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Integrating Renewable Energy Systems: Exploring New Approaches to Hybrid Renewable Energy Generation

Taher Abdallah Ali Galouz [1*], Mustafa Ahmed Benhkoma [2]

[1] Department of Electrical and Electronic Engineering, Faculty of Engineering, Sabratha University, Libya

[2] Department of Project Management, Faculty of Technological Science, National Authority for Technical and Vocational Education, Libya

[*]*Corresponding author: tgalouz@yahoo.com*

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Abstract:

The increasing demand for clean and sustainable energy has led to the exploration of innovative solutions for integrating renewable energy systems. Hybrid renewable energy generation, which combines multiple renewable sources, offers a promising approach to achieving a reliable and efficient power supply. This research explores the concept of hybrid renewable energy generation, highlights the benefits of integration, and discusses new approaches and technologies being developed to optimize hybrid systems.

The study concluded that Solar photovoltaic (PV) and (WGT) wind power systems have emerged as key contributors to the global transition towards renewable energy sources. HRES is now gradually being employed for the electrification of rural areas due to the cheaper cost of Wind Turbine (WGT) and Solar Photovoltaic (SPV). It is intended to support the provision of electricity for the more than a billion people in developing nations who lack access to it. Using HRES in place can boost power dependability.

Keywords: Renewable Energy, Hybrid renewable Energy, Integration, Sizing Optimization Techniques, Solar Photovoltaic, Wind Turbine.

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دمج أنظمة الطاقة المتجددة: استكشاف نهج جديد لتوليد الطاقة المتجددة الهجينة

د. الطاهر عبد الله علي قلعوز [1*]، د. مصطفى أحمد بن حكومة [2]

[1] قسم لكهربائية والإلكترونية، كلية الهندسة، جامعة صبراتة، ليبيا

[2] قسم إدارة المشاريع، كلية العلوم التقنية، الهيئة الوطنية للعليم التقني، ليبيا

الملخص

أدى الطلب المتزايد على الطاقة النظيفة والمستدامة إلى استكشاف حلول مبتكرة لدمج أنظمة الطاقة المتجددة. يوفر توليد الطاقة المتجددة الهجينة، الذي يجمع بين مصادر متجددة متعددة، نهجاً واعداً لتحقيق إمدادات طاقة موثوقة وفعالة. يكشف

هذا البحث مفهوم توليد الطاقة المتجددة الهجينة، ويسلط الضوء على فوائد التكامل، ويناقش الأساليب والتقنيات الجديدة التي يتم تطويرها لتحسين الأنظمة الهجينة.
وخلصت الدراسة إلى أن أنظمة الطاقة الشمسية الكهروضوئية (PV) وطاقة الرياح (WGT) برزت كمساهمين رئيسيين في التحول العالمي نحو مصادر الطاقة المتجددة.. يتم الآن استخدام أنظمة الطاقة المتجددة الهجينة (HRES) تدريجياً لكهربة المناطق الريفية بسبب التكلفة الرخيصة لتوربينات الرياح والطاقة الشمسية الكهروضوئية، والغرض منه هو دعم توفير الكهرباء ملايين الأشخاص في الدول النامية الذين لا يستطيعون الوصول إليها، وبالتالي يمكن أن يؤدي استخدام HRES بدلاً من ذلك إلى تعزيز الاعتمادية على الطاقة.

الكلمات المفتاحية: الطاقة المتجددة، الطاقة المتجددة الهجينة، دمج، تقنيات تحسين الحجم، لطاقة الشمسية الكهروضوئة، توربينة الرياح.

1. Introduction

In recent years, the field of hybrid renewable energy generation has made remarkable progress as researchers and engineers seek innovative approaches to fully exploit the potential of multiple renewable energy sources. Hybrid systems provide distinct advantages by integrating various renewable energy technologies, including solar, wind, hydro, biomass, nuclear, and even hydrogen, both at the central power generation level and at the customer level in reorganized renewable energy systems (RES) [1]. The term "HRES" (Hybrid Renewable Energy Systems) refers to a power system that incorporates two or more energy sources. In comparison to methods that rely on a single energy source, these systems often exhibit superior reliability and cost-effectiveness [2]. HRES aims to increase overall energy production, grid resilience, and reliability. There is a rising need to delve into the world of hybrid renewable energy generation and perform an in-depth examination of the topic given the growing global emphasis on switching to clean and sustainable energy solutions [3].

In order to maximize their efficiency, dependability, and cost-effectiveness, hybrid renewable energy systems must be planned and configured using sizing optimization approaches. These methods entail choosing the right number, arrangement, and positioning of different system elements, such as generation sources, energy storage systems, converters, and control mechanisms. The system can be adjusted to meet particular energy needs, reduce losses, and make the best use of renewable energy sources by optimizing the sizing of various components [4].

An in-depth examination of managing sizing optimization methods for hybrid renewable energy systems offers insightful knowledge into the major factors, approaches, and difficulties involved in attaining the best system design. It entails a thorough investigation of several variables, including load characteristics, the availability of renewable energy resources, system restrictions, and performance measures. Researchers and practitioners can create reliable approaches and strategies to optimize the sizing and configuration of hybrid renewable energy systems by carefully studying these elements. Furthermore, an in-depth analysis allows for the identification of trade-offs and synergies between different system components and their impact on system performance. It enables an understanding of the dynamic nature of hybrid renewable energy systems and the need for adaptive sizing optimization techniques to account for changing environmental conditions, load demands, and energy storage requirements. By considering these factors, system designers can effectively balance energy generation, consumption, and storage, resulting in improved system efficiency and resilience [5].

HRES can combine solar photovoltaic (SPV), hydropower, and wind turbine generation (WTG). In such cases, a backup unit consisting of diesel generators and storage batteries can be used to meet peak hour demand. To efficiently utilize electrical energy while using energy sources like WTG, SPV, and building management systems, the proposed design must be optimized.

The global transition towards sustainable and clean energy solutions has placed a significant emphasis on integrating renewable energy systems. This article delves into the exploration of new approaches to hybrid renewable energy generation, which involves the seamless integration of different renewable energy sources. By combining multiple sources, such as solar, wind, hydro, biomass, and others, hybrid systems offer unique advantages in terms of efficiency, reliability, and cost-effectiveness. This article provides an in-depth analysis of this topic, highlighting the benefits, new approaches, system design, challenges, and solutions associated with integrating renewable energy systems.

1.1 Architectures of Hybrid Renewable Energy Systems

Nearly all RES, including WTG and SPV, are clean and friendly to the environment. Numerous scholars have examined the hybrid microgrid that combines WTG with SPV. The investigation makes it evident that HRES performance is superior to individual WTG or SPV systems and more affordable [6]. Compared to conventional sources, hybrid WTG and SPV have fewer drawbacks if improperly built. The storage battery bank, for instance, can be used to offset the heterogeneous nature of solar radiation and wind speed, which fluctuate in power generation. When there is a lack of electricity, these batteries can store the surplus energy and provide the load [7]. The WTG and SPV oversight issue prevents the use of the battery storage technology. If the battery has reached.

Figure (1) shows the typical HRES model. Because they incorporate the necessary electrical load and two or more renewable energy sources (RESs) to supply the AC or DC load or both at once, these energy systems are referred to as "hybrid." Non-renewable, renewable, and energy storage sources are all possible sources of energy [7]. In this process, the deficiency of some energy units is increased by naturally or artificially firming other energy units. It can be seen that they have surprising availability and present additional designs despite some alternative sources (such WTG and SPV) [15]. HRES can be used in standalone and grid-connected modes. To meet the local energy demand, HRES can be employed as a grid-connected system.

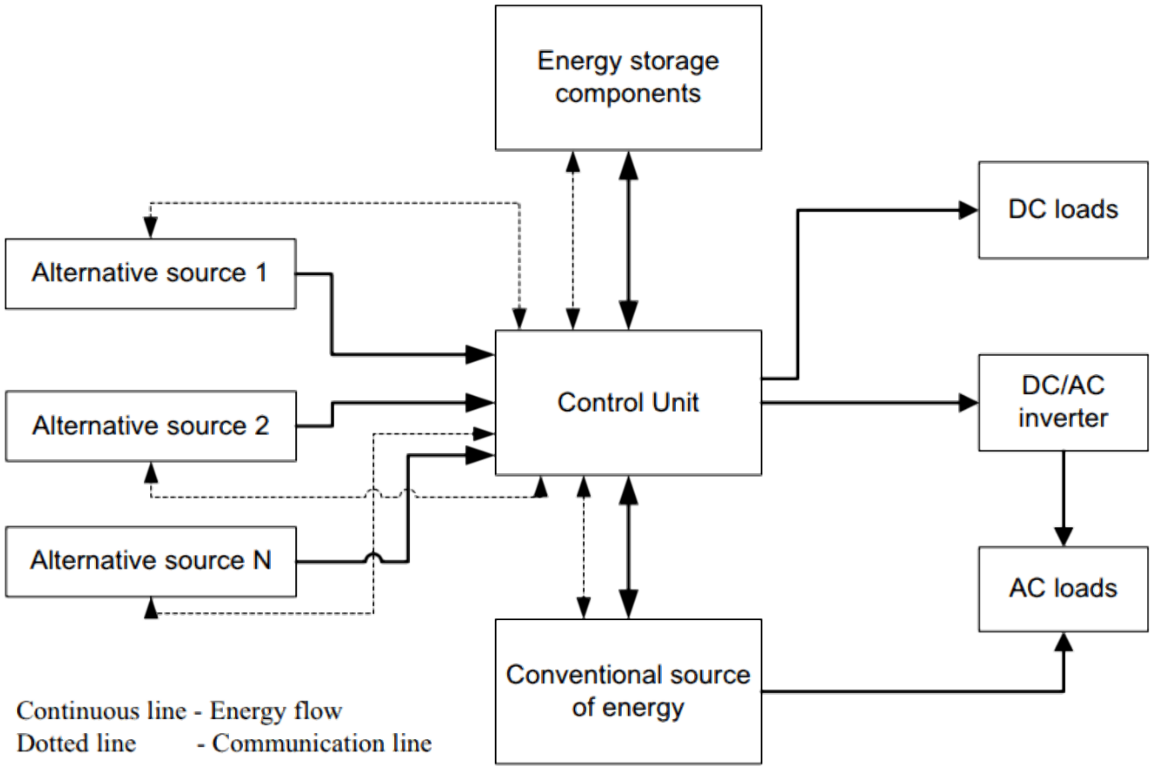

Figure 1 Typical HRES Model [8].

1.2 Status of Global Energy

As the globe struggles to address issues like climate change, energy security, and sustainable development, the global energy environment is undergoing tremendous changes. The current state of the world's energy is discussed in this article, with an emphasis on important trends, problems, and prospects. It examines the switch from fossil fuels to renewable energy sources, the rise in energy consumption, and the initiatives to slow down global warming. Examining the current energy situation helps us understand how to move toward a sustainable and low-carbon future [9].

Global energy consumption has grown by nearly a third since 2000, and it is expected to keep rising in the near future. Global energy demand increased by 2.9% in 2018, and under a status quo forecast, by 2040, consumption will have increased by a further 30% to 740 million terajoules. This will result in a rise in worldwide energy consumption of 77% from 2000 to 2040. Global energy consumption could treble between 1980 and 2050, rising from roughly 300 to 900 million terajoules. The majority of the energy we use, 83%, is derived from fossil fuels. The largest energy source is oil, which is followed by coal and natural gas. Innovation in green energy is therefore very necessary. For the time being, burning more coal and gas will be used to make up the majority of the rise in global energy demand. That is not ideal. Massive volumes of CO2 are released into the atmosphere by it [10]. Figure (2) indicates World net electricity generation by energy source, 2012–40 (trillion kilowatt-hours).

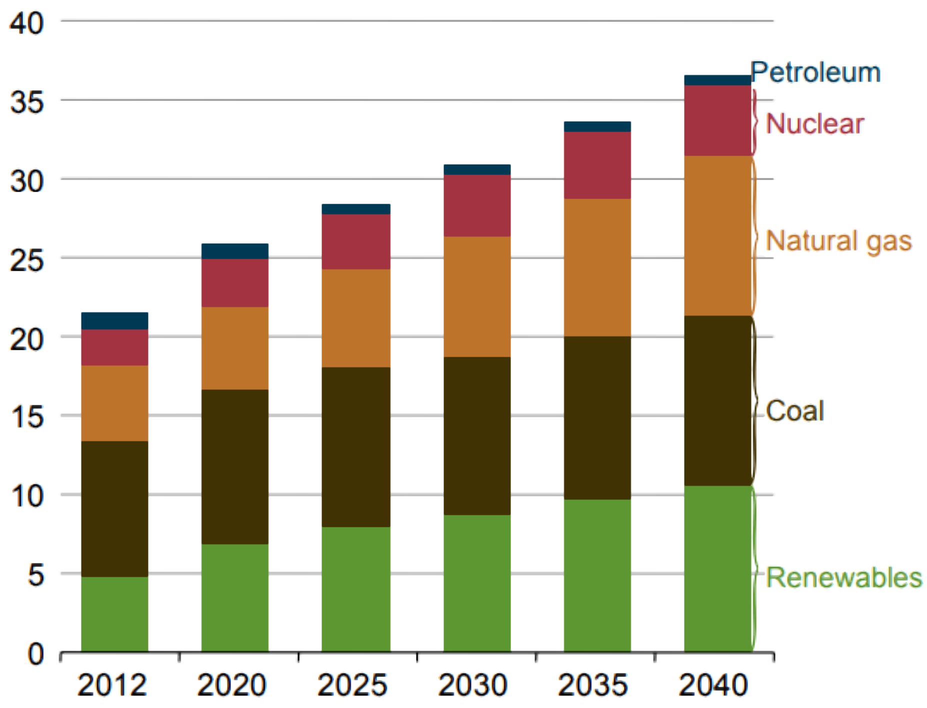

Figure 2 World net electricity generation by energy source, 2012–40 (trillion kilowatt-hours) [11].

The two sources of energy generation that are generating the most electricity globally, according to the IEA's World Energy Outlook 2020, are solar PV and wind power. As of 2020, there were over 770 GW of solar PV systems installed worldwide, up from only 40 GW in 2010 (IEA). China has installed the most solar PV capacity globally, followed by the US, Japan, Germany, and India (IEA). Rooftop solar system implementation has accelerated, especially in the residential and commercial sectors, enabling consumers to produce their own electricity (REN21). Worldwide development of large-scale solar PV power facilities has increased the solar PV industry's overall capacity. Examples include solar farms in the United States, China, India, and United Arab Emirates (IEA) [12].

By the end of 2020 (GWEC), the installed wind power capacity had surpassed 743 GW globally. China has installed the most wind power capacity, followed by the US, Germany, India, Spain, and China (GWEC). With large capacity installed in nations like China, the United States, Germany, India, and Spain, onshore wind farms have been the most common way that WTG energy has been used. Additionally, offshore wind farms are becoming more popular, especially in nations like the United Kingdom, Germany, China, and Denmark (GWEC). To address the energy needs of domestic, commercial, and industrial consumers globally, WTG energy is incorporated into electricity grids (IEA). Research is being done on hybrid systems that combine WTG energy with other renewable energy sources like solar PV or energy storage [12]. Fig. (3) indicates Shares of global electricity generation by source, 2000-2040.

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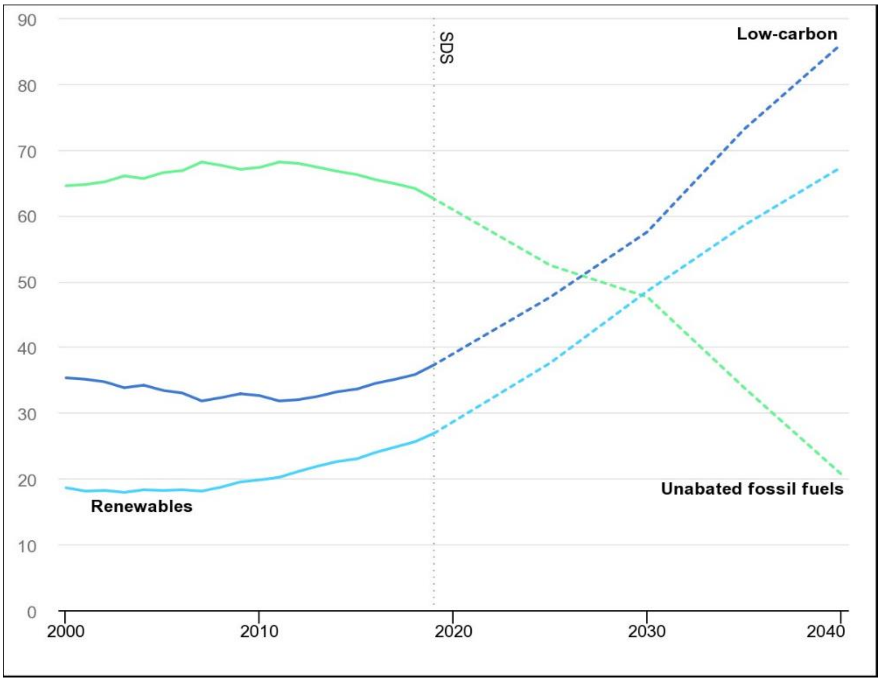

Figure 3 indicates Shares of global electricity generation by source, 2000-2040 [13]

2. Literature Review

2.1 Hybrid Renewable Energy System (HRES):

In order to solve the issues of energy sustainability, climate change, and rising energy demands, hybrid renewable energy systems (HRES) have become a promising option. These systems establish a dependable and effective power generating and distribution infrastructure by combining several renewable energy sources, including sun, wind, hydro, biomass, and geothermal [14].

The idea behind hybrid renewable energy systems is to diversify energy sources and take use of the complementing qualities of various renewables. The intermittency and variability that are frequently associated with individual renewable sources can be solved by these systems' integration of numerous sources, resulting in a more reliable and consistent supply of energy [15].

Maximizing the use of renewable energy is one of the main benefits of hybrid renewable energy systems. They can maximize energy output and lessen reliance on non-renewable sources, such as fossil fuels, by integrating several sources to more efficiently tap into the energy resources that are already accessible. This helps to lessen greenhouse gas emissions and the negative effects of energy production on the environment [16].

Moreover, hybrid renewable energy systems offer enhanced reliability and resilience. The combination of diverse sources increases system robustness, as any fluctuations or failures in one source can be compensated by others. This improves the overall energy supply security, particularly in remote or off-grid areas where access to conventional power infrastructure may be limited [17].

The integration of energy storage technologies is another crucial aspect of hybrid renewable energy systems. Energy storage enables the capture and storage of excess energy during periods of high generation for use during low generation or high demand periods, improving system reliability and grid stability. This integration facilitates the effective management of intermittent renewable sources and enables the delivery of a more consistent and reliable power supply [18].

Hybrid renewable energy systems have seen an increase in deployment and uptake across the globe in recent years as a result of technological improvements, cost reductions, and supportive regulations. Governments, businesses, and communities are becoming more aware of how these systems can help them achieve their energy goals, lessen their dependency on fossil fuels, and advance sustainable development [19].

2.2 Benefits of Integration:

Integrating renewable energy systems brings several benefits such as [20]:

1. It optimizes energy production by leveraging the complementary nature of different renewable sources, maximizing resource utilization.
2. Hybrid systems enhance reliability by mitigating the intermittency and variability associated with individual renewable sources.
3. Integration offers cost advantages through economies of scale, shared infrastructure, and optimized system configurations.
4. It enhances energy efficiency by optimizing the utilization of available resources. By combining complementary renewable sources, energy production can be more consistent, reliable, and responsive to demand fluctuations.
5. Integrated systems improve energy reliability and resilience by reducing the reliance on a single energy source and mitigating the intermittency associated with renewable energy generation.

They contribute to cost savings through economies of scale, shared infrastructure, and optimized system designs, making renewable energy more competitive with conventional energy sources.

2.3 Solar photovoltaic system (SPV)

Solar photovoltaic (PV) systems have become a crucial piece of technology in the switch to sustainable and clean energy sources. These systems use the photovoltaic effect to harness the energy of sunshine to produce electricity. Solar PV systems are extremely advantageous for the environment and the economy since they transform sunlight directly into electrical energy. Due of SPV's intermittent nature and inability to produce power 24 hours a day, battery storage is required. The average stated cost for systems fixed in 2011 was around 6.13 $ per Watt for applications in small commercial premises up to 10 kW and approximately 4.87 USD/W for applications in commercial establishments higher than 100 kW [21]. The SPV system is the most cost-effective way to supply electricity in rural areas. The SPV system's economic viability has been examined and its electiveness for villages with roughly 100 families has been confirmed in a decentralized generation. An illustration of an SPV-hybrid microgrid with a diesel generator serving as a backup [22]. The threshold of starting and stopping for the backup diesel generator taking into account the diesel unit's pre-operating time was evaluated using FORTRAN in the model for hybrid SPV in [23] with regard to the unit capacity of the battery. In order to achieve the best combinations of the battery unit and SP, a technique has been developed to feed the load demand [24]. The load and insulation have been determined using a statistical model. The losses of power supply probability (LPSP) were computed in [59] using a solution approach based on the closed procedure of the unconnected (SPV-battery storage) hybrid microgrid. For expansion from the adjacent power line, tilt, and azimuth angle, the best combinations are required based on the cost of electricity production [25].

2.4 Wind turbine system (WTG)

A wind turbine system, also known as a wind power system or wind turbine generator (WTG) system, harnesses the kinetic energy of the wind to generate electricity. It consists of several components working together to convert wind power into usable electrical energy. To control loads, many WTGs are built with variable pitch or variable speed modes. During 1887, when Charles was the first person during the winter to create electricity [26]. The area of choice needs to have significant year-round wind energy potential should be utilized more efficiently and affordably than the hybrid WTG. Europe was leading in terms of installed wind power capacity and utilization. Countries like Germany, Spain, the United Kingdom, and Denmark were among the top wind energy producers. The United States and China were also significant contributors to global wind power utilization. wind WTGs cannot generate electricity at speeds, hence additional sources must be used to supply [12]. It's important to note that the utilization of wind turbine systems can vary over time as new projects are developed, and technological improvements allow for more efficient generation and integration of wind power into the electrical grid. For the most up-to-date information on the current global utilization of wind turbine systems, I recommend referring to recent reports and studies from reputable sources such as the International Energy Agency (IEA) or the Global Wind Energy Council (GWEC) [12]. To more efficiently and economically use the hybrid WTG, the area must have sufficient year-round wind energy potential. Nowadays, WTG is connected to both large and small WTG for different structures. In contrast to solar energy, WTGs have a longer operating period, which allows them to produce electricity day and night even on overcast days [26 , 27]. Only about 35,000 MW of electricity is produced by wind energy in Europe. Low wind speeds prevent WTGs from producing electricity; as a result, alternative sources are needed to provide the load. As a result, in order to utilize excess energy when there is a shortage of electricity to fulfil demand, energy storage systems are needed for both wind and solar systems.

2.5 Hydropower system

Hydropower is a sustainable energy source that produces electricity by harnessing the kinetic energy of falling or flowing water. Hydropower, a renewable energy source, has been utilized for centuries to generate electricity by harnessing the energy of flowing or falling water. With its clean and reliable nature, hydropower plays a significant role in global energy production [28]. It is among the oldest and most popular kinds of renewable energy in the world. Hydropower systems are made up of a number of parts that work together to transform water energy into electrical energy. Hydropower systems come in a variety of sizes, from massive dams that produce hundreds of megawatts of electricity to smaller run-of-river or micro-hydropower systems that supply power to small towns or individual homes. It's important to remember that the environmental effects of hydropower systems might change based on the size, location, and design of the dam. Large dams have the potential to have a large ecological impact, including community displacement and changes to river ecosystems. Modern hydroelectric projects, however, make an effort to include environmental mitigation strategies to lessen their impact on nearby ecosystems and populations [29].

Multiple renewable energy sources are combined in hybrid renewable energy systems, which have drawn a lot of interest as a sustainable and dependable way to fulfill the world's rising energy demand. In order to increase the efficiency, dependability, and cost-effectiveness of hybrid renewable energy systems, this article examines the optimization approaches employed in these systems.

3. Sizing Optimization Techniques in HRES

Multiple renewable energy sources are combined in hybrid renewable energy systems (HRES), which offer a dependable and environmentally friendly way to meet energy demands. Determining the ideal capacity and layout of system components depends heavily on the sizing optimization of HRES approaches [30]. Sizing optimization ensures that the capacity of renewable energy sources, such as solar, wind, or hydro, is appropriately matched with the energy demand. By accurately sizing the system components, HRES can maximize the utilization of available renewable resources and reduce reliance on non-renewable sources. Sizing optimization helps in achieving cost-effective HRES solutions. Oversized components lead to unnecessary capital investment, while undersized components may result in insufficient energy generation or excess reliance on backup systems [31]. Optimizing the size of system components ensures an optimal balance between capital costs and energy generation, resulting in cost-efficient HRES implementations. Proper sizing of HRES components is essential for maintaining system performance and reliability. Oversized components can lead to inefficient operation and reduced system efficiency, while undersized components may result in frequent system overloading or underperformance. Sizing optimization aims to achieve an optimal balance that ensures reliable and effective system operation [32].

Mathematical optimization techniques, such as linear programming, mixed-integer linear programming, or nonlinear programming, are commonly used for sizing optimization in HRES. These models consider various factors, including energy demand, renewable resource availability, system constraints, and cost parameters, to determine the optimal sizing and configuration of system components. Genetic algorithms (GA) are evolutionary optimization techniques inspired by natural selection. GA-based approaches iteratively evolve a population of potential solutions, adjusting component sizes and configurations to optimize system performance. Genetic algorithms can handle complex HRES systems and provide near-optimal solutions even in the presence of uncertainties or non-linear relationships [33].

Particle Swarm Optimization (PSO) is a population-based optimization algorithm that simulates the social behavior of a flock of birds or a swarm of particles. In PSO, particles move and search for the optimal solution by adjusting their positions and velocities in a multidimensional search space. PSO has been successfully applied to HRES sizing optimization problems, providing efficient and reliable solutions [].

Simulation-based approaches involve modeling the HRES system and conducting performance analysis under different sizing scenarios. By simulating the system behavior, including energy generation, storage, and consumption, sizing optimization can be performed by iteratively adjusting the component sizes and evaluating system performance metrics [32, 33, 34]. Table (1) shows types of optimization techniques:

Table (1): Types of Optimization Techniques [34]

Methods of optimization		Source Energy	Comments
A	**Graphical Construction**	Battery storage and SPV	Two parameters are used in this method.
B	**Probabilistic approach**	Performance of hybrid-system	Data collection is based on a statistical technique.
C	**Deterministic Approach**	Stand-alone SPV with battery storage	Equations are used to determine specific values based on constant parameters.
D	**Alternative Approach**		Based on LPSP, a plausible solar-wind combination was discovered.
1.	Hill Climbing		
2.	Dynamic Programming	Hybrid SPV-WTG with battery	Based on the evolution Technique
3.	Linear Programming		
4.	Multi-objective		
E	**Artificial Intelligence**	Hybrid SPV-WTG with battery	
1.	GA		
2.	PSO	storage	
3.	FL		
4.	ANN		
5.	Hybrid of AI		
F	**HOMER Software**	All RE element	An input file containing all relevant data is provided. The software handles other tasks

3.1 Graphical construction method

The load-duration curve method, also known as the graphical construction method, is a graphical technique used in the design and analysis of hybrid renewable energy systems (HRES). This method aids in determining the best sizing and configuration of system components based on the load profile and availability of renewable energy resources [35]:

Here's an overview of the graphical construction method for HRES:

1. ***Load-Duration Curve:*** The first step in the graphical construction method is the construction of the load-duration curve. The load-duration curve represents the cumulative frequency distribution of the load demand over a specific time period, typically in hours or days. The load demand is plotted on the y-axis, and the duration (percentage of time) for which the load demand exceeds a certain value is plotted on the x-axis. The load-duration curve provides insights into the variability and magnitude of the load profile.
2. ***Renewable Energy Resource Curve:*** Simultaneously, the renewable energy resource curve is constructed, representing the cumulative frequency distribution of the renewable energy resource availability (e.g., solar radiation, wind speed) over the same time period. The resource availability is plotted on the y-axis, and the duration (percentage of time) for which the resource availability exceeds a certain value is plotted on the x-axis. The resource curve provides information about the temporal variability and magnitude of the renewable energy resource.
3. ***Sizing Component Intersections:*** The load-duration curve and the renewable energy resource curve are superimposed on the same graph. By analyzing the intersections between these curves, the sizing of system components can be determined [36].

- Intersection Point Analysis: The points where the load-duration curve intersects the resource curve indicate the duration for which the load demand can be met by the available renewable energy resource. These points help in determining the sizing and capacity of the renewable energy generation components (e.g., solar panels, wind turbines) to meet the load demand.
- Storage Sizing: The gaps between the load-duration curve and the resource curve represent the periods when the load demand exceeds the available renewable energy resource. These gaps indicate the need for energy storage systems (e.g., batteries) to bridge the energy deficit. The sizing of the storage component is determined by the magnitude and duration of these gaps.
- Backup Systems: If the renewable energy resource is unable to meet the load demand even with energy storage, backup systems (e.g., diesel generators) may be required. The sizing of backup systems is determined based on the remaining load demand that cannot be met by renewable energy and storage.

4. ***Sensitivity Analysis and Optimization:*** Once the initial sizing of system components is determined using the graphical construction method, sensitivity analysis and optimization techniques can be employed to fine-tune the component sizes. By varying the component capacities and analyzing the

impact on system performance metrics (e.g., renewable energy penetration, energy balance), an optimal sizing configuration can be achieved.

It's crucial to remember that the graphical construction technique only provides a simplified picture of the behavior of the system and may not take into account complicated system dynamics or issues like the need for grid integration, cost concerns, or environmental limits. Therefore, for a thorough HRES design, other analysis and modeling methods should be applied in addition to the graphical construction method.

3.2 Probabilistic approach technique

In order to meet the rising need for energy while lowering reliance on conventional fossil fuel-based sources, hybrid renewable energy systems (HRES) are being used more and more. Power generation is made variable and uncertain by the inclusion of numerous renewable energy sources in HRES. By taking into account the stochastic nature of renewable energy resources and loads, the probabilistic approach technique provides an invaluable way to evaluate and optimize the performance of HRES [38].

To account for the variability and uncertainty of renewable energy resources (such as solar radiation and wind speed), probabilistic models are used. These models utilize historical weather data or probabilistic forecasting techniques to estimate the probability distribution of renewable energy generation. Statistical methods like probability density functions (PDFs) or cumulative distribution functions (CDFs) are employed to represent the variations in energy resource availability accurately [39].

3.3 Deterministic approach method

The use of hybrid renewable energy systems (HRES) to meet energy needs and lessen reliance on traditional fossil fuel sources is growing in popularity. When designing and analyzing HRES, the deterministic approach method offers a useful strategy that takes fixed values for renewable energy sources and load demand into account [40]. The deterministic approach method involves estimating the size of renewable energy sources based on fixed values of energy resource availability. Historical data or standard reference values are used to determine the average energy generation potential of renewable sources such as solar panels or wind turbines. The sizing of these components is based on meeting the average energy demand while considering the renewable resource's capacity factor or conversion efficiency [41].

3.4 Iterative approach method

Sources of renewable energy. By iteratively improving system configurations and control strategies, the iterative approach method provides a useful strategy for creating and optimizing HRES. The iterative approach method involves refining the system configuration through iterative iterations. Initially, a preliminary configuration is established based on system requirements and available resources [42]. The performance of this initial configuration is evaluated using simulation or modeling tools. Based on the results, the system configuration is iteratively adjusted, such as adding or removing renewable energy sources, energy storage, or backup power options, to optimize the system's performance [43]. The iterative approach method also involves refining the control strategies of HRES. Initially, control algorithms are developed based on simplified models and assumptions. The system's performance is evaluated through simulations or real-time monitoring, and the control strategies are iteratively adjusted to improve system efficiency, reliability, and response to changing conditions. This iterative process may involve parameter tuning, switching thresholds, or the introduction of advanced control algorithms [44].

3.5 Models of Artificial Intelligence (AI) approaches

The field of artificial intelligence (AI) is concerned with developing software and machines. AI is composed of fuzzy logic (FL) methods that mix two or more branches. Multi-renewable energy sources, energy storage, and control techniques are all included in hybrid renewable energy systems (HRES), which are sophisticated energy systems. In recent years, the use of Artificial Intelligence (AI) methods in HRES has attracted a lot of interest. When AI tools are used properly, they produce systems with better AI performance or other structures that might not be appropriate for outdated techniques [45]. Neural networks are widely used AI models in HRES for various tasks, including system modeling, prediction, and control. These models are capable of learning complex relationships between input parameters and system behavior. Neural networks can be trained using historical data to predict renewable energy generation, load demand, or optimize control strategies. They offer flexibility and adaptability in capturing non-linear and time-varying dynamics of HRES components [46].

3.6 HOMER Software

In order to generate electricity in a sustainable and effective manner, hybrid renewable energy systems (HRES) are essential. High-end software that can simulate, analyze, and optimize system configurations is necessary for designing and optimizing HRES. Software called HOMER (Hybrid Optimization of Multiple Energy Resources) has become an effective method for modeling, evaluating, and improving HRES. This article examines how HOMER software is used in HRES, emphasizing its attributes, advantages, and contributions to system design and analysis [47].

HOMER software is a widely used tool for designing and simulating HRES. It provides a comprehensive platform for analyzing the technical and economic feasibility of renewable energy systems. Developing sustainable and effective electricity generation requires the use of hybrid renewable energy systems (HRES). Sophisticated tools that can simulate, evaluate, and optimize system configurations are needed for designing and optimizing HRES. For modeling, evaluating, and optimizing HRES, the software HOMER (Hybrid Optimization of Multiple Energy Resources) has become a potent tool. This article examines how HOMER software can be used in HRES while highlighting its advantages, capabilities, and contributions to system design and analysis [48].

4.Conclusion

Hybrid renewable energy systems provide a workable and sustainable way to fulfill the world's growing energy needs with the least amount of negative environmental effects. These systems offer a dependable, adaptable, and scalable method of power generation by integrating a variety of renewable energy sources. Hybrid renewable energy systems are essential to creating a more robust and sustainable energy future as the world continues to emphasize the shift to clean and renewable energy.

HRES is now gradually being employed for the electrification of rural areas due to the cheaper cost of Wind Gas Turbines (WGT) and Solar Photovoltaic (SPV). It is intended to support the provision of electricity for the more than a billion people in developing nations who lack access to it. Using HRES in place of can boost power dependability.

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