Journal of Engineering and Applied Sciences 12 (24): 7463-7471, 2017
ISSN: 1816-949X
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Airborne Wind Turbines and Flying Electric Generators for Marine Propulsion

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Abstract: The ever escalating costs of bunker fuel for the shipping industry together with Stringent International Regulations on air pollution has led to the search for alternative forms of energy which is pure, available in plenty, renewable and cost effective. Energy harnessed from ocean winds is a viable proposition. This study discusses the reasons for the rising costs of fuel oil, the steps to mitigate it by using green ship technologies and slow steaming. This study examines how ocean winds can be harnessed to provide power for ship propulsion. Ocean winds are available in abundance are stronger and steadier than land winds and easier to harness. Various technologies for harnessing surface or close to surface winds, like the Flettner rotor employing the Magnus effect, increasing the size of the hull (Maersk) using kites to assist ship propulsion (SkySails) and wind turbines are described in this study. Wind at ground level is relatively weak (low speeds) and inconsistent. As a generalism, it becomes stronger (high speeds) and more consistent the higher up you go. Using this fact, more advanced technologies have been developed like the Airborne Wind Turbine (AWT), air rotor system and air rotor wind generator (Magenn), Flying Electric Generators (FEG)-SkyWind power and the Makani wing. These new developments are also technically discussed in detail. Finally, the benefits and limitations of these devices are described. This study concludes by stating that the use of the wind energy by the use of wind turbines has a great scope in the shipping industry and is also a renewable source of energy. The initial cost of installation of the systems would be high but is a very cost efficient system for a longer run.

Key words: Rising cost of ship fuel, effect of international air pollution regulations, green ship technology, slow steaming, harnessing ocean winds, low level winds-Flettner rotor, hull size, kite tethered to ship, conventional wind turbine, high level winds-airborne wind turbines, air rotor systems, flying electric generators, the Makani wing

INTRODUCTION

Most of the world's trade is carried out by the shipping industry which is constantly expanding. But day by day, the operating costs of shipping are also increasing exponentially, mainly due to the phenomenal increase in the cost of bunker fuel oil which is used by the marine diesel engines on board to supply power for the propulsion plant, the electric power plant, cargo handling, navigation, hoteliering in cruise ships and a host of other purposes. Airborne wind turbines is discussed by Anonymous (2013) and Kolar *et al*. (2013).

Bunker fuel oil used on ships, being a fossil fuel is a non-renewable resource whose reserves are fast depleting. Now a days when crude oil is refined, there is more demand for refined products, so less bunker oil is produced. Flying windmill is described by Unger (2013). Decreasing supply, coupled with ever increasing demand has increased the fuel costs. Figure 1 illustrates the rising trend of the cost of fuel oil. International regulations have become more stringent on air pollution and has drastically reduced the permissible amounts of emissions of SO_X-NO_X-CO_2 (Oxides of Sulphur, Nitrogen, Carbon), resulting from the burning of fuel oil into the atmosphere as these cause global warming and destruction of the ozone layer. Analysis on capillary pressure curves by wettability modification through surfactants is discussed by Julius *et al*. (2015). These can be met only by using distillate fuels with sulphur content <0.5% or by employing scrubbing technology to clean the exhaust gases from residual bunker fuel. This in turn will escalate fuel and operating costs. Soft computing approach on ship trajectory control for marine is explained by Sethuramalingam and Nagaraj (2015). Figure 2 illustrates the effect of international regulations in increasing ship's bunker fuel oil prices.

Figure 2 shows how the internationally renowned classification society Germanischer Lloyd projects fuel

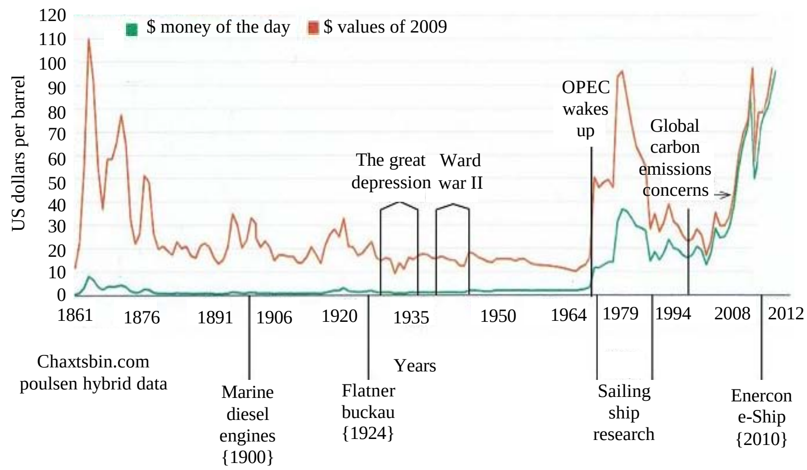

Fig. 1: Historical crude oil prices, 1861 to present

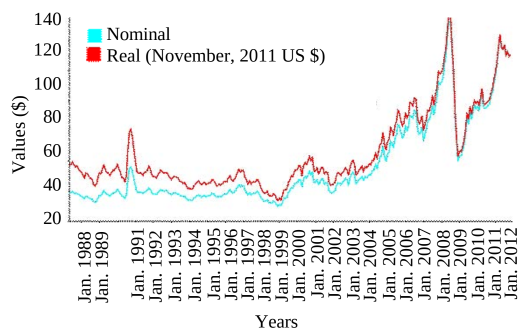

Fig. 2: Effect of international regulations in increasing ship's bunker fuel oil prices; May 1987 to November 2011 monthly average Brent spot prices Conversian to November 2011 dollars uses US CPl for all urban consumers (CPI-U), Energy Information Administration and Bureau of Labor Sattistics

prices will develop within the shipping industry (the prices given exclude any increase in costs due to inflation). Cost increases more from the CO_2 emission-based increments from the year 2013 on as well as making it mandatory to use more expensive distillate diesel fuels beginning in 2020 are clearly recognizable.

Recent research has yielded green ship technologies like more efficient engines and propellers, less resistant hull shapes and coatings, waste heat recovery systems, hybrid turbochargers, etc. which has resulted in substantial fuel savings and mitigating carbon emissions. An efficient approach for the removal of bipolar impulse noise using median filter is described by Kadali and Rajaji (2015). But these mainly apply to newly built ships and cannot be implemented cost effectively to existing vessels.

Therefore, for the majority of the 40,000 ships around the world, slow steaming remains the only alternative for fuel savings and reduced emissions. This seems to be the most straightforward way of reducing sea-borne pollution would be to impose a speed limit on the oceans. Carbon emissions would drop by 23% if ships cut their speed by 10% but shipping experts say that slower cargo movements would lead to more vessels being deployed and pollution would return to its former levels.

Hence, it has now become imperative to look into and harness alternate forms of energy for the shipping industry which is both cost effective and available in abundance, preferably from a renewable source. This will not only effectively mitigate unwanted emissions but also provide means of lowering the costs and increase the savings.

Fortunately, we do not need to look far. The oceans themselves, home to many thousands of shipsare a very good source of wind energy. Ocean winds are available in abundance are stronger and steadier than land winds and easier to harness. Average ocean wind speeds have continued to increase at the rate of 0.25% per year due to climatic changes. The transition back to the age of tall sailing ships is in strong favour.

The concept of using wind energy evolved many 100 years ago, like the windmills on land and ships with sails at sea. For ships, various means have been tried to harness wind energy like kites, conventional soft sails, rigid sails, Flettner rotors and wind turbines.

MATERIALS AND METHODS

Flettner rotors for ship propulsion: The Magnus effect is a force acting perpendicularly to the airstream around a spinning body (Fig. 3).

The German Engineer Anton Flettner was the first to use this effect and in 1924 the Buckau shown in Fig. 4 was

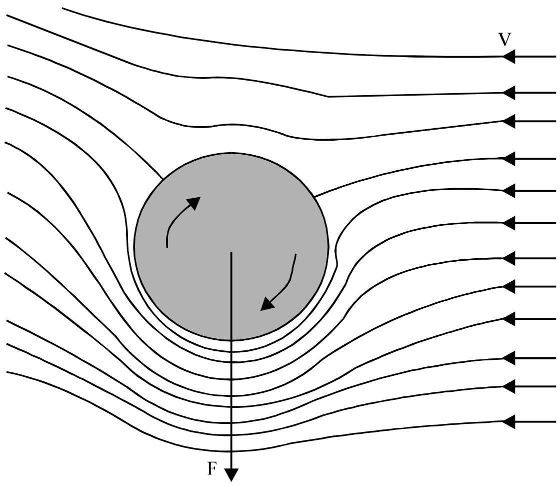

Fig. 3: The Magnus effect and the direction of this force

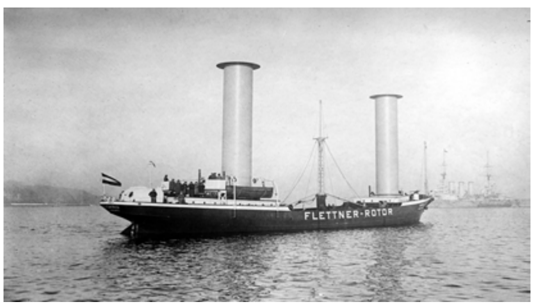

Fig. 4: The Buckau flettner rotor ship

Fig. 5: The e-Ship 1

built. This idea worked but it was seen that the propulsion force generated was less than what the motor would have generated if it had been connected to a standard marine propeller. Also, the rotor system could not compete economically with the diesel engines at that time.

Later in the 20th century, further interest was renewed in this concept and in 2010, the e-Ship 1, shown in Fig. 5 was built. Energy efficiency has been the focus of this shi's design and together with the 4 mounted Flettner-rotors the 123 m-long cargo ship is said to reduce the fuel consumption by up to 30-40%.

Fig. 6: The ship's hull being used as a solid sail

One way of increasing the energy efficiency of shipping is to increase the size of the vessel which big shipping operators like Maersk are already pursuing. The increased size of the hull will enable wind energy to be absorbed for propulsion as shown in Fig. 6.

Using kites to assist ship propulsion-the kite ship: Another way to reduce fuel consumption for shipping is being promoted by German company SkySails-attaching a kite the size of a football field (about 160 m^2) to a vessel and using wind power to help save fuel costs. It was first used in the Beluga SkySail, lowering the fuel consumption by about 10-15% per year. Larger kites can possibly provide savings of upto 30-35%. One estimate predicts this could save around US$10 million over the lifetime of a vessel (Fig. 7).

Using wind turbines on ships: The wind turbine has a distinct advantage over other forms of wind assisted propulsion. It can provide propulsive force when sailing against the wind force which is impossible with the other forms (Fig. 8 and 9).

Why then has the wind turbine not found much favour for ship board use?: The main limiting factors are the height and weight of the wind turbine equipment. Many bridges span the seaward approaches to the world's major ports which restrict the air draft of ships crossing below these bridges to about 60 m. If the wing/sail masts can be folded down or telescopically lowered, the height need not be a limiting factor. The weight of the wind turbine equipment may reduce the cargo carrying capacity of the ship if it has additional diesel engines for ship propulsion.

How to make the wind turbine viable for ship's use: To overcome the limitations imposed by the conventional

(a) (b)

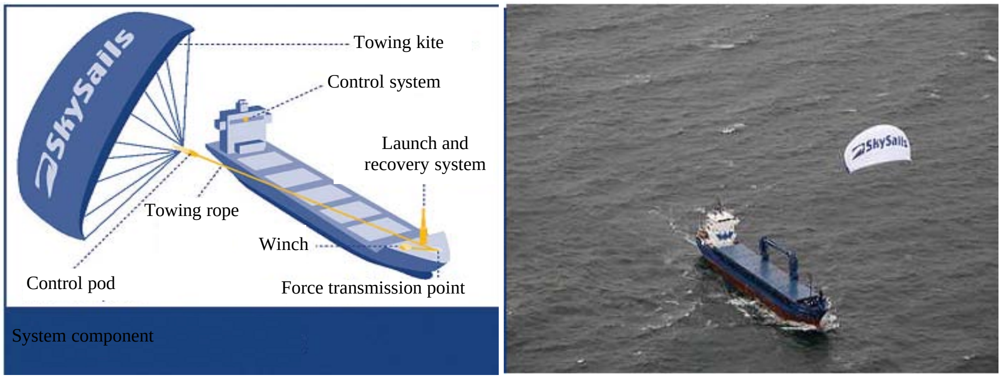

Fig. 7: a, b) Cargo ship using the patented SkySails for auxiliary propulsion

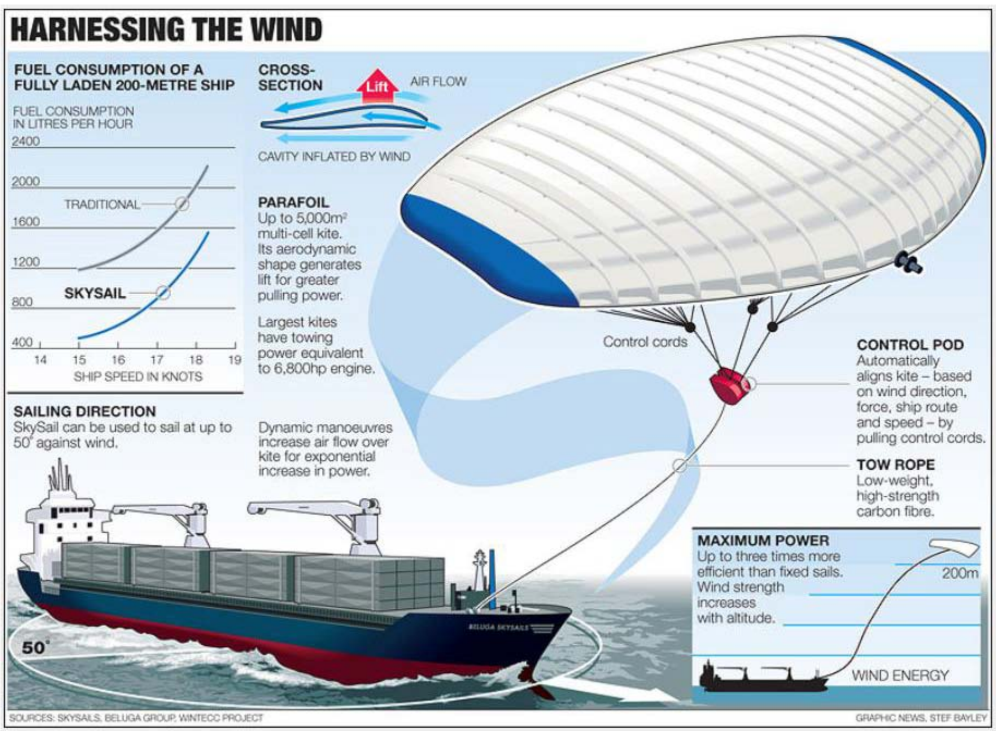

Fig. 8: Reduced fuel consumption on container ships using SkySails

Fig. 9: A tanker ship using the conventional wind turbine

wind turbine, so that, the wind turbine can still be used to harness the wind energy, newer methods, designs and technology are in various stages of development and evolution. The tall rigid structure of the turbine, firmly fixed to the base has been done away with. Instead, a cluster of turbines forming one unit is airborne and need not be attached to or mounted on the ship's hull. The original geometric structure of the ship is therefore not disturbed. This is the new Airborne Wind Turbine (AWT).

It is the object of this study to highlight the importance of these new technologies, so that additional

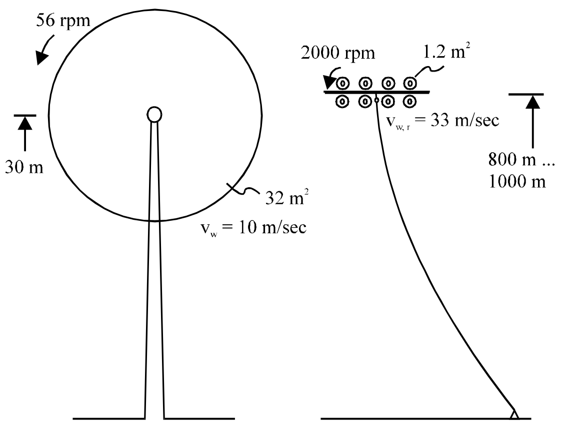

Fig. 10: Comparison of conventional/airborne wind turbine (for 100 kW rated power)

research and experiments will enable the manufacture of better designs of wind turbines and harness the abundant wind energy more efficiently and effectively and enable it to be used for ship propulsion to reduce its dependence on fossil fuels.

Why should the wind turbine be airborne?: Wind at ground level is relatively weak and inconsistent. As a generalism it becomes stronger and more consistent the higher up you go. For this reason, wind turbine's towers are tall. However, tower material adds greatly to the expense of building a wind turbine and it would not be feasible to build towers that go thousands of feet high.

In order to raise feasible altitudes for turbine deployment, airborne wind turbines are being looked into. These are attached to the ground only by a tether through which electricity is transferred. They are held up either by a balloon or in a fashion akin to how gliders fly by the wind itself.

The driver for these schemes is that the intermittency issue which reduces the effectiveness of wind turbines operating at ground level is asserted to be much less of a problem at 1000 ft where the winds tend to blow steadily. Proponents of airborne wind power like Ken Caldeira at the Carnegie Institution's Department of Global Ecology at Stanford University, say that if we could tap into 1% of the energy in high-altitude winds it would be sufficient to provide all our power needs (Fig. 10).

The air rotor system: The company that has garnered the most attention in this field is Ottawa-based Magenn power. Magenn's system is a lighter-than-air wind turbine capable of powering a rural village the 30 m wide, helium-filled "air rotor system" contains a turbine that spins around a horizontal axis and can produce 10 kW of energy as it floats above the ground while attached to a copper tether. Larger models ones that might power a skyscraper are also reportedly in the works. The company claims the governments of India and Pakistan have expressed interest in the first version (Fig. 11 and 12).

Flying Electric Generators (FEG): SkyWind power of California is proposing (to) use clusters of Flying Electric Generators (FEGs) on the end of a current carrying tether in the jet stream at 15,000-30,000 ft.

The company has done wind tunnel tests and low altitude tests to prove their idea. They are hoping to build a 200 kW model, flying at 15,000 ft, somewhere in a remote area of the US. They envision a commercial FEG will have four or eight rotors each generating 2.5 MW. Clusters of FEG's could provide as much power as need for a given site.

The FEG would fly up into the sky with its rotors powered by electricity off the grid, pulling up its tether. Once it is at its desired altitude it would change the pitch on its rotors and start generating power from the wind. GPS technology would be used to assure that the rotorcraft stays within a few feet both horizontally and vertically of where it is programmed to be and a computer would control the rotorcraf's attitude, i.e., pitch, roll and yaw.

The amount of power that you can produce in a wind turbine varies as the cube of the velocity and linearly as the density. So, although, the density decreases with an increase in altitude, the increase in velocity that you gain with higher altitudes more than makes up for the decrease in density. This further explains the advantage that FEG's have flying at high altitudes and allows the rotors to be smaller in diameter. The wind speed in addition to being higher is more uniform.

It is much steadier, blowing at high, useful velocities a much greater percent of the time than do winds at ground level. This gives FEGs the advantage of having a higher capacity factor. Capacity factor is the percentage of energy actually captured relative to what would be captured if the wind turbines were operating at full capacity all the time. Ground based sites that can produce a capacity factor of 35% are hard to find. Capacity factors in the jet stream range from about 70% in the southern parts of the US to over 90% in the North. At a capacity factor of 90%, FEGs could become the natio's cheapest source of electricity with an estimated cost per kilowatt hour of <2 cents about half the price of coal.

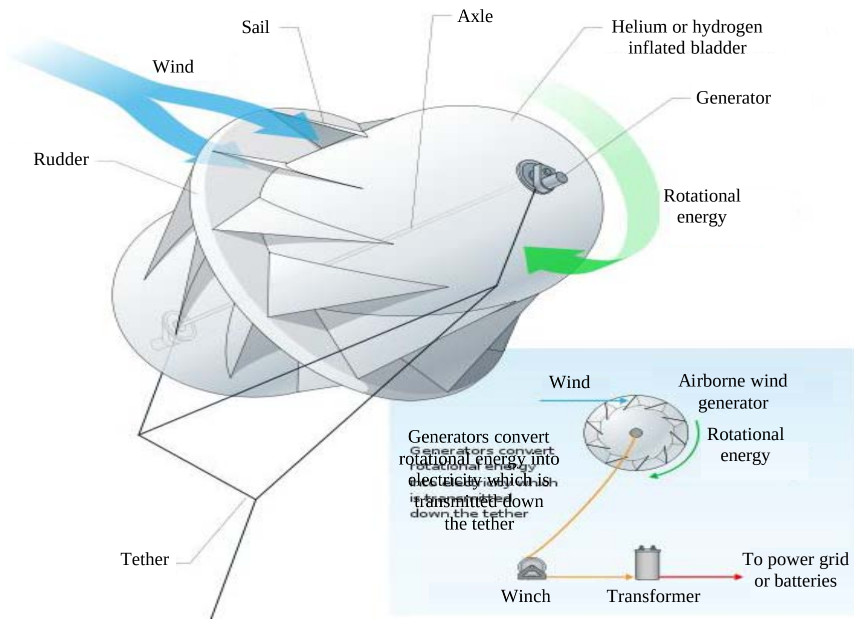

Fig. 11: Air rotor wind generator

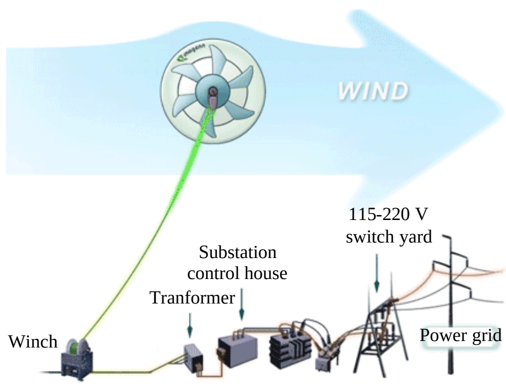

Fig. 12: The Magenn air rotor system

Fig. 13: Airborne wind turbine

Fig. 14: Airborne wind turbine

Using airborne wind turbines to assist ship propulsion: We have examined how wind energy can be harnessed both effectively and efficiently. Let us examine, the extension of the flying electric generator concept by the California based Makani group more closely. It is pursuing a way to extract high altitude wind energy by using a flying wing with turbines, so-called "Airborne wind turbine", mounted to the groundin a Tether. The research has been ongoing, since, 2006 and they have so far come up withpromising results in their field testing.

In the following study some of the benefits withusing such a wing for producing electricity for ship propulsion will be discussed. Sky windpower AWT concept:

- Tethered rotorcraft-quadrupole rotor arrangement
- Inclined rotors generate lift and force rotation/electricity generation (Fig. 13-16)

Fig. 15: The airborne wind turbine getting ready

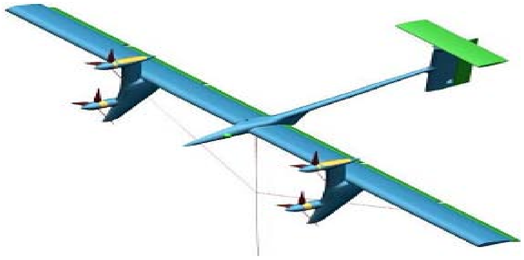

Fig. 16: Makani wing with 4 mounted for launching from land turbines and the connecting tether

The cluster of airborne wind turbines stays aloft due to wind speeds that induce the lift forces which prevents the AWT from descending. This cluster is fitted on a tether carrying current to or from the ship's generators. Once the cluster has been launched into the air, the wind turbines adjust itself to the wind's directions and are ready to absorb the wind energy and convert it into electrical energy. As for other AWTs, dynamic positioning and GPS technology would be used to ensure that the rotorcraft stays within a few feet in its designated position both horizontally and vertically. A computer will control the rotorcraft's pitch, roll and yawing actions (Fig. 17 and 18).

Why is the Makani wing special?: The Makani wing operates on the same aerodynamic principles as a conventional wind turbine. Due to the air moving across the turbine blades, the turbine blades mounted on the Makani wing will be forced to rotate in the same way as the turbine blades on a wing turbine. But where the windmills have their limitation in size, the Makani solution is to only build the tip of the blade as seen in Fig. 11 on the previous page.

This is an efficient way of extracting the most of the wind energy as it is stated by Makani that the last 25% of the blade on a windmill produces more than 50% of the

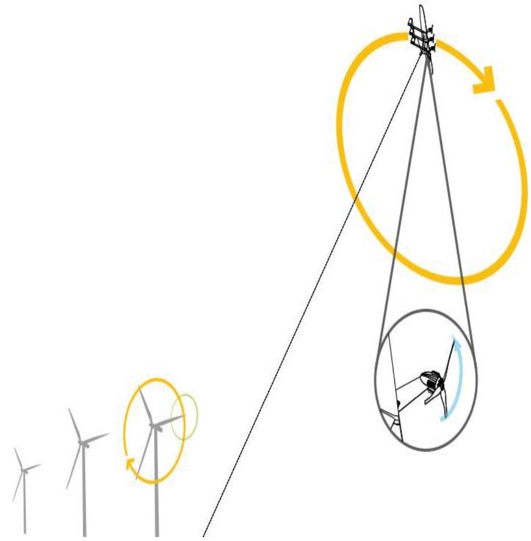

Fig. 17: Windmills with varying size

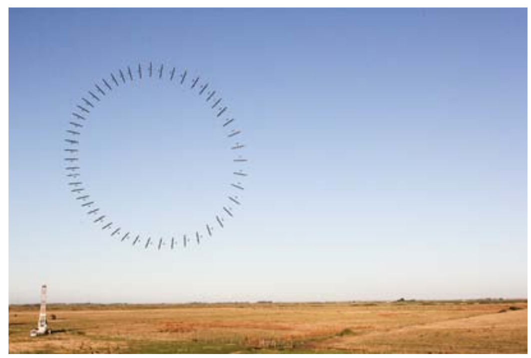

Fig. 18: Step-by-step overview of the Makani compared to the Makani wing rototype in one orbit

total energy. It also shows in Fig. 12 that the Makani wing is going in even bigger circles than the biggest windmill.

This means that the incoming wind velocity on the turbines can be very high and as the power produced is proportional to incoming velocity cubed, the potential power output is therefore very high. For these reasons, its use on board ships for aiding propulsion must be seriously considered.

RESULTS AND DISCUSSION

Advantages of the AWT:

- They have the benefit of working at high altitudes where the winds are steady and blow with strong force

- The swept area of the turbine cluster is many times (nearly 8 times) more than the conventional surface based turbine; the turbine therefore feels strong winds at all times
- This system results in significant cost savings, because the 2 MW AWT produces the energy equivalent of 2 MW conventional turbines but requires only 1/20th of the materials

Does the AWT have any disadvantages?: Questions may arise about its feasibility if the wind dies out. Makani has the answers. "MakanI" states that the AWT will stay aloft up to a minimum wind speed of 3.5 m/sec. If the speed gets lower than this, there is provision to supply power to the system so that the turbines act as propellers for a short interval of time. If the wind speed remains low for a much longer time, the AWT is automatically lowered and secured and the diesel propulsion engine takes up the complete load.

Safety factors and other concerns addressed: Makani's prototype raises some concerns about conflict with air traffic but the craft would remain well below normal commercial and civilian air traffic, the company says. Some criticize the death toll inflected on birds by wind turbines but Makani says its AWT flies above most birds and its absence of a tower discourages nesting.

They can't promise uninterrupted power all the time, however. In an electrical storm, the power-carrying tether becomes the biggest lightning rod you've ever seen (Hello, Benjamin Franklin). Their website says this problem is "frequently brought to our attention and must be addressed". Their plan is to take the flyers down to land before a storm gets bad and wait for it to end.

The future of shipping and wind energy: It is predicted that by the year 2025, oil prices have doubled. The cost of heavy fuel is $2,000/ton adjusted for inflation and slow steaming and fuel conserving measures including wind assistedpropulsion would be made mandatory by many nations.

Average ocean wind speeds have continued to increase at a rate of 0.25% per year due to climate changes. This is favorable for the transition back to the age of the tall sailing ships. Route mapping and preparation is also now meticulously laid out based on the wind forecasts and speeds.

CONCLUSION

The shipping industry is in need of a serious transition towards much more cost efficient and greener ways for operation. The use of the wind energy by the use of wind turbines has a great scope in the industry and is also a renewable source of energy. The initial cost of installation of the systems would be high but is a very cost efficient system for a longer run. The economics of mass production and installation may bring down installation costs.

Work on windmill technology has been going on in the last few years. But, there is still a lot of scope for research in the future. The shipping industry needs revolutionary ideas that improve performance parameters (installation cost and power per unit) and which will significantly decrease (by 5-10 times) the cost of energy production. The airborne wind turbines discussed in this study has a lot of advantages such as:

- Ocean going vessels can use this installation for its primary or secondary propulsion source
- The proposed system is relatively inexpensive, it can be made with a verylarge blades thus capturing wind energy from an enormous area (tens of times more than typical wind turbines)
- The will be a tremendous savings in the operation costs as no fossil fuels are burnt
- There will be no environmental pollution which will further reduce the carbon and sulphur emissions in the atmosphere

RECOMMENDATIONS

Thus, by the use of these airborne wind turbines the wind energy industry can move from a stagnation point to a revolutionary potential in the future.

The more farfetched longer term goals include harnessing the power of the jet stream where wind travels faster than 100 mph (160 kmph) and beaming down power through microwaves or lasers rather than channeling it through a tether.

This is because the thrust to the propeller delivered by the power produced in the AWT/wing must be higher than the resistance on the ship due to the horizontal forces in the tether. The political impetus behind renewable energy is growing and space is limited at ground level. Perhaps it is time for the wind power industry to reach for the sky.

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