



Potential and Development of Horizontal Axis Wind Turbine Systems and Technologies: A Review

Mohammed A. Habib^{*a}, Abdullateef A. Jadallah^b, Ahmed A. Hussein^a

^a Electromechanical Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.

^b College of Engineering/ Tikrit University, Tikrit, Iraq

*Corresponding author Email: 51841@student.uotechnology.edu.iq

HIGHLIGHTS

- Review developments and improvements in wind turbines to know the economic and social aspects that affect their implementation.
- Special focus on multiple rotors and compare them with conventional turbines in terms of blade length, power Coefficient, and system productivity.
- Facts relating to the technological and economic issues of global wind energy such as (grid integration, system efficiency, expansion of small-scale industry, installation and maintenance costs, etc.).
- Effects of modeling and control of wind turbine performance.

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ABSTRACT

Wind energy has a potency of playing a vital role in the future of energy demand providing and environment freshening in many areas of the world. Utilizing wind turbine systems has become a competitive recourse among other renewable energy sources in terms of cost-effectiveness and the transition toward renewable energy usage. Researchers and developers are constantly dedicated to innovating to improve the technology of designing wind turbine systems. Wind energy depends mainly on the wind velocity and the area that swept them, increasing the wetted area. This is done by either upscaling the area of the wind rotor or constructing multi-wind turbines according to the type of designs that fit modern innovative systems. Though large wind turbine units do not fit with all sites, especially in cities, these turbines may be installed offshore and onshore. This paper aims to explore the relevant works technologies related to the wind energy potential, developments, design improvements, and multi-rotor horizontal axis wind turbine systems (HAWTs). This was achieved based on favorable characteristics such as economic viability and clean energy resources. Hence, these aspects reduce the environmental impacts and improve technological advantages and profitability. The results of this paper provide a recognizable system's facts and platforms that can be easily utilized. Wind Energy has the potency of hybridization with other renewable energy resources, which play an important role in urban planning, smart cities, and Buildings integration.

1. Introduction

Wind energy is used as an alternative source of electric power generation. It is considered one of the most important discoveries that led to a technological breakthrough to increase the efficiency of energy production. Moreover, its future looks promising as the price of its generation is descending rapidly. The Global Wind Energy Council (GWEC) reported that the average growth rate of wind power generators was 30% from 1996 to 2011. At the end of 2011, commercial wind power installed nearly 240 GW in a group of more than 80 countries [1].

At the beginning of the development of wind energy technology, researchers tended to create larger advanced machines with more powerful generators, taller towers, and longer rotors. Expanding wind turbine systems require new designs, configuration modifications, and innovative solutions [2]. The design and performance of wind turbines have been given great attention to reach the highest productivity. Wind energy technologies got a great concern in the early 1980s concerning the installed capacity in the available sites in the world, as presented in Figure 1 [3].

There are many designs for wind turbines that depend on the wind rotor type (vertical or horizontal), the number of blades, the geometry of the blade, and the number of turbines in the system. It is now possible to replace conventional wind turbines with a larger rotor size with multi-rotor wind turbines of small size and equivalent performance [4]. The multi-rotor wind

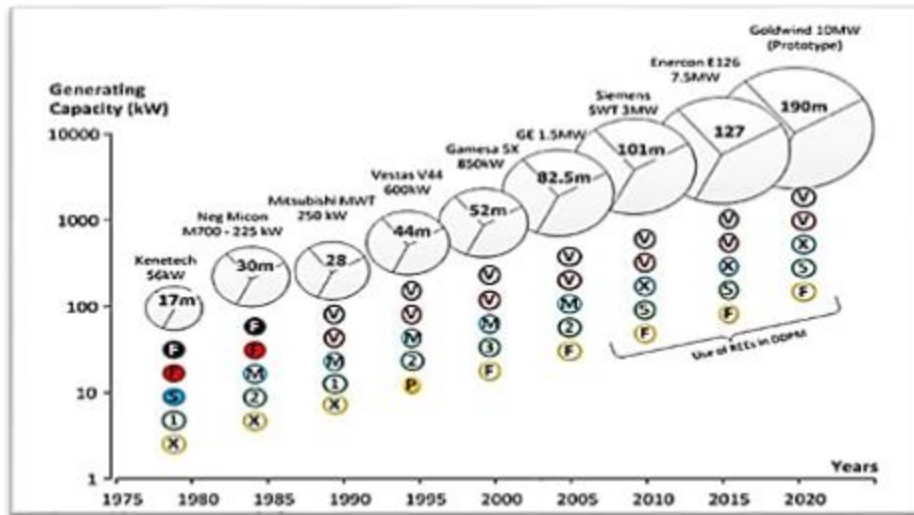


Figure 1: Wind turbine evolution as a function of rotor size with generation capacity(kilo Watts) for the years 1980 to 2020 [3]

turbine (MRWT) system design is derived from the sequence of multi-spool gas turbines. They consist of a set of rotors for wind turbines installed in a single support structure. One of the advantages of this design is to compensate for the area of wind energy for large turbines and the difficulty of making very large blades due to technological limitations. Moreover, it will not cause all the wind turbine power to be lost in the event of a fault in a single turbine, thus increasing the power output from multiple rotors instead of a single rotor [5,6,7].

Twin-rotor wind turbine (TRWTS) contains two rotors mounted on one or two axes. In other words, the system contains one turbine with two opposite or parallel rotors in motion or two separate turbines in motion. Despite Iraq's low wind speed, the ministry of electricity has nominated nine sites with a good power density and plans to install wind farms .

The main objective of this paper is to present the developments and improvements of wind turbines to know the economic and social aspects that affect their implementation, with a special focus on multiple rotors. In contrast, the CR-HAWT is characterized by the production of higher energy with the lowest wind speed, this type of wind turbine is commensurate with areas of low wind speed, such as Iraq. Therefore, this work compares CR-HAWT wind turbines with state-of-the-art conventional turbines in terms of blade length, power Coefficient, and system productivity. Furthermore, in this work, some significant facts related to global wind energy's technological and economic issues have been addressed, such as (grid integration, system efficiency, expansion of small-scale industry, installation and maintenance costs, etc.). Moreover, a brief description of the impacts of modeling and controlling the wind turbine performance has been presented. Finally, state-of-the-art relevant works outcomes have been presented and addressed in this work.

2. Wind Turbine Evolution

The history of wind energy investment goes back to five thousand years ago. Over the past three decades, contemporary societies have relied exclusively on fossil fuels to cover their electricity needs [8]. In 1939 Horizontal Axis Wind Turbines (HAWT) were installed near Rutland, with a rotor diameter of 53.3 meters and an average power of 1.25 MW. This was considered a pioneering work in mechanical engineering at the time, and the Smith Putnam project marked a difference between the decline of fully developed wind turbines and the new growth of stand-alone utility-line wind power plants that generate DC power for local use, as shown in Figure 2 [9].

There has been a clear race in energy growth relative to the location (offshore or onshore) as UK offshore wind growth has seen costs rise around 3 million per megawatt while onshore wind costs are lower at 1.5-2 million/MW. In addition, 84 GW of offshore wind capacity could be saved per plans for the recent increase in offshore wind power subsidies.

Until 2019, the government has confirmed that its commitment and support for offshore wind energy will increase from 135 MW/hr. To 140 MW/hr. After 2020, offshore wind has the potential to become a major source of electricity in the UK [10]. At the same time, onshore wind farm projects that align with the set goals have been seen, and by 2030 it seems possible to exceed 1 terawatt of wind energy installations, especially as shown in Figure 3. Considering the challenges presented by each country's need to protect clean energy technologies. Besides, the role of the European Union throughout the development of wind energy is leading despite the reflection in the explosive growth of the wind energy industry in China, the performance of the twin-rotor turbine has been improved in multiple areas [8,11].

Each new wind farm development increases industry knowledge and continues to push the boundaries of technology. There are other methods that have influenced wind energy development, the most important of which is education, as education through the interaction between turbine producers and owners is a challenge in the first place. The education aimed to develop a platform for large wind turbines based on advanced scientific research results. The problem is caused by a lack of communication between wind turbine producers and researchers. The Danish Research Institute has been the main reason for Denmark's success in the innovation system for learning through the interaction between turbine users and turbine producers. The innovation system for education is very important for the success of the scientific and practical innovation process, as innovation is the quality and activity of the network [12]. Several teaching aids, cameral packages, and platforms were created for wind energy systems.

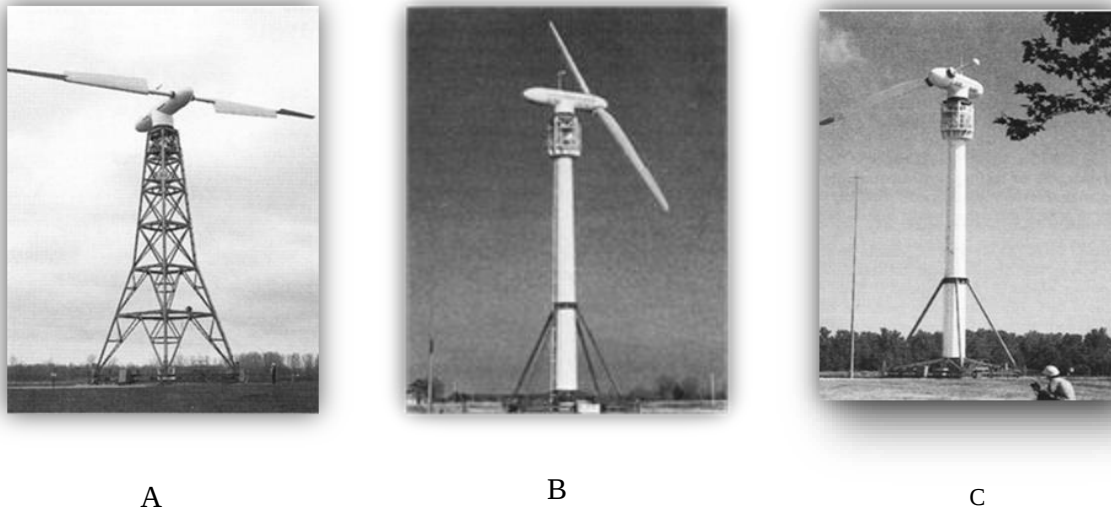


Figure 2: Different Mod-0 configurations during a decade of research. (a) 1979: Upwind rotor, (b) 1982: Inboard blade sections of limitation wood, Shell tower. (c)1985: One-bladed. (Courtesy of NASA Lewis research center) [9]

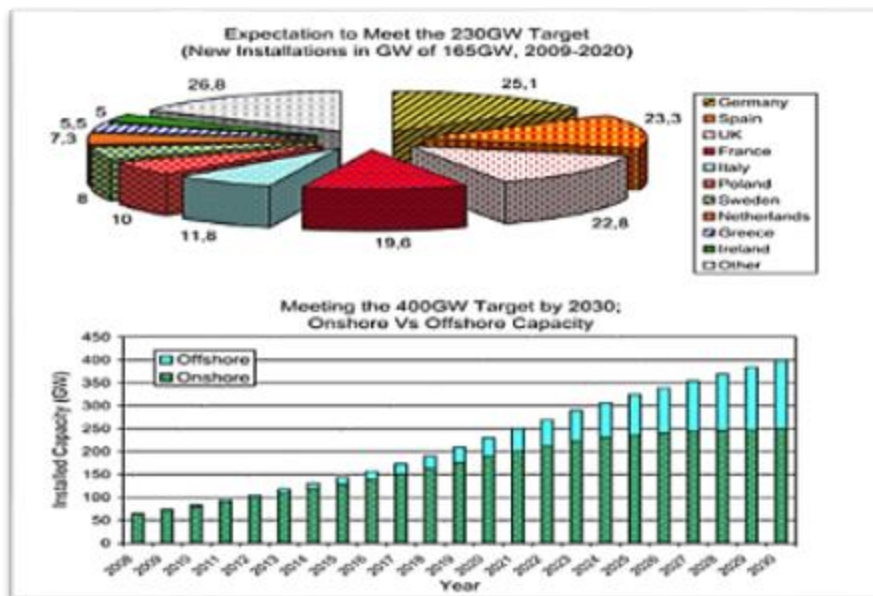


Figure 3: Targets of wind energy are futuristic [8]

3. Technological Development

Technological development produces a close link between the development of scientific knowledge and the technological path of wind turbines. Furthermore, these results help broaden the understanding of environmental innovation factors by providing new empirical evidence of their association with scientific knowledge, such as comparing maps of scientific papers and patent data [13].

Technological advances in wind energy conversion technology in recent years are considered the main factors in the rapid growth of wind energy. It has become possible to install wind systems in cities or in favorable working environments to improve the efficiency and reliability of wind energy conversion systems. Furthermore, further factors in fluid dynamics have contributed to realizing wind turbine aerodynamics [14,15]. Modern technology refers to the remarkable development in wind turbine design, which showcases a technological methodology for advanced wind turbines [16]. The modern methodology includes improving mechanical design considerations for data analysis and the feasibility of adopting wind energy projects.

Despite the advances in modern wind energy technology, wind energy technology trends and potential challenges have been thoroughly studied. It is estimated that wind turbines will occupy less land area in the near future than those designed in the last three decades, which increased their capacity 30-40 times. Therefore, many areas require reducing the cost of wind energy which must be improved.

The size of the large rotor in the horizontal turbine (HAWTs) has a high power that is directly proportional to the wind speed and torque. In contrast, small turbines with low speeds need less torque due to the length of the blade—taking into account the rotational speed of the generator, the number of blades, the length of the rotor blade [17], and the large size of the

turbines. The distances between the wind turbines in the farms were 6-10 diameters apart in the direction of the wind and 3-5 diameters in the direction of the crosswinds to maintain—over 90% of the performance of isolated HAWTs in such cases. Using a VAWT or multiple MR-HAWT or DR-HAWT small turbines on the same land area, it was possible to produce more than 10 times more wind energy [18].

The improvement of the combination process is related to increasing the turbulence's intensity, leading to increased stress loads on the downstream turbines [19]. Permanent magnets are used instead of a complete transformer and gearbox, which reduces the size of the wind system and thus reduces the amount of special ground required [21,22]. The air duct system is one of the improvements that has increased the efficiency and performance of wind energy systems, and it has many forms (straight, convergent, and divergent) [23].

4. Econoenvironmental Impact of Wind Energy Technologies

The environmental effects of wind power generation are inherently positive compared to the negative impacts associated with fossil fuels. The econ-environmental advantages of generating power from wind energy play a significant role in establishing the energy policy goals regarding climate challenges. Employing wind energy technologies in power generation is recommended because of their lower costs of economic and social and lower pollutant emissions. Furthermore, the wind energy system plays a crucial role in developing countries. Developments and modernization of wind turbine technologies will serve in migration of the effects of greenhouses and global warming on the environment [20].

Environmental innovations are one of the most important and widespread factors associated with technological change in wind turbines. They rely on wind turbines' technological path to map scientific knowledge development. They build an original database of scientific articles using two different algorithms to analyze the path of accumulation of knowledge related to the development of wind turbines.

Regular maintenance is critical to ensure technological improvement and reduce wind turbine costs. Maintenance contributes to keeping wind turbines operating and facilitating product recovery in end-use (EOU) remanufacturing. It has been proven that the results of periodic maintenance indicate 2-3 per year. It positively affects the reliability of the EOU, and the reliability ratio reduces 21% of the gap between the desired and the actual. Furthermore, the time required to reuse is shorter (6 months) than corresponds to (9 months) without the maintenance of Wind Turbine Life [3]. Artificial intelligence (AI) wind turbines may play a vital role in developing efficiency. Through machine learning, human intelligence (HI) is elevated to the supervisory level by using the digital twin in systems that lead to high-level decision-making through a human-machine interface. To this end, these key enabling technologies, KETs, must be integrated into HCPS to achieve more independence and intelligence so that future wind turbine development will jump from 4.0 to 5.0. This can be seen at the beginning of the third decade of the twenty-first century on the horizon, as shown see Figure 4. It achieves sustainable development goals in clean, affordable energy [23].

All these improvements lead to an ever-increasing cost reduction. As a result, in the medium term, wind energy will be able to compete with fossil energy generation technology for power generation [24].

Technological development does not focus on the expansion process but on developing innovative solutions for design and cost reduction that coincide with dealing with different landscapes, such as reliability, network code requirements, wind resource quality or prices, and availability of certain commodities. Thus, wind energy can compete with existing conventional generation technologies, such as fuel, by reducing costs and increasing capacity. Technology development can be inferred from increasing the production of manufacturers of high importance to the domestic wind resource [25].

5. Design and Innovation of Wind Turbine Systems

The wind turbine industry's motto was once "bigger and bigger", but now it's "better and better". This change is in the areas of innovation. It turns out that the latter design of the turbine may be the same as the previous one, with many different aspects and differences within the blades that must be considered. "Design" tools have been prominent in the development of wind technology. Originally, they were analysis tools, and they can analyze well in any presented configuration but are not accompanied by guidance on the preferred configuration. In designing wind turbines, the focus should be placed on power and torque-force as a measure of energy capture potential [26] and value as a strong indicator of weight and cost, usually while retaining many advantages. Failure to do so results in a waste of resources, concepts that had to be challenged at a fundamental level and under the best innovative technologies. No matter how vital innovations are in the most obvious advantages that drive them forward, they do not consider major obstacles [27]. The design evolution of the wind turbine is summarized in the flow diagram shown in Figure 4.

Among the obstacles in the design of wind farms are (multiple interrelated variables and constraints). The solution is usually through previous experience or trial and error. Effective treatment of the wind facility problem can be improved by utilizing evolutionary algorithm techniques when planning electrical infrastructure and turbines and evaluating all solutions. Optimization algorithm deals with proposals within constraints such as the wind farm location being close to the road with one or two energy disposal lines with limited evacuation capacity and restricted areas such as terrain with low carrying capacity. To improve the site problem and turbine selection versus investment, 75% of the initial investment for a wind farm is consistent with the costs calculated in the first sub-problem, which plays a major role in the annual production of electric power [28]. To also overcome obstacles in the main design problems, we can use the TRIZ method (Theory of Innovative Problem Solving) to identify the technical contradictions of the wind turbine system. The TRIZ methodology states solutions as innovative principles derived from the final design of thirteen principles [29]

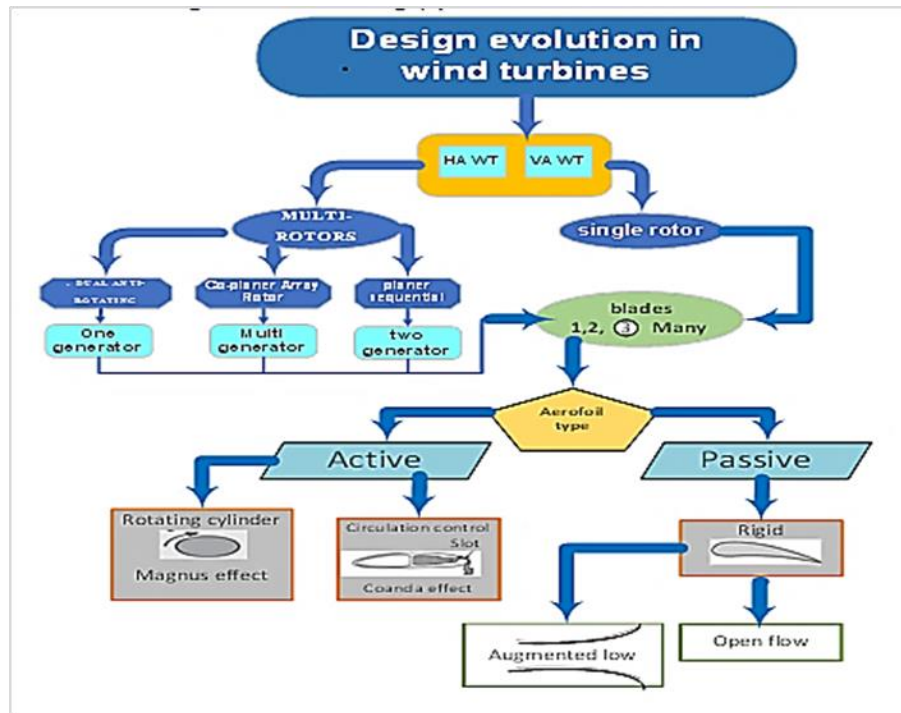


Figure 4: Flow chart of the design evolution of the wind turbine and its types

6. Multi-rotor Technology

Increasing rotor size creates problems, and the MRWT system design is a mature technology concept with accelerated growth. The multi-rotor technology has a long and continuous history and a variety of innovative modern systems. It is considered a suitable alternative to a very large single rotor with several small turbines because it has the same wind area and increases the development by increasing the survey area. But this concept has been regressed due to the prevailing perception that it is complicated and unnecessary, and the technical issues of the traditional turbine are available. At the same time, it must be evaluated based on (technological advantages, expected energy performance, feasibility, reliability, and cost).

The basic versions of multiple wind turbines showed three types of designs:

1. Multi-Rotors Wind Turbines (MRWTs)
2. Dual Anti-Rotating Wind Turbine (DRWTs)
3. Single-rotor, unidirectional, or counter-directional wind turbine

Multi-Rotors Wind Turbines (MRWTs) are technologically robust and reliable. However, its efficiency depends on the number of small turbines [30]. Linked together and installed on one tower, as shown in Figure 5. The tower is considered the most important part of this design. To study the dynamic responses of the tower, the flexibility of the tower's loads and deformations must be taken into account, especially with the addition of the number of turbines. The top deflection of the tower's top is directly proportional to the increase in the additional turbine. Moreover, the natural frequencies of the rotor also increase with the change in the tower deflections and loads. Hence, the torsional strength of the tower is a critical factor because the two rotors do not rotate simultaneously, assuming that there is no aerodynamic interaction between the rotors and the selection of the optimum distance to improve performance [31, 32].

One of the challenges faced by multiple turbines (MRWT) is the system's network connection because it contains more than one generator, so it can be connected to the same connection of wind farms if they have direct or alternating current [33]. To reduce cost in multi-rotor systems, standardization in manufacturing can be used for rotors of small sizes, given that the costly part is the blade [34]. In addition, the design provides useful predictions and allows inferences about the system's behavior. With increasing versatility, MRWTs can become useful in some applications [35].

The concept of designing a multi-turbine is focused on connecting more than one generator with one rotor and collecting its energy. However, the large size of the system and the low winds inside the cities make these types of turbines unsuitable for installation inside the cities. In addition, the air interference in the root area of the blade (near the axis) in the wind farms leads to obvious losses [36].

For the above reasons, this remarkable design was invented, which connects two opposing turbines in motion on one generator and considers that the generator contains two parts, Figure 6.

The size of the second turbine must be 25% less than the main turbine to have a net CP benefit of 7%. Since the variance in turbine radius has an important effect on turbine performance, the power factor increases when the dimensional difference in the radius of the front rotor decreases relative to the rear rotor [37,38,39].



Figure 5: (a) Multi rotor by Hermann Honnef, 1930 [31], (b) Four rotor Array [33], (c) Rotor array [30]

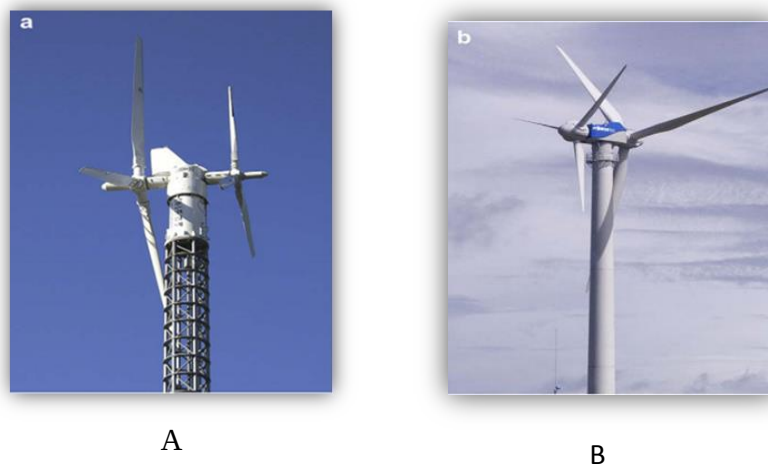


Figure 6: Dual rotor wind turbine generator system (a) 30KW proto-type, (b) 1MW commercial type [37]

7. Modeling and Control of the Wind Turbine Performance

Challenges associated with wind power are the unstinted behavior of the wind. Wind power forecasting is based on the interrelations among wind speeds, wind power, and ambient condition. Wind farm data are important primarily for the reliability, safety of grids, and wind speed prediction. Blade element momentum theory (BEMT) was developed, and modeling was developed to predict an activity flow at the front of the front turbine and then applied to the backflow of the turbine. The BEM theory was corrected by the vortex grid method in comparison with the curve of the energy. The effects of design parameters on the aerodynamic performance of counter-rotating wind turbines have been considered as a means of improvement, where the convective velocity of the terminal vortex from the front turbine is higher than that of the back turbine. According to the difference in the distance between the two turbines, the change was little in the total power factor [40]. The prediction method showed reasonable performance of headwind turbines [38], Considering reducing the secondary turbine radius at a 1:2 ratio, torque balance, and stiffness ratio Distributed along the blade for different tip speed ratios. The higher value is at the root and lowers the more we go to the tip of the blade and the estimated wind speed (the higher the velocity ratio, the better the effect than the lower velocity value) [41,42]. As a result, the annual energy production can be increased to about 43.5%, compared to a conventional wind turbine [43].

Several studies on computational fluid dynamics (CFD) are found to simulate and know the effect of the relationship between the characteristic parameters and the power ratio [44], the time it generates more electricity. The optimum target is higher energy and shorter life, with longer life and less energy harvesting capacity [45].

The models obtained for such turbines are non-linear depending on the wind speed. Therefore, the system needs modeling and control techniques to control the quality within the system. Reliable methods must be established and represented by the transformers that are controlled by the system. They vary according to the design (constant and variable speed wind turbines). The wind turbine speed is controlled either by moving the pitch angle of the rotating blade, often hydraulic or electric or by using electronic circuit devices (MPPT). The rotor speeds are adjusted PMSCs according to the instantaneous wind speed and voltage control. The main objective of the control unit is the safety of the system in the first place and the control of the resulting energy. [46,47]

Table 1: Summarization of relevant studies that contributed to the development and improvement of wind energy

N O	Auth or/s Nam e/s	Methods /techniques	turbi ne type	Air speed/rotat ion speed	blade design	Enhanced parameters	advantage	limitations
1	Li, Z., et al. [22] 2021	Pilot study and software simulation	multiple rotors	200 (rpm)	–	torque	Modern incorporation of adjustable eddy currents containing permanent magnets and the percentage of permanent magnetic maturity is 30% when the sliding speed is less than 200 rpm	The torque increases to 2.5 when the eddy current density is less than 50 amperes, and it is higher than 300% for a low sliding speed,
2	Lipian, M., et al. [46] 2019	Pilot study (shrouded wind turbine systems)	twin-rotor	4-17 (m/s)	SG6040 and SG6041 airfoil.	Shielded system	The performance of wind turbines increases for the covered and counter-rotating rotors. The increase is for cp 11-13% for the shrouded, and from 4-5% for the unshielded.	The maximum cumulative Cp strongly depends on the rotors' mutual position. This is because the range of TSR decreases dramatically.
3	Erturk, E., et al. [48] 2018	Pilot study and software simulation	Dual Rotor	2-14 (m/s)	airfoil symmetry	pitch angles	Derivation of a mechanical and electrical model for a twin-rotor wind turbine, the cp increases as the pitch angle decreases	The power of the turbine depends on the intensity of the wind speed remaining from the front rotor coming to the rear rotor
4	Moghadassian, B., et al. [19] 2016	software simulation	Dual Rotor	3-12 (m/s)	Flatback airfoils	Atmospheric boundary layer	The twin-rotor enhances the entrainment of turbulent axial momentum by 3.3% and improves the isolated aerodynamic performance by 56%.	The highest entrainment is observed in the neutral stability case when the turbulence in the ABL is moderately high.
5	Nikolich, V., et al. [29] 2016	review	general	-	-	TRIZ theory	Using TRIZ Theory of Inventive Problem Solving as a systematic approach to innovation, 39 engineering parameters were used according to TRIZ theory.	TRIZ achieved four steps of wind turbine design development. discrepancy analyzes
6	Jadallah, A. et al. [17] (2014)	software simulation	general	-	-	Developed methodology	A developed methodology has been used to predict the optimum performance of a horizontal axis wind turbine in terms of the most important parameters such as tip velocity ratio, pitch angle, blade	Find the range (5 to 11) of the tip velocity ratio is optimal. The negative pitch angle has a high-power coefficient at high wind speed. It may give a TSR range of rank (0.6 - 11)
7	Rosenberger, A. et al. [36] 2014	software simulation	Dual Rotor	8(m/s)	-	Secondary turbine size and location	The energy polarization potential of the DRWT increases by about 4.6%, and RANS predicts a net cp benefit of 7%. The volume of the secondary rotor turbine should be 25% and 0.2 times the distance from the main rotor	Aerodynamic inefficiencies in the blade root zone, and the increase in vertical energy retention, which would reduce turbine losses, are not evident.
8	Hoang, A. D., & Yang, C. J. [45] (2014)	software simulation	twin-rotor	10(m/s)	S822 and S823.	Opposite wind turbine modeling	39% power factor increase with dual reverse rotation concept at TSR 5, more efficient at a lower rotor speed	The reverse additive rotor shows significantly lower performance than the primary rotor. The second rotor can capture 2-8% more of the total power in the stream.
9	Lee, S., et al. [40] 2013	Pilot study and software simulation	twin-rotor	424.5 rpm 10(m/s)	DU 91-W2-250, RISØ A1-21 and NACA 64e 418	free spiral lattice	12% cp increase for the opposite rotor compared to the single rotor, and the terminal vortices of both rotors are radially enlarged more than the single rotor	The tip vortex of the rotor from the rear was much lower than that for the single rotor.
10	Hwang, B., et al. [49] (2013).	Pilot study	twin-rotor	8(m/s)		model development BEMT	The BEMT method was corrected by the vortex grid method. The optimal solution was found using a multi-islet genetic algorithm. Max Cp was found to be 0.4	Torque balance and stiffness ratio are taken into account for operation with synchronous rotation, and the rear rotor radius and rated wind speed can be reduced

Table 1: Continued

N O	Author/s Name/s	Methods /techniques	turbine type	Air speed/rotat ion speed	blade design	Enhanced parameter s	advantage	limitations
1 1	Kale, S.A., & Sapali, S. N. [30] (2012)	Critical review	Dual Rotor	--		evaluation form	Evaluation of this innovative wind turbine based on feasibility and technological advantages, an array of wind turbines	21% power factor increase at inter-rotor space 0.5D
1 2	Lee, S., et al. [38] 2012	Critical review	twin-rotor	-		model development BEMT	When the dimensional difference in radius increases by about 0.2 for the front rotor, the power factor increases, and aerodynamic performance can be improved by using combinations of tilt angles	c p increases when each rotor correctly shares the total power, and it has also been shown that c p increases when the rear rotor speed decreases
1 3	Shen, W. Z., et al. [42] 2007	software simulation	twin-rotor	10(m/s)		Computational procedur-	The analysis shows the annual energy production increases by 43.5%. The highest CP is obtained at low wind speed	increase of using a CRWT instead of an SRWT may be a bit smaller, but at high wind speeds, it would work like the present case
1 4	Shikha et al. [15] 2003	review	general	-		Comparison	Analyzing the important gaps between theoretical and practical research results regarding the technological development of wind turbines, and their impact on the cost of this system	There must be harmony between designer companies and researchers to overcome obstacles,
1 5	Ushiyama, I. et al. [26] 1996.	Pilot study	twin-rotor)	6-10(m/s)		Self-starting properties	Developing the starting characteristics of the combined rotor type, increasing the rotational speed of reverse rotation, and having a technical possibility for generators operating with opposite rotation	The test is carried out in a wind tunnel. The technical possibility of the alternating type wind generator

Dual rotor wind turbines are more efficient and can secure more energy. Increasing the efficiency of small wind turbines by dynamic optimization of blade shape is limited. The ideal solution to increase the efficiency of the wind turbine system was the design of a dual rotating wind turbine (DAWT). Due to the use of the twin-turbine system, it is possible to better perform the pressure distribution on the blades of both turbines, especially if it is installed inside an air duct [23]. This can be achieved by reducing the thrust coefficient of the upstream turbine and the Tip Speed Ratio (TSR) by about (33% for downstream and 20% for upstream) for one turbine, respectively, due to the interaction between the same turbines when working in an opposite group rotation [48,49,50,51]. The efficiency of CRWT at the half-stiffness of a single turbine is 30% more and at the same stiffness of the single rotor is 5% (15.2). Rather, the technology for the improved mixing rate with twin-rotor wind turbines DRWT has been shown to have the potential to improve the efficiency of secondary turbine design in wind farms, or it runs optimally.

The contributions of researchers to the design, and optimization technologies of wind energy, related to the origin of the research, were reviewed in a comparative manner shown in Table 1.

8. Conclusions

Wind energy can be involved potentially in electrical power generation, water pumping, desalination, and other applications. The utilization of wind energy systems may help involve renewable energy resources to provide the energy demand and achieve the policy and strategy goals. Wind turbines are characterized by their ability to be hybridized with other energy resources such as solar and geothermal. The cost of wind energy systems becomes cheaply feasible among the other renewable energy resources. The multi-rotor wind turbine will significantly reduce costs compared to conventional wind turbine configurations.

On the other hand, the multi-rotor wind turbine is the best strategy for several reasons. It contains twice the number of blades concerning the traditional turbine, and the area of wind exploitation is larger. Furthermore, the main goal of producing multiple rotor turbines is to achieve the highest energy with the lowest wind speed. Hence, these features make this design suitable for regions with low wind speed, such as Iraq. The technical aspects of the modern wind energy systems can easily recover, which inched all the accessories of the WECS. The wind energy conversion system was found to be easily hybridized with other RE resources and may play a vital role in planning and smartening cities for a good establishing merit

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

Authors declare that their present work has no conflict of interest with other published works.

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