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Wind Energy Conversion Systems - A Review

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Abstract

Wind energy is favored as an alternative to fossil fuels as it is plentiful, renewable, widely distributed, and produces lower greenhouse gas emissions. The widespread distribution of suitable wind patterns and the declining cost of wind energy production make wind energy a viable alternative. Although wind energy exploitation dates back five thousand years ago, contemporary societies are based almost exclusively on fossil fuels for covering their electrical energy needs. During the last thirty years, security of energy supply and environmental issues have reheated the interest for wind energy applications. This paper presents a review on wind energy conversion system – wind turbines. It brings out the historical developments carried through ancient times to the present world scenario. Different types of wind turbines, their parts , sub types have been reviewed. Classification of wind turbines according to the capacity (rated power), technological advancements have been listed here.

1. Introduction

Wind power is the power obtained by harnessing the energy of the wind, such as using wind turbines to produce electrical power, windmills for mechanical power, wind pumps for water-pumping or drainage, or sails to propel ships [1].

Fig: 1. Arizona windmills, USA Scotts of Waco, Texas [2]

Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind-powered pumps drained the polders of the Netherlands, and in arid regions such as the American mid-west or the Australian outback, wind pumps provided water for live stock and steam engines [3].

2. Types of Wind Turbines

Wind turbines are classified according to its rotor axis orientation and the type of aerodynamic forces acting to take energy from wind.

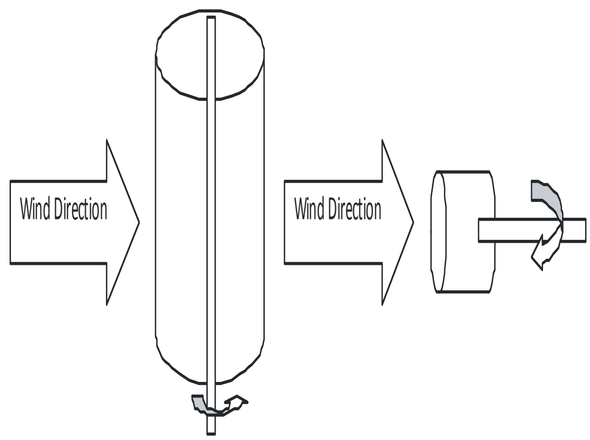

Fig: 2. Rotor Orientation [4]

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Table: 1. Wind Turbine Classification According to the Rotating Axis Position with Respect to the Wind

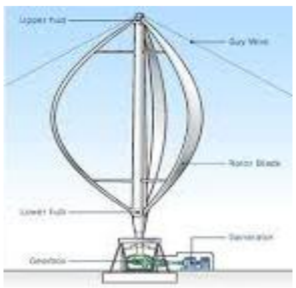
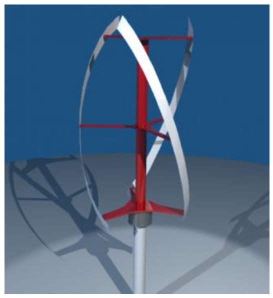
Sl. No.	Types Of Wind Turbines	Rotor Axis Orientation	Advantages	Disadvantages	References
1.	 Horizontal Axis Wind Turbines (HAWT)	Parallel to the wind in order to produce power.	• Access to stronger wind in sites with wind shear. • High efficiency	• Massive tower construction • Braking or yawing device in high winds.	[5]
2.	 Vertical Axis Wind Turbines (VAWT)	Perpendicular to the wind direction or the mounting surface.	• Does not need to be pointed into the wind. • Building redirects wind over the roof and this double the wind speed.	• Creates drag when rotating into the wind. • Less efficiency.	[5]

Table: 2: Sub Types of Wind Turbine

Sl. No.	Type	Sub type	Features
1.	HAWT	Up Wind Turbine	• Large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction. • Smaller wind turbines use a tail vane to keep the blades facing into the wind.[6]
		Down Wind Turbine	• The wind passes the tower before striking the blades. • Without a tail vane, the machine rotor naturally tracks the wind in a downwind mode.[6]
		Shrouded Wind Turbine	• Some turbines have an added structural design feature called an augmentor. • The augmentor is intended to increase the amount of wind passing through the blades.[6]
2.	VAWT	 Darrieus [7]	• Invented by Georges Darrieus in 1931. • High speed, low torque machine. • Develops lift from 2 or 3 'c' shaped blades. • Unable to self start
			• Giromill known as an 'eggbeater 'windmill . • Uses the same principal as a Darrieus. • 2 or 3 straight blades individually attached to a vertical axis .

		 Giromill [7]	
		 Helical blade [7]	• Helical blades wrapped in a dna-like structure. • Minimizes the pulsating torque.
		 Savonious [7]	• Slow rotating, high torque machine, ideal for driving pumps. • Uses drag and therefore cannot rotate faster than the approaching wind speed.

3. Structural parts of wind turbine

Wind turbine has four main parts: base, tower, nacelle and blades. Wind energy captured by blades will spin the generator in the nacelle.The tower contains the electrical accessories will support the nacelle and provides access to the nacelle for maintenance. The base will support the whole structure. Table gives the list of parts of wind turbine.

Table: 3. Wind turbine structural parts [8]

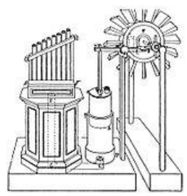
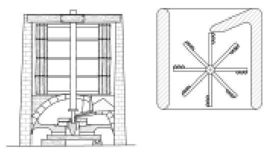
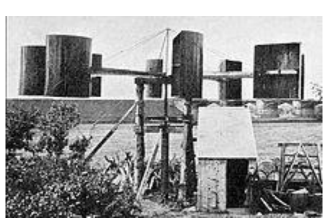
Sl. No.	Parts	Remarks
1.	Base	• Made of concrete reinforced with steel bars. • Two basic designs – (i) Shallow flat disk - 40 feet in diameter and three feet thick. (ii) Deeper cylinder - 15 feet in diameter and 16 feet deep.
2.	Tower	• Tower design white steel cylinder - 150 to 200 feet tall &10 feet diameter. • Some use a lattice tower, like the eiffel tower. • Ladder running up the inside and a hoist for tools and equipment.
3.	Nacelle	• Houses a generator and gearbox. • Spinning blades are attached to the generator through a series of gears. • The gears increase the rotational speed of the blades to the generator speed of over 1,500 rpm. • Generators can be either variable or fixed speed: ➢ Variable speed generators produce electricity at a varying frequency, which must be

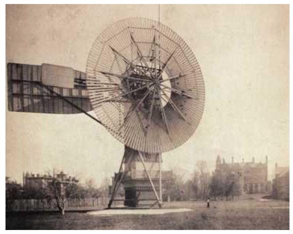
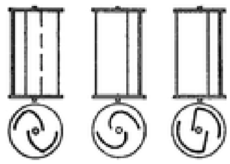
		corrected to 60 cycles per second before it is fed onto the grid. ➢ Fixed speed generators don't need to be corrected, but aren't as able to take advantage of fluctuations in wind speed.
4.	Blades	• Designed like airplane wings • Blades use lift to capture the wind's energy. • Spins at a slow rate of about 20 revolutions per minute (rpm), although the speed at the blade tip can be over 150 miles per hour.

4. From the post windmill to the Western mill

Development of wind turbine from ancient time to present world scenario has been listed in table 4 as follows -

Table: 4. A list indicating the historical developments in wind turbines

Sl. No.	Year	Wind turbine type	Description
1.	1st Century A.D.	 *Heron's wind-powered organ, [3]*	• The earliest machine powered by wind. • The wind wheel of the Greek engineer Heron of Alexandria is the earliest known instance of using a wind-driven wheel to power a machine.
2.	7th Century	 *The Persian, horizontal windmill [9]*	• The first practical windmill used in Sistan. • Horizontal windmill· • Used to grind corn and pump water, and in the grist milling and sugarcane industries.
3.	8th Century	 *Medieval depiction of a windmill [3]*	• Wind-powered statues that "turned with the wind over the domes of the four gates and the palace complex of the Round City of Baghdad.
4.	12th Century	 *Vertical windmills, Campo de Criptana, [3]*	• Early European windmills were sunk post mills. • The earliest certain reference to a windmill dates from 1185, in Weedley, Yorkshire. • The European vertical windmills were of significantly different design than the horizontal windmills of Afghanistan.
5.	1887	 *Blyth's windmill, Marykirk [9]*	• Built in Scotland by Prof James Blyth. • Cloth-sailed wind turbine.. • It was 10 m high, • Used for the production of electricity and charge accumulators, to power the lighting in the cottage.

6.	1888	 *Wind Dynamo, Cleveland [9]*	• Designed and constructed by Charles F. Brush. • Rotor diameter:17 m & tower height: 18 m • Rated at 12 kW with 144 no. of blades. • Used either to charge a bank of batteries or to operate up to 100 incandescent light bulbs.
7.	1922	 *Drawing by Savonius, [10]*	• Invented by the Finnish engineer Sigurd Johannes Savonius. • He experimented with his rotor on small rowing vessels on lakes in his country.
8.	1927	 *Giromill-type wind turbine[7,11]*	• The long blades of Darrieus design replaced with straight vertical blade sections attached to the central tower with horizontal supports.
9.	1931	 *Darrieus wind turbine, Magdalen Islands [12]*	• Patented by Georges Jean Marie Darrieus, French Aeronautical Engineer. • Number of curved aerofoil blades mounted on a vertical rotating shaft or framework. • The curvature of the blades allows the blade to be stressed only in tension at high rotating speeds.
10.	1957	 *Gedser wind turbine Gedser coast, Denmark [3]*	• Johannes Juul installed a 24 m diameter wind turbine at Gedser. • It ran from 1957 until 1967. • Three-bladed, horizontal-axis, upwind, stall-regulated turbine.
11.	1941	 *Smith-Putnam wind turbine[3]*	• Designed by Palmer Cosslett Putnam and manufactured by the S. Morgan Smith Company. • World's first megawatt-size wind turbine. • Rated Output: 1.25 MW. • Operated for 1100 hours before a blade failed.

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12.	1981	 *The NASA/DOE 7.5 megawatt MOD-2 three turbine cluster, Goodnoe Hills, Washington [3]*	• From 1974 through the mid-1980s the United States government worked with industry to advance the technology and enable large commercial wind turbines. • The NASA wind turbines were developed under a program to create a utility-scale wind turbine industry in the U.S.
13.	1987	 *MOD 5B WIND TURBINE SYSTEM,[13]*	• Largest single wind turbine operating in the world. • Rotor diameter 100 meters and a rated power of 3.2 megawatts. • The MOD-5B had the first large-scale variable speed drive train and two-blade rotor.
14.	June 2012	 *X-Wind Plant [14]*	• NTS GmbH, German company had successfully tested X-Wind technology on linear rail system in Freidland, Germany. • Harness the energy of wind at an altitude of up to 500m.

5. Modern Wind Turbines

With advancement in technology and need for generating more power output from wind turbines has led the technology to improve its capacity generation levels.

Table: 5. Different VAWT models with respective specifications [21]

Sl. No.	Model	Capacity (w)	Rotor diameter/ height (m)	Tower height (m)	Generator Type	Wind speed range (cut-in / cut-out) (m/s)
1.	*H-type darrieus; Straight blade*	5 kw	4/ 4.6	5.5m	Pmg 3 phase	2 / 25
2.	P 10 – s	10 w	0.3/ 0.3	0.18	Pmg 3 phase	2/ 40
3.	*P300*	300 w	1.36 / 1.4	5.5	Pmg 3 phase	3/25
4.	*P 1000 ab*	1000 w	1.8 / 2	5.5	Pmg 3 phase	2.5 / 25
5.	*P 3000 ab*	300	3/3.6	5.5	Pmg 3 phase	3.5 / 25
6.	*P 5000 ab*	5000	4/ 4.6	5.5	Pmg 3 phase	2/ 25
7.	*Pk 10*	10 kw	6 / 6.2	5.5	Pmg 3 phase	2 / 25
8.	*Pk 60 ab*	60 kw	13 / 9	11.5	Pmg 3 phase	2 / 25

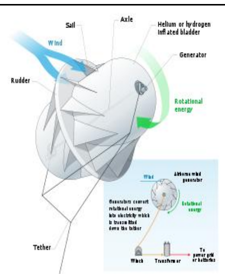
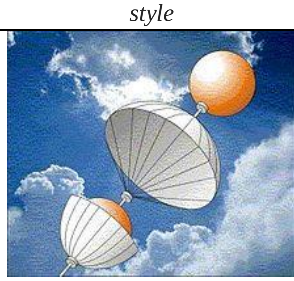
Table: 6. Wind Turbine Development In Accordance with Capacity- HAWT [15, 16, 17, 18, 19, 20]

Sl. No.	Year	Capacity (mw)	Wind turbine model	Manufacturer
1.	1996	1.5	Ge's 1.5i	Ge
2.	2000	0.6	E40	Enercon
3.	2001	1.3		An bonus
4.	2002	1.75	V66	Vestas
5.	2003	1.5	Nm64	Neg micon
6.	2004	1.75	V66	Vestas
7.	2005	0.66, 1.65, 2	V47, V80, E70	Vestas, Vestas, Enercon
8.	2007	1.5, 2 3	Nm72c, V80 V90	Repower, Vestas, Vestas
9.	2008	3, 2.1	V90, S88	Vestas, Suzlon
10.	2009	1.5, 2, 2	Aw 1500, mm82, S88, V90	Acciona, repower, Suzlon, Vestas
11.	2010	3, 2.1	V90, S88	Vestas, Suzlon
12.	2011	1.5, 2.1	Aw 1500, S88	Acciona, Suzlon
13.	2012	1.5, 2.1	Gw82, S88	Goldwind, suzlon
14.	2013	2.05, 3	Mm92, V112	Repower, Vestas
15.	2014	2.05	Mm92	Repower

6. Evolution of The Most Spectacular Wind Turbines Designs In The World

With respect to different applications of wind turbines, new and innovative methods have been developed as listed in table 7.

Table: 7. Modern & Innovative Wind Turbine Technologies: [14, 22, 23]

SL. No.	Technology	Features
1.	 *Airborne wind generator of flip-wing style*	• A rotor supported in the air without a tower, thus benefiting from more mechanical and aerodynamic options • The higher velocity and persistence of wind at high altitudes. • Avoiding the expense of tower construction or the need for slip rings or yaw mechanism. • An electrical generator may be on the ground or airborne.
3.	 *Twind technology*	• Uses a pair of captive balloons at an altitude of 800 meters. • The tether cables transmit force to a rotating platform on the ground. • Each balloon has a sail connected to it. • The two balloons move alternately, the balloon with the sail open moves downwind and draws the other balloon upwind, and then the motion reverses. • The tether cable can be used to turn the shaft of a generator to produce electrical energy or perform other works (grinding, sawing, pumping).

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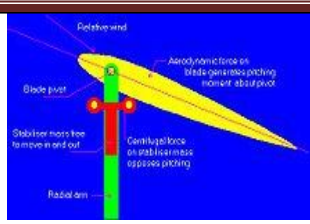
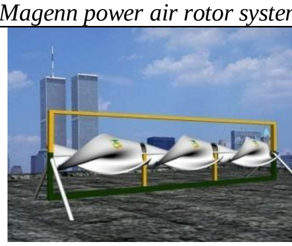
4.	 *Cycloturbine*	• Each blade can rotate around its own vertical axis. • Blades always have some angle of attack relative to the wind. • Torque generated remains almost constant and near maximum possible, resulting in more power. • On the downside some sort of wind-direction sensor required to pitch the blades properly. • Self-start, by pitching the downwind moving blade flat to the wind to generate drag and start the turbine spinning at a low speed.
5.	 *Magnetically levitated wind turbine*	• Generates one gigawatt of power (enough to power 750,000 homes) and delivers clean power for less than one cent per kilowatt hour using this wind turbine. • Blades are suspended on a cushion of air, and the energy is directed to linear generators with minimal fiction losses. • Reduces maintenance costs, and increases the lifespan of the generator. • Requires less land space than hundreds of conventional turbines.
6.	 *Magenn power air rotor system*	• Filled with helium, capable of flying much higher than other wind turbines in order to gain access to higher wind speeds. • Design ideal for farms and remote locations. • Lighter-than-air wind turbine, rotates around a horizontal axis irrespective of where the wind is blowing to generate electrical energy. • This electrical energy passes down the tether to a transformer and then can be transferred to the electricity power grid. • Helium is used to keep the mars air rotor aloft, while its rotation keeps it stable and in a optimal position.
7.	 *Helical structured wind turbine*	• These are the future of wind mill technology. • Amazingly unique looking twists and turns will replace those long and boring blades which represent the conventional image of a windmill. • Designed much like the old ones when it comes to converting their circular motion in to mechanical work, but it is the structural design that makes them unique and special. • Should function better than the traditional windmills as the helical structures seems to not just utilize the energy of the wind, but maximize it by containing the wind.
8.	 *The loopwing*	• The e1500 model turbine is a home windmill and sports a very unique wing design that operates with low vibration and at wind speeds as low as 1.6 m/sec. • The efficiency specs on the turbine are vague — "43% power performance at optimum wind speeds".
9.	 *The v-lim – a rooftop wind turbine*	• It is a vibration free, silent, self indexing, high-bandwidth wind turbine suitable for rooftop mounting. • This twelve foot, self indexing turbine can produce 3kw at 15mph winds. • Unaffected by air turbulence that can adversely affect most open bladed designs allowing rooftop mounting without tall towers. • Can be screened to prevent harm to birds and other wildlife. • The turbine can be used in both rural and urban locations with good wind resource.

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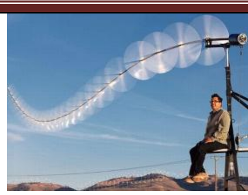
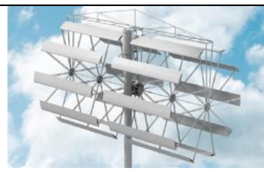
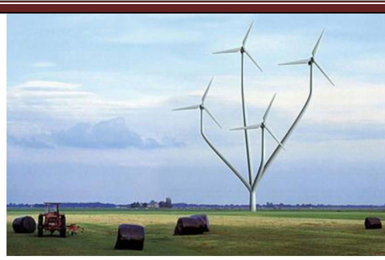
10.	 *Sky serpent – an array of small rotors*	• Doug selsam's sky serpent uses an array of small rotors to catch more wind for less money. • Requires figuring out the optimal angle for the shaft in relation to the wind and the ideal spacing between the rotors. • The payoff is machines that use one tenth the blade material of today's mega-turbines yet produce the same wattage.
11.	 *The highway turbine*	• Novel way of re-capturing some of the energy expended by vehicles moving at high speeds on highways which is being proposed by an arizona state university. • Air turbulence is generated by vehicles moving at speed particularly trucks and the proposal would involve mounting horizontal wind turbines above the roadway that would be driven by the moving air generated by the passing traffic. • The electricity generated by spinning these turbines could be fed back into the grid. • Based on vehicle speeds of 70 mph each turbine could produce 9,600 kwh per year.
12.	 *Broadstar aerocam*	• Design is based on principles first established by the french aeronautical engineer georges jean marie darrieus (1888-1979), who invented a wind turbine capable of operating from any direction and under adverse weather conditions. • Darrieus machines typically have a vertical axis, whereas the aerocam design has a horizontal axis with multiple blades, giving it the appearance of a water wheel. • Ability to automatically and interactively adjust the pitch or angle of attack of the aerodynamic blades as the turbine rotates, thereby optimizing its performance for much the same reasons a bird changes the shape of its wing in flight.
13.	 *The 'nano skin' spiral twist wind turbine*	• This design proposal would incorporate tiny, biological self-repairing wind turbines into the outer layer of a building. • As wind played over the building's "skin," the turbines would spin and create energy that would be fed into the building's electrical grid. • They would also absorb carbon dioxide. • The outer skin of the structure absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside the nano-wires which then is sent to storage units at the end of each panel. • Each turbine on the panel generates energy by chemical reactions on each end where it makes contact with the structure. • Polarized organisms are responsible for this process on every turbine's turn. • The inner skin of each turbine works as a filter absorbing co2 from the environment as wind passes through it.
14.	 *The 'helix' wind turbine*	• The helix wind savonious 2.0 uses a unique rotor capable of capturing omni-directional winds to provide quieter, kinder small wind power for urban home. • The helix s322 is compact, elegant, sophisticated and versatile. • Provides smooth power and torque delivery across a broad range of wind speeds and under the most difficult of physical environments. • No furling or shutting down, simple to install, modular and scalable, the s322 is ideally designed for urban environments, low draw, off-grid applications and liquids pumping.

15.	 *The 'dutch windmill tree'*	• The proposed mill is shaped like a tree and can hold up to 8 turbines and be as high as 120 meters. • The dutch government feels that tree shaped mills are less intrusive in the flat dutch landscape than the mill-parks they use.
16.	 *The 'bahrain world trade centre' turbines*	• Three turbines which are allocated between the two adjourning towers were turned together . • The three 29m-diameter turbine blades on bahrain's iconic landmark are the first in the world to be integrated on such a scale into a commercial development and are forecast to provide the equivalent of 11-15% of the power for the two towers when fully operational.
17.	 *The anara tower – dubai*	• Another skyscraper, in dubai and in the shape of a giant wind turbine. • Dubai based property developer tameer holding has decided on the 600meter-plus skyscraper design to be build on the famous sheik zayed road.
18.	 *The sweet-escott set*	• Invented by british inventor sweet-escott . • It is silent and virtually hidden from view. • Has vertically mounted blades fixed under the influence of two opposing magnets. • As the blades catch the wind and start to spin, they form an airfoil by means of boundary layers.
19.	 *Windspire, VAWT*	• Size: 30-foot tall, 4-foot wide turbine • Generates 2000 kilowatts per hour. • Cut-in-wind speed: 12-mph winds. • Cut-out-wind speed: 105 mph. • Has a tall, thin propellerless rotor.
20.	 *Windbelt*	• Created by Shawn Frayne, is a small-scale wind turbine. • Generates 40 milliwatts. • Pair of magnets fitted on a membrane oscillate between two wire coils to generate electricity. • Cut-in wind speed 10-mph winds. • Motive is to help the poor power their lights cheaply and safely.

7. Limitations for Existing Designs

- Structural and mechanical failures (which can result in a tower collapse) are primarily due to control system errors and lack of effective maintenance.
- Many field-operating failures are a consequence of gearbox bearing failure.
- The gearbox is situated just where the winds are the strongest - as high as 300 feet. In addition, offshore installations encounter rough seas. The engineer will have to gain access up the tower via an internal ladder (or elevator in some cases), which is demanding and specialized work.

8. Need of Modern Wind Turbines

For future modern wind turbines several work areas have been found upon which work should be done leading to reliable, efficient, easy to maintain wind turbines.

Table 8: List of factors for scope of improvements in functioning and performance of wind turbines [19, 24, 25, 26]

Sl. No.	Need	Remarks
1.	High efficiency	Large generator and large-diameter rotor; Rotor blades can be built with a subtle twist.
2.	Siting	Wind availability, aesthetic and environmental concerns, and land availability.
3.	Bearings	High-load/low-speed conditions lead to the breakdown of the lubricating film. Automatic greasing system & special gearbox oil filter.
4.	Frequency	Wind power can be more effective in maintaining frequency than thermal generation when wind farms are equipped with grid friendly controls.
5.	Temperature change effect	Develop low-turbulence rotors that would result in less vertical mixing of the air and would also be more efficient for energy generation or locating the turbines in areas that already have a turbulent atmosphere so the consequence of turbulence from the rotors in minimal.

9. Conclusions

- The present work traces the long stages of wind energy development from the 1st Century A.D wind mills to the construction of huge offshore wind farms worldwide.
- Literature review shows that Vertical Axis Wind Turbines offer several advantages over Horizontal-Axis Wind Turbines for small scale or residential use, including easier maintenance and potentially lower noise output for comparable power harnessing capability [27]. It is accepted that vertical axis wind machines represent a suitable alternative for wind power extraction in many developing countries. The reason for this is mainly because of the advantage over the horizontal axis type such as –
  i) Simple construction
  ii) Extremely cost effective [28].
  From table 5 & 6, HAWT and VAWT with max capacity of 3 MW of 60 kW respectively have been designed and developed.

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