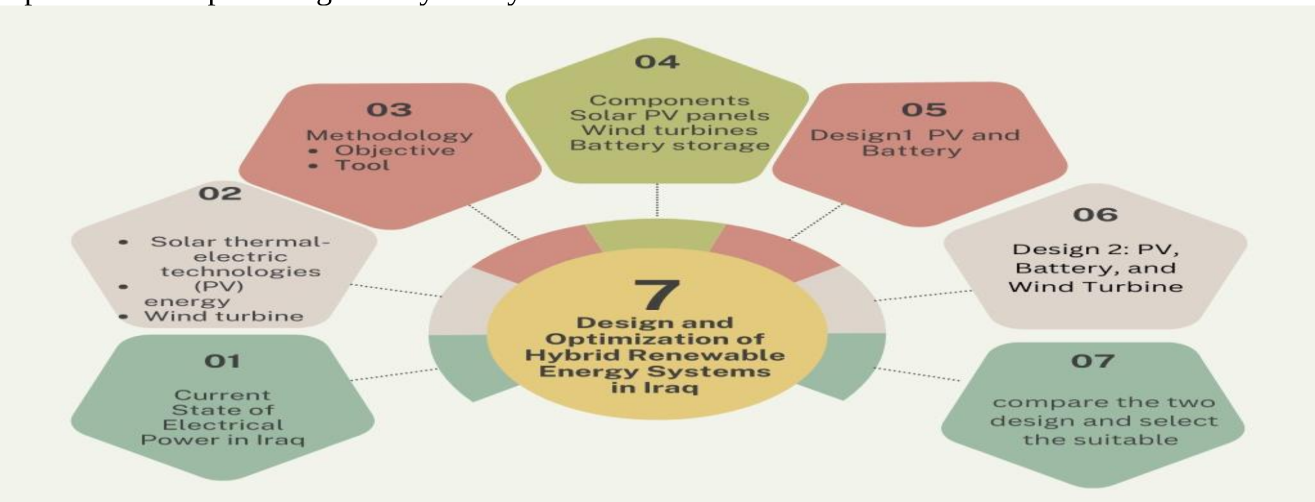

Figure 1. Flow chart represents the step of design and optimization of hybrid renewable energy system

3.SOLLAR ENERGY

Various technologies are able to capture solar radiation and convert it into useable energy. sun thermal-electric refers to the process of concentrating sun radiation using specialized equipment, mirrors are used to generate high-temperature heat for the purpose of producing energy[8, 9]

Solar photovoltaic (PV) energy refers to the process of converting sunlight into electricity using photovoltaic (PV) modules. The majority of the photovoltaic modules have the capability to be installed on the exteriors of buildings, including both the facades and roofs. [8], solar energy is an inexhaustible resource that is considered a divine gift. The sun's irradiation began 4.6 billion years ago. Solar PV Energy refers to the generation of electricity using photovoltaic (PV) technology, which converts sunlight directly into electrical energy, the solar energy system possesses several advantageous characteristics. It is dependable, plentiful, eco-friendly, and can be installed in a decentralized manner. It requires minimal maintenance, is clean and lightweight, and can be integrated with IC technology. Moreover, it has a long lifespan of over 25 years. Most importantly, the majority of solar energy systems are made from silicon, which is the most abundant element in the earth's crust. Additionally, once operational, it can generate electricity at a low cost. The annual solar radiation incident at the Earth's surface exceeds the total primary global energy consumption by a factor of over 10,000. In other words, the solar radiation incident at the Earth's surface in one hour is greater than the overall primary energy consumption.[10, 11], The solar radiation rate is influenced by the sun's latitude and the environmental conditions in various zones on Earth, the solar energy varies based on the geographic location, season, and monthly fluctuations , additionally, the amount of solar energy is also affected by the specific geographical location.[10, 12]

3.1 PHOTOVOLTAIC CELLS

A photovoltaic cell is a type of semiconductor device designed specifically to transform sunlight into electrical energy. The process of converting light into electricity within a solar cell is referred to as photovoltaic (PV) conversioni mpact. Photovoltaic is derived from the words "photo," which refers to light, and "voltaic," which refers to electricity. [13]The efficiency of a solar cell is contingent upon the type of material used for its fabrication, as different materials possess distinct absorption spectra.[14], after many years of study, technological progress, and economies of scale, silicon solar cells are now widely used. This has made the business mature and well-established, scientists and researchers have been looking into other materials to make solar cells even more efficient and to fix some problems with silicon [15]
Although there are many different types of solar panels, they are generally classified into a few main categories based on their material and construction.[16, 17]

- *Polycrystalline Silicon Panels*
- *Monocrystalline Silicon Panels*
- *Thin film panel*

In practical cases, a solar cell will absorb light that includes both direct solar radiation and diffused light that is reflected from nearby surfaces. In order to maximize radiation absorption, solar cells are frequently coated with anti-reflective material [18] The photovoltaic cells can be arranged in a series to form a panel, and these panels can be connected in parallel rows to produce various configurations, as depicted in the figure (2)

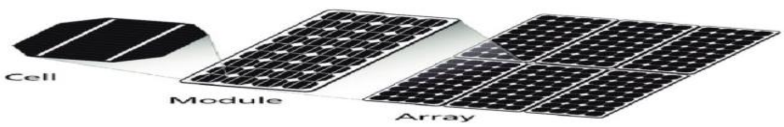

Figure 2 *Execution of Solar Arrays module[19]*

3.2 Review of Various Battery Technologies

1. *Lead-Acid Batteries:*
    - *Pros: Low initial cost, widely available, reliable for short-term storage.*
    - *Cons: Lower energy density, heavy, limited lifespan, and higher maintenance.*
    - *Appropriateness: Suitable for applications with lower energy demands and where cost is a significant concern. Not ideal for high-efficiency or long-term applications due to shorter lifespan and higher maintenance requirements.*
2. *Lithium-Ion Batteries:*
    - *Pros: High energy density, longer lifespan, lower maintenance, better efficiency.*
    - *Cons: Higher initial cost, potential safety concerns if not managed properly.*
    - *Appropriateness: Ideal for applications requiring high energy efficiency, long-term storage, and lower maintenance. Suitable for residential and commercial energy storage where reliability and efficiency are critical.*
3. *Nickel-Cadmium (NiCd) Batteries:*
    - *Pros: Durable, can handle a wide range of temperatures, relatively long lifespan.*
    - *Cons: Cadmium is toxic, has lower energy density, high initial cost.*
    - *Appropriateness: Useful in industrial applications where environmental conditions are harsh and reliability is essential. Less appropriate for residential due to environmental concerns.*
4. *Flow Batteries:*
    - *Pros: Scalability, long cycle life, can be fully discharged without damage.*
    - *Cons: High initial cost, complex system, larger space requirements.*
    - *Appropriateness: Best suited for large-scale storage applications like grid storage or large commercial facilities where long-term storage and scalability are necessary.*
5. *Sodium-Sulfur (NaS) Batteries:*
    - *Pros: High energy density, long discharge duration, good for large-scale storage.*
    - *Cons: High operating temperatures, safety concerns, high initial cost.*
    - *Appropriateness: Suitable for utility-scale energy storage where large amounts of energy need to be stored and delivered over long periods. Not ideal for residential use due to safety and temperature requirements.*
    -

Selecting suitable battery technology is vital for maximizing the efficiency and durability of energy storage systems, lithium-ion batteries presently provide the optimal equilibrium between efficiency, longevity, and upkeep, rendering them well-suited for a diverse array of uses, such as household and commercial energy storage. Nevertheless, in certain scenarios, alternative technologies like as flow batteries or sodium-sulfur batteries might be more suitable, despite their greater upfront expenses, because of their flexibility to be scaled up and their long-term discharge capabilities. To choose the most appropriate battery technology, it is crucial to comprehend the precise requirements of the application, such as energy requirements, environmental conditions, and budget limitations.

4. Advantages of the Hybrid System for the Environment

1. Reduced Greenhouse Gas Emissions

A hybrid renewable energy system offers a notable advantage in terms of environmental impact by effectively decreasing the release of greenhouse gas (GHG) emissions. Conventional energy sources, such as coal, oil, and natural gas, play a significant role in the release of greenhouse gas (GHG) emissions, which are a fundamental cause of climate change. The hybrid system effectively reduces these harmful pollutants by using renewable energy sources such as solar and wind.

2. Decreased Air Pollution
Hybrid systems not only contribute to the reduction of greenhouse gas (GHG) emissions but also aid in the mitigation of air pollution. Fossil fuel power plants release a range of harmful substances, such as sulphur dioxide (SO2), nitrogen oxides (NOx), and particulate matter, that can have detrimental effects on both human health and the environment.
3. Preservation of Natural Resources
Hybrid systems that include renewable energy sources aid in the preservation of limited natural resources. Fossil fuels are finite resources that cannot be replenished and their extraction and utilisation result in the depletion of natural reserves, disturbance to ecosystems, and damage of the environment, the hybrid system encourages sustainable resource usage by harnessing solar and wind energy, so meeting energy needs without destroying natural reserves.
4. Mitigation of Climate Change Impacts
Hybrid renewable energy systems can mitigate the effects of climate change by decreasing the dependence on fossil fuels and reducing greenhouse gas emissions.

5. METHODOLOGY

The primary goal of this paper is to design a hybrid energy system capable of supplying sufficient electrical power to satisfy the energy requirements of a residential home located in Iraq in Babylon to achieve this, the study utilizes the HOMER software, a powerful tool for simulating and optimizing hybrid power systems, this software helps in determining the most effective combination of different energy sources, such as solar, wind, and Battery, to ensure reliable and cost-effective power supply to the house. The use of HOMER allows for detailed analysis and modeling of various system configurations, optimizing them to meet specific load demands while considering factors like cost, reliability, and environmental impact. This approach not only provides a sustainable solution to energy needs but also enhances the efficiency of the system by carefully selecting and sizing the components to maximize performance and minimize costs and its explores the feasibility of using a hybrid renewable energy system to make a residential home entirely off-grid. It posits that such a system, carefully designed and optimized using the HOMER software, is capable of meeting all the electric power needs of the house. HOMER software plays a crucial role in this analysis by simulating various combinations of renewable energy sources such as solar panels,and wind turbines to identify the most efficient and sustainable configuration, this approach demonstrates the practicality of off-grid living through renewable energy solutions, promoting sustainability and independence from traditional power figure 3 represent the house model.

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Figure 3 *Model with pictures (ground floor and first floor).*

The assumed lifespan was 25 years. A 90% derating factor was applied to the electrical output of each PV panel. The panels were designed to be stationary and inclined towards the south at an angle that matches the latitude of the location since the system operates continuously for 24 hours, the inclusion of a battery and controller is essential throughout the battery's entire lifespan, HOMER assumes that the battery parameters remain constant and are not affected by external factors, such as temperature the selected battery has a capacity of 6 volts and 360 ampere-hours, is essential for effectively storing renewable energy and ensuring a continuous power supply. It is designed to be durable, cost-effective, and efficient, making it a suitable choice for use in hybrid energy systems, figure 4 represents the specifics of the battery, and figure 5 represents the meteorology and solar energy database in Iraq taken from NASA.

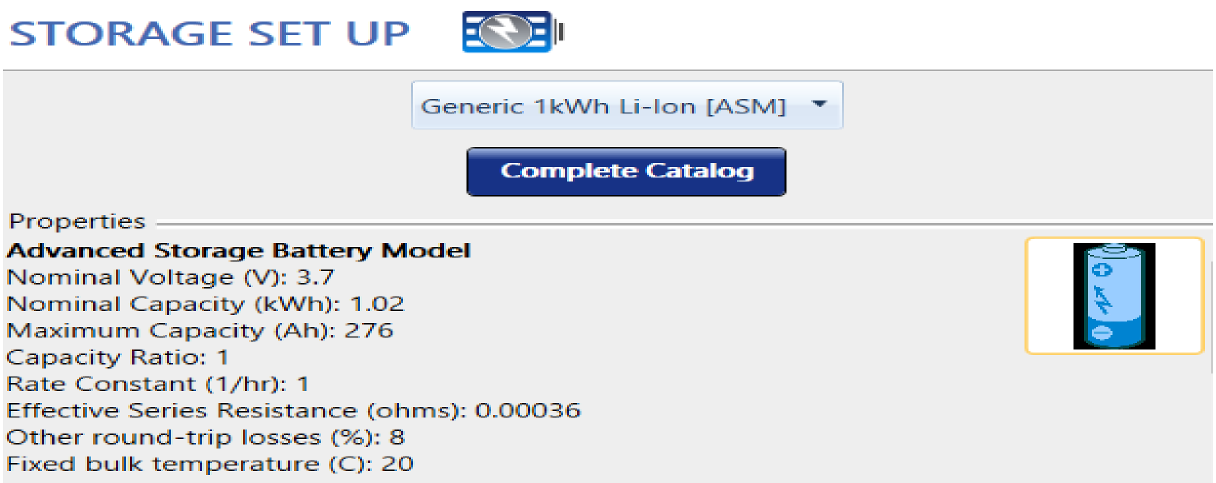

Figure 4 *the specific properties of battery model used*

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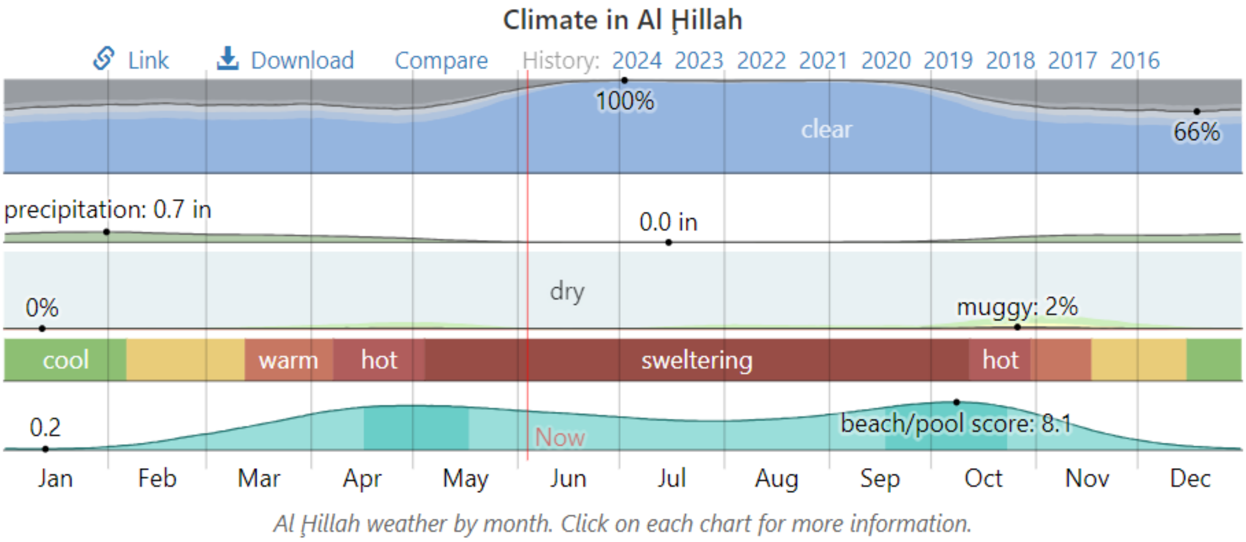
(a)



(b)

***Figure 5** surface meteorology (a) from NASA (b)from Weather Spark[20]*

5.1 LOAD

Energy consumption assumed is 13.54 kilowatt-hours per day, remaining consistent both throughout the day and at night. There is a minor increase in power consumption in the morning, reaching a few hours before noon. It then slightly increases again in the evening, with the peak load value at 2.88 kW. This includes the use of compact lamps and some DC voltage devices such as TVs, figure 6 Represents energy consumption in kilowatts (kW), ranging from 0 to 3 kW of the the months from January (Jan) to December (Dec) and showed Energy consumption increases during the hotter months (June to September), indicating higher usage of cooling systems , its lowered during the colder months (December to February), indicating reduced use of heating or air conditioning systems.

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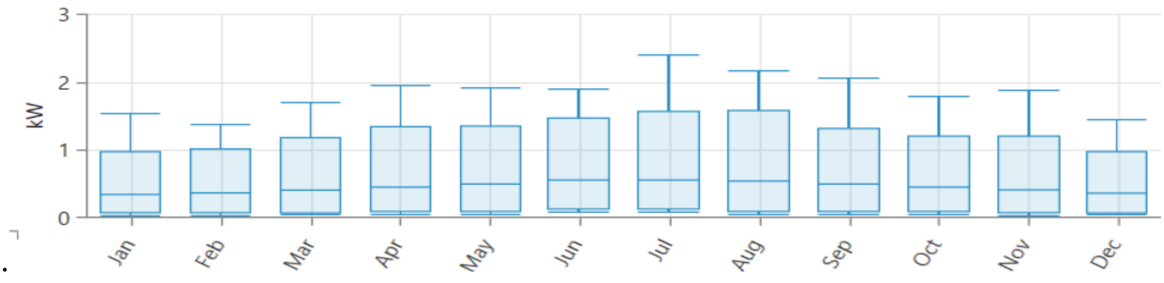

***Figure 6** seasonal profile*

In figure 7 Energy consumption starts to increase gradually from the early morning (around 3 AM) as people begin to use electrical devices. This increase continues until it reaches the first peak around 9 AM., during the daytime, energy consumption remains relatively steady with slight increases, reflecting the continuous use of electrical appliances such as computers, lighting, and cooling devices, in the evening, energy consumption rises significantly again, with a clear peak around 6 PM, this indicates heavy use of electrical appliances such as ovens, air conditioners, televisions, and lighting, the highest energy consumption (peak consumption) occurs in the evening, suggesting that this is the time when the most energy is used. Conversely, the lowest energy consumption levels are during the late night to early morning hours, indicating minimal use of electrical devices as most people are asleep.

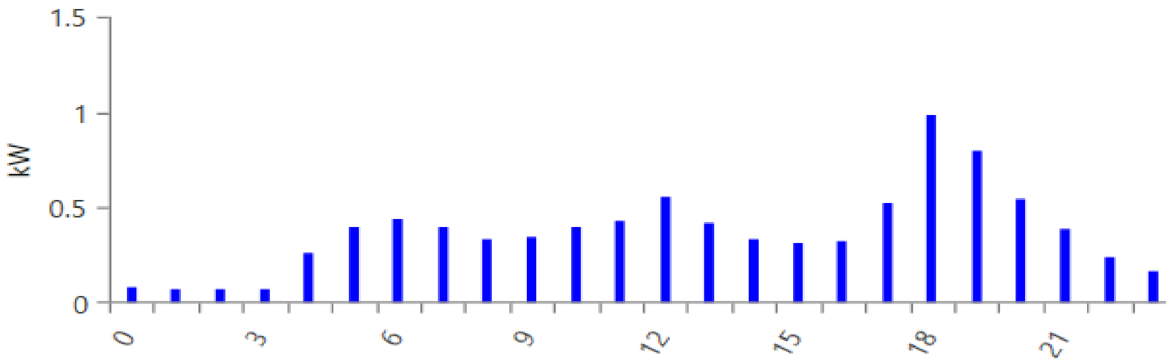

***Figure 7** load profile*

Figure 8 depicts the energy consumption pattern over an entire year, with the horizontal axis representing the days of the year (from 1 to 365) and the vertical axis representing the hours of the day (from 0 to 24). The color scale on the right indicates the intensity of energy consumption in kilowatts (kW), ranging from 0 kW (black) to 2.5 kW (red), throughout the year, the graph shows consistent bands of color that indicate regular patterns of energy consumption. The most intense energy usage occurs during the late afternoon to evening hours, approximately from 16:00 (4 PM) to 20:00 (8 PM), as shown by the yellow and red bands. This period likely corresponds to peak household activity, such as cooking, lighting, and the use of electronic devices, during the early morning hours (0:00 to 6:00), the graph shows lower energy consumption, indicated by the darker blue and black colors, this suggests minimal use of electrical devices when most people are asleep. Energy consumption gradually increases in the morning, with moderate usage throughout the daytime, as indicated by the lighter blue and green colors, the consistency of these patterns over the entire year highlights the predictable nature of daily energy usage, with peaks in the evenings and lower consumption during the night and early morning

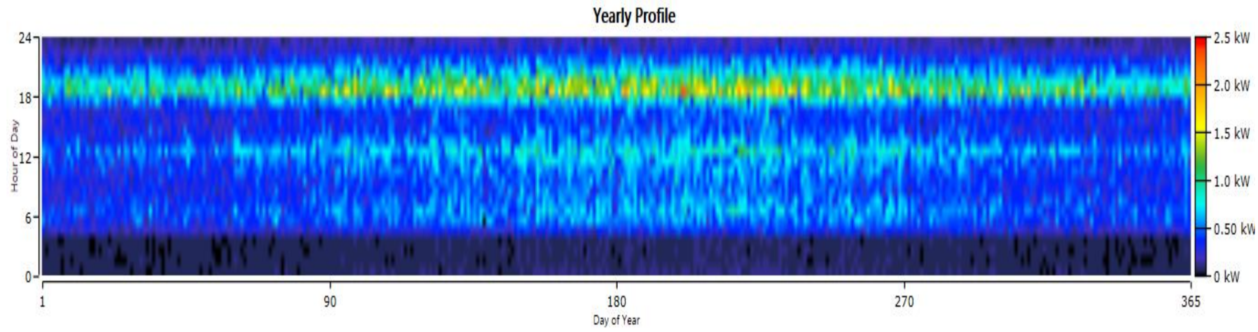

***Figure 8** yearly profile*

5.2 DESIGN 1 (HYBRID POWER SYSTEM (PV AND BATTERY) OFF GRID

The figure 10 signifies that the renewable sources that are relevant in that area are solar panels and batteries, ahybrid power system is composed of a primary load of 13.45 kWh/d and 2.39 kW peaks that are connected to the AC bus.Photovoltaic (PV) modules provide direct current (DC) electricity, which is then transformed into alternating current (AC) via an inverter in order to power the AC load. The electricity generated can be stored and utilized during nighttime by adopting a storage mechanism, such as a battery. Batteries utilized for this objective possess a substantial storage capacity. The system comprises PV modules, an inverter, batteries, circuit breakers, and specialized cables to provide efficient power for the designated load the solar system specification are:

1. *The chosen model from the HOMER collection is the Schneider ConextCoreXC 540Wp with Generic PV, which has an expected lifetime of 25 years, based on local market pricing, the anticipated cost of the installation is $900 per kW. This cost includes the panel, wiring, and mounting hardware.*
2. *The battery's nominal voltage can be set automatically or manually which improves its ability to adapt to changing energy storage needs, choice the type (Lithium-Ion (Generic 1kWh Li-Ion) For residential homes, lithium-ion batteries are generally considered the best choice for most applications due to their high efficiency, long service life, and low maintenance requirements.*
3. *The power output of each unit is 4 kilowatts, and it is possible to connect up to 15 units in parallel. The system has a capacity of 60 kW, with each individual unit capable of generating 4 kW. It is possible to connect up to 15 units in parallel to attain the total capacity ,this scalability enables substantial energy generation, making it appropriate for larger installations or meeting growing energy needs.*
4. *A completely customizable 4-step charger designed to extend battery life. The device incorporates a fully customizable four-step charger that maximizes the longevity of the battery. Multi-stage charging is a method that effectively preserves battery condition over long periods by carefully controlling the charging process to avoid overcharging or undercharging.*
5. *PV input voltage: The system is capable of accepting solar panel input voltages of up to 150 Volts DC, allowing for versatile panel designs and removing the requirement for extra voltage conversion.*
6. *In Figure 9 the inverter is designed for use in a renewable energy system with a capacity of 1 kW. It has an initial and replacement cost of $300 each, with no additional annual maintenance costs. With a high efficiency of 95% and a lifetime of 15 years, it ensures minimal energy losses during the DC to AC-conversion process. Additionally, it is capable of operating in parallel with an AC generator, providing versatility in hybrid energy systems.*

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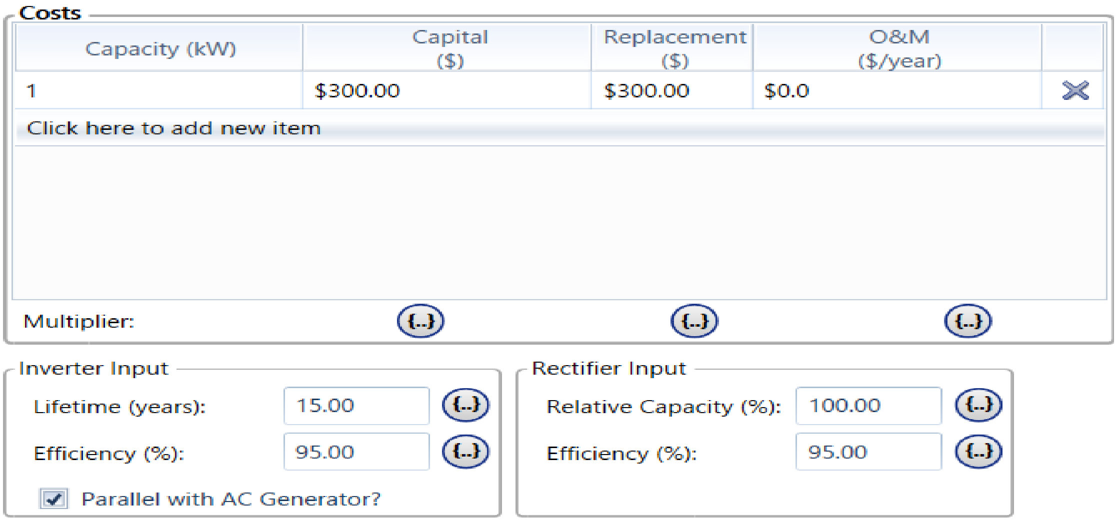

Figure 9 *The specific parameter of the inverter choice*

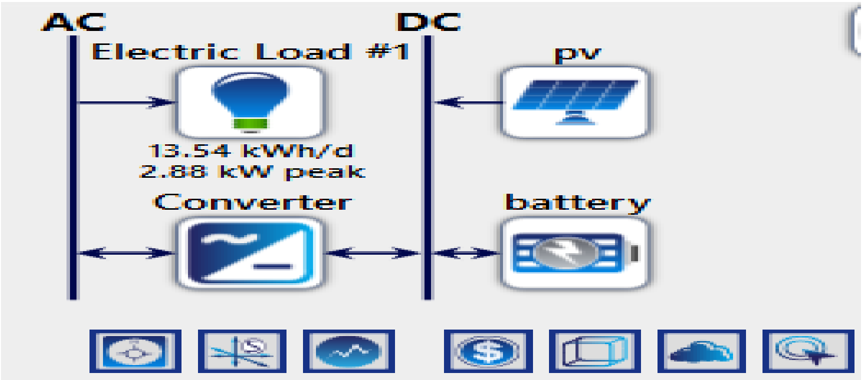

Figure 10 *Homer Simulation offers Hybrid Power Systems.(PV and battery)*

5.3 DESIGN 2 (HYBRID POWER SYSTEM (PV , BATTERY AND WIND TURBINE) OFF GRID

Figure 13 shows The second design is similar to the first but incorporates wind energy into the system, the wind turbine used in this setups starts generating electricity when the wind speed reaches approximately 4 meters per second, shown in Figure 11 a typical threshold for small-scale residential or commercial turbines, as the wind speed increases, the power output of the turbine also rises, the turbine is installed at an optimal hub height of 17 meters, which helps capture higher wind speeds since wind velocity generally increases with elevation, this wind turbine requires an initial capital investment of $950, with an identical replacement cost of $950. The annual operation and maintenance (O&M) cost for the turbine is relatively low at $100, indicating its robust construction and durability. Designed to last up to 20 years with minimal maintenance, the 1 kW turbine, despite its higher capital and replacement costs, offers long-term reliability and efficiency. This addition of wind energy not only enhances the overall energy production capacity of the system but also ensures a more stable and sustainable energy supply by diversifying the energy sources.

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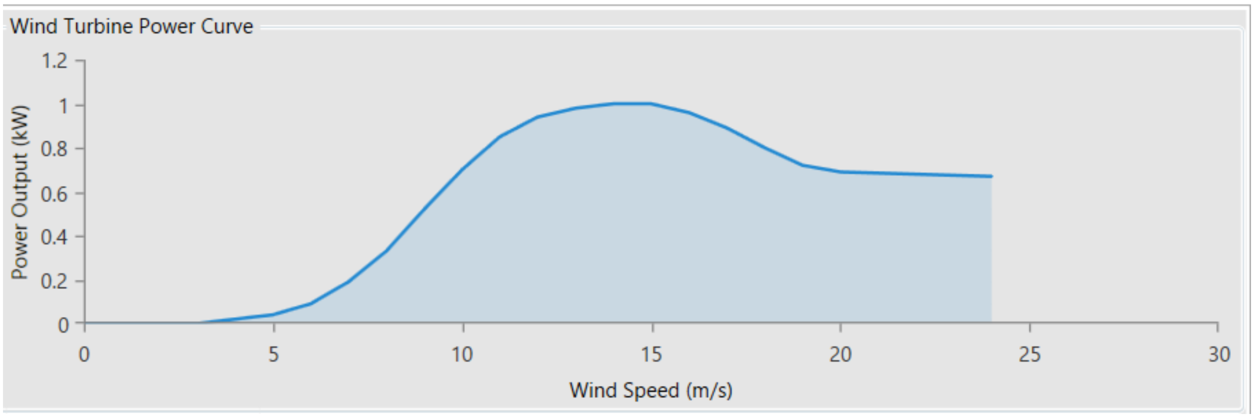
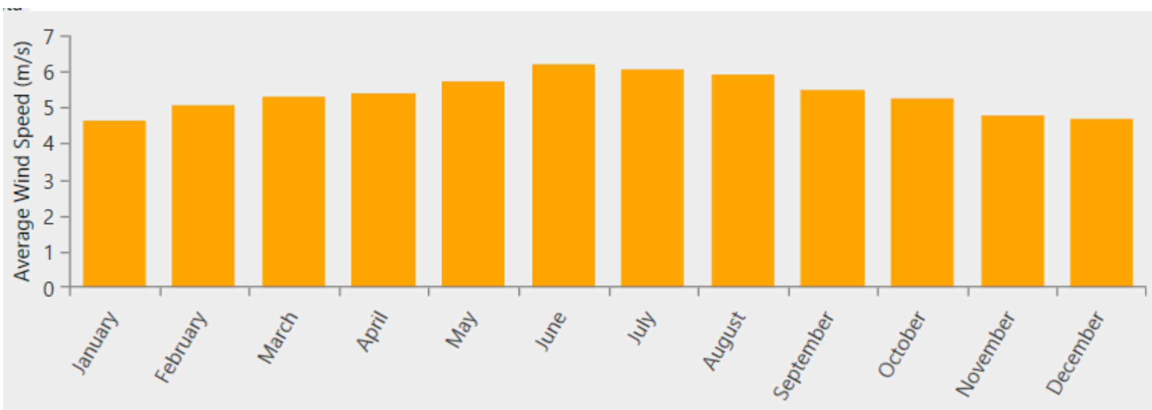


Figure 11 *Wind turbine power curve for Homer software*

figure 12 (wind speed from NASA) shows that wind speeds are generally higher during the spring and summer months, providing an ideal period for wind energy harvesting, in contrast, the lower wind speeds in the winter months might pose a challenge for consistent wind energy generation. This seasonal variation in wind speed is crucial for planning and optimizing the use of wind turbines in renewable energy systems



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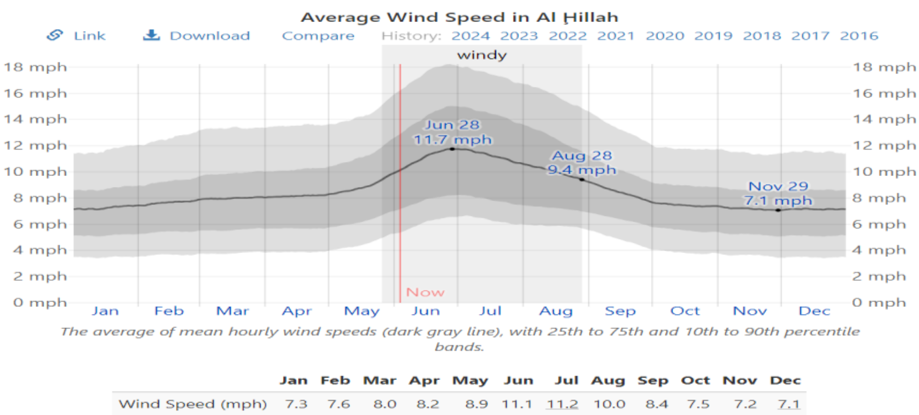

(b)

Figure 12 *wind speed (a) from NASA(b) from weatherspark[20]*

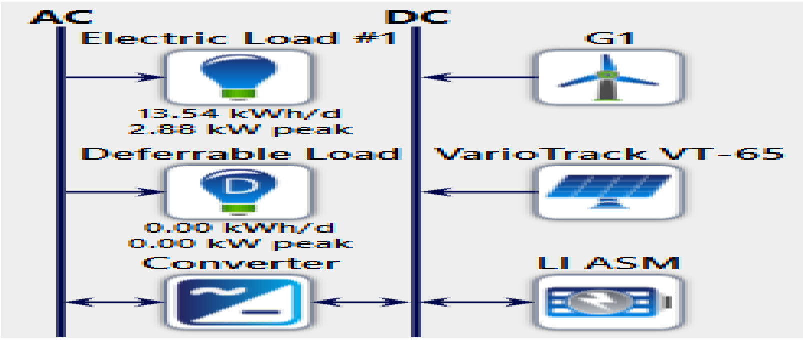

Figure 13 *Homer Simulation offers Hybrid Power Systems (PV, battery and wind)*

5.4 DESIGN 3 (HYBRID POWER SYSTEM (PV , BATTERY , WIND TURBINE) ON GEID

Figure 14 shows the third design is similar to the second design but its on grid system: the grid system is utilized when there is a scarcity of renewable energy resources to sustain the system and fulfill the load demand, the cost is fixed at $0.10 per kilowatt-hour (kWh).

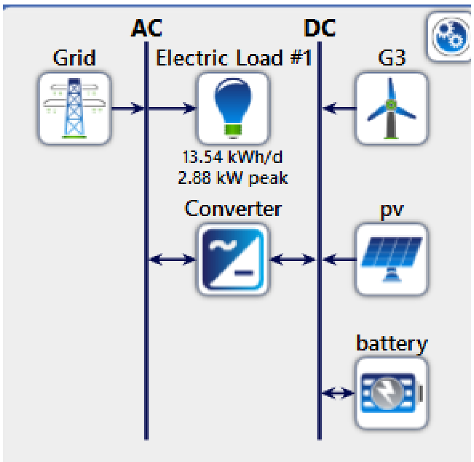

Figure 14 *Homer simulation offers Hybrid power systems on the grid*

6. RESULTS AND DISCUSSION

6.1 RESULT

The result in Figure 15 shows that different energy system configurations, highlighting their architecture, costs, and performance metrics

Architecture						Cost		pv	G3	Grid	
					Grid (kW)	Operating cost ($/yr)	Initial capital ($)	Capital Cost ($)	Capital Cost ($)	Energy Purchased (kWh)	Energy Sold (kWh)
					999,999	$494.21	$0.00			4,942	0
					999,999	$513.13	$720.12			4,942	0
					999,999	$522.46	$1,075		950	4,118	25.3
					999,999	$593.71	$2,803		1,900	3,565	92.5
					999,999	$26,754	$614,376	612,072		2,091	13,787
					999,999	$26,772	$615,057	612,072		2,091	13,787
					999,999	$26,751	$615,594	612,072	950	1,580	15,097
					999,999	$26,771	$616,282	612,072	950	1,580	15,073

(a)

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Architecture	Cost		pv	G3
	Operating cost ($/yr)	Initial capital ($)	Capital Cost ($)	Capital Cost ($)
	$2,152	$41,888		6,650
	$27,435	$621,183	612,072	
	$27,544	$622,078	612,072	950

(b)

Figure 15: *Result and compare of all designed(a) on grid (b)off grid*

6.2 DISSCUSION:

Upon careful examination of the result, the subsequent deductions can be made:

1.Off-Grid Systems:

- *PV & Battery:*
  - *Initial Capital: $41,888*
  - *Operating Cost: $2,152/year*
  - *This system has the lowest initial capital and lowest operating cost among all configurations, it is suitable for locations where grid connectivity is not an option, providing a cost-effective solution for energy independence.*
- *PV, Wind & Battery:*
  - *Initial Capital: $621,183*
  - *Operating Cost: $27,435/year*
  - *The addition of wind energy significantly increases both the initial capital and operating cost, making it less economical compared to the off-grid PV & Battery system.*

2.On-Grid Systems:

- *PV & Battery:*
  - *Initial Capital: $614,376*
  - *Operating Cost: $26,754/year*
  - *This system has a slightly lower initial capital compared to the on-grid system with wind energy but provides the benefit of selling excess energy back to the grid.*
- *PV, Wind & Battery:*
  - *Initial Capital: $615,057*
  - *Operating Cost: $26,772/year*
  - *The inclusion of wind energy increases the initial capital and operating cost marginally compared to the on-grid PV & Battery system. It offers diversified energy sources, which can be beneficial in varying weather conditions.*

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Table 1 represents the cost analysis of all the designed on-grid and off-grid

Attribute	*Operating Cost ($/yr)*	*Initial Capital ($)*	*PV Capital Cost ($)*	*Wind Capital Cost ($)*	*Battery Capital Cost ($)*	*Energy Purchased (kWh)*	Energy Sold (kWh)
Off-Grid PV & Battery	$2,152	$41,888	$6,650	*0*	*0*	N/A	N/A
Off-Grid PV, Wind & Battery	$27,435	$621,183	$612,072	*0$*	$950	N/A	N/A
On-Grid PV & Battery (Blue,	$26,754	$614,376	$612,072	*0$*	$950	2,091	13,787
On-Grid PV, Wind & Battery)	26,772	615,057	612,072	950	950	2,091	13,787

Table 1 : cost analysis

7. CONCLUSIONS

Choosing the most suitable hybrid renewable energy system is essential for attaining cost-effectiveness and sustainability in household energy solutions, analyzed were multiple energy configurations to ascertain the optimal solution in terms of efficiency and cost-effectiveness, the Off-Grid PV & Battery system is the most economically efficient option, with the lowest initial capital of $41,888 and running cost of $2,152 per year, this technology is optimal for attaining energy self-sufficiency, particularly in regions lacking access to an electrical grid, introducing wind energy in other setups raises both the initial investment and ongoing expenses, rendering them less cost-effective in comparison to the Off-Grid PV & Battery solution.

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