Review Paper: Overview of the Vertical Axis Wind Turbines

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Abstract

This paper gives an overview of a vertical axis wind turbine. The behaviour of the Vertical Axis Wind Turbine (VAWT), present technological state, new finding through modelling work and future direction of VAWTs were reviewed. It was observed that VAWT plays a vital role in the present energy crisis. Ones can foresee that human being dwelling in a world with wind turbines and solar panels due to present energy crisis with the non-renewable energy. Wind energy has been identified as a promising renewable option

Although the full life cycle accounting shows VAWTs are advantageous on a cost basis or materials basis over horizontal axis wind turbines (HAWTs), Currently the VAWTs do not generate enough electricity due to some challenges which discussed in this paper. Drag driven VAWT (Savonius type), lift driven VAWT (Darrieus type) and hybrid of both (D+S) turbine efficiencies can be increased by adding the deflector system that guides the wind towards the turbine blades. A lot of researches are ongoing at present in this level.

From the vast survey of the present technological states of VAWT, it was observed that China is the leading researcher in this field for the past few years while European countries serve their place in this research area.

1. Introduction

Renewable energy is the most important topic in the world at present. It was identified that the fossil fuel reserves in the world are diminishing rapidly and no reserves were identified. In addition to that, energy generation from fossil fuel may cause so many environmental problems like emission of greenhouse gasses, global warming and acid rains. Renewable energy sources play a major role in these type of situation. Renewable energy is the energy that extracts from renewable sources such as Winds, Sunlight, Rain, Tides, Waves, Geothermal heat…etc. Normally renewable energy provides energy for four different areas. They are electricity generation, air and water heating/cooling,transportation, and rural (off-grid) energy services. [1] As an example, Iceland and Norway already generate their electricity by using renewable energy. A lot of countries have set up a goal to reach 100% renewable energy in the future. For example, the government of Denmark has decided to switch the total energy supply (electricity, mobility and heating/cooling) to 100% renewable energy by 2050. [2]

Wind energy has been identified as a promising renewable option. Many nations in the world have identified and they have formulated policies to ensure that wind power has a growing role in energy resources.

1.1. Wind

The Wind is generated due to pressure difference of atmosphere. Because of the atmospheric pressure difference, air particles move high-pressure end to lower pressure end. During the air flowing, air molecules are subjected to Coriolis effect except exactly on the equator. The winds are often referred to according to the direction from which the wind blows and its force. Small bursts of high-speed winds are called gusts. Strong winds of intermediate duration are called squalls. Long lasting winds have different names such as breeze, gale, storm, and hurricane.[3]

1.2. Wind Power

Wind turbines produce electric power by using the power of wind to drive an electric generator.[4]The generator generates electricity and moves from the tower to an available transformer and switches from the output voltage (usually about 700 V) to a nationwide grid (33000 V) or personal use (about 240 V).[5]Wind power is an attractive and alternative power source for both large scale and small scale and distributed power generation applications. one of the most important advantages of wind energy is being modular and scalable. It is possible to often find applications in both large wind farms and distributed power generation. As a side effect of using wind energy, the dependency on fossil fuel also is reduced.

With largely untapped wind energy resources throughout the world and declining wind energy costs, people moving forward into the 21st century with an aggressive initiative to accelerate the progress of wind technology and further reduce its costs, to create new jobs, and to improve environmental quality.

The onshore wind is an economical source of electric power, competitive than coal or gas plants. [6][7][8]Offshore wind is more stable and strong than onshore, and offshore farms have less visual impact, but construction and maintenance costs are much higher than onshore construction and maintenance. [9]

1.3. Growth of Wind Energy in the World

There is a rapid growth in wind power development globally. This utilization of the wind for electricity generation is expanding quickly, due to large technological improvements, industry maturation and increasing concerns with greenhouse emissions associated with fossil fuel burning. Given the enormous wind resources, only a small portion of the usable wind potential is being utilized presently. Government and electrical industry regulations, as well as government incentives, have a large role in how quickly wind power will be adopted.

European countries have also widely harnessed this energy source. Germany, Denmark and Spain are notable users of wind power. Denmark pushing to generate 40% of its electricity through wind turbines. The UK has the largest wind energy resource and it is set for large expansion to bring down the price of wind energy. The Global Wind Energy Council (GWEC) released the global wind report. More than 54 GW of wind power was installed around the global market in 2016.GWEC's five-year forecast provides for about 60 GW of new wind installations by 2017, reaching an annual market of around 75 GW by 2021, to increase the cumulative installed capacity of more than 800 GW by the end of 2021.[10]

Not only wind turbine technology but also other technologies develop day by day. As an example drones with turbine blades send to the sky and harness wind energy as much as possible and send back that energy through cable. As well as kites use for harness wind energy.

1.4. Harnessing Wind Energy Potential in Sri Lanka

According to the National Renewable Energy Laboratory (NREL) wind mapping results, there are many areas that concentrated wind energy in Sri Lanka. These areas are concentrated largely in the northwestern coastal region of the Kalpitiya Peninsula to Jaffna Peninsula and central highlands in the interior of the country and near areas. Other regions with notable areas of good wind resources include the exposed terrain in the southern part of the North Central Province and coastal areas in the southeastern part of the Southern Province. High-quality wind measurement data were available to confirm the map estimates of wind resource in specific areas, such as the Kalpitiya Peninsula, the central highlands, and the southeast coast. So it would very helpful for the future to initiate many efforts on wind energy power generation which may benefit us vastly with the resources we have in Sri Lanka.[11]

1.5. Wind Turbine

Wind turbine blades extract some kinetic energy from the wind and that energy is converted intomechanical power of the wind turbine as below.

$P_{Mechanical} = 1/2\times \dot{m}\times V_i^2 - 1/2\times \dot{m}\times V_o^2 (Vi > Vo)$ …………………Eq.01

Where $\dot{m}$ is the mass flow rate (kg/s), V_i is the upstream wind speed (m/s) and V_o is the downstream wind speed (m/s). [12]

There are two types of wind turbines. They are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Normally, Horizontal axis wind turbine (HAWT) gives high power output than Vertical axis wind turbine (VAWT). [13]. But, HAWT needs high speed of air velocities (around Rating speeds) to give its maximum performances. And also, moving wind turbine blade experiences the wind relatively. According to the wind speed and the directions, the relative velocity angle of the wind also changes. As the blade velocity increases to the tip, the relative wind speed becomes more inclined towards the tip. Then generates tip vortices which are caused to high noise.

Figure No. 01 shows the two main type of wind turbines.

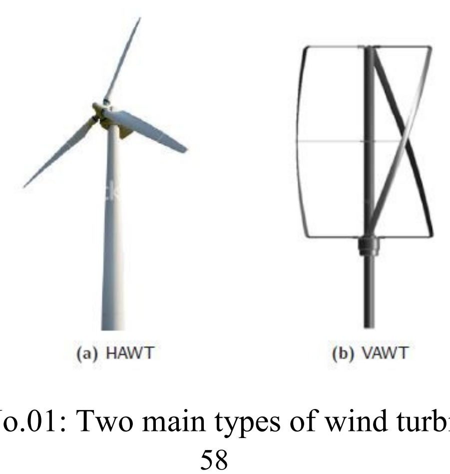

Figure No.01: Two main types of wind turbines [18]

The aim of this review paper is to study the behaviour of the Vertical Axis Wind Turbine, present technological state, new finding through modelling work and future direction of VAWTs.

1.6. Vertical Axis Wind Turbine

VAWTs offer a number of advantages over traditional horizontal-axis wind turbines (HAWTs). They can be packed closer together in wind farms, allowing more in a given space. They are quiet, Omni-directional, and they produce lower forces on the support structure. They do not require as much wind to generate power, thus allowing them to be closer to the ground where wind speed is lower. By being closer to the ground they are easily maintained and can be installed on chimneys and similar tall structures. [14]

When the wind passes through the blades of a HAWT, all of them contribute to energy production. When the wind passes through a VAWT, only a fraction of the blades generates torque while the other parts merely 'go along for the ride'. The result is comparably reduced efficiency in power generation. Getting high efficiency from small scale VAWT is somewhat difficult. It is because of the performance of VAWT is very sensitive to the lift/drag ratio of theblade and it is not good in the low Reynolds number condition of small applications. There are a number of obstacles in scaling VAWTs to commercial size. The first is that they aren't as sturdy by design as a HAWT. This is because of where a HAWT carries most of its stress compared to widely-used VAWT models. VAWTs' advantage is only in niche environments. [15] At present, VAWTs don't generate enough electricity that the full-lifecycle accounting shows them to be advantageous on a cost or materials basis over HAWTs. VAWT designs have the blades much closer to the ground than HAWTs, so they are losing significant amounts of wind. [16]

There are two main types of VAWTs called thedrag driven VAWT (Savonius type) and the lift driven VAWT (Darrieus type). The Savonius type functions similar to a water wheel that uses drag forces. On the other hand, the Darrieus type has blades similar to the HAWTs. [15]Main rotor shaft of the VAWT is arranged vertically. The generator can be connected by using that axis shaft. The rudder is unnecessary for this type wind turbines because it accepts the wind which comes from any direction. The maximum possible efficiency of lift driven turbines is larger than the drag driven turbines, the main attention today is focused on lift driven turbines. The first turbine of this design was patented in 1931 by G.J.M. Darrieus. [18]

Figure No. 02 shows that main types of vertical axis wind turbines

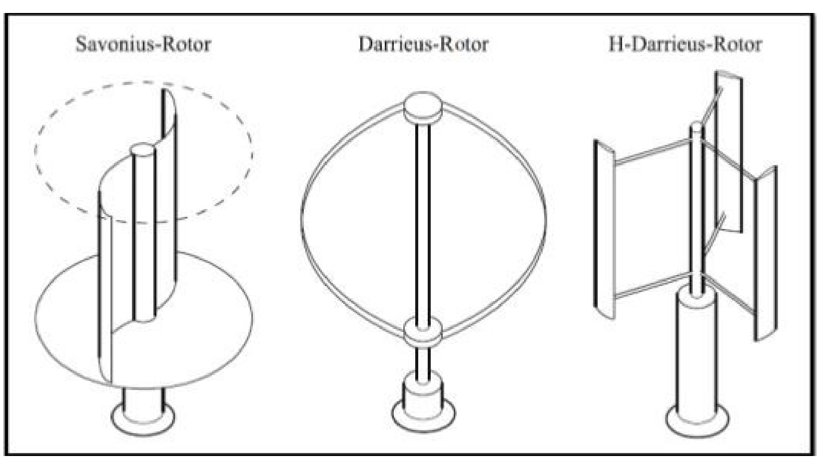

Figure No. 02: Main types of vertical axis wind turbines [20]

The main drawbacks of the initial designs were (Savonius, Darrieus and Giromill) significant variation of torque during each rotation and the huge bending moment on the blades. Subsequent projects addressed the issue of torque ripple by sweeping the blades helically. [17]

power coefficient (C_p) is a measurement of the wind turbine efficiency. C_p is the ratio of actual electric power produced by a wind turbine divided by the total wind power into turbine blades at a specific wind speed. [23]Power coefficients of different VAWTs as shown in the below figure.

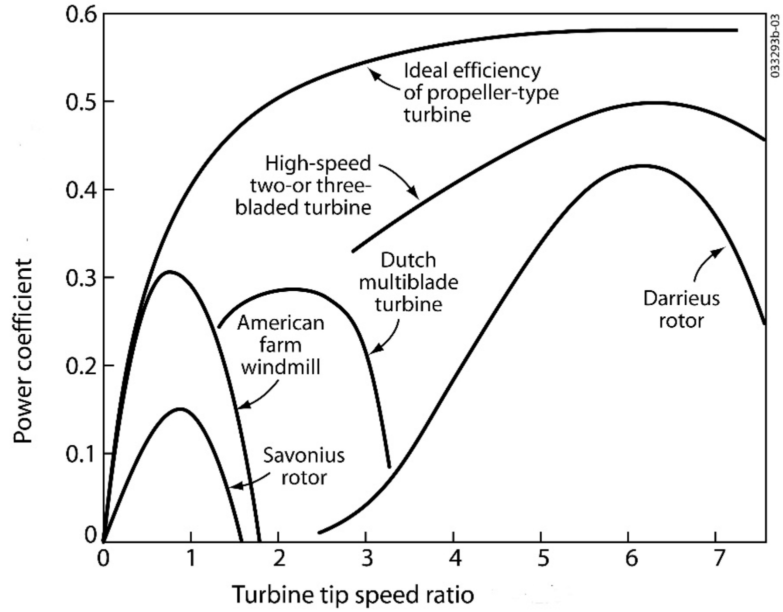

Figure No. 03: Power coefficient of different VAWTs[22]

From the vast survey of the present technological states of VAWT, it was observed that China is the leading researcher in this field for the past few years. Following graph shows that the interest of research on VAWT in European countries during the year 2010 -2014.

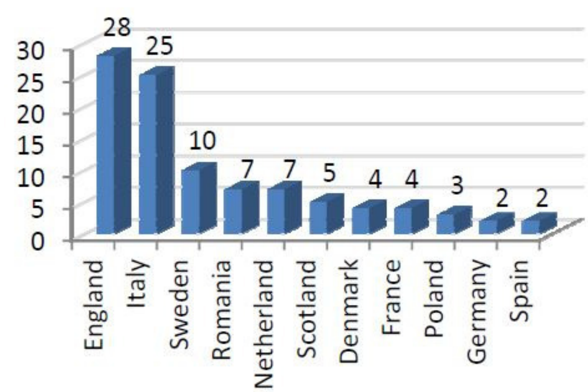

Figure No. 04: Research publications on VAWTs in European countries (2010-2014) [[22]

The “Espacenet” is a free access web that includes over 95 millions patents all over the world.
A search of patents registered in the past years (up to July 15, 2017) in the field of VAWT, 1603 worldwide patents found in the worldwide database.

1.6.1. Darrieus type Vertical Axis Wind Turbine

Darrieus wind turbine was invented by Georges Jean Marie Darrieus and first patented in 1927. [19]Blades are aerodynamically shaped, usually NACA style, with different layouts and with a certain distance from the rotation axis. [22] There are so many challenges when protecting the Darrieus turbine from extreme wind conditions and making it as a self-starter. This wind turbine is high speed and low torque turbine which suitable for generating Alternative Current (AC). [19]The largest Darrieus wind turbine is located in Cap-Chat, Quebec. It is about 60 m wide and almost 100 m tall. [31]It has a nameplate capacity of 3.8 MW[21]

Figure No. 03 shows that how Darrieus wind turbine moves with respect to the wind directions.

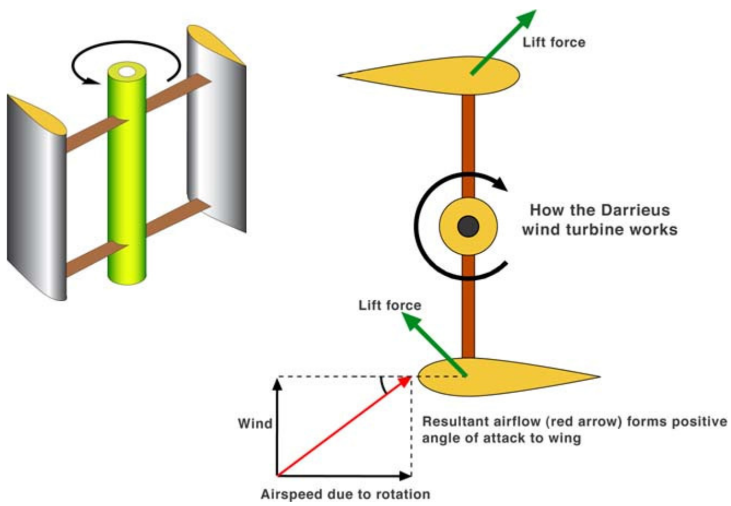

Fig. No. 05: Darrieus wind turbine operating principle [21]

The original version of Darrieus designs was symmetrical and had zero rigging angles. This arrangement is equally effective regardless of the direction in which the wind is blowing. Darrieus type needs an electric support to start, and its removal rate around 4-5 m/s , while the Savonius type starts at 1 m/s or lower. By solving the staring problem of the Darrieus type turbine, the hybrid system has been introduced. That system combines the Savonius type which staring at low speeds. Darrieus type takes high power coefficient *(C_p)* than the Savonius type at high-speed winds.

The angle of attack of the turbine blades should not exceed $\pm 20^0$ since it becomes turbulent causing stall. The angle of attack in between zero and 20 requires sufficient high blade speeds.[24]Generally lift forces as well as the drag forces increases with the angle of attack. Tangential component of lift force support to blade rotation and drag force opposed to it. A wind turbine can give its maximum performance when lift to drag ratio is maximum. This is happening when the optimum angle of attack. Airfoil cross sections should be aligned with the optimum angle of attack. These are the points that researchers address right now.

Present researchers are trying to improve the performance of Darrieus type wind turbine by introducing the wind deflectors. [25] Slow air stream will be inside the deflector system and fast air stream will be outside the deflector system. When the two flows meet from different angles, they create rapid mixing vortex. That means low-pressure zone will be created by vortices, like atyphoon. It causes to reduce the downstream air pressure and increase the turbine efficiency.

The power in the wind is well known to be proportional to the cubic power of the wind velocity approaching a wind turbine. This means that even small amount of its acceleration gives a large increase in the energy generation. Therefore, many research groups have tried to find a way to accelerate the approaching wind velocity effectively.[26][27][28][29][30] This upstream deflector system generates large size of separation behind it, where a very low-pressure region appears to draw more wind compared to a wind turbine without deflectors. Owing to this effect, the flow coming into the deflectors will be effectively concentrated and accelerated.

1.6.1.1. Giromill

Due to the several limitations of the Darrieus wind turbine, several modifications have been made to improve productivity, efficiency and design downtime. Giromill is a subtype of Darrieus turbine with straight blades, as opposed to curved. It (also known as ‘eggbeater windmill' / H-rotor/H-bar)uses 2 or 3 straight blades individually attached to a vertical axis. This type has avariable pitch along the blade to reduce torque pulsation. The advantages of this type are, it has higher starting torque, torque curve with less fluctuation and higher coefficient of performance. The blades are in lower bending stresses due to a lower speed. [21]

The following figure shows that the Giromill type wind turbine design

Fig. No. 06: Giromill type wind turbine[21]

1.6.1.2. Cycloturbines

Another type of Darrieus turbine is the Cycloturbines. Blades around the vertical axis are embedded in this design, which allows them to be appropriately pitched so they always have an angle of attack and are self-starting, a distinct advantage over the original Darrieus design.[19]This change increases theoverall efficiency of the turbine, but increases its complexity. In the beginning, the Blade angle changes and reduces the startup torque required and avoids the need for a starter.

1.6.1.3. Helical Blade Vertical-Axis Wind Turbine

Another type of Darrieus design is called Helical Blade Vertical-Axis Wind Turbine. This idea firstly inspired by Gorlov Helical Water Turbine. By replacing the blades of a Giromill with helical blades attached around a vertical axis (as DNA structure), it is possible to minimize the pulsating torque that can cause the main bearings to fail on Darrieus-derived designs. Helical blade design is used by the Turby, Urban Green Energy, Enessere and Quiet Revolution brands of wind turbines. [19]

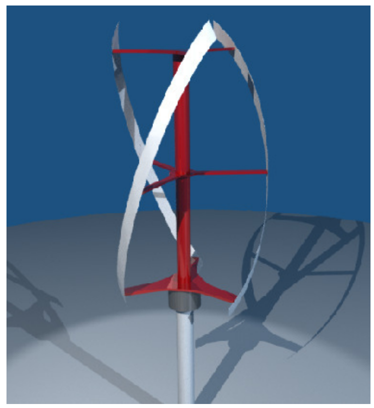

Fig. No. 07:Helical Blade Vertical-Axis Wind Turbine [19]

1.6.2. Savonius type Vertical Axis Wind Turbine

Another type of VAWT was invented in 1922 by Sigurd Johannes Savonius from Finland.It is called Savonius type VAWT.It is a drag based VAWT which operates in the same way as a cup anemometer.However, Savonius wind turbines efficiency is around 15%.That meansjust 15% of the wind energy hitting the rotor is turned into a mechanical energy. It is much less than Darrieus type. [32]

A Favonius wind turbine cannot rotate faster than the speed of the wind and it has tip speed ratio in between 0 – 1. [32] That means the Savonius type will rotate slowly but will generate a high torque. Therefore, Savonius type is not suitable for electricity generation, because turbine generators need to be turned into hundreds of RPM to generate high voltages and currents. A gearbox can be used to reduce torque and increase generator RPM.

Below figure shows that the Savonius type VAWT design.

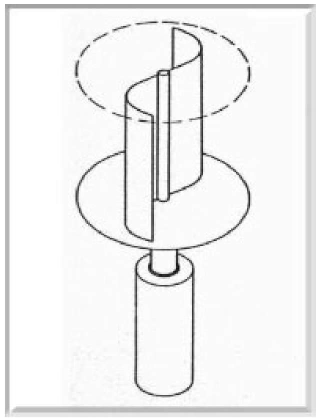

Fig. No. 08: Savonius type Vertical-Axis Wind Turbine [32]

As Savonius type has low efficiency, many researchers are focused on the improvement of turbine efficiency, because it gives many advantages over other turbines.

One of the research is the improvement of the performance of Savonius type wind turbine by adding up stream wind deflectors. The deflector system can guide the wind towards the turbine blades. [33]

1.6.2.1. Twisted Savonius

Twisted Savonius is a modified version of Savonius type VAWTs. It has long helical scoops to provide smooth torque.

1.7. Future trends of VAWTs

Although predicting the future, based on the presently available data is not always fully accurate, we can get some idea where the Vertical Axis Wind Turbine technology goes.

A major problem encountered during the operation of VAWTs is low air capture, as it very close to the ground level. The deflector system that guides the wind towards the turbine blades will be solved that problem. It increases the power, speed and torque in these sorts of environments. A lot of researches are ongoing at present in this level.

A lot of researchers have developed basic wind turbines, and discover significant parameters that directly involve to changing performances of turbines. Some of them are blade solidity, lift force, drag force and angle of attack. Furthermore, so many researchers have done with considering blade profile. The modern VAWTs occupied blades that developed by NACA which has the ability to self-start. However, researchers are involved to modify common VAWT and increase its efficiency while global attention on it. Most popular self-starting NACA blades are NACA 4415and NACA 4418[34]

Because of the low self-starting capabilities of the Darrieus type turbine, integrate the Savonius type blades by making ahybrid system. This will be very popular use in small generating installations, especially in urban environments that currently have winds that are not exploited.

It has been verified by simulations the helical arrangement of the turbine blades increases the power coefficient in comparison with the straight arrangement of the blades from 33% to 42% under same operation conditions. [22] Lot of researches are ongoing through the modelling work in this category.

The VAWT application of the offshore conditions for the major productions is discarded, but ones can be designed to supply weather buoys and boats, either individually or through a wind / PV hybrid system. [22]

2. Conclusion

Local authorities in Sri Lanka, as well as the foreign authorities, will face, lots of problem in the near future due to lack of non-renewable energy sources. So, they are moving for the renewable energy sources like wind, solar energy, tides, rain, sea waves, geothermal heat…etc.

If we can improve the performance of the Vertical Axis Wind Turbines(VAWTs), it's huge advantage for the authorities. They can implement the VAWTs every possible place and generate the electricity while contributing to the reduction of CO_2 production and economic growth.

Thus, by the researches related to the VAWTs, it is accepted to substantial step forward in this field in the foreseeable future. By introducing there search out comes to the country, it would gain for the national development.

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