WIND ENERGY 101

ENVIRONMENTAL DESIGN SOLUTIONS PVT LTD [EDS]

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INTRODUCTION

29% of the world's new energy installations in 2017 came from wind energy, the second largest after solar energy. In the US, this figure stood at 40%. Globally, the total installations of wind turbines were around 539 GW as of 2017 and are expected to rise to 840 GW by 2022.[1]

While fossil fuels continue to be the significant source of energy generation, 2017 was a record-breaking year for renewable energy in terms of the increase in renewable power capacity as well as falling costs, increase in investment and advances in enabling technologies[2]. Today, renewables meet around 25% of the world's energy requirements.

With the latest IPCC report[3] highlighting the severe impacts of a 1.5-degree Celsius global temperature rise, there is an urgent need to transition from a fossil fuel-based economy to a clean energy economy. At the same time, meeting energy requirements is one of most crucial aspects of development and integral to life as we live today. The power sector, contributing to the largest share of global greenhouse gas emissions, may hold the greatest potential in mitigating climate change while meeting the world's rapidly rising energy needs.

Of all the renewable sources, wind energy has 'lowest lifecycle emissions'. Wind first gained prominence as an energy resource in the 1980s and 1990s in response to the detrimental effects of climate change and global warming. As an alternative to burning fossil fuels, wind energy is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water and uses little land. With rapid technological advancements and the continued drop in prices, the wind energy sector is on the cusp of tremendous growth.

Wind energy has been harnessed for centuries. We have come a long way from using windmills for pumping water and grinding grains to generating electricity at a large scale. Today wind powered generators operate in every size from battery charging at isolated residences to large scale wind farms that power utility grids.

[1] http://files.gwec.net/files/GWR2017.pdf

[2] https://www.iea.org/geco/renewables/

[3] https://www.ipcc.ch/pdf/session48/pr_181008_P48_spm_en.pdf

CAPTURING WIND ENERGY

Figure 1: A wind turbine

Wind turbines are used to capture the wind energy as electric energy. These are tall structures fitted with propeller-like blades, made to rotate by the wind. The blades convert the wind energy into usable shaft power called torque. This is achieved by extracting the energy from the wind by slowing it down or decelerating the wind as it passes over the blades.

The reason that they are tall is to be able to access the constant wind speeds prevalent at higher altitudes of 100-300 m. The rotor blades transfer their energy to a shaft, which drives a generator. This electric energy can be stored and transported over distances.

Turbines must be facing the direction of the wind to operate efficiently. Advances in technology have led to new turbines that have some ability to pivot towards the wind. Further, turbines require optimum wind speeds, wind consistency and distribution to function efficiently. To start a turbine, a minimum wind speed of 3.5m/s is required. To generate maximum power, wind speeds should range between 10m/s and 15m/s. Moreover, the wind turbines should be placed in the direction of the prevailing winds. The taller the turbine, the more efficient it becomes since the wind speeds increase with the altitude.

Usually wind farms are located far away from the cities and power grid access requires provision of transmission lines and other equipment to tap the energy generated. For maintenance and future operations, the wind farm site needs to be easily accessible by the workers.

There are primarily two types of wind turbines based on the axis of rotation- Vertical Axis Wind Turbines (VAWTs) and Horizontal Axis wind turbines (HAWTs). The rotor in a VAWT rotates perpendicular to the direction of wind flow while in a HAWT, it rotates parallel to the wind stream. Let’s understand these in greater detail.

Horizontal Axis Wind Turbines

A HAWT consists of a rotor, generator and tower. The tower supports the wind turbine and allows power cables to run through it. The rotor comprises the rotor blades and the hub, around which blades are places. The rotor connects to a gear box in the nacelle, which helps drive the generator more efficiently. Generators come in various sizes, to produce different amount of electricity. The electrical energy then flows down the tower of the turbine.

A step-up transformer increases the voltage by at least 50 times so that it can transmitted to required establishments.

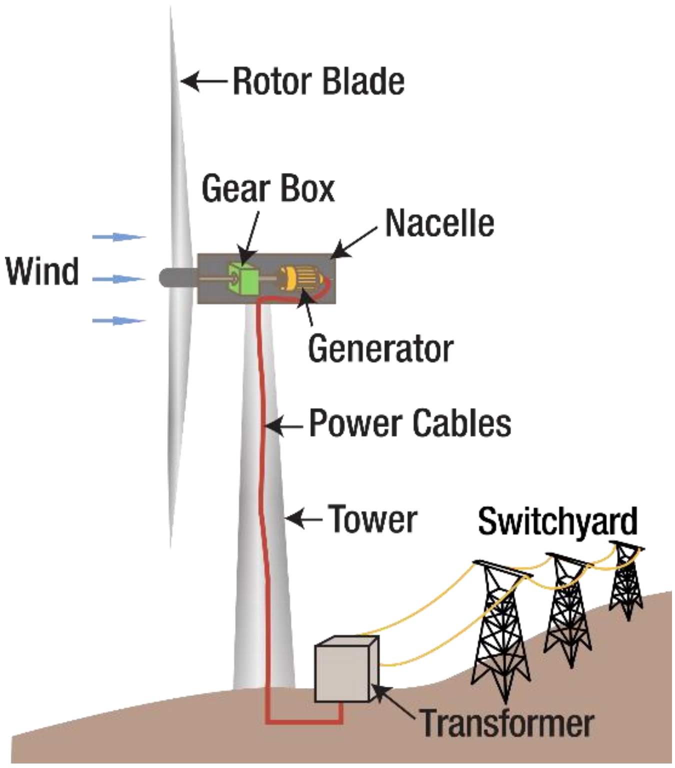

Figure 2: Components of a HAWT

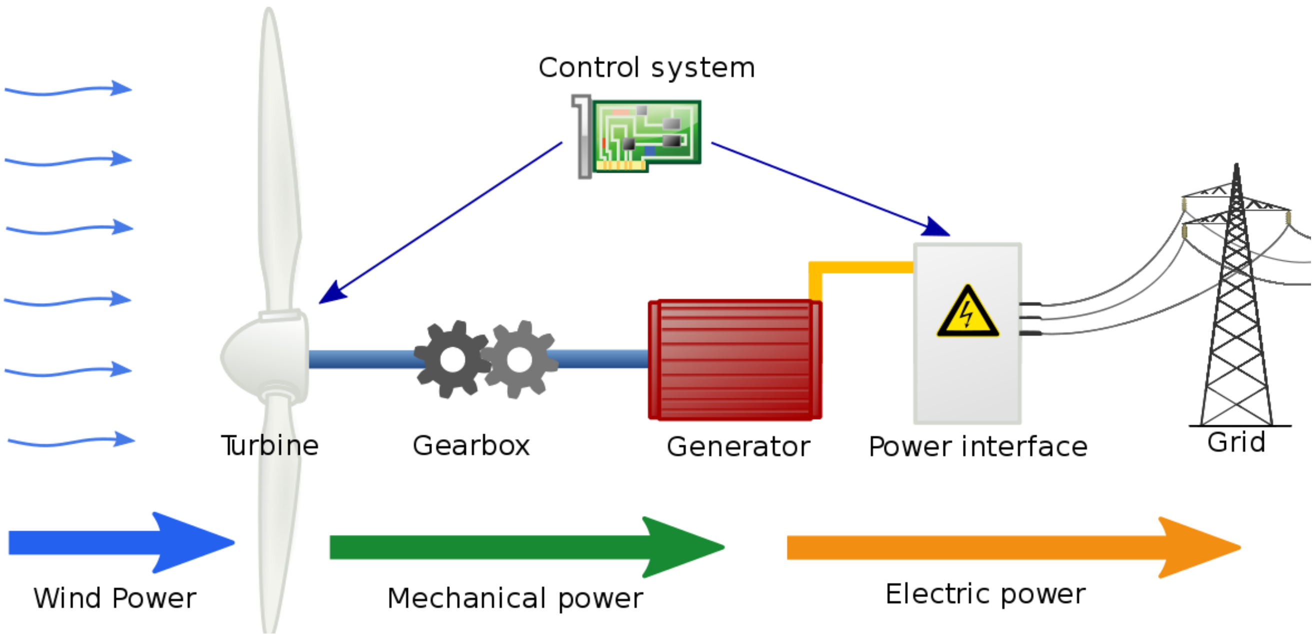

Figure 3: Working mechanism

FACTORS IN WIND TURBINE DESIGN

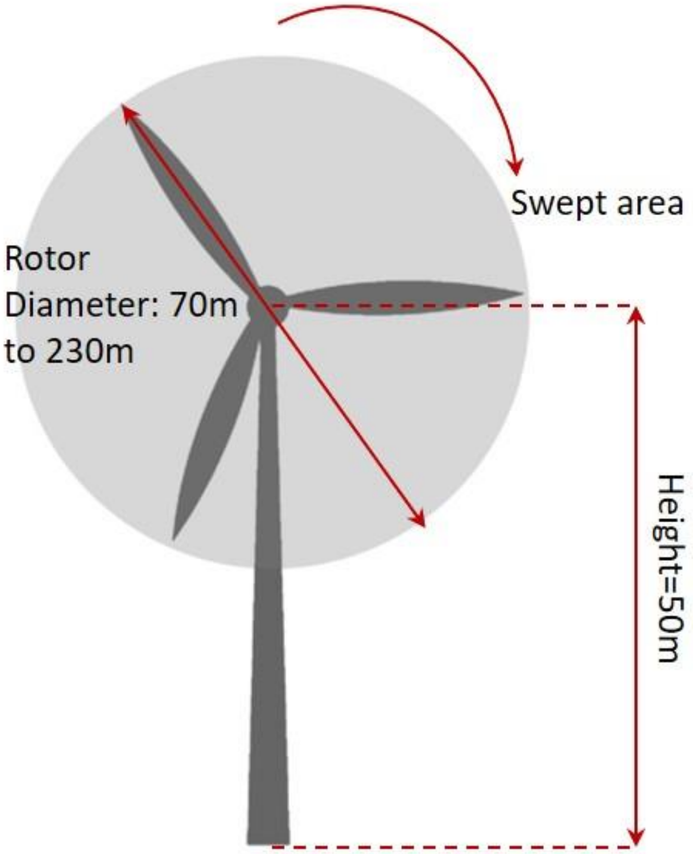

Figure 4: Figure 4: Average HAWT size

The design of wind turbine blade is based on the same principle as the curved design of aeroplane wings- the side with the most curve generates low air pressure while high pressure air beneath pushes on the other side of the blade shaped aerofoil.

The net result is a lifting force perpendicular to the direction of flow of the air over the blade.

The rotor blade is designed to create the right amount of rotor blade lift and thrust producing optimum deceleration of the air and therefore better blade efficiency. If the rotor blades move too slowly, most of the wind passes through the them undisturbed, whereas if they move too fast, the rotating blades act like an obstructing wall. Hence an optimal rotor tip speed must be designed.

According to the Betz law, the maximum obtainable efficiency of the turbine is around 59%. In practice the maximum efficiency obtainable at optimal rotation speed is around 35%. Efficiency of the overall system is affected by the design of the rotor blades, rotor tip speed, efficiency of generator and cabling losses.

Technological advancements in the form of manufacture of innovative blade structures with advanced materials such as polyester, fiberglass, vinyl ester resins etc., improved gearboxes, increased rotor dimensions along with larger wind turbines and off-shore wind technological systems are propelling the movement to new heights.

Vertical Axis Wind Turbines

VAWTs are turbines which rotate transverse to the rotor shaft. The generator and the gearbox are located at the base of the tower. There are two types of Vertical Axis turbines which are currently available in the market: Savonius and Darrius.

SAVONIUS WIND TURBINES

A Savonius vertical-axis wind turbine is basically two cups or half drums placed in opposing directions fixed to a central shaft. Each drum captures the wind, thereby turning the shaft and conversely bringing the other drum/cup in the direction of the wind, indicating the completion of one rotation.

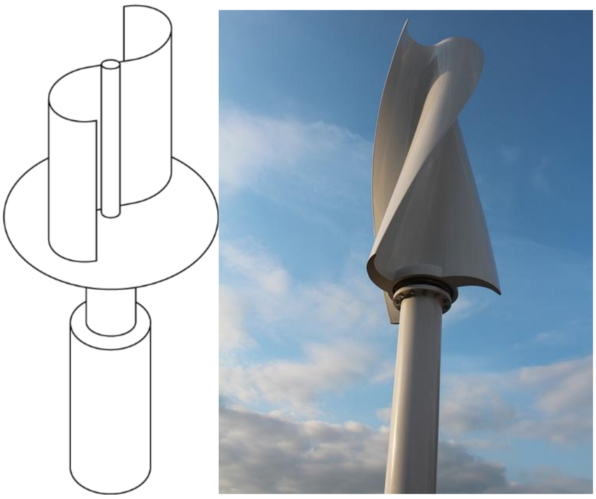

Figure 5 Savonius wind turbines
Source: https://pixabay.com/en/savonius-rotor-vertical-wind-turbine-3084781/

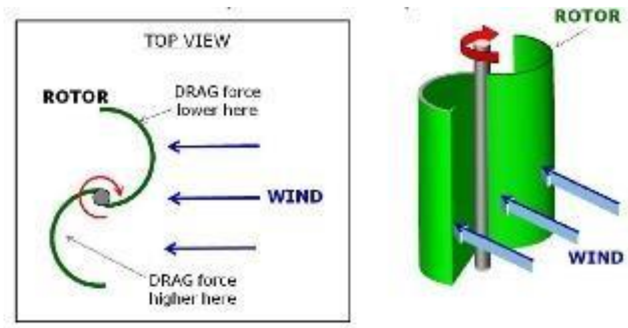

Figure 6 Working Principle
Source: http://people.bu.edu/dew11/liftanddrag.html

DARRIEUS WIND TURBINES:

The design consists of flexible air foil blades placed around a central shaft. Air foils have a curved side and a flat side. When the wind blows over the air foil blades, an aerodynamic lift is created thereby pulling the blades along with it. The air foils are secured to a hub which is in turn connected to a generator at the foot of the turbine.


Figure 7:Darrieus wind turbines
Source: Wiki Commons

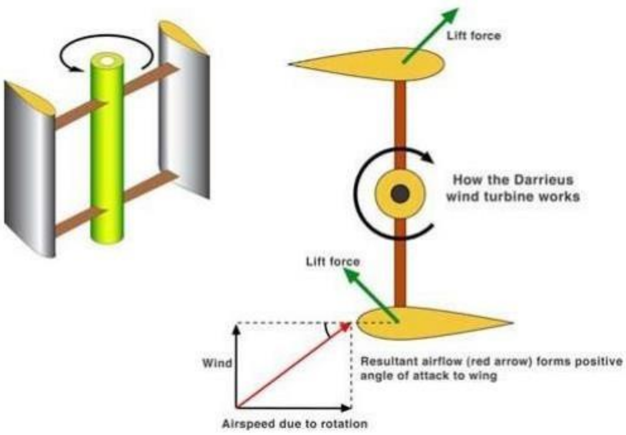

Figure 8: Working of Darrius wind turbine.
Source: https://www.researchgate.net/figure/Fig-No-05-Darrieus-wind-turbine-operating-principle-21_fig4_319678764

VAWTs vs HAWTs

VAWTs can capture wind from any direction. They are cheap and reliable with practically no maintenance required. Also, they can operate at very low speeds of even 2m/s and even in turbulent winds with lower noise levels. However, they are less efficient. They are most suited for urban cities since they can handle turbulent flows.

On the other hand, HAWTs are more efficient and reliable compared to the VAWTs. Moreover, they can tolerate higher wind velocities.

STORAGE DEVICES

Providing storage is extremely important to enable the supply to meet the demand. There are four broad types of storage devices for wind energy. Battery Storage like lead acid batteries are used as storage for both solar and wind. Compressed air storage devices store the energy by compressing air, which is then stored in underground caverns. When electricity is needed, the compressed air is released and heated by combusting natural gas to allow the expansion of air. This drives turbines which produce electricity.

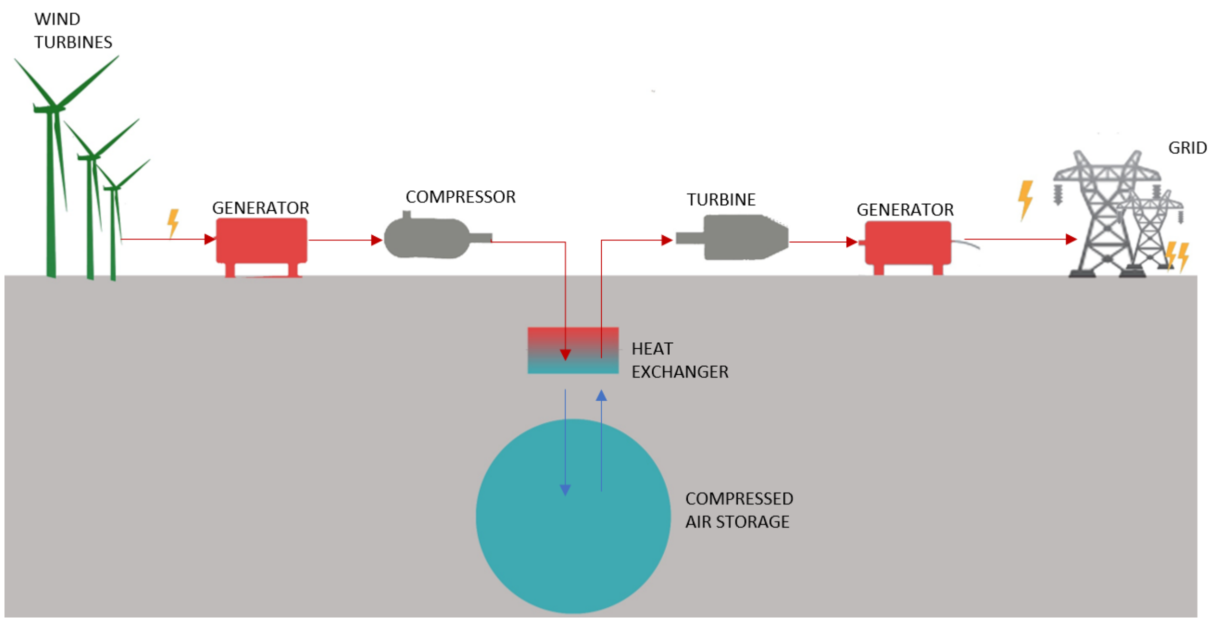

Figure 9: Compressed air storage

Hydrogen fuel cells can also be used to store excess energy. Renewable electrolysis is a process that uses energy from renewable sources like solar and wind to split hydrogen and oxygen atoms in water. Hydrogen atoms can function as energy storage media. A relatively small amount of hydrogen cans tore large amount of energy. A fuel cell or engine converts the stored energy into electricity, which is transported to the grid.

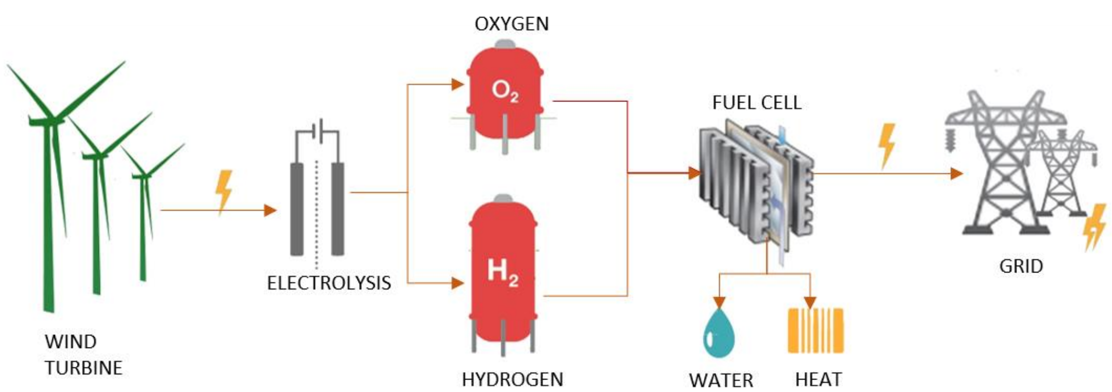

Figure 10: Hydrogen fuel cells

Pumped storage uses excess energy to pump water in an upper reservoir, which is released into a lower reservoir, over a turbine, to generate electricity at the time of excess demand.

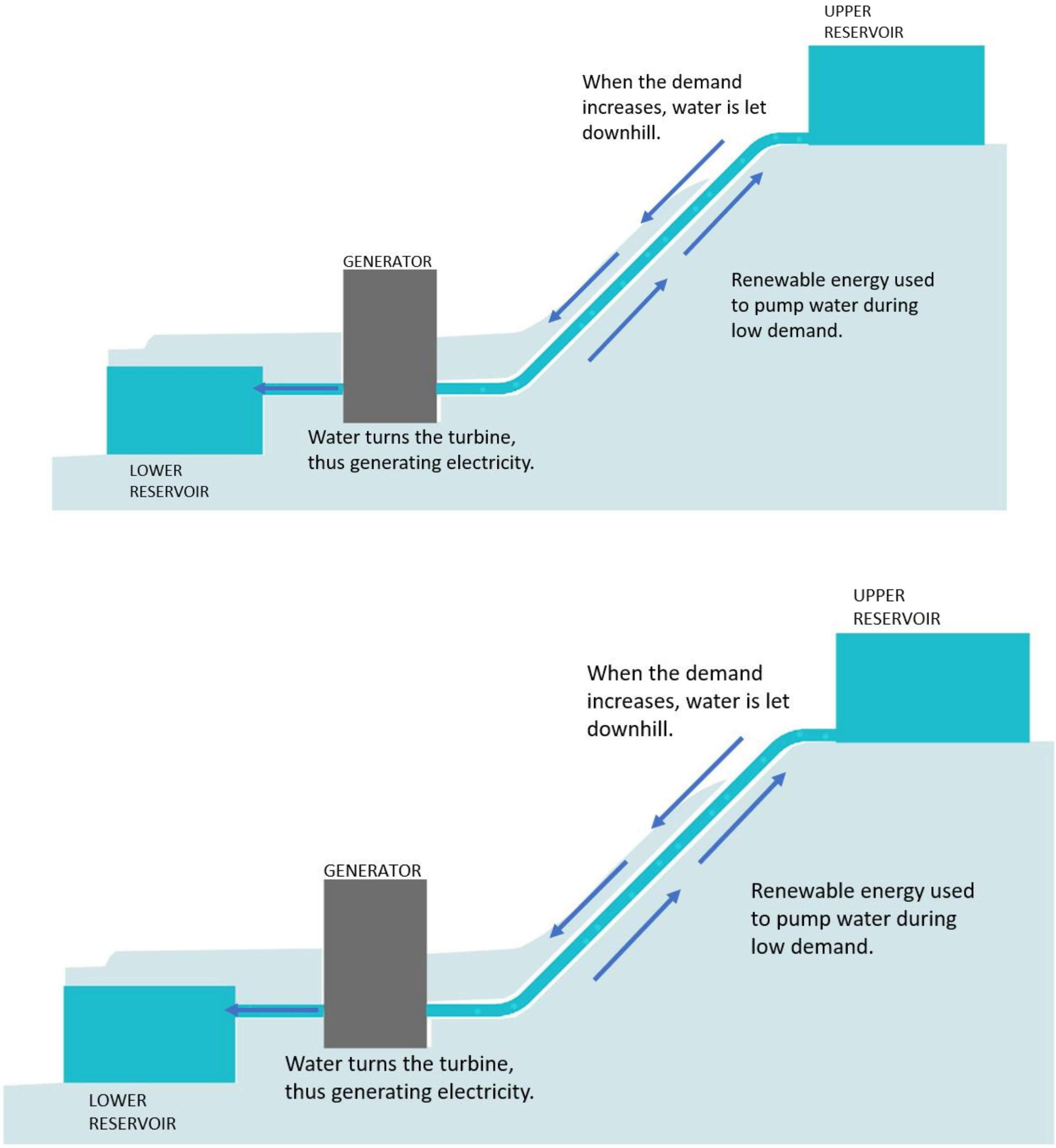

Figure 11: Pumped storage

ENVIRONMENTAL CONSIDERATIONS

The manufacture and installation of wind energy systems for both commercial and residential application entails heavy initial investments. Regions are grouped under power classes ranging from 1 to 7. Class 3 indicates that the wind speeds in the area are around 3-3.5m/s, suitable for utility-based power generation. It is ideal if the wind turbines are located on hilly areas rather than valleys to tap high speed wind. Sites chosen should be large enough to accommodate the turbines as well as other facilities such as storage devices, concrete cranes and other installation equipment. Moreover, other criteria such as stability of the soil, its slopes and direction towards which the site is oriented should be considered.

Wind turbines have their share of environmental hazards, for instance they are perceived as threats to birds and animals. Wind turbines create noise pollution which is a nuisance to people.

WIND TURBINE INSTALLATIONS

Wind turbines come in a range of sizes. Those rated below 100 kW can be employed for small applications such as water pumping while wind turbines rated from 100 kW to several MW can be used in larger applications such as wind farms. Greater the capacity of the wind turbine, greater its height.

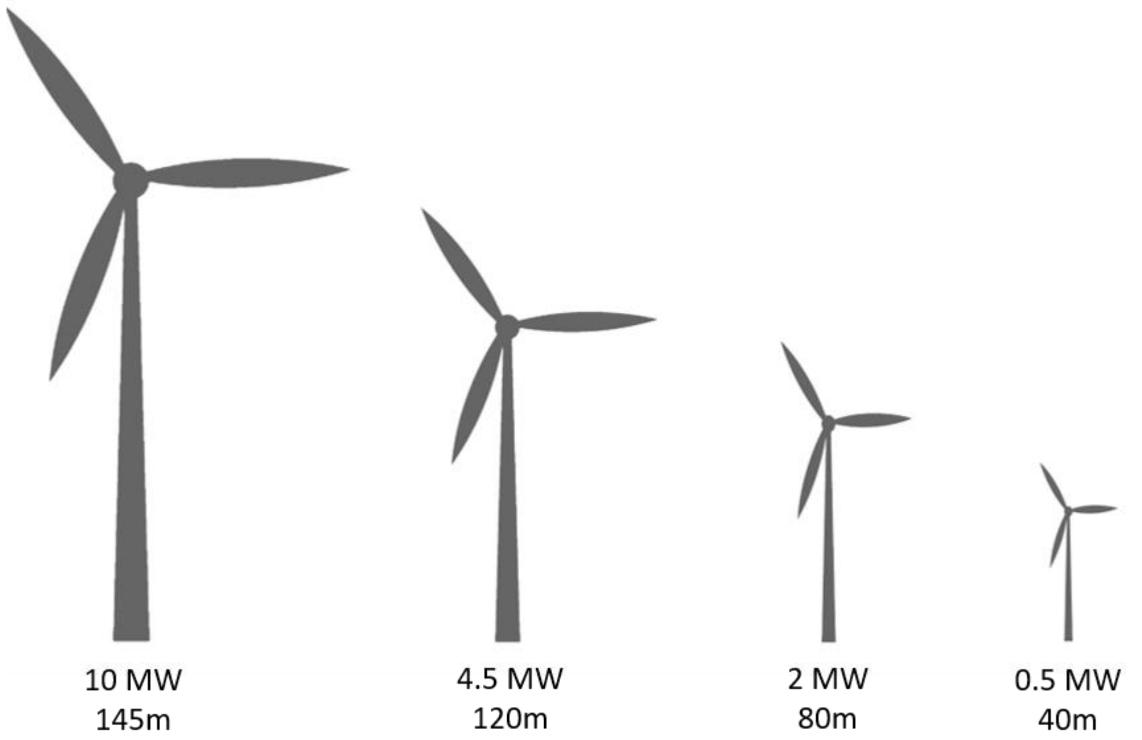

Figure 12: Different sizes of wind turbines available in the market

Onshore and offshore wind farms

Small scale wind turbines are generally off-grid systems which supply energy locally to a site while complementing another energy generating system like PV panels and diesel generators.

Small wind turbines will capacities below 30kW can be installed in backyards to meet household demands. The wind turbine would have to be 9m higher than any obstacle such as trees etc within a 90m radius. Usually zoning bye-laws prevent the installation of these turbines in sites any smaller than an acre.

Large wind turbines are grouped together in wind farms to produce electricity to meet the required energy demands. Horizontal axis wind turbines are generally used for utility based large scale purposes since they have higher efficiencies.

Onshore wind farms are land based wind farms. The land between the turbines is generally used for agriculture. The space between two wind turbines is generally 3-10 rotor diameters. For example, two 1.3MW wind turbines with rotor diameters of 60m would be placed 180-600m apart[4]. According to the EWEA, an average onshore wind turbine with a capacity of 2.5–3 MW can produce more than 6 million kWh in a year, enough to power around 1,500 average EU households with electricity.

The drawbacks of on-shore wind farms are that poor wind speeds and turbulences affect their efficiency. Also, when they are located near developments, noise becomes a major issue.

Figure 13: On-shore wind farms

[4] https://www.planningni.gov.uk/index/policy/planning_statements_and_supplementary_planning_guidance/pps18/pps18_annex1/pps18_annex1_wind/pps18_annex1_technology/pps18_annex1_spacing.htm

Wind-farms may be located offshore as well. Offshore installations have access to steady and faster wind speeds and thus function more efficiently. Additionally, since they are located on bodies of water, land area is not wasted on them. An average offshore wind turbine can generate about 3.6 MW of power, enough to power about over 3000 EU households. Wind turbines are installed at depths of between 30-50 metres (or 100 to 160 ft) using monopiles or tripods.

On the downside, they are expensive and associated with high transmission losses due to the long cables required for their distribution. Overall, costs of onshore wind farms are relatively cheaper compared to offshore farms. Moreover, there are less voltage drops due to the shorter distances between the farms and the grid.

Offshore is still only about 8% of the global annual market, and represents about 3.5% of cumulative installed capacity, but it’s growing quickly. At the end of 2017, the total worldwide offshore wind power capacity was 18.8 GW. The United Kingdom and Germany together account for over two thirds of the total offshore wind power installed worldwide. Recently, a 659-MW offshore wind farm, the word’s largest so far, became operational in the Irish seas.

Figure 14: Offshore wind turbines

Building Integrated wind turbines

Defining a shift in the evolution of wind turbines, the idea of placing wind turbines in buildings is gaining importance. These save land resource and cut down on transmission losses by directly delivering energy to the site.

These systems of course account for design considerations like appropriate building height, the prevailing wind speeds, building orientation and so on, and the wind paths and patterns generated by the surrounding urban terrain like wind shadows, eddy currents, pressure difference.

VAWTs are more proven to be more efficient compared to HAWTs in urban environments because they can handle turbulent flows and are omni-directional.

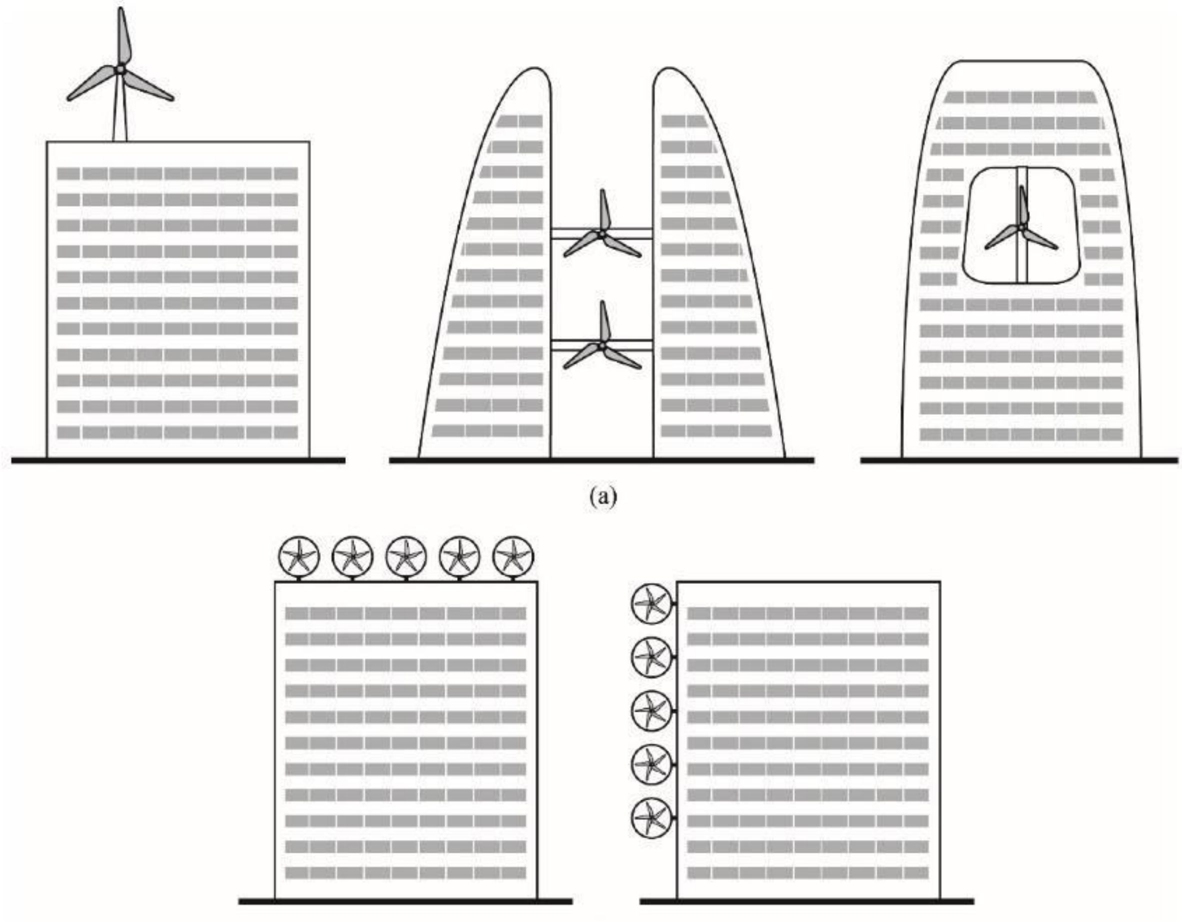

Figure 15: Mounting of wind turbines
Source: https://www.mdpi.com/1996-1073/8/10/11846

These may even be retrofitted onto an existing building, usually on the rooftop. Some buildings are even integrating wind harnessing systems into their façade. For example, the Pearl River building in Guangzhou, China integrates wind production mechanism into its form. The facade has been sculpted with 4 wind portals on the façade. These wind portals are shaped to accelerate wind velocity thus increasing the wind power potential. Darrius rotors wind turbines are placed in the portals to tap into the accelerated wind velocity to generate electric energy. Each of the turbines have a rated capacity of around 10,000 kWh/year, offsetting around 1% of the building's total energy consumption.

Figure 17: Rooftop wind turbines

Figure 16: Wind portals in Pearl tower, China

GLOBAL WIND ENERGY MARKET

The current global market is driven by an increased demand for energy and a rising awareness about the adverse impacts created by non-renewable sources of energy on the planet.

China accounts for more than one-third of the world's wind power cumulative capacity. It is also the largest manufacturing hub for wind turbines and its components. In 2016, 46% of the country's energy demand was met by wind turbines. Other countries like USA, India, UK, Germany, Brazil and France have showcased immense commitment to the advancement of this movement with a total of 220 GW of installed capacity. Denmark has the largest wind energy penetration, with 40% of its total electricity generation coming from wind farms. by 2030.

NEXT-GEN WIND TECHNOLOGIES

Next-gen wind technologies aim at producing wind energy without the challenges of conventional systems. For example, the bladeless wind turbine proposed by Vortex Bladeless engineers does away with rotor blades altogether and can function in turbulent flows as well. Instead it uses wind-induced vibrations in a tall cylinder-like structure to generate electricity using a linear alternator system.

Other prototypes eliminate the need for tall towers. Google subsidiary Makani is developing air-borne wind energy kites. Researchers at MIT have proposed the Buoyant Airborne Turbine, a giant floating generator housed inside a helium dirigible, or airship.

Figure 19: Bladeless wind turbines

(Image courtesy: https://www.geograph.org.uk/photo/3777495)

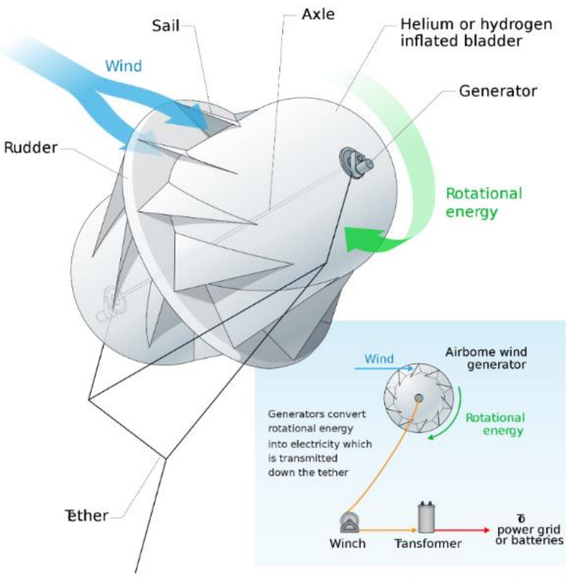

Figure 18: Buoyant Airborne Turbine

(Image courtesy: https://commons.wikimedia.org)

CONCLUSION

The popularity of renewables as a source to meet the energy demands is rapidly advancing. If the current trend continues, by 2020 wind energy will eliminate the emission of 342 million tonnes of CO_2 which is equivalent to taking 80% of the EU's car fleet off the road. The formation of stable policies, government incentivization, continued research and development and funding mechanisms that can compete with global players will play a huge role in ensuring continued growth of the wind energy sector.

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