Wind Energy Resource Utilization: A Review of its Necessity, Interception Technology and Implementation Challenges

ABSTRACT

The continuous use of non-renewable energy sources has caused a lot of harm to the earth's atmosphere and humans, leadin. The need to increase the share of renewable energy in global energy usage has been strongly advocated internationally. In this work, wind energy was presented as a viable renewable energy option. Renewable energy with emphasis on wind energy, wind turbines and its types, the need for it to replace other injurious energy sources and the associated challenges hampering its deployment is a contribution toward the UN advocacy. The potential of wind energy and their technologies in terms of the turbine types: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) including their mix were reviewed. Looking at the pros and cons of both the HAWT and the VAWT, and those of Savonius and Darrieus, it is imperative to strike a balance using their combinations. Such a hybrid offers the benefit of harnessing the gains on either side of the divide. This is the reason attention is being devoted to research and development on combined VAWT in order to optimize the low starting torque of a Savonius with the high-performance coefficient of the Darrieus as the efficiency of VAWT increases when combined together with diverse modifications. With the volume of on-going research targeted at the implementation challenges and various design considerations and practices to solve the problems, it is certain that these impediments will be tackled technologically and policy wise and society will be on its way to better utilization of enormous wind energy resources via interception using wind turbines. The technical challenges on the pathway towards the smooth implementation of wind energy technologies were identified to include output fluctuations and intermittencies; and to which solutions were proffered to include the need for a technology to always align and realign the blade position in a way as to maximally interact with the current prevailing wind direction and another to reinforce the rotors rotational speed with an appropriate speed required to meet up the rated output. It was recommended that attention be devoted to research and development on the combined vertical axis wind turbine (VAWT) in order to optimize the high starting torque of the Savonius turbine with the high-performance coefficient of the Darrieus turbine.

Keywords: Savonius rotor, Darrieus rotor, Rotation per minute (RPM), vertical axis wind turbine (VAWT), combined Darrieus and Savonius wind turbine

INTRODUCTION

Energy is the quantity of force that when applied can move one object from one point to another [1] or a conserved quantity that can be transferred or given to an object in order to produce useful work. The sun is the ultimate source of all energy present in the world. In order to harness this energy, there is a need for design intelligence so as to develop solutions that are beneficial to our major survival. Energy is one of the important components of any developed society [2]. Hence, both the economic and social development of any country depends mostly on how it plans to use this energy [3]. So, government should develop policies aimed at increasing the output of renewable energy in the future energy system through the 2015 Paris agreement [4], due to these policies, there was a significant increase in the capacity generation same year, which grew by 8.3% and later, between 2019-2020, there was only 3% increase. This decline results from inadequate policies and improper enforcement of the policies by government.

It is important to state that, the earth is suffering from global warming and if not properly addressed, humans will find it difficult to live their daily lives. Many harmful substances are released by either burning wood or fossil fuels. This leads to high emissions of greenhouse gases causing atmospheric changes [5[and Climate change, which is an effect of global warming, is a major challenge primarily caused by the use of fossil fuels in our societies [6]. This means that non-renewable energy sources have an adverse effect of affecting the lives of many when used or burn by releasing CO_2 gases into the atmosphere and hence causing the depletion of the Ozone layer leading to global warming.

The IEA in recent years has always encouraged the development of renewable energy technologies in order to replace and augment the available conventional energy sources and also to reduce the carbon emission into our atmosphere. Due to these concerns, renewable energy technologies are being developed and could reduce the emission of CO_2 gases by replacing fossil fuels in the power generating industry and the transportation sector respectively [7].

Sources of energy

Energy forms can be categorized into two: renewable energy resources and non-renewable energy resources.

Non-renewable Energy Sources

Non-Renewable energy resources are energy gotten from sources that cannot be replenished and they deplete with time after use [8]. Some examples of non-renewable energy resources are petroleum, natural gas, coal and energy from radioactive materials (Nuclear energy). Most of the energy currently used in the world now comes from non-renewable energy sources and this is a problem that will significantly affect the energy output in the future since these types of energy deplete with time [9]. Non-renewable energy is currently consumed globally in large quantities, and because of this, the release of carbon dioxide into the atmosphere has also increased significantly causing a greenhouse effect. However, the earth is constantly suffering from uneven change in its average temperature because of the depletion of the ozone layer by carbon dioxide leading to global warming and acid rain.

One of the major demerits of non-renewable energy is that, it can deplete and finish, when this happens, the world will run out of energy to power its machines since the total world demand for energy is increasing exponentially [10].

In Nigeria, based on the report available, 11251 barrels of oil were spilled in the year 2021 [11], which is due to the vandalization of oil pipelines and lack of proper maintenance in the oil industries, this resulted in oil spillage that pollutes the rivers, the rivers flow to drinking stream and even farmlands, this causes ill-health among the people living in the areas who are predominantly farmers and fishermen, thereby crippling their means of livelihood. The cost of producing and maintaining a nuclear power plant is very discouraging not to talk about the hazards from radioactive waste to human health and the environment at large. A typical example is the Chernobyl nuclear power plant disaster in 1986 that render 237 people hospitalized from acute radiation sickness [12], 28 died within 3 months and still, after 10 years, 14 people accounting for 7% of the remaining population claimed to have suffered from the radiation, also died [13], thereafter, many people later died of cancer suffered from the radiation aftermath.

The only solution to this catastrophic effect of a long time use of non-renewable energy is to replace non-renewable energy sources with renewable energy sources

Renewable energy

Renewable energy is that energy that is naturally and constantly replenished [14] [15]. They cannot be exhausted and are used every day by man. The source of this energy is called renewable energy sources. They vary from the sun, wind, water, heat emitted by the earth, energy from waste etc. Renewable energy sources cannot be exhausted because they are constantly replenished through the natural process, so any energy from water and wind, is capable of supplying the world energy for almost another 1 billion years without being exhausted [16].

Renewable energies are clean energy sources with zero emission of harmful gases into the atmosphere. If fossil fuel is not utilized, then harmful gases will not be released into the environment, there will be safe air to breath, clean water to drink, little or no climate change, reduction in fuel price and fuel dependence [17]. In spite of all these points, Frederikus et al., 2015 [18] reported that only a small proportion of the energy currently used comes from renewable energy sources such as solar, wind etc. Some renewable energy sources are discussed below:

Solar energy

"The sun supplies the earth with energy in the form of solar energy or solar radiation. These radiations reach the earth as ultra-violet, visible and infrared radiation. The amount of solar radiation that reaches any given location is dependent on several factors like geographic location, time of day, season, landscape and local weather" [19]. A device used to harness this solar energy for electricity generation is called a Photovoltaic cell (PV) made mainly from semi-conducting materials and recent technology make use of Concentrated Solar Power (CSP) [20]. When the solar panel is exposed to the sun, it can trap or harness both direct, indirect and diffuse radiation. One of the major drawbacks of Solar panels is that, if not properly oriented in the direction of the incident radiation, a shadow will be cast on it, cutting off the incident radiation from reaching it [21]. Another disadvantage of using a solar panel is that, it harnesses its energy from the sun. However, during the night or winter period when there is little or zero amount of solar radiation, electricity production is halted for the time being until the sun rises again to give out its light [22]. Furthermore, the efficiency of a PV cell tends to reduce with time [23]. Lastly, PV cells are not economically friendly. This is evident in the cost of producing and maintaining it, a PV cell requires a very large area to be installed and also requires only expert to install and perform maintenance [24].

Hydroelectric Power

Many countries of the world are widely into the production of electricity from hydroelectricity. This is a systematic way of trapping a large amount of water in Dams and then carefully releasing the water in order to provide a torque that can be used to mechanically turn a turbine. Hydropower electricity generation technology is one of the cheapest in terms of electricity generation costs [25]. According to Chiyembekezo *et al.* in (Roth, 2005) [26], stated that, “the energy conversion system e□ciency for a well-operated hydroelectric power plant can be around 85%, while the system e□ciencies for thermal-electric plants are less than 50%”. “Even though hydroelectric power is widely used worldwide, the cost and of course, maintenance is a di□cult process to manage due to production disruption and due to the interruption of production during the process, costly in terms of time, labor and material requirement and due to the specific limitations of these components” [27].

Askari *et al.* [28] highlighted some disadvantages of using hydroelectricity, in which they stated that,

1. Dams are extremely expensive to build and must be built to a very high standard. So, the high cost of dam construction means that they must operate for many decades to become profitable.
2. The flooding of large areas of land means that the natural environment is destroyed and can be a good catalyst for earthquakes.
3. People living in villages and towns that are in the valley to be flooded, must move out. This means that they lose their farms and businesses. In some countries, people are forcibly removed so that hydro-power schemes can go ahead.
4. Dams built blocking the progress of a river in one country usually means that the water supply from the same river in the following country is out of their control. This can lead to serious problems between neighboring countries and can hinder the flow of water for irrigation purposes to farmland.

Wind Energy

Wind arises because of the uneven heating of the earth's surface by the sun [29]. This means that wind is a convectional process that results from the thermal movement of air molecules as facilitated by the sun. Wind energy is the kinetic energy associated with the movement of large masses of air, which is a result of thermal movement of the air particles, and this means that, wind energy is a converted form of solar energy [30]. However, “wind is an environmentally friendly source of energy that can satisfy the energy needs of people living around localities with regular wind speed and can also serve as a means of combating climate change from greenhouse gases emitted by the burning of fossil fuels” [18]. There are many retarding forces faced by wind technology in which one among them being the constant change in wind speed and its direction of flow [31].

Since wind energy is the kinetic energy ($K.E$) of moving particles of air, it can be described by equation (1) as,

$$K.E = \frac{1}{2} MV^2 \quad (1)$$

The mass flow of air particles M is given by;

$$M = \rho V \quad (2)$$

Where ρ is the density of air and V is the speed of the wind. Substituting (2) into (1) yields the power P, extracted from the wind (32).

$$P = \frac{1}{2} \rho V^3 \quad (3)$$

The Necessity of Wind Energy

Wind is becoming the most harvested and cost-efficient replacement presently in the world for power generation [33]. “Among renewable sources of energy, wind is the most widely used resource due to its commercial acceptance, low cost and ease of operation and maintenance, relatively less time for its realization from the concept to operation, least adverse effect on the environment and creation of new jobs” [34]. Wind has the potential to support more than 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050. Studies have also proven that, the capacity of wind energy on a global scale has risen to more than 500 GW in the past years and some European countries like Portugal, Germany, Spain, Sweden and Ireland are actually producing more than 10% of their energy from wind [35].

The use of Wind energy dates back to 5000 years ago [36] when it was used to drive ships, grind grains and turn windmills for irrigational purposes and is currently, gradually finding its way into the global market replacing other forms of energy. So, in recent years, the energy from wind has posed to be a serious contender among renewable resources and also compliments the other alternative energy resources like solar energy [37]. Figure 1 is a chart of the world’s renewable energy generation capacity.

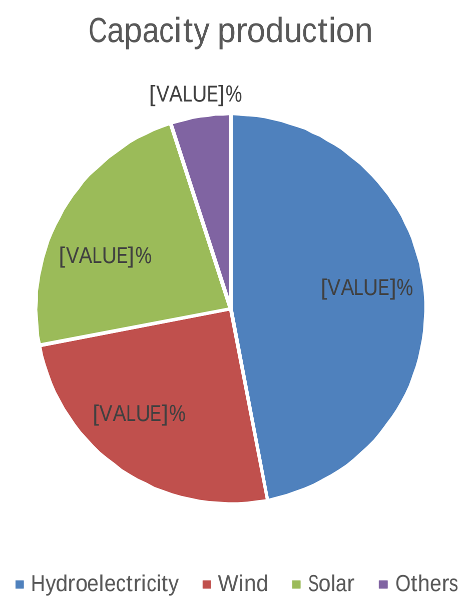

Figure 1: world renewable energy capacity (38)

"Before the beginning of 2020, the global renewable generation capacity reaches 2537GW. Hydropower accounts for the largest share of the global total renewable energy capacity, reaching a total capacity of 1190 GW. Wind and solar energy accounted for most of the remainder, with capacities of 623 GW and 586 GW respectively. Other renewables included 124GW of bioenergy and 14GW of geothermal, plus 500 MW of marine energy" [38].

Wind Turbine

"In order to harness the energy present in the wind, a device called a wind turbine is used to convert the kinetic energy of the wind to mechanical energy of the turbine. This energy technology for capturing and converting the available wind energy appears to be a conceptually simple technology; a set of turbine blades driven by the wind turns a mechanical shaft coupled to a generator which produces electricity" [29].

The wind helps the turbine to rotate about its axis. It works by allowing the kinetic energy of wind to rotate it and in turn convert it to mechanical energy that rotates its rotors which in turn move the coil around a magnet of the generator. This rotation produces electrical energy that is utilized [39].

Centuries ago, Man has been using wind turbine to propel boats along the Nile River as far back as 5,000 B.C., and also helped Persian's pump water and grind grain between 500 and 900 B.C. and by the Chinese between 500 to 900 A.D. This means that wind power has been utilized for thousands of years. It was recorded that the Arabs were the first to use windmills to grind their grain and pump water, and then much later the Chinese joined the race. These windmills mainly use drag forces of the wind to rotate, that was why they were called drag turbines. It has also been recorded by History that, around 480BCE, the Persians uses ships to sail through the sea in order to attack their rival Greece, these ships were powered by the wind, the ships were made up of a curve shape cloth hanged on top of it, which helps to capture the kinetic energy of the wind and convert it into mechanical energy of their ships.

Around 1300 A.D, windmills started entering Europe through trade and commerce between the Arabs, Chinese and Europeans. The Europeans modified the windmill by giving it a high structural tower made of bricks and sand in order to have a high elevation which gives a higher rotational speed because of the energy present in the wind at that altitude. These windmills were all used for the purpose of grinding grains and pumping water.

Types of wind turbine

"There are two types of wind turbine. These are the Horizontal Axis Wind Turbine (H.A.W.T) and the Vertical Axis Wind Turbine (V.A.W.T)" (40).

Horizontal Axis Wind Turbine (H.A.W.T)

The main reason why they are called horizontal axis wind turbine is that, the rotor is oriented horizontally with the generator with respect to the ground. They are the most common wind turbine found today and take the shape of the blades of a ceiling fan. They range from single blade to three bladed turbines elevated at a very high altitude on a high tower made of metal in order to capture enough wind for maximum efficiency. Horizontal axis wind turbines are turbines produced by the careful complex aerodynamic design of blades attached to a rotor that drives a generator [41].

One of the disadvantages of a horizontal axis wind turbine is that, the horizontal axis wind turbine cannot be installed around residential households and requires a yawning device to orient it to the direction of flow of the incoming wind. It does so by increasing the energy capture by pointing the rotor blades steadily towards the incoming wind direction and thus maximizing the general power input of the wind turbine. Although, yaw devices are not very reliable, this disadvantage leads to a horizontal axis wind turbine having more than one yaw device, in which the second serves as a temporarily yawning device in case the first one fails, which evidently indicates more cost.

Vertical Axis Wind Turbine (VAWT)

The VAWT's took their names from the fact that, the rotors are always oriented with the generator vertically with respect to the ground. Their main shaft is set transverse to the wind (but not necessarily vertical) while the main components (generators) are located at the base of the turbine. This arrangement allows the generator and gearbox to be located close to the ground, encouraging, facilitating service and repair. Therefore, they do not need to be pointed in the direction of the wind, this is why a yawning device is not necessary in its design [42] [43] [44].

"VAWTs were first recorded about 2,200 years ago in ancient Persia and were primarily used to grind grain" [45]. "All vertical axis wind turbines can harvest wind coming from any direction, as the wind direction changes, the incoming blade orients itself in the path of the wind. A conventional Savonius rotor is a vertical axis wind turbine that can start on its own at a lower wind speed" [46]. They are, however, suitable for small scale production of electricity because it is less expensive and easier to manufacture and very easy to maintain than the horizontal axis wind turbines [47]. That is why people living in areas of high wind potential can afford vertical axis wind turbines due to their easy installation and maintenance. The power output of the turbine is a function of the cube of the wind speed as shown in equation (3), so doubling the wind speed gives higher wind energy potential. This is why a vertical axis wind turbine requires a wind as low as 2.5 to 4m/s to start it up, with the maximum output being at 12-25 m/s (the excess energy being spilled above 25 m/s). While relatively few areas have significant prevailing winds in this range, many locations throughout the earth's surface have enough wind to be harnessed. Though the bigger the size of a wind turbine, the more they tend to have higher capacity factors [48]. There are basically two types of vertical axis wind turbines and they include; the Savonius and Darrieus vertical axis wind turbine

Savonius Vertical Axis Wind Turbine

A Finnish engineer called J. Sigurd Savonius invented the Savonius turbine in 1922 [49] and patented it in 1931 [18]. His model was two blade rotors shaped like a cup anemometer and looks like a cylindrical drum cut into two semi-cylindrical halves. Nowadays, they are always curved making a convex and concave shape backing each other and separated by a small distance called an overlap, just like the letter 'S' shape, this helps them to easily and effectively capture wind attacking it at an angle and creates a torque effect that pushes the rotor in other to rotate. One of the disadvantages of the Savonius rotor is that, as the concave part traps the wind and rotates, the convex part is also dragged by the wind, this action and reaction effect does not cancel out, rather, the dragging effect on the concave part is higher than that on the convex part, so the difference in the concave and convex torques gives the net torque dragging and rotating the turbine. In order words, there is loss of energy due to this effect which tends to alter the performance of a Savonius turbine by reducing its efficiency [50]. "It was also recorded that Savonius used a rotor, which was formed by cutting a cylinder into two halves along the central plane and then moving the two semi-cylindrical surfaces sideways along the cutting plane” [51],

The Savonius vertical axis wind turbine among all other types of wind turbine present in the market, is the simplest to construct as it does not require any complex aerodynamic parameters, in its simplest form, a drum can be divided into two equal halves, with both halves attached sideways and facing different directions, reducing cost. The Savonius rotor is widely considered to be a drag device and the wind acting on its blades, is the only driving force. However, it is observed that at low angles of attack the lift force also generates a torque that turns the turbine [52].

In an experimental study on the performance of Savonius wind turbines related to the number of blades by comparing the performance of two, three and four bladed Savonius rotor, it was concluded that, since tip speed ratio is an important factor to be considered when checking for performance, the three bladed Savonius wind turbine models show significant tip speed ratio at lower wind speed and was more stable at a wind speed of 7 m/s [18]. Figure 2 shows different designs of the savonius VAWT.

Figure 2: Various designs of Savonius Vertical Axis Wind Turbine [18]

There are several previous and ongoing types of research to improve the performance of the Savonius rotor. These researches include:

The factors that affect the performance of Savonius rotor were highlighted by Alexander and Holownia to include: the number of blades, tip speed ratio, overlaps ratio, shrouded blades and aspect ratio. Meanwhile, the ratio of the height of the rotor to the diameter of the curved blade is called the aspect ratio which can be used to improve the performance coefficient and plays an important role in improving the efficiency of the rotor [53].

An experimental study on the performance of Savonius wind turbine related to the number of blades shows that the number of blades has a great effect on the rotation of any rotor of wind turbine. In 2008, multiple blades with subjected to the same wind speed of 7m/s and concluded that, three blade Savonius rotor has the highest performance in terms of tip speed ratio at a lower wind speed [54]. On the same note, increasing the number of blades from two to four tends to increase the reverse torque on the blade which causes a decrease to the resultant torque pushing the blades, two bladed rotors have the highest power coefficient at the same tip speed ratio of 0.8 [50].

Using a wind tunnel, two, three and four blade Savonius rotors were all subjected to the same wind speed, the results show that, three blade Savonius rotor has the best performance at a higher tip speed ratio [18].

In an attempt to achieve high efficiency of the Savonius, modifications were made by adding a shroud to the rotor and this yielded an increase in the power coefficient [55] [56].

An experimental study to improve the Savonius rotor performance using two, three and four blade rotors to investigate how shrouding a blade, aspect ratio and overlap gap affect the performance of a Savonius rotor concluded that, two blade shrouded rotors perform better than the rest, power coefficient increases with an increase in the aspect ratio and finally, the rotors having overlap gap are more efficient in performance than those without it [57].

However, ElSayed and Wageeh [58] also investigated the performance of a multi-step or stage oscillating vertical axis wind turbine. Their design was four stages or step Savonius rotor shrouded at each step to maximize harnessing of wind. They concluded that, their design was a step superior to the normal classical Savonius rotor with higher torque and power coefficient. The Savonius rotor is a drag device. This means that, its turning effect is a result of a push by the wind. There are no airfoil inclusions in the Savonius turbine and as a result, the tip speed of the blade can never become higher than the speed of wind actuating it.

Darrieus Vertical Axis Wind Turbine

“About 1000 years ago, in the north-eastern part of Iran reside a village called Nashtifan, a straight bladed vertical axis wind turbine was built and primarily used to grind grains. Much later, French inventor Jean Marie Darrieus got his invention Darrieus VAWT patented in France in 1925 and subsequently in the United States in 1931. His invention drew hardly any attention at that time until in the late 1960s; two Canadian researchers re-invented his concept without knowing about Darrieus patent” [59]. “The concept of a Straight Bladed VAWT or H-Rotor was also an invention included in the Darrieus patent” [49]. “The H-Rotor is also called Giromill or Cycloturbine. The traditional Darrieus rotors and the H-rotors are vertical axis wind turbines provided with two or more blades having airfoil. One major advantage of the Darrieus rotor is that the rotor can take wind energy from every direction. The serious disadvantage is that the starting torque coefficient is zero and at low tip speed ratios, it is even negative” [60]. Therefore, a special motor is required to start the rotor [61] since it cannot self-start at a very low wind speed. This is the major drawback of Darrieus turbine whereaas the Savonius turbine is of obvious advantage. “The H-rotor Darrieus is the most common configuration of a straight bladed vertical axis wind turbine (SBVAWT). The “H” rotor received its name due to the single horizontal arm supporting its two or more blades” [62]. Figure 3 shows the various designs of Darrieus blade vertical axis wind turbines.

Figure 3: Images of Darrieus Blade Vertical Axis Wind Turbine [63]

Combined Darrieus and Savonius Vertical Axis Wind Turbine

Both Savonius and Darrieus wind turbines have their advantage and disadvantage. Savonius has the advantage of self-starting at a lower wind speed while Darrieus has the advantage of high rotational speed after eventually starting. Since they are both vertical axis wind turbines, both advantages can be optimized when both rotors are combined in a single system. Elmabrok [64] measured "the performance of a combined Darrieus-Savonius rotor experimentally, by computationally analyzing a three-bladed Darrieus turbine combined with a two-bladed Savonius rotor. A maximum C_p of around 0.34 was obtained without overlap condition". Gavalda *et al*., [65] measured "the performance of a self-adapting combined two-bladed Savonius-Darrieus rotor with Savonius rotor mounted on top of Darrieus rotor. A maximum C_p of 0.35 was reported at 16% overlap". Gupta et al. [66] experimentally evaluated "the performance of a combined two-bucket Savonius and three-bladed Darrieus rotor within overlap range of 16.2%-25%. A maximum C_p of 0.25 was obtained at 20% overlap at a low tip speed ratio of 0.32". Gupta *et al*. [67] again made "a comparative study between a three-bucket Savonius rotor and a combined configuration of a three-bucket Savonius and three-bladed Darrieus rotor within the overlap range of 16.2%-35%. The maximum C_p of the combined rotor without the blockage effect was higher than the Savonius rotor, and it was reported to be 0.51 at a low tip speed ratio of 0.61".

Alishan *et al*. [68] conducted an experimental study and analysis of a combined Savonius and Darrieus wind turbine. The setup was in three stages, stage 1: the Savonious rotor was mounted directly beneath the Darrieus. Stage 2: the Savonius was mounted at the middle of the Darrieus blades and stage 3: the Savonius was mounted at the top of the Darrieus blade. In their research, they found out that, when a Savonius rotor is connected beneath the Darrieus blade, the combined system performs better with a higher performance of coefficient.

Musa *et al.* [69] constructed, field tested and compared "a standalone Darrieus VAWT and a standalone Savonous VAWT adaptable for the Usmanu Danfodio University community, Nigeria in terms of their revolution per minute under the same wind speed conditions. The results of this test showed that under the prevailing wind condition of the study area, the Savonius VAWT has a higher starting torque than the Darrieus VAWT but when the Darrieus blade starts it takes a longer time to stop, given its higher rotational speed reaching a maximum rotation per minute (RPM) of 93 and 89 to the Savonius at a wind speed of 9.28 ms^{-1} and 8.9 ms^{-1} respectively. It is therefore a general consensus among researchers that the combined system has a better performance coefficient than any of the individual turbines standing alone".

HAWT and VAWT

Some researchers compared and contrasted the performance of HAWT and VAWT with interesting outcomes. Magedi [70] compared both types of turbines, they stated the advantages and disadvantages of both types and concluded that each type has its applications which directly depend on the wind speed and place to be fixed on. The vertical axis wind turbine can be placed at any height, close to the ground and high above the ground, unlike the horizontal axis wind turbine which can only be placed at a very high altitude above the ground in order to capture sufficient wind.

Also in another attempt, Wahab *et al*. [71] concluded that, when a VAWT is cautiously and systematically designed, it tends to perform better than the HAWT in generation of electricity. They also stated that the output power can be ten times greater than a HAWT wind farm of the same size.

In a review of vertical and horizontal axis wind turbine, Vivek *et al*. [72] concluded after careful comparison between the two types of turbines that horizontal axis wind turbine requires a large tower and blade to install, and the transportation cost is nearly 20% of the equipment cost. Highly skilled labor is also required to install the horizontal axis wind turbine.

Challenges Associated with Wind Power Interception using Wind Turbine

Although wind energy is a clean and sustainable energy source that is cost-effective and creates jobs as evident in Wind Vision Report [73]. Wind energy technology involved in the building and installation of wind turbines have advantages over other energy technologies in that, wind turbines can be built and installed in either residential or industrialized areas, rural or urban areas, on land or water, stationary or movable, small scale or large scale. In spite of these advantages, the gains of wind energy interception using wind turbines still face several challenges. Some of the technical and implementation challenges bedevilling the attainment of wind energy utilization agenda are highlighted below:

Output fluctuation: wind is not always constant, and its speed or power changes from time to time. Therefore, the non-availability of wind with sufficient speed capable of rotating and sustaining a wind turbine at all times gave rise to the technical challenge of a fluctuating nature of output in response to the sufficiently fast-moving wind of varying magnitudes. This causes the output from the wind turbine to be low and high alternatively. In order to curb this challenge of fluctuation (high and low), there is a need for a mechanism to always reinforce the rotor's rotational speed with an appropriate speed required to meet up the rated output.

Output intermittencies: the ever-changing wind direction frequently associated with wind gives rise to the technical challenge of the intermittent (on-and-off) nature of the output supply corresponding to times when wind direction aligns or dis-aligns with blade rotation. There is therefore a need for appropriate technology to always align and realign the blade position in a way as to maximally interact with the current prevailing wind direction

Location for a wind farm: wind farms are mostly built-in remote areas, a little far from the residential areas, so the cost of transferring electricity from that location to the consumers will not be cost-effective since the cables (wires) needed are expensive in the market and the power loses associated with such energy transport are high. Household capacity and off-grid wind turbines are advocated as a way out of this challenge.

Turbine Noise: wind turbine noise is one of the major hindrances in the development of wind power industry [74], so they can be very noisy when in use, this noise pollutes the immediate environment and can even affect human life and animals (mostly birds) living within the same location. But there are current wind turbines built to reduce the amount of noise produced. There are two major sources of noise present during operation: mechanical and aerodynamic, and the way of reducing aerodynamic noise includes adaptive approaches and wind turbine blade modification methods while strategies such as vibration suppression, vibration isolation and fault detection techniques are utilized for mechanical noise [75]. In a review of Wind turbine noise and its mitigation techniques by Shubham *et al.,* [76], they stated that, some of the techniques of reducing noise from a wind turbine include reduction of inflow turbulence noise, reduction of trailing edge noise and reduction of tip noise. These methods have in recent years proven efficient in the design.

CONCLUSION

Due to the side effects of the over-dependence on non-renewable energy sources, governments around the world are coming up with policies and strategies to explore and develop other sources of energy in order to gradually replace the existing non-renewable. Also, the sustainable energy for all initiative which was aimed to make energy accessible to all by doubling the share of renewable energy in the global energy mix has been advocated by the United Nations. This work in which an in-depth review of renewable and non-renewable energy has been presented, with emphasis on wind energy, wind turbines and its types, the need for it to replace other injurious energy sources and the associated challenges hampering its deployment is a contribution toward the UN advocacy. Looking at the pros and cons of both the HAWT and the VAWT, and those of Savonius and Darrieus, it is imperative to strike a balance using their combinations. Such a hybrid offers the benefit of harnessing the gains on either side of the divide. This is the reason attention is being devoted to research and development on combined VAWT in order to optimize the low starting torque of a Savonius with the high-performance coefficient of the Darrieus as the efficiency of VAWT increases when combined together with diverse modifications. With the volume of on-going research targeted at the implementation challenges and various design considerations and practices to solve the problems, it is certain that these impediments will be tackled technologically and policy wise and society will be on its way to better utilization of enormous wind energy resources via interception using wind turbines.

The focuses of future research are:

1. Generation of various design considerations and handling practices to curb the identified technical challenges hampering the gains of energy interception via a wind turbine.
2. Incorporation, adaption and implementation of design considerations in the construction of smart wind turbines that can best maximize the available wind energy resources at all times.

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