Software Modeling of Direct Wind to Energy Generator

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ABSTRACT

The Wind Energy is one of the cleanest sources of electrical energy. Commercial wind turbines deliver the promise of being practically realizable with the cost of having an extremely large footprint and being haunted by the Betz Limit. This paper gives an idea of Direct Wind to Energy Conversion which aims to produce electrical energy by harnessing wind's kinetic energy, devoid of any rotational mechanism. The method in question utilizes the technique of Electro-Hydro-Dynamic Atomization (EHDA) to atomize charged working fluid to deposit its particles on collector electrodes using wind as a carrier. A comparative analysis of several working fluids was conducted to optimize energy production. Simulations on the charged particle trajectory were conducted based on historical average wind speed values to enhance electrode placement which in turn led to design iterations and increased efficiency.

Keywords: Direct Wind Energy Conversion, EHDA, Vanless Turbine

INTRODUCTION

Electrical Energy is one of the most critical facets of modern life. Without electricity, it would not be possible to ship, interact or manufacture goods (Ucan, O et al., 2014). More than 80% of the world's energy consumption is provided by the burning of fossil fuels. Rises to global warming and the decline of these fossil fuels, changing fuel demands from non-renewable energy sources to renewable energy sources became unavoidable (Al-Ghussain, L., 2019). Since ancient times when humans were unfamiliar with the idea of sustainable energy sources and did not know how to make use of such energy sources, they met their fuel needs with renewable sources, such as directing the flow of water for agriculture or using wind to sail in water. Renewable technology tends to be the only way to sustain the present level of life without undermining the interests of future generations. Renewable energy supplies are either regenerative or renewable carbon flows, such as wind turbines (Djairam, D et al., 2007). In order to meet the long-term carbon emission targets set by the world, significant changes to the goals are to be met. (Ezhil jenekkha et al., 2020) Wind energy is also the main component of these various renewable energy sources accounting for about 2.5% of the energy production.

Wind energy utilization has been around for millennial, as its primary usage was witnessed in the ships that were powered by wind for the purpose of travel. The earliest evidence of the construction of the windmill dates from 500-900 A.D. The mills seen after were made out of a wooden structure using a cloth sail to rotate on a vertical pole, this helped in pumping water into the fields for the sake of agriculture. The design allowed the sail to catch on to the wind and allow a better rotation, resulting in quicker paper production and sawing of wood, but they are well known for draining lakes (Ragheb, M., 2017) (Djairam, D et al., 2005). The invention of the steam engine later renewed the perspective of energy production for humans as it turned out to be less labor intensive and more efficient in energy production, seeing the usage of mills.

(a)

Figure 1. Offshore Wind generation of 3.45 MW

Figure 2. Onshore wind farms

The Wind Energy sector benefits from various projects and aerospace growth in the 20th century (**Lian, J** et al., 2020). Applications range from supplying energy for villages to huge systems of wind turbines generation MWs, both onshore and offshore is shown in figure 1 and 2 (Raju, K et al., 2020). Wind energy added 2.1 /kWh of overall power generation is adjusted annually for inflation. Nonetheless, although this proportion is comparatively low, wind energy is the most efficient method of renewable energy generation (Djairam, D et al., 2014).

Electro-Hydrodynamic Atomization is a process of developing and emitting a stream of charged particles, in this case the working fluid. The system depends on the voltage provided to it from the supply. The resulting voltage provided gives rise to Taylor cones. The EHDA process is useful in producing positive charged particles (Rai, P et al., 2019). It can produce negatively charged particles as well if needed.

The work is to develop a feasible large scale DWEG system design, by increasing its existing efficiency by iterating the working fluid materials and the system design using simulation techniques. The simulation design used to predict power output for a large scale system which can be deployed and use in real world scenarios and while achieving this goal. The main objective is to use the pressurized sprinkler system to release charged particles along with the working fluid which with the help of wind will displace to the collector plates creating a potential difference between the points and eventually charge will flow between those two points.

The system is developed to minimize the wastage of available energy from the wind that can be used to generate electrical energy for usage in multiple equipment that require the energy or the generated energy can be stored in batteries. Even though the generated energy is comparatively not equivalent to the turbine, it helps minimizing the overall effect of wind energy generation in the fields of noise, size and space.

The Electrode plays a major role in the system as it uses the charge on the working fluid which after getting energized, depending on the wind speed, it uses the wind to travel in a certain direction. Using simulation software such as COMSOL and Lorentz we are able to develop a model that can simulate various conditions in which the electrode, wind and working fluid play a role to develop a certain outcome.

WIND ENERGY CONVERSION

The early windmills, the architecture of the wind turbine has been greatly improved. Materials have grown tougher and lighter. (Rosenberg, R.H., 2007) Aerodynamic construction has become influential in the conversion to electrical energy making it more successful, resulting in a turbine with a diameter of 126 meters, producing 7.5MW of power. Despite technical advances, the basic idea, i.e. wind energy is converted into rotational energy, has not changed. In a traditional wind turbine, the blades convert the kinetic energy of wind into rotational force. A gearbox assists the rotor to rotate during the slower speeds to maintain rotation and help in reaching faster speeds. The generator converts the rotational force into electricity. These components are put within a nacelle which is fixed on a pole. At higher wind speeds, the pitch is altered in order to maintain the blade to rotate at rated speeds without requiring additional energy and the resulting energy from the turbine is at rated levels. To avoid damage to the turbine at rated capacities, cut- out speed exists which stop the turbine from rotating.

The Bet’s law, which states the capability of converting the wind energy into suitable mechanical rotation of the blades defined by the rule of Betz rule (Sumathi, S et al., 2015). The strength of the wind is given by: where A is the surface region, the density of the air, as well as the velocity of the wind.

$$P_w = \frac{1}{2} A \rho_a v_w^3 \qquad (1)$$

Where 'A', 'a' and 'v_W' are the surface area, air density and the wind velocity respectively. There is a most favorable ratio between the wind speed before and after converter, which should be 1:3 for the maximum power to be extracted. The max recovery power, (Pmax) of a wind energy converter shall be calculated by (2)

$$P_{max} = \frac{8}{27} A \rho_a v_w^3 \qquad (2)$$

Combining equations 1 and 2 results in the efficiency of the system.(3)

$$\frac{P_{max}}{P_w} = \frac{16}{27} \approx 59 \qquad (3)$$

This restriction extends to all conversion approaches, including the latest one to be defined in this report; It Direct Wind to Energy Generator (DWEG). This implies that, long though the basic functions are understood, there is little increase in the overall performance of the wind-to-energy generation method with regard to traditional energy generation.

MODELING OF ENERGY GENERATING SYSTEM

The operating theory of the energy generation method will be clarified in this part. The particles containing charge, which are caused by specific electrical and mechanical forces, resulted in an increase in the electrical capacity of the system. The forces that act on a single molecule containing charge will be discussed.

The theory of an energy-generating device is the function of a charged object, which is carried out by a magnetic force attributable to a magnetic effect (Narita, F et al., 2018). The force (F) on a particle with a charge (q) in an electrical field (E) is given by means of an electrical force (E)

$$\overrightarrow{F} = q\vec{E} \quad (4)$$

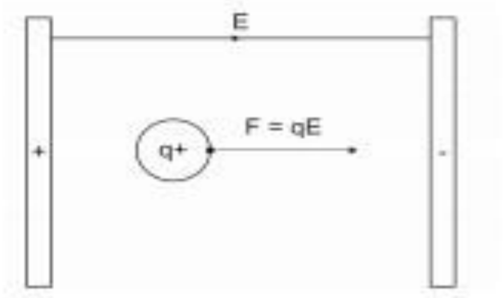


Figure 3 Force applied on the molecule generates work.

The wind would be the reason for the movement of the molecule containing charge in an energy generation device. The Work (W) performed is seen by the molecule's displacement (x) of the force provided on it.

$$W = \vec{F}\vec{x} \quad (5)$$

The power consists of the mechanical and electrical elements of the wind and the magnetic field respectively. Every element has its own sense and its own direction, hence the resultant force by the wind must be greater than the molecule then electrical potential of the molecule containing charge would rise. Potential energy (U) increases as a molecule of charge is pushed against the force of attraction

dW= -dU (6)

The possible energy differential will be determined from the research performed on a single molecule. Overall energy produced can be mathematically proven by integrating the research performed on the arbitrary I molecule is given in equation 7.

$$W_i = \int(\overrightarrow{F_i} - \overrightarrow{F_{i,w}})\overrightarrow{dl} \quad (7)$$

Where $\overrightarrow{dl}$ the direction of the molecule is, $\overrightarrow{F_{i,w}}$ is the force of drag on the molecule. $\vec{F_i}$ is the sum of all the forces acting on this molecule. In the $\vec{F}_{i,w}$equation, the flow cycle is considered to be laminar.

$$\vec{F}_{i,w} = \frac{3\pi\eta_a d_i(\vec{v}_w - \vec{v}_d)}{C_c} \quad (8)$$

Where η_a is the elastic absolute viscosity of the liquid, d_i the diameter of the molecule, $\vec{v}_w$ the wind direction, $\vec{v}_d$ the height of the molecule and C_c (= 1, 1 for molecules > 1 μm), Cunningham correction factor. Mechanical powers are the power of friction and the power of acceleration.

$$\vec{F}_i = \vec{F}_{i,g} + \vec{F}_{i,B} + \vec{F}_{i,w} + \vec{F}_{i,E} + \sum \vec{F}_{i,j} = m_i \vec{a}_i \quad (9)$$

The buoyancy is shown in equation 10 and 11, respectively.

$$\vec{F}_{i,g} = m_i \vec{g} \quad (10)$$

Where, m_i is the mass of this molecule and $\vec{g}$ the gravity constant.

$$\vec{F}_{i,B} = -\rho_a V_d \vec{g} \quad (11)$$

The electrical forces calculated by the ambient electrical field and the charge of the corresponding molecules as defined in formulas 12 and 13, respectively.

$$\vec{F}_{i,E} = q_i \vec{E}_{ext} \quad (12)$$

Where, q_i molecule charge and $\vec{E}_{ext}$ the external electric field.

$$\vec{F}_{ij} = \frac{1}{4\pi\varepsilon_0} \frac{q_i \cdot q_j}{r_{i,j}^2} r_{i,j} \quad (13)$$

Where the (ε_0) dielectric constant of vacuum and $P_{\ i,j}$is the interval between the i and j molecules. This estimate is based on a molecule ratio-ed at 30% ethanol and 70% vapor. The inference from the table that at the highest voltage levels, the diameter of the molecule is about 10μm, wind speeds reach to about 6 m/s at which the maximum voltage intensity achieved is about 105 V/m. Forces evaluated on a single charged molecule over a 10 μm & maximum charge molecule, present in a field of electricity of 105 V/m.

An electrical field, as well as a carrier of charge, is necessary. This charge would have to be changed by the power of the wave, so the device will be able to maximize the demand for electrical energy. Depending on the phase of charge, there is always a condition on the limit of charge that may be taken up by a single molecule given by the Rayleigh restriction.

$$q_{max} = 8\pi \sqrt{\gamma \varepsilon_0 r_d^3} \quad (14)$$

Where, q_{max} is the charge limit of a molecule, γ is the surface tension of the molecule, ε_0 is the dielectric constant of vacuum and r_d the molecule radius. The movement is considerable, the direction is the next concern as any random direction can only be acceptable if the earth is considered as a collection plate instead

$$CMR = \frac{q}{m_{droplet}} \qquad (15)$$

The cumulative charge of a molecule as defined in the limit should be monitored controllably for the evaporation of the liquid molecule (Liu, Y.F et al., 2014). This causes the molecule to lose its size and shape over a certain period. The disparity between velocity of the molecule and the ambient air is one of the key conditions controlling the evaporation rate (Chan, H.K et al., 2011.). If the molecule is propelled by the wind, less disparity between them reflects on the evaporation rates. This disparity definitely appears to be greater when the molecule containing charge is formed and released from the system into the flowing air.

An analytical model, which can be used to measure the flight times of the molecules containing charge, will be obtained (Cuevas-Zuviría, B et al., 2020.). When equate the evaporation times with the flight times, it will decide if the molecules containing charge will be a part of the occurring changes. The certain uncertainty is induced, as the higher charged molecules tend to block the nozzle with its electric field hence disrupting the flow, and in order to maintain that very thing from happening, load release periods are typically brought upon, the range of 100 m /s is flow rate developed. Thus, in compared to water molecules, ethanol does not show the similar properties; hence end up with a mixture of the both to counter the problems.

SIMULATION ANALYSIS

The fluid is the most crucial component in this project as it facilitates the energy generation. The combination of water-Alcohol mixture in a ratio of 7:3. The use of alcohol (Ethanol in this case) is relevant because it serves its purpose in reducing the surface tension of water as well as provide a surface for charge carrying is very useful and in overall reduce the voltage that is required for producing charge particles. The analysis worked on different working fluids through iteration such as follows.

Table 1. different working fluids

S.No	Liquid	Surface Tension (N/m)	Density (kg/m^3)	Absolute Viscosity (mPa s)
1	Acetone	0.025	785	0.316
2	Butanol	0.025	810	2.95
3	Ethanol	0.033	789	58
4	Glycerol	0.063	1258	1410

The models need to be in precise dimensions to work efficiently in accord with the wind speed and the installation place. The Solid Works to design the frame of our model. Solid work is 3D CAD software and is a versatile design program. It found it user friendly and very easy to work with and make changes in whichever point it is required. The pipe designed to deliver an idea while working on putting holes in the hardware. This design of pipe with holes is further replicated to make a series of pipes is shown in figure 4.

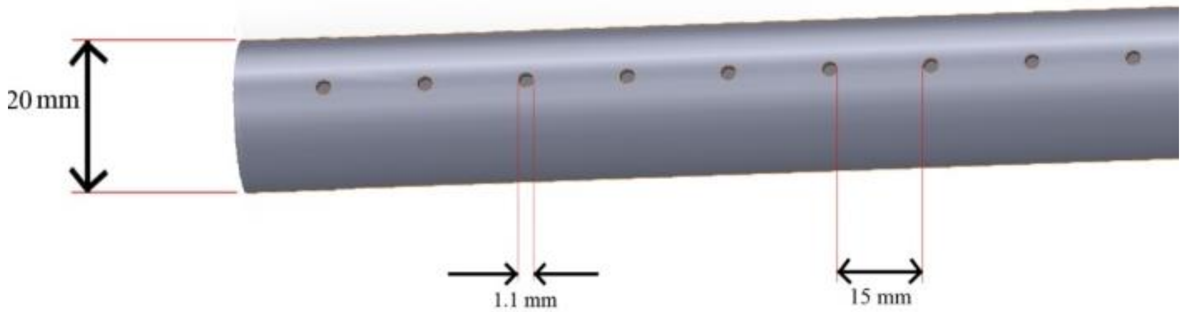


Figure 4 Series of 1.1mm holes (nozzle) in a pipe with a gapping of 15mm.

The simulation for tracing the working fluid particles throughout the system. Laminar flow happens when the liquid flows in infinite layers flowing alongside each other with no disruption between these layers. In laminar flow, fluid layers slide in parallel, swirling twisters or currents normal to its respective flow itself. Basically fluids with high viscosity flow in laminar manner. Viscosity is the internal resistance to flow. They just move in orderly layers with one later slipping over another. It can be taken into consideration because the relative motion of a hard and fast of concentric cylinders of fluid, the only fixed on the pipe wall and the others shifting at increasing speeds as the center of the pipe is approached is shown in figure 5.

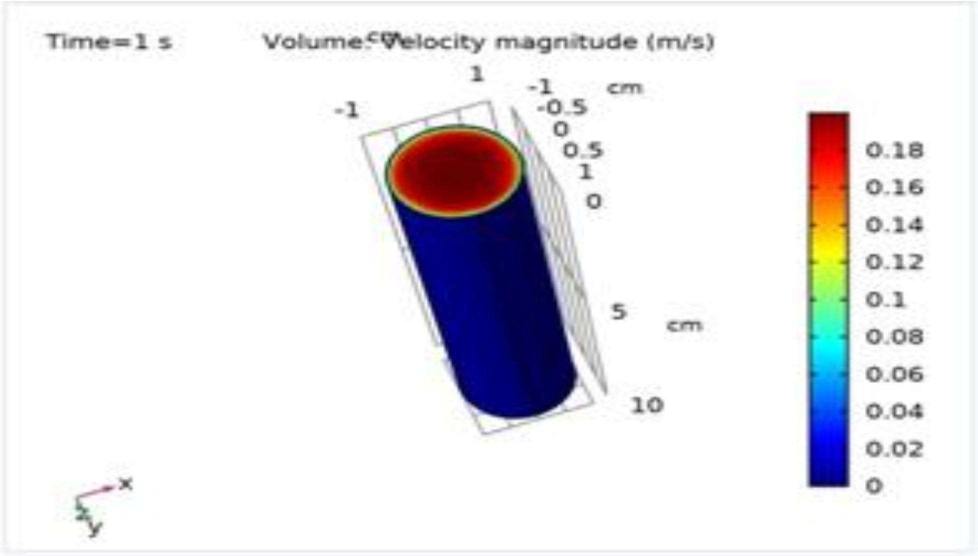


Figure 5. Laminar flow of Working fluid showing flow rate is maximum in the middle of any cross-section

The particle tracing of the working fluid is done to acquire trajectory of particles in a fluid or electromagnetic field and particle field interaction which can help us to combine the particle tracing module with any application specific module for computing the fields that drive particle motion is shown in figure 6.

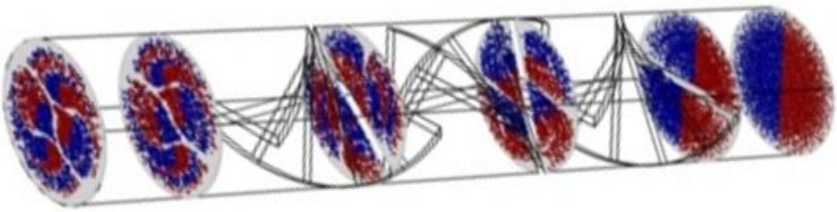


Figure 6. Particle tracing inside a pipe: Particles at different cross-sections of a pipe

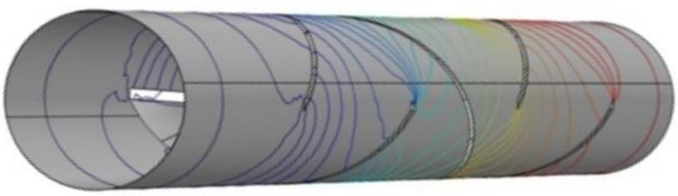


Figure 7. Particle tracing inside a pipe: Particles tracing at the wall of the pipe

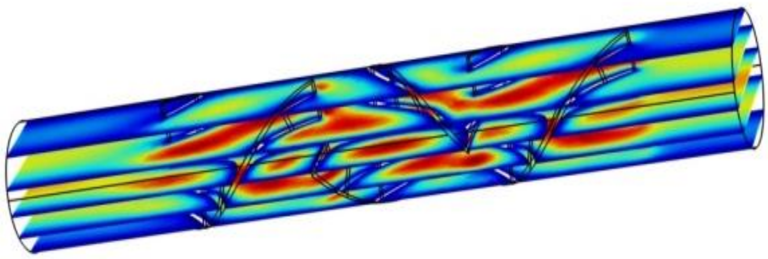


Figure 8. Particle tracing inside a pipe: Velocity of particles at different layers

Particles are released to move through coils to the nozzle and passes via a collimator.

The collimator can be manually set to eliminate stray electrons. A simple DC coil generates an axial magnetic field. This rotationally symmetric, inhomogeneous magnetic field results in non-axial electrons experiencing a radial force causing them to rotary motion about the axis. As they start to move in helical motion, they have a higher velocity component which is perpendicular to the mainly axial magnetic field, therefore the radius of their spiral/helical path reduces gradually. Thus, a parallel beam of electrons arriving at the lens will converge to a point.

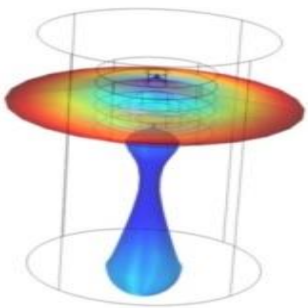


Figure 9. Particle Trajectory from a nozzle: Pressure applied by the charged particles

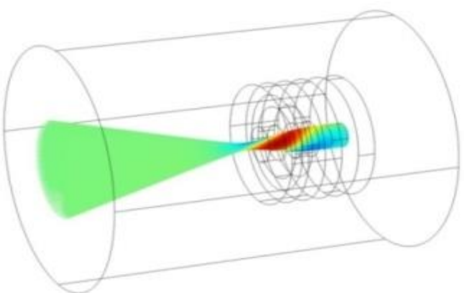
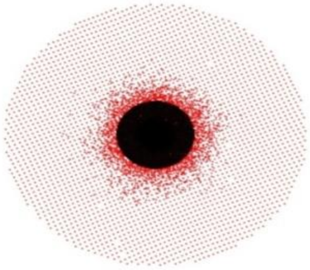
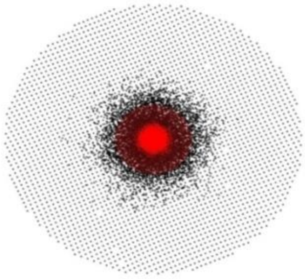


Figure 10. Particle Trajectory from a nozzle: Flow rate of the charged particle.

Poincare maps are obtained for plains which displays the particles concentration at each point of the cross section of the outlet. It helps to determine the pressure and velocity of the particle at which it will leave the outlet. In this simulation at low pressure release and high pressure release of the working fluid to check which gives us the best results and as the results shown below, gradually increase the pressure at the fluid releasing nozzle, the scattering of the charged working fluid is more than the low pressure release and hence it consider to set up a high pressure nozzle to release the working fluid is shown in figure 11.



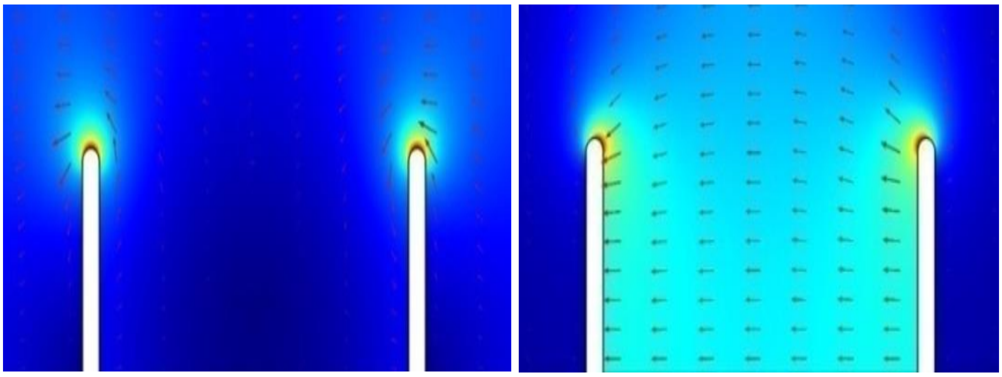
a).low pressure



b).high pressure

Figure 11. Poincare Mapping

This simulation is a presentation of the pressure and velocity of the particles moving from one point to another. It will help us determining the placement of our frame and electrodes, such that the gap between them will be the most efficient way for simulation model to work.



(a) (b)

Figure 12. Movement of charged particles: (a) same charge, (b) different charge

The simulation software, COMSOL Multiphysics is used for the numeric computation of the working fluid throughout the model using real time parameters. The 3-D square shaped frame is designed using the CAD designing software, Solid Works which was later imported into COMSOL for our simulations. The determining the working fluid through iteration i.e., ethanol and water in 3:7 ratio, working of fluid pressure in nozzles at different heights and velocity of working at the tip of the nozzles at different heights is presented in Table 2.

Table 2. Pressure and velocity of fluid at nozzles in different height.

Pipes at different height	Fluid Pressure (Pa)	Velocity (km/h)	Distance Estimated (m)
Top most pipe (1.5m above ground level)	114148	7.4	3.7
Bottom most pipe (0.7m above ground level)	120997	9.1	3.16
Average	117572.5	8.25	3.43

The combination of 70% water and 30% ethanol along with other working fluid options such as glycerol or acetone instead of ethanol need to tested. The major part that is needed to be finished is to concatenate all of the information which include the working fluid and hardware layout alongside wind speed and simulate it in step with the real lifestyles eventualities with the aid of taking different factors of nature in attention like humidity, air pressure and potential loss as a way to have a definite effect at the charged droplets and rate loss. In addition, through taking that simulation is attention, altering the hardware layout and working fluid ratios and simulating it with respect to the real world simulation in order to get the maximum achievable efficiency to about 59.3%.

CONCLUSION

The need for renewable energy is more than ever before and is being encouraged by almost every organization around the world. This is a setup which can be deployed even in urban environments. The need for a technology to harness the wind energy in a safe and silent manner in urban locations was far pending and this novel effort towards the same. The direct wind to energy generator has the potential to increase the effective use of renewable energy by great factor using the locations which were unsafe for other renewable energy sources to be deployed. The technology proposed in this report is very novel and primitive and has a huge scope for improvement in future with development in other fields.

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