Review on Unconventional Wind Energy

Gaurav Gulabani, Beegum Shahnaz Abdul Karim, Jayakrishnan Radhakrishnan[1], Satish Shenoy B & Mohammad Zuber[*]

Department of Aeronautical and Automobile Engineering, Manipal Institute of
Technology, Manipal Academy of Higher Education, Manipal, 576104 India
*E-mail: mohammad.zuber@manipal.edu

Highlights:

- A brief introduction to the need for wind energy and the limitations of conventional wind energy generation.
- A detailed description of the floating offshore wind turbine, its challenges, advantages and recent technological advancement, including a table providing data about various projects.
- An introduction to airborne wind energy generation with its benefits and the challenges faced during its development.
- An explanation of the working principle of highway wind energy and its application.
- An introduction to the conceptual method called locomotive mounted wind turbine and its requirements and possible application.

Abstract. Fossil fuel is currently the major source of energy but it is a fast depleting resource. The phenomenal increase in fossil fuel consumption over recent times has adversely affected our carbon footprint, severely impacting the environment. With strict environmental regulations in place, the focus towards renewable sources of energy is gaining momentum, supported by recent advancements in technologies in wind, hydro and solar. Wind energy was the first form of clean energy and has seen a major increase in power production. However, site restrictions limit the wind turbine from being used to its maximum potential. In recent years, the concept of some unconventional methods have been proposed. In this review, various types of wind turbines are discussed with their recent advances and depicting the challenges faced related to various aspects. The review contains details mainly about 4 types of wind turbines, i.e. floating offshore wind turbines, airborne wind turbines, highway wind turbine systems, and locomotive mounted wind turbines.

Keywords: *airborne wind energy systems; floating offshore wind turbine; highway wind turbines systems; locomotive mounted wind turbine; renewable energy*.

1 Introduction

Fossil fuel is the main source of energy and a resource that is rapidly depleting. The phenomenal increase in the consumption of fossil fuel over recent times has adversely affected our carbon footprint. Especially after the industrial revolution,

---

Received January 30th, 2020, Revised June 11th, 2020, Accepted for publication July 2nd, 2020.
Copyright ©2020 Published by ITB Institute for Research and Community Services, ISSN: 2337-5779,
DOI: 10.5614/j.eng.technol.sci.2020.52.4.8

first coal and then fossil fuels were used in the 19th century to meet global energy demands. This has caused serious problems, such as pollution of lower layers of the atmosphere and a significant increase in harmful gases. Secondly, fossil fuels have limited potential and at the current rate of exploitation, they are expected to deplete within a couple of decades [1]. Figure 1 shows global fossil fuel consumption since the beginning of the 21^{st} century [2-5].

The focus on renewable energy sources is gaining traction with strict environmental regulations in place supported by recent advances in wind, hydro and solar technologies. As the first form of clean energy, wind energy has seen a significant increase in power generation. It is anticipated that the share of wind energy in total global electricity generation will be 4.5% in 2030 and after hydro energy, wind power will become the second-largest renewable energy source in fulfilling energy requirements [6]. Global wind resources (land and near-shore) are estimated at 72 TW, which accounts for 7 times the world’s total electricity requirements and 5 times the world’s total energy demand [7]. Installed wind power generation, which currently exceeds 440 GW, is expected to exceed to 760 GW by 2020, making this form of renewable energy an important component of modern and future energy supply systems [4, 5, 8, 9]. Over the past decade, the United States and Europe have seen growth with a rate of 20-30% per annum [10].

From Figure 1, it can be seen that since 2001-2017 there has been a rapid growth in the field of wind energy, especially after 2009, whereas other fuel growth rates were very low. Despite this rapid growth in the field of wind energy, it presently accounts for only 1% of total United States electricity consumption. An increase in the height and size of wind turbines has resulted in an increase in the efficiency of energy generation. Their size is not be expected to increase in the future as dramatically as has been seen in the past. It is expected by many turbine designers that land-based turbines cannot further increase in length over a diameter of 100 m, with power outputs restricted to 3-5 MW. Bigger sizes are structurally possible, but potential barriers are the logistical constraints of transporting the components across the road and getting cranes that are capable to lift the parts and components [10]. Site limitations restrict the use of wind turbines to their maximum potential. Such growth may decline in the future due to the saturation of windy inland areas suitable for installations [11].

In parallel, industrial research has been investing in offshore installations since the early 2000s. Wind speeds are generally higher far from the coast towards water bodies, as the wind there is very strong and much more regular, allowing a more uniform rate of usage and precise production with planning, and providing increased power generation. The predicted growth rate of offshore facilities is very promising; according to current projections, the globally generated power is expected to reach 80 GW by 2020 [11]. The large energy potential associated with the vast scattered areas and the stronger winds that lead to increased energy generation is promising with respect to offshore wind farms, although they require greater initial capital investment, cost of operation and maintenance [7]. Uninterrupted wind over vast water bodies has drawn the attention of wind turbine researchers and manufacturers towards the floating wind turbine concept.

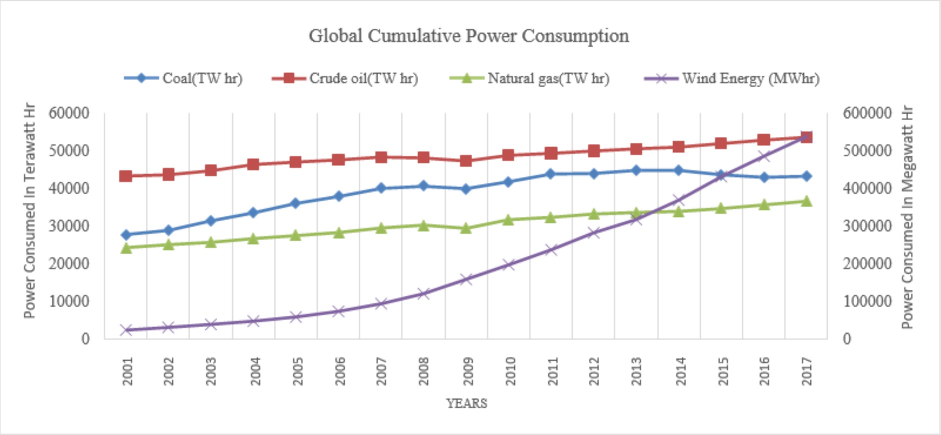

Figure 1 Global energy consumption from 2001 to 2017.

A new wind energy class was designed as one of the new technologies for electricity production from renewable sources by means of airborne wind energy systems (AWESs). In order to generate electrical energy, this new technology allows us to reach the lower atmospheric layers to capture high wind speed energy. At a height of 500-1000 m, wind speeds are greater than four times the speed at 50-150 m [12]. In terms of patents and scientific research, this field of study is growing fast [11-13]. Wind energy has great potential but one of the main limitations is that there are few regions in the world that experience windy conditions that are sufficient to produce a substantial amount of energy. But many researchers have found alternatives. One of the alternatives is, whether it is a train, car or even a bike, any vehicle produces wind currents in motion along its direction. This occurs due to the air disturbance caused by the vehicle's body. If tapped effectively over a long period of time, this wind will result in significant power production [14].

This review discusses a number of unconventional wind energy generation methods, i.e. floating offshore wind turbines (FOWT), airborne wind energy systems (AWESs), locomotive mounted wind turbines (LMWT) and highway wind turbine systems, emphasizing their conceptual design and the latest technological advancements. The review also contains some factual data regarding different projects for the various wind turbine generation systems.

2 Floating Offshore Wind Turbine

Offshore wind turbines are less overwhelming than onshore turbines, as distance mitigates their size and noise. Because water has less surface roughness than land, the average wind speed over open water is generally significantly higher. Europe is a major contributor to offshore wind power generation. As of 2010, 39 offshore wind farms with a combined operating capacity of 2396 MW were operated in Belgium, Denmark, Finland, Ireland, the Netherlands, Norway, Sweden, and the United Kingdom. A series wind turbines of 40 GW (100,000 MW) is planned to be installed by 2020 and 150 GW by 2030, as stated by the European Wind Energy Association. The Thanet project in Great Britain is the largest offshore wind turbine project since November 2010 with a 300 MW ratio, followed by the 209 MW Horns Rev II wind turbine installation in Denmark [22]. For offshore wind turbines, various types of foundations are available. The two mainly used types are the fixed bottom and the floating bottom concepts. A wind turbine installed on an offshore floating botoom construction for generating electricity is called a floating wind turbine (FOWT). Table 1 presents various FOWT design with specifications.

Table 1 FOWT designs with specifications.

Year	Major Partners	Concept	Specifications	Locations
2009	Statoil and Siemens Wind Energy	Scale floating spar type wind turbine (Hywind) [7, 15, 16]	Power Output: 2.3 MW Turbine model: SWT 2.3-82 Rotor diameter: 82.4 m Spar Length: 100 m Hub height: 65 m	Norwegian coast Water depth: 200 m
2013-2015	Toda, Kyoto University, Hitachi, Ministry of Environment	Floating offshore spar type wind turbine [17, 18]	Power Output: 2 MW Turbine model: Hitachi 2.0 MW Hub Height: 56 m Draft: 76 m	Kabashima, Japan Water depth: 100m
2015	Mitsubishi Heavy Industries (MHI), IHI, MITI, Hitachi	Floating offshore wind turbine (semisubmersible) [19-21]	Power Output: 7 MW Turbine model: MWT167H/7.0 Rotor diameter: >165 m Blade: >80 m Hub height: 110-120 m Height over the sea: approx. 20 m	Fukushima Water depth: 100-200 km

2.1 FOWT Platform Classification

FOWT platform configurations may vary greatly. Generally, the study of the first-order static stability defines the overall structure of the floating platform, although there are many other critical factors deciding the scale and complexity of the ultimate model. Nonetheless, a rudimentary economic feasibility analysis is possible once the platform topology has been identified. In order to focus the analysis on the classification system, all platforms are divided into three general categories based on the physical theory and technique that is used for stability [23]:

1. **Ballast**: the platform achieves stability by using ballast weights hung under a central tank that produces the right moment and high pitch and roll resistance and usually sufficient tension to offset heave motion [24]. This technique is used by spar-buoys as shown in Figure 2 for stability [25,26].
2. **Mooring Lines**: the platform uses mooring line tension in order to achieve stability. Like the one in the center of Figure 2, the tension leg platform (TLP) relies on mooring line tension for stability [24].
3. **Buoyancy**: the platform achieves stability by using distributed buoyancy, using a weighted area of the water plane as a righting moment [27]. This the basis of the barge as shown in Figure 2.

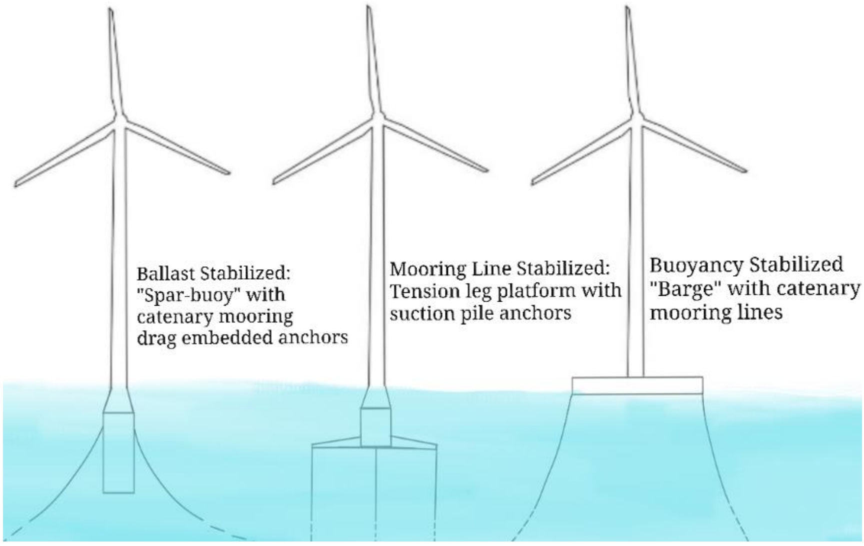

Figure 2 Different types of floating platform constructs.

Each of these platform solutions for achieving stability can be thought of as a vessel of limited properties; some of these may be required while others may not be required for the purpose of FOWT. The perfect spar boom has, for example, a tank with zero water surface that is suspended with a suitable ballast under the waterline to make up for the tower's top moment. The main function of the mooring lines is to hold the station in place. Likewise, an ideal TLP is weightless tank containing zero water planes, which is held by vertical tendons only. Furthermore, an ideal barge is weightless and is only moored to avoid drift. The weighted surface would be enough to stabilize the platform in static load conditions [23].

2.2 Benefits

Offshore wind turbines push deeper into the water to harness the vast offshore wind resources. As water depths rise beyond 50 to 60 m, adverse structural features, together with increasing cost of foundation and planting, make fixed-floor wind substructures unfavorable [28].

Floating platforms are less costly alternatives because a fixed platform substructure replaces the expensive mooring lines and floating substructure. An added benefit is that all construction (also maintenance) can be done on the ground and after which the platform is carried back to the sea. For the near future, innovations have been proposed for advanced designs of the drive train, improved monitoring systems, bigger rotors using modern lightweight improved materials and taller towers with the latest architectural designs and materials [7].

These new platforms are different from conventional land and fixed platform approaches since floating platforms are not constrained by a rigid connection to the seafloor, because flexible mooring lines are utilized to achieve six-level freedom of platform movement. With the help of a couple of buoyancy weights (the center of gravity is much lower than the center of buoyancy), rolling and pitch restoration moments are provided for floating spar bodies, while the mooring lines provide restoration of translational forces and moments [28].

2.3 Challenges

The combination of aerodynamics, hydrodynamics, structural and nonlinear turbine control interactions makes it difficult to design floating wind platforms [28]. Horizontal wind turbine axis flow characteristics are more complex for a floating offshore turbine than for a fixed offshore wind turbine. Pitching and yawing motions of the platform during movement lead to significantly unstable aerodynamic effects on the blades, combining the effects of wind shear, rotor disk gradient, dynamic stall, blade-wake interaction, and skewed flow, etc. [25-31].

Although considerable experience has been transferred from the oil and gas industry, conditions for offshore winds differ remarkably. Offshore wind turbines are subject to harsh conditions in the environment; the retention of overall quality and protective material over the long term is a continuous problem because of wear and biofouling. Offshore wind systems have small support structures and the overall conditions are dynamic and have a great impact on the design process. Hydrodynamic effects of offshore wind turbines are difficult to predict effectively because of their complex and diverse hydrodynamic phenomena due to difficulties related to free surface flow and turbulence [32].

From an engineering point of view, FOWTs have several problems: they require advanced blade control, they experience a huge amount of tower and nacelle inertial loading because of accelerations caused by floating movement, their installation process is more costly and complex, etc. [25, 33]. Classical, conceptual numerical approaches are restricted to completely solving unsteady aerodynamic calculations compared to the advanced computational fluid dynamic approach, which must be improved so that complex aerodynamic interactions through FOWT motion can be predicted more accurately [25]. Studies of the present standards have revealed that the method underestimates pile displacement in sandy soil and overestimates soil resistance against large side forces [32,34]. This is critical because the degradation of ground rigidity due to dynamic and cyclic loads could cause the turbine to move from its position, which could jeopardize its performance [35].

The gearbox, generator and electric power supply drive the wind turbine system. They are always low in reliability and availability. In addition, the installation of turbines in deep water is technically and meteorologically challenging. Wind speeds, wave heights and currents are among the weather conditions in the sea that could pose challenges during construction [32]. There are no specific models to predict fatigue life and there is very limited knowledge of structural health monitoring [34]. In order to predict the relation between the state of damage and the remaining component life, structural health monitoring is required. For rotor blades, this explicit relationship does not exist yet. Pillar erosion or scour phenomena pose a challenge for the model of the soil. During extreme events like storms, scour occurs and since there is no adequate stochastic model for predicting scour and its development, its solution may not be sufficient to predict the conditions [32].

2.4 Sway System

A sway system is an offshore floating spar wind turbine at depths of 60-300m+. Sway has been patented worldwide solely for both tension bearing mooring and slack mooring in the general continuous type floating tower concept. A tension-torsion leg, which is equipped with a passive subsea yaw swivel, anchors the floating tower to the seabed, i.e. when the wind changes direction, the whole tower yaws with the turbine. The yaw movement is controlled entirely by the individual pitch of the rotor blades, even when there is no wind. The rotor can be rotated in motoring mode by using a generator [36, 37]. This free yawing effect is like the mechanism of a weather vanning system found in the offshore oil and gas sector of floating production storage and offloading (FPSO) units. This turbine is favorable because it is always directed toward emerging wind and thus optimizes power generation, which may result in an unconstrained drift of the floater in the event of failure in the case of a single vertical tendon [37].

3 Airborne Wind Energy Systems

Airborne wind energy is a new class in the field of wind energy generation, which uses airborne equipment to extract and convert kinetic energy from wind to electricity [38-41].

Airborne equipment can be attached to a land station, an anchored buoy, an offshore platform or a ship via tethers on it. The tethers are made of robust and lightweight artificial fibers, some of which are even made of conductive materials, for example, aluminum [38]. Figure 3 illustrates the airborne wind turbine's conceptual design [42].

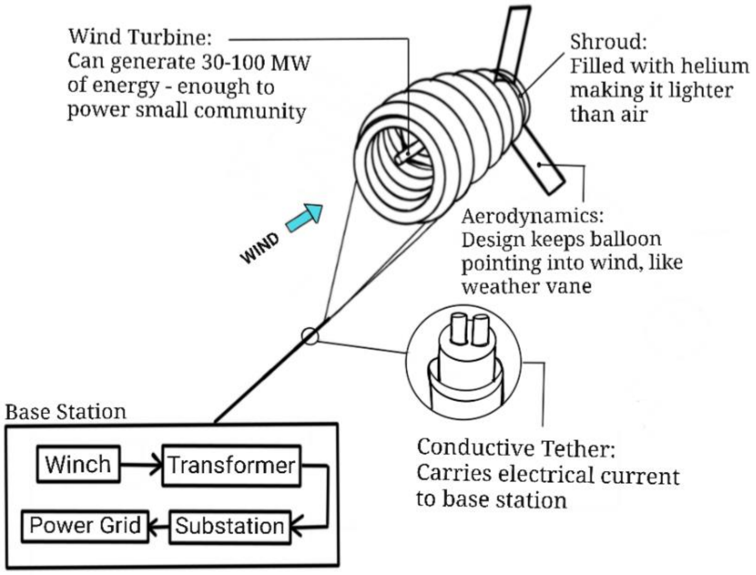

Figure 3 Conceptual design of airborne wind turbine.

3.1 Classification of AWES

Typically, AWESs are made of two main components: a ground system and at least one aircraft that is linked mechanically by ropes (commonly referred to as tethers). We may differentiate between Groundgen systems, where mechanical energy is transformed into power on land, and Flygen systems, where such a conversion is performed on the aircraft [43]. Figure 4 shows schematic diagrams of both types of systems [11].

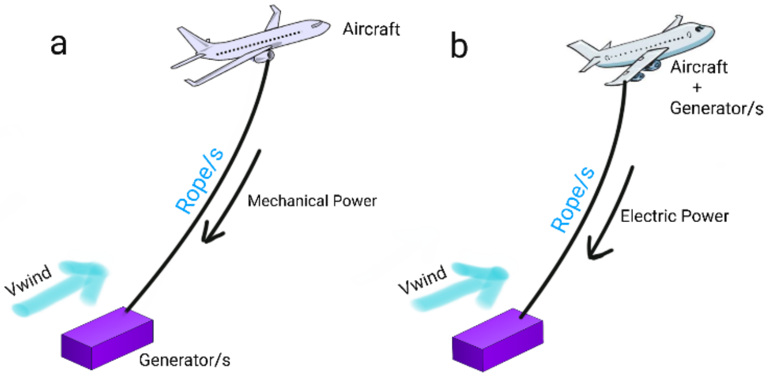

Figure 4 (a) Groundgen system; (b) Flygen system.

Electric energy is produced on the ground in a Ground-Gen AWES (GG-AWES) through the mechanical work performed by traction forces transmitted by one or more ropes from the aircraft to the ground that propel an electrical generator. It is possible to distinguish between fixed-site GG-AWES devices that are fitted to a ground station and those that are moving-in-surface systems that are moving vehicles [11].

On the aircraft, electric energy is generated and transmitted to the ground via a special rope that carries cables transferring electric power. In this case, wind turbines generally produce electrical power conversion. With the exception of takeoff and landing maneuvers, FG-AWESs continuously generate electrical power when operational. Crosswind and non-crosswind systems can be found among FG-AWESs based on how energy is generated [11].

3.2 Challenges

Major challenges faced by AWEs are: sophisticated fully autonomous control systems should be developed over time; stronger, lighter and more durable tied materials are required at low cost in order to reduce altitude limitations, future operation and maintenance costs; tests and validation, time and cost may delay commercialization; it takes time to develop strict operational and safety standards, but these are necessary to receive public support, sponsorship and financing; despite having great potential, there is still no commercial product on the market, forcing companies to focus on remote and off-grid markets, where it is easier to satisfy market needs [11, 44].

Even though the highest wind power and wind densities are found in the jet stream on earth [12, 45], they are very difficult to reach with airborne wind energy systems at the high altitude required. As AWE systems have long tethers in order to make it possible to fly at higher altitude, resulting in an increment in payload and drag these systems can cause interference with airspace, and strong jet winds could damage the AWE. Thus, only a small number of firms are planning to reach such altitudes and most of them are aiming for altitudes between 200 to 3000 m above ground level. In order to generate electricity via a perfectly efficient and ideal wind turbine, the maximum efficiency possible is 59.3%, calculated using the Betz limit [38, 46, 47]. The efficiency of currently working advanced wind turbines on the ground has approximately half as much efficiency as an ideal one. Due to the fact that airborne wind energy systems are not yet available for sale in the market, the exact proportion of wind energy density convertible into electricity cannot be quantified [38].

3.3 Potential Advantages

Despite all these challenges, AWE systems have several of advantages compared to other wind turbine systems. First of all, there are limited renewable resources, which can provide enough energy to fulfill the requirements of human power consumption and wind energy is one of them [42]. Secondly, airborne wind power devices can reach higher altitude levels and tap into a vast wind energy resource, which is currently unused. Winds are usually stronger and more consistent at higher altitudes in comparison to the vicinity of both land and sea [42]. Thirdly, they are not as noisy as other wind turbines and do not cause visibility issues as they fly at altitudes high enough to reduce these effects [38]. Fourthly and most importantly, these wind power systems require less material investments per consumable power unit relative to other sources of renewable energy. The large-scale use of these systems at low cost combined with the high power to mass ratio is promising for the future [42].

3.4 Advancements

The power kite from Makani is an aerodynamic wing that is attached to a ground station. When the kite flies in loops, rotors spin on the wing as the wind passes them to generate energy that is transmitted down to the grid [48]. Ampyx Power developed an AWE system tethered to an aircraft to convert the wind into electricity at higher altitudes.

An automatic aircraft was built that was connected to the ground. It moves from 200 m to 450 m in a regular cross wind pattern. When the plane moves, the tether driving the generator is pulled up. The device automatically returns to a lower altitude when the tether is reeled out to a predetermined tether length of about 750 m. Then the process starts over and repeats [49]. The use of a large number of airborne wind energy systems such as a wind farm at high altitude can help to reduce electrical storage needs [11].

In the Aerial and High Altitude Wind Energy Project (HAWE) [50, 51], a system based on Magnus has been used. German scientist Gustav Magnus identified the Magnus effect phenomenon in 1852. His research showed that a spinning cylinder generates a force that is like the lifting force produced by airfoils in the wind. The rotation of the cylinders causes an unequal pressure distribution at the top and the bottom, leading to an upward-lifting force. Airborne wind energy systems based on this effect have an edge over similar systems because the symmetry axis makes them more robust with respect to turbulence as they are insensitive to the apparent wind direction [50].

This industry is accelerating extremely fast. Many firms have entered for harvesting wind energy at high altitude business and have registered hundreds of patents and developed several prototypes and demonstrations [11]. There is a wide range of different types of airborne wind turbines, such as buoyant [52], flip-wing style (Mars) [53] and kite (SkySails power system) turbines [54, 55].

4 Highway Wind Turbine Systems

Presently, vehicle density is rising very quickly and because of the development of road transport facilities such as highways and motorways, vehicles are moving at very high speed, which produces large amounts of wind currents from moving vehicles along these highways [56].

If someone is standing near the road, the wind pressure caused by passing vehicles will make them feel that the wind pressure is varying because of the volume, speed and mass of the vehicles. This induced wind produces drag force created by the motion of a body in a fluid medium [57, 58]. Turbulence caused by moving traffic on the road is called vehicle-induced turbulence (VIT).

In addition to VIT, there are two additional mechanisms that produce turbulence along highways. The first occurs because of the road structure and is called structural road induced turbulence (S-RIT). The second is caused by the temperature difference between the road and its surroundings and is referred to as T-RIT [59]. Among the three mechanisms mentioned above, VIT is the most crucial mechanism for generating turbulence along roads [60]. Figure 5 shows a schematic diagram of a highway wind turbine [61].

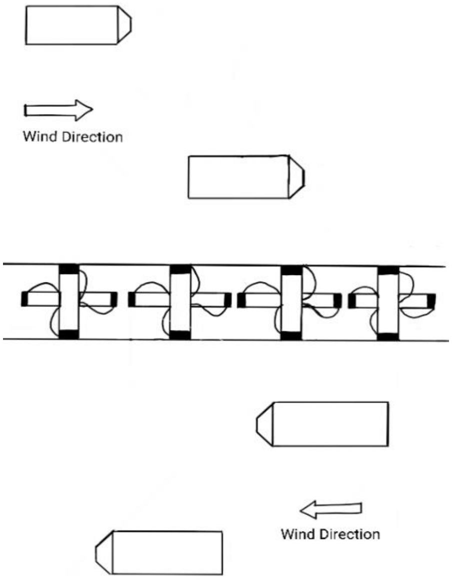

Figure 5 Schematic diagram of a highway wind turbine.

Some research studies have shown how this idea can be applied and its advantages when the idea to obtain clean energy from unused wind energy along highways is implemented for different applications [62,63]. A vertical wind turbine (VAWT) can be installed on the divider of the road to receive wind from two sides. The airspeed will be higher on one side of the road than on the other, which can be used to generate electric power. The electricity generated would be stored at night in batteries to light the road. In addition to considering certain other factors, such as wind speed, blade length and shape, height and design of the turbine, surface treatment and tip speed ration, wind turbine design and blade selection play an important role in the efficiency of the wind turbine. A field test has shown that larger sized vehicles produce a higher amount of turbulent kinetic energy (TKE) compared to smaller vehicles and the higher the traffic frequency, the greater the TKE [57].

The capture of wind turbulence induced by moving vehicles can be used to generate electricity along highways [62]. This electricity can be used as free electricity to illuminate streetlamps or for other road services. This concept is not new, but it still needs improvement . Some attempts have been made by individuals or groups to obtain wind energy using moving vehicles along highways. However, the idea has not been successfully implemented yet [57].

5 Locomotive Mounted Wind Turbine

For the generation of energy for small-scale application, commercial wind turbines cannot be used because of various factors, such as the size of the wind turbine, the area required and economic reasons. Electric vehicles are becoming a major part of modern society. Hence, the concept of small and portable wind turbines that can be easily mounted on the roof of heavy trucks and buses can be used. A rapidly moving locomotive, such as a heavy passenger train or a freight train, generates sufficient energy for the production of wind power [64]. Figure 6 shows the relationship between vehicle speed, torque and wind speed. The chart shows that torque varies in direct proportion with wind speed and vehicle speed [64].

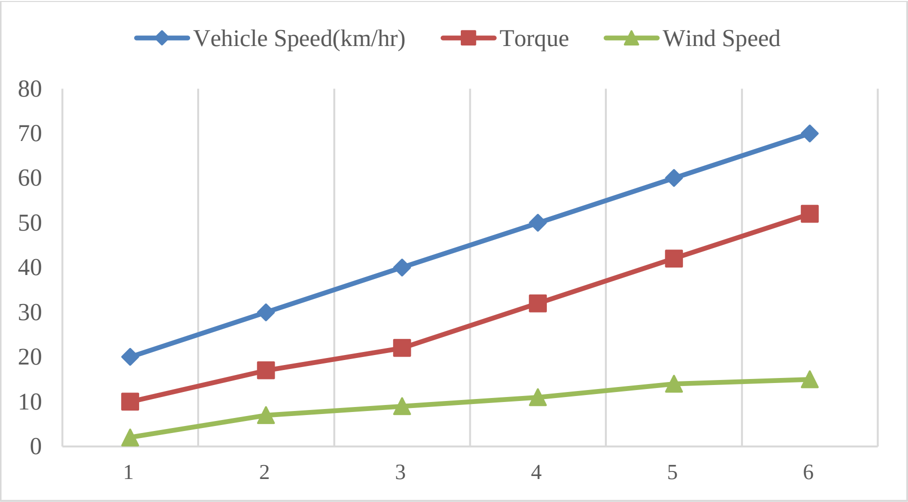

Figure 6 Relation between vehicle speed, torque and wind speed.

While designing LMWT, careful considerations must be made. LMWTs work based on the concept of the horizontal axis wind turbine configuration, however, they differ from conventional HAWTs in the field of application. Compared to conventional HAWTs, LMWTs have a number of additional design criteria. The designs of the rotor, generator, gearbox (optional) and storage system vary. In addition, as opposed to conventional designs, an LMWT must be lightweight, high RPM, highly rigid and cost-effective, because it has to be carried by a vehicle. The LMWT must be carefully designed to conform to these requirements. The airfoil can be directed either naturally or artificially to the rotor. It collides in a modified direction and form a resulting force. This happens in accordance with Bernoulli's Law [64, 65].

Several attempts have been made in order to generate electric power using various locomotive vehicles [66]. The intended systems are not at all satisfactory because none of them met the practical implementation thresholds. These models are either not efficient or affect vehicle performance [64, 67-70].

This concept could effectively be executed by rail networks such as metro networks in large cities like New York, Tokyo, Mumbai, London, Berlin, etc. The majority of major cities are served by large metro lines. There are also many stations in these metropolitan hubs that serve people from all over the world. This concept of power generation can be extended to very rapid trains such as bullet trains, Shanghai maglev trains, French TGV POS, Hyperloop trains, etc. Of course, the energy generated by these superfast trains is much higher than by a local metro. This principle can also be used on motorways, expressways and even on pathways for free electricity generation at airports around the world, with various minor modifications [14].

6 Conclusion

In this review, multiple unconventional wind turbine concepts to meet global energy demand is discussed. These wind turbine concepts counteract disadvantages of conventional methods and can be used for various needs, considering several factors, such as power requirement, economic factors, application and size.

Floating wind turbines generate a higher amount of energy when compared to other wind turbines but require a significant amount of financial resources and engineering to withstand the harsh conditions of deep waters. Airborne wind turbines provide a cheaper and viable alternative but produce a limited amount of energy taking into consideration the energy loss due to energy transmission to the ground, but they have the benefit of portability, so they can be used to provide energy in remote locations. Highway wind turbine systems can provide energy for lighting roads and other road applications, but because of the limited amount of power generation this method cannot be used for meeting major energy needs.

Similarly, locomotive mounted energy systems can also be used to generate enough energy to run electrical equipment in a vehicle but not sufficiently for other applications. However, unconventional wind energy generation cannot be limited to these methods only. Readers can further research and work on other unconventional methods, such as harvesting wind energy from trains moving in a tunnel or roof turbine ventilators. There is scope for further improvement for the various unconventional wind energy extraction methods discussed in this paper. Researchers can gain some insights into these methods and for future research purposes further work on them.

References

[1] Chakraborty, S., Dutta, S. & Biswas, N., *A Review Paper of Wind Energy*, in National Conference on Advances & Research in Electrical System Technology, April, pp. 202-206, 2011.

[2] *Historical Energy Consumption Statistics | The Shift Project Data Portal*, [Online]. Available: http://www.tsp-data-portal.org/Energy-Consumption-Statistics#tspQvChart. (29 March 2019)

[3] BP, *67th Edition Contents is One of the Most Widely Respected*, Stat. Rev. World Energy, pp. 1-56, 2018.

[4] P.A., Marques., *_02_Book_C1- [02] Renewables 2016 global status report_REN21*, 2016.

[5] L.W.E.C., Fried, *Global Wind Statistics 2016*, Glob. Wind Energy Counc., pp. 7-10, 2016.

[6] Salari, M.E., Coleman, J., & Toal, D., *Airborne Wind Energy—A Review*, A.Y. Oral, B. Oral, Z. Banu (Eds.) , 3rd International Congress on Energy Efficiency and Energy Related Materials (ENEFM2015), pp. 81-92, 2017.

[7] Konstantinidis, E.I. & Botsaris, P.N., *Wind Turbines: Current Status, Obstacles, Trends and Technologies*, IOP Conf. Ser. Mater. Sci. Eng., **161**(1), pp. 1-7, 2016.

[8] Blaabjerg, F. & Ma, K., *Wind Energy Systems*, Proc. IEEE, **105**(11), November 2017.

[9] Tyler, E.Y., Daniel, M., Ilas, K. & So, A., *Renewable Power Generation Costs in 2014*, Int. Renew. Energy Agency, pp. 1-8, January 2015.

[10] Thresher, R., Robinson, M. & Veers, P., *Wind Energy Technology: Current Status and R & D Future*, Natl. Renew. Energy Lab., pp. 1-21, 2008.

[11] Cherubini, A., Papini, A., Vertechy, R. & Fontana, M., *Airborne Wind Energy Systems: A Review of The Technologies*, Renew. Sustain. Energy Rev., **51**, pp. 1461-1476, 2015.

[12] Archer, C.L. & Caldeira, K., *Global Assessment of High-Altitude Wind Power*, Energies, **2**(2), pp. 307-319, 2009.

[13] *AWE Community is Growing Fast*. Available: http://www.antonellocherubini.com/awe-community-is-growing-fast.html. (01 April 2019)

[14] Joshi, S. & Mathur, A., *Generation of Electricity Using Wind Energy Produced Due to the Motion of Trains*, J. Energy Technol. Policy, **2**(7), pp. 19-24, 2012.

[15] *Hywind – Leading Floating Offshore Wind Solution – equinor.com*. [Online]. Available: https://www.equinor.com/en/what-we-do/hywind-where-the-wind-takes-us.html. (01 April 2019)

[16] Skaare, B., Nielsen, F.G., Hanson, T.D., Yttervik, R., Havmøller, O. & Rekdal, A., *Analysis of Measurements and Simulations from the Hywind Demo Floating Wind Turbine*, Wind Energy, 2015.

[17] Grandum, S., Ishihara, Y. & Norway-Tokyo, I., *An Overview/Status on Offshore Wind Situation in Japan*.

[18] Sacramento, H.R., *BOEM Offshore Renewable Energy Workshop: Day 1 – Offshore Wind BOEM Offshore Renewable Energy Workshop: Opening Session*, 2014.

[19] *World's Largest Floating Turbine Installed at Fukushima | Windpower Offshore*," Available at https://www.windpoweroffshore.com/article/1358221/worlds-largest-floating-turbine-installed-fukushima, (30 March 2019)

[20] *MHI floating 7MW Ready for Deployment | Windpower Offshore*, Available at https://www.windpoweroffshore.com/article/1352499/mhi-floating-7mw-ready-deployment, (02 April 2019)

[21] *Mitsubishi Heavy Industries Wind Power Technologies-PDF*, https://docplayer.net/25640878-Mitsubishi-heavy-industries-wind-power-technologies.html. (03 April 2019)

[22] Anonymous, *Wind Turbine Paper*, AIMU Tech. Serv. Comm., no. January, pp. 1-24, 2012.

[23] Butterfield, S., Musial, W. & Jonkman, J., *Engineering Challenges for Floating Offshore Wind Turbines*, 2007.

[24] Musial, W., Butterfield, S. & Boone, A., *Feasibility of Floating Platform Systems for Wind Turbines Preprint*, 23rd ASME Wind Energy Symposium, Reno, Nevada, January 5-8, 2004.

[25] Tran, T.T. & Kim, D.H., *The Platform Pitching Motion of Floating Offshore Wind Turbine: A Preliminary Unsteady Aerodynamic Analysis*, J. Wind Eng. Ind. Aerodyn., **142**, pp. 65-81, 2015.

[26] Jonkman, J.M., *Dynamics of Offshore Floating Wind Turbines-Model Development and Verification*, Wind Energy, **12**(5), pp. 459-492, 2009.

[27] Newman, J., *Marine Hydrodynamics*, The MIT Press, Cambridge Massachusetts, 1977.

[28] Driscoll, F., Jonkman, J., Robertson, A., Sirnivas, S., Skaare, B. & Nielsen, F.G., *Validation of a FAST Model of the Statoil-Hywind Demo Floating Wind Turbine*, Energy Procedia, **94**, pp. 3-19, 2016.

[29] Barchowsky, A., Parvin, J.P., Reed, G.F., Korytowski, M.J. & Grainger, B.M., *A Comparative Study of MPPT Methods for Distributed Photovoltaic Generation*, 2012 IEEE PES Innov. Smart Grid Technol. ISGT 2012, pp. 1-7, 2012.

[30] Sebastian, T. & Lackner, M., *Analysis of the Induction Andwake Evolution of an Offshore Floating Wind Turbine*, Energies, **5**(4), pp. 968-1000, 2012.

[31] Sebastian, T. & Lackner, M.A., *Development of A Free Vortex Wake Method Code for Offshore Floating Wind Turbines*, Renew. Energy, **46**, pp. 269-275, 2012.

[32] Babatunde, S.A. & Najafi, F.T., *Overcoming the Challenges of Implementing Offshore Wind Farm Development in the U.S. through Education and Research*, in proceeding of ASEE Southeastern Section-2018, Embry-Riddle Aero. Uni., Daytona Beach, FL, ASEE, 2018.

[33] Luo, N., Pacheco, L., Vidal, Y. & Li, H., *Smart Structural Control Strategies for Offshore Wind Power Generation with Floating Wind Turbines*, Renew. Energy Power Qual. J., **1**(10), pp. 1200-1205, 2012.

[34] Isijokelu Gift, I., Lopez-Querol, S., Lajara Camacho, J. & Bhattacharya, S., *Improved P-Y Curves for Design of Offshore Wind Turbine Foundations*, Soil Dynamics and Earthquake Engineering, 2016.

[35] Jose, N.M. & Mathai, A., *A Study on Lateral Deformation of Monopile of Offshore Wind Turbine due to Environmental Loads*, Procedia Technol., **24**, pp. 287-294, 2016.

[36] *Sway | Sway Concept*, available: http://www.sway.no/?page=166. (30 March 2019)

[37] Wang, C.M., Utsunomiya, T., Wee, S.C. & Choo, Y.S., *Research on Floating Wind Turbines: A Literature Survey*, IES J. Part A Civ. Struct. Eng., **3**(4), pp. 267-277, 2010.

[38] Archer, C.L., Delle Monache, L. & Rife, D.L., *Airborne Wind Energy: Optimal Locations and Variability*, Renew. Energy, **64**, pp. 180-186, 2014.

[39] Fagiano, L. & Milanese, M., *Airborne Wind Energy: An Overview*, pp. 3132-3143, 2014.

[40] Archer, C., *An Introduction to Meteorology for Airborne Wind Energy*, in Ahrens, U. *et al.* (eds.), *Airborne Wind Energy*, Green Energy and Technology, 3, Springer-Verlag Berlin Heidelberg, pp. 81-94, 2013.

[41] Canale, M., Fagiano, L. & Milanese, M., *Power Kites for Wind Energy Generation*, IEEE Control Syst. Mag., **27**, December, pp. 25-38, 2007.

[42] Gera, K. & Grewal, J.S., *Airborne Wind Energy: Optimal Locations and Power Produced*, IOSR J. Mech. Civ. Eng. Ver. IV, **12**(4), pp. 2278-1684, 2015.

[43] Diehl, M., *Airborne Wind Energy: Basic Concepts and Physical Foundations*, in Ahrens, U. *et al.* (eds.), *Airborne Wind Energy*, Green Energy and Technology, 3, Springer-Verlag Berlin Heidelberg, pp. 3-22, 2013

[44] Lütsch, G., *Airborne Wind Energy Network HWN500–Shouldering R& Din Co-operations*, AWEC01, pp. 86-87, 2015.

[45] Vance, E., *Wind Power: High Hopes*, Nature, **460**(7255), pp. 564-566, 2009.

[46] Masters, G.M., *Renewable and Efficient Electric Power Systems*, pp. 323-327, John Wiley & Sons, 2004.

[47] Burton, T., Jenkins, N., Sharpe, D. & Bossanyi, E., *Wind Energy Handbook*, Second Edition, 2011.

[48] X – Makani, available: https://x.company/projects/makani/. (03 April 2019)

[49] *Technology – Ampyx Power B.V.*, available: https://www.ampyxpower.com/ technology. (03 April 2019)

[50] Gupta, Y., Dumon, J. & Hably, A., *Modeling and Control of A Magnus Effect-Based Airborne Wind Energy System in Crosswind Maneuvers*, IFAC-PapersOnLine, **50**(1), pp. 13878-13885, 2017.

[51] aerial platforms | Omnidea | omnidea.net, available: https://www.omnidea.net/ aerial-platforms. (30 March 2019)

[52] Mcdonald, A., Sola, P.J., Mcdonald, A.S. & Oterkus, E., *A Lightweight Approach for Airborne Wind Turbine Drivetrains a Lightweight Approach for Airborne Wind Turbine Drivetrains*, Poster session presented at European Wind Energy Association, EWEA, Paris, France, pp. 1-9, 2015.

[53] *Altaeros Energies Poised to Break World Record with Alaska High Altitude Wind Turbine – The World Renewable Energy Association (WoREA)*, Worldofrenewables.com, 2014, https://worldofrenewables.com /altaeros_energies_poised_to_break_world_record_with_alaska_high/. (01 May 2019).

[54] Shelke, K.N. & Duraphe, M.D., *Magenn Air Rotor System (Mars)*, Int. J. Eng. Res. Appl., **2**(6), pp. 1566-1568, 2012.

[55] *SkySails Group GmbH – Technology*, Available: https://www.skysails.info/en/power/technology/ (03 April 2019)

[56] Mithun K.K. & Ashok, S., *Design and Simulation of a Vertical Axis Wind Turbine for Highway Wind Power Generation*, **7**(1), pp. 251-259, 2015.

[57] Al-Aqel, A.A., Lim, B.K., Mohd Noor, E.E., Yap, T.C. & Alkaff, S.A., *Potentiality of Small Wind Turbines along Highway in Malaysia*, 2016 International Conference on Robotics, Automation and Sciences, Ayer Keroh, pp. 1-6, , 2016. DOI: 10.1109/ICORAS.2016.7872634.

[58] Zarkesh, A. & Heidari, M., *Developing A New Application for Wind Generators in Highways*, Proc. 5th Int. Conf. Comput. Intell. Commun. Syst. Networks, CICSyN 2013, pp. 279-282, 2013.

[59] Wang, Y.J. & Zhang, K.M.A.X., *Modeling Near-Road Air Quality Using a Computational Fluid Dynamics Model*, CFD-VIT-RIT, **43**(20), pp. 7778-7783, 2009.

[60] Kim, Y. & Kim, Y., *Quantification of Vehicle-induced Turbulence on Roadways Using Computational Fluid Dynamics Simulation by Quantification of Vehicle-induced Turbulence on Roadways Using Computational Fluid Dynamics Simulation*, M.S. Thesis, Dept. of Chem. Eng. and Applied Chem., Uni. of Toronto, Canada, 2011.

[61] Pandey, A. & Devi, R., *Study and Development of Hybrid Wind Turbine for Highway Side Application*, IJAREEIE, **6**(9), pp. 6763-6767, 2017.

[62] Wiegel, T.F. & Stevens, K.C., *Traffic-Driven Wind Generator*, US. Patent no. **7098553 B2**, 2006.

[63] Gene, E.M. & Fein, S., *System and Method for Creating a Networked Infrastructure Distribution Platform of Small Fixed and Vehicle Based Wind Energy Gathering Devices along Roadways*, US Patent No. 8791596, 2009

[64] Abraham, V., *Power Generation from a Moving Locomotive by Wind Turbine*, in Proceedings of ERTEE-2018, Kalady, Kerala KTU,GRD Journals., March, pp. 20-26, 2018.

[65] Ingram, G., *Wind Turbine Blade Analysis Using the Blade Element Momentum Method*, Version 1. School of Engineering, Durham University, UK. Jamal, A Baroudi, Venkata Dinavahi, 2005.

[66] Ferdous, S.M., Bin Khaled, W., Ahmed, B., Salehin, S. & Ghani, E., *Electric Vehicle with Charging Facility in Motion using Wind Energy*, World Renew. Energy Congr. 2011-Sweden 8-13 May 2011, pp. 3629-3636, 2011.

[67] Ripley, P.W., *Wind Turbine for Electric Car*, US Patent No. 8513828, 2013.

[68] Tran, D., *Vehicle Air Turbine*, US Patent No. 2013/0043082 A1, 2013.

[69] Owens, A.J., *System for A Vehicle to Capture Energy from Environmental Air Movement*, US Patent No. 8344534, 2013.

[70] Diaz, J., *Electrical Generator System for Capturing Wind Energy on A Moving Vehicle*, US Patent No. 8618683, 2013.