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INNOVATIVE MULTI ROTOR WIND TURBINE DESIGNS

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ABSTRACT

Among the renewable energy sources, today wind energy is the most recognized and cost effective. Developers and researchers in this sector are optimistic and continuously working innovatively to improve the technology. The wind power obtained is proportional to the swept area of wind turbine. The swept area is increased by using a single rotor of large diameter or multi rotors in array. The rotor size is growing continuously with mature technology. Multi rotor technology has a long history and the multi rotor concept persists in a variety of modern innovative systems but the concept has fallen out of consideration in mainstream design from the perception that is complex and unnecessary as very large single rotor units are now technically feasible. This work addresses the evaluation of different multi rotor wind turbine systems. These innovative wind turbines are evaluated on the basis of feasibility, technological advantages, security of expected power performance, cost, reliability, impact of innovative system, comparison with existing wind turbine design. The findings of this work will provide guidelines for the practical and economical ways for further research on the multi rotor wind turbines.

Key Words: multi rotor, co-axial, co-planer, counter rotating

1. INTRODUCTION

The wind is a free, clean, and inexhaustible energy source, served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water. After, Energy crisis of 1973, people began to realize that the world's oil supplies would not last forever and other energy sources besides oil and natural gas must be developed[1]. Furthermore, due to concerns for environmental issues, *i.e.*, global warming, *etc.*, the development and application of renewable and clean new energy are strongly expected. Among others, wind energy technologies have developed rapidly and are about to play a big role in a new energy field [2]. Wind power has become a low-cost, low-risk and non-polluting energy option as a pillar of the energy supply in many countries.

Today wind energy is the most recognized and cost effective renewable energy source. Over the past few decades, many different blade designs and generator designs of a wind turbine have been developed to improve the maximum power coefficient. Developers and researchers in this sector are optimistic and continuously working innovatively to improve the technology. Traditional three bladed horizontal wind turbines had already proven its popularity through large numbers of installation and satisfactory performance. On the other hand some researchers are working on innovative wind turbines such as multi rotor wind turbines, diffuser augmented wind turbines, vari-blade wind turbines, horizontal axis spiral wind turbines, etc. This paper mainly focused on multi rotor wind turbines.

2. CONVENTIONAL HORIZONTAL AXIS WIND TURBINE

The amount of power produced by a horizontal axis wind turbine depends on the rotor area, and third power of the wind velocity [4]. The more power is produced by increasing the rotor area or wind velocity. The rotor size is growing continuously with mature technology and scientists have now presented the first design basis for developing wind turbines of 20 MW, will be possibly erected by the year 2020. The largest modern wind turbines depend on strength composite material for their rotor systems. These composites have a much higher strength to weight ratio than steel and allow much larger rotors to be realized. Some researchers are also working on second option to increase power output. Diffusers are used to increase the approach wind velocity. A slight increase in wind velocity increases power output significantly. Researchers have claimed two-three fold increase in power output with diffuser augmented wind turbines. Still they are working to reduce the diffuser length.

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Increased rotor diameter will raise some problems as described in this paragraph. Bending and tensile stresses induced in the longer blade, makes the mechanical design complicated [5] .The mass of the plant varies with cube of the diameter. With increasing diameter, blade weight increases drastically than power output, resulting in to poor economy [6, 7] .As rotor diameter increases, rotor shaft speed decreases. The gearbox is required to increase the speed of input shaft to the generator, which increases number of rotating parts in the system. The weight of gearbox varies with the cube of radius. The wear of gears and bearings in gearbox, lubrication, noise, etc are the problems associated with the gearbox. Low speed direct drive generators are bigger in size and add cost to the small wind turbine system [8].

3. MULTI ROTOR WIND TURBINES

To solve the problems discussed in previous section some researcher thought about the innovative multi rotor wind turbines to increase the swept area without increasing the rotor diameter. All present mainstream wind energy conversion systems rely on the rotor concept. The rotor consists of the hub and blades of the wind turbine. Multi-rotor turbines have for nearly a century challenged the imagination of engineers and inventors. The technology offers the prospect of achieving much higher capacities per tower compared with conventional single-rotor types by making use of multiple state-of-the-art series-produced devices. For example, a system with five 4 MW units makes a 20 MW multi-rotor system. [11] The multi rotor concept persists in a variety of modern innovative systems but the concept has fallen out of consideration in the mainstream design from a perception that it is complex and unnecessary as very large single wind turbine units are now technically feasible.

The multi rotor wind turbines can be classified as,

1. Co-planer multi rotor or Array wind turbines
2. Co-axial wind turbines

In co-planer multi rotor wind turbine, rotors are arranged in parallel as shown in Fig.1 and rotate in the same plane. This is an old concept and developed in last century. These types of turbines are also called as array wind turbines. In co-axial multi rotor wind turbine rotors arranged in series as shown in Fig. 2 & Fig. 3 and have only one axis of rotation. This new concept is developed in last decade. Co-axial multi rotor wind turbines are developed in two models. First is counter rotating wind turbine limited to use only two rotors rotating in opposite direction to increase the relative speed between stator and rotor. Second model uses two or more number of unidirectional rotors rotating simultaneously to drive a common generator shaft.

3.1 Co-planer Multi Rotor Wind Turbine

Multi rotor wind turbine technology has a long history. One of the most famous multi-rotor pioneers was German engineer and manufacturer Hermann Honnef, who started work in 1931 on beautifully detailed large-capacity systems. One of his most famous designs comprises a 250 m high lattice type tower fitted with three double-rotors arranged with a 120 m diameter front rotor and two 160 m diameter rotor at the rear (Fig. 1a). A striking design feature was that the complete rotor assembly could pivot into a safe horizontal position during stormy weather. Also unique at the time was the application of ring generators [9]. A Three-Rotor Wind Turbine is developed by Lagerwey, a Netherlands based company (Fig. 1b). During the mid-1980s a joint venture of Dutch companies Multiwind and the former Lagerwey erected the 300 kW Quadro, comprising four 75 kW two-blade Lagerwey 15/75 turbines (Fig. 1c). After some teething problems the installation performed well for about 15 years at the Maasvlakte industrial area near the port of Rotterdam [9]. In the same decade a wind turbine erected with three rotors along with individual generator together on a tower. (Fig. 1d)

The Windship systems were developed by William Heronemus, an engineering professor at the University of Massachusetts at Amherst. Combined with onboard hydrogen production through electrolysis, it was planned that one million of the Windships could completely power and fuel the U.S. Land versions were also possible. Heronemus is a main originator of the Multi-Rotor Turbine concept, the Offshore Turbine concept, and the Floating Offshore Turbine concept (Fig. 1e). More recently German wind pioneer Professor Friedrich Klinger, also known for the Genesys 600 and Vensys 62 projects, developed a 2.4 MW multi-rotor system comprising four 600 kW turbines. Lattice wind turbine tower specialist SeeBa of Germany developed a 4.5 MW system with three 1.5 MW turbines, and Multiwind of the Netherlands proposes a patented 6 MW system comprising three 2 MW units.

a. Hermann Honnef's Wind Turbine

b. Three rotor Array Wind Turbine

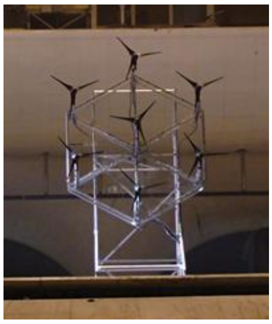
c. Four rotor Array Wind Turbine

d. Three rotor Array Wind Turbine

e. Windship multi-rotor Wind Turbine

f. Four Rotor Array Wind Turbine

g. Octopus Wind Tech. 250MW Wind Turbine



h. Seven Rotor Array Wind Turbine

Fig.1 Co-planer Multi Rotor Wind Turbines

3.2 Counter rotating horizontal axis Wind Turbine

As per Betz limit, theoretically maximum 59 % energy is abstracted by a rotor. Practically, this number is even small. The energy wasted from first rotor can be used by second rotor [11]. In 2004 Jung S N, et all developed a 30kW counter-rotating wind turbine system (Fig. 2a). The main (downstream) rotor had a diameter of 11m and the auxiliary (upstream) rotor had a diameter of 5.5m. The main rotor rotated with half the speed of the auxiliary rotor. The mechanical power output of both rotors was combined by a series of gears and was finally used to drive a generator. They found that a turbine with two rotors produced higher power than a single rotor turbine, depending on the distance between the rotors. It was found that there is a 21% increase in power coefficient (up to 0.50) when the distance between the rotors is half of the main rotor. Counter-rotating turbines can be used to increase the rotation speed of the electrical generator. If the turbine blades are on opposite sides of the tower, it is best that the blades at the back be smaller than the blades at the front and set to stall at a higher wind speed. This allows the generator to function at a wider wind speed range than a single-turbine generator for a given tower. Overall, this is a more complicated design than the single-turbine wind generator, but it taps more of the wind's energy at a wider range of wind speeds [11].

3.3 Unidirectional Co-axial Series rotor wind turbine

Two or more rotors may be mounted on the same driveshaft, with their combined co-rotation together turning the same generator and fresh wind is brought to each rotor by sufficient spacing between rotors combined with an offset angle from the wind direction. Wake vortices are recovered as the top of a wake hits the bottom of the next rotor. Power has been multiplied several times using co-axial, multiple rotors (Fig. 2a) in testing conducted by inventor and researcher Douglas Selsam, for the California Energy Commission in 2004.

In the 2005 year we developed a co-axial series rotor wind turbine (Fig. 2b) consists of four rotors of 700 mm diameter separated by 1 m distance. The developed wind turbine is tested (not as per IEC). It produced around two fold power compare to single rotor of same diameter. It is also observed that it runs smoothly in high wind speed. It has only two moving parts – Long driveshaft and vertical shaft for yawing. Self Aiming characteristic is observed.

a. Counter Rotating Wind Turbines b. Selsam's Four Rotor Wind Turbine c. Four Rotor Wind Turbine developed by authors

Fig.2 Co-axial Multi Rotors Wind Turbines

4. EVALUATION OF MULTI ROTOR WIND TURBINES

Co-planer multi rotor wind turbine, counter rotating wind turbine and unidirectional co-axial series rotor wind turbine are three basic versions of multi rotor wind turbines. These innovative versions of multi rotor wind turbines are evaluated on the basis of feasibility, technological advantages, security of expected power performance, cost, reliability, impact of innovative system, comparison with existing wind turbine design.

4.1 Feasibility

The co-planer multi rotor wind turbines shown in Fig. 1a to 1c are not feasible as they faces yawing problem. They may suitable for the region in which wind direction remains same for most of the period. The researchers claimed that the experimental results obtained for seven rotor wind turbine (fig. 1h) in NASA wind tunnel are encouraging and further work should be carried out to make this system realistic [10]. The counter rotating wind turbine and unidirectional co-axial series rotor wind turbines are seems feasible.

4.2 Comparison with existing wind turbine design

The most suitable method to evaluate new technology is to set it alongside existing state of the art technology and conduct a side by side comparison. Here we are assuming the tower cost and/or structure remains constant. Comparison is carried out for single rotor replaced by multi rotors, along with associated parts such as drive trains, generators and nacelle. In these entire multi rotor wind turbines large single rotor is replaced by number of small rotors of equivalent area. Counter rotating wind turbine emphasis on improving performance through reuse upwind rotor wake.

4.3 Technological advantages

These innovative designs must be checked for technological advances delivering extra benefits. Peter Jamieson [14] has explained that, when a system of *n* rotors is compared with a single large rotor of equivalent capacity, the ratio of total mass and cost of rotors and drive trains of multi rotor system to that of single rotor system is given by $1/\sqrt{n}$. On the other hand there are evidently challenges in the support structure and a yawing mechanism for the co-planer multi rotor array wind turbines. But, Co-axial series rotor wind turbines had put positive observation for structural stability and yawing to face the wind direction because of upwind and downwind rotor arrangement. The cantilever high speed shaft of unidirectional co-axial series rotor wind turbine should be properly analyzed and designed for safe life. At this stage limitation seems on size of unidirectional co-axial series rotor wind turbine because of this reason. Also the advantages of direct drive gearless generator will not possible for large size turbine.

4.4 Security of expected power performance

The analytical calculation shows the better performance for multi rotor wind turbines. But, radically new system designs it is critical to evaluate system for security of expected power performance. Especially the unidirectional wind turbine shows maximum security of expected power performance, because it delivers power in low wind also compare to other models. CFD investigations carried out in NASA have shown positive results. But, there is a scope for downside performance because of yawing. The expected performance can be achieved through variations in different design parameters, use of modern available technology, etc.

4.5 Cost

The scaling relationship between conventional single rotor and multi rotor wind turbine shows that economical advantage increases with rotor numbers. Some researchers have shown that maintenance cost occurs for small rotors wind turbines is more than larger rotor wind turbines. The cost of additional support structure and maintenance can be well compensated by cost reduction of blades, drive-trains. The counter rotating wind turbine is limited to use only two rotors, so scaling economy is not too much effective for it.

4.6 Reliability

Reliability plays significant role in case of any product. The system parts should be designed and manufactured to give expected reliability. Basic need of all multi rotor wind turbine systems is the reliable yawing mechanism.

4.7 Impact of innovative system

The impact or acceptability of innovative system depends on mainly two factors cost and performance. The system with better worth performance with low cost is always accepted and competes with existing system. The unidirectional co-axial series rotor wind turbine with limited number of rotors may prove a cost effective system.

4.8 Safety

The well designed structures will capable to provide required safety as per International Electrotechnical Commission (IEC) norms.

5. DEVELOPMENT OF COMPREHENSIVE ASSESSMENT MODEL BASED ON COMPARATIVE SCALE

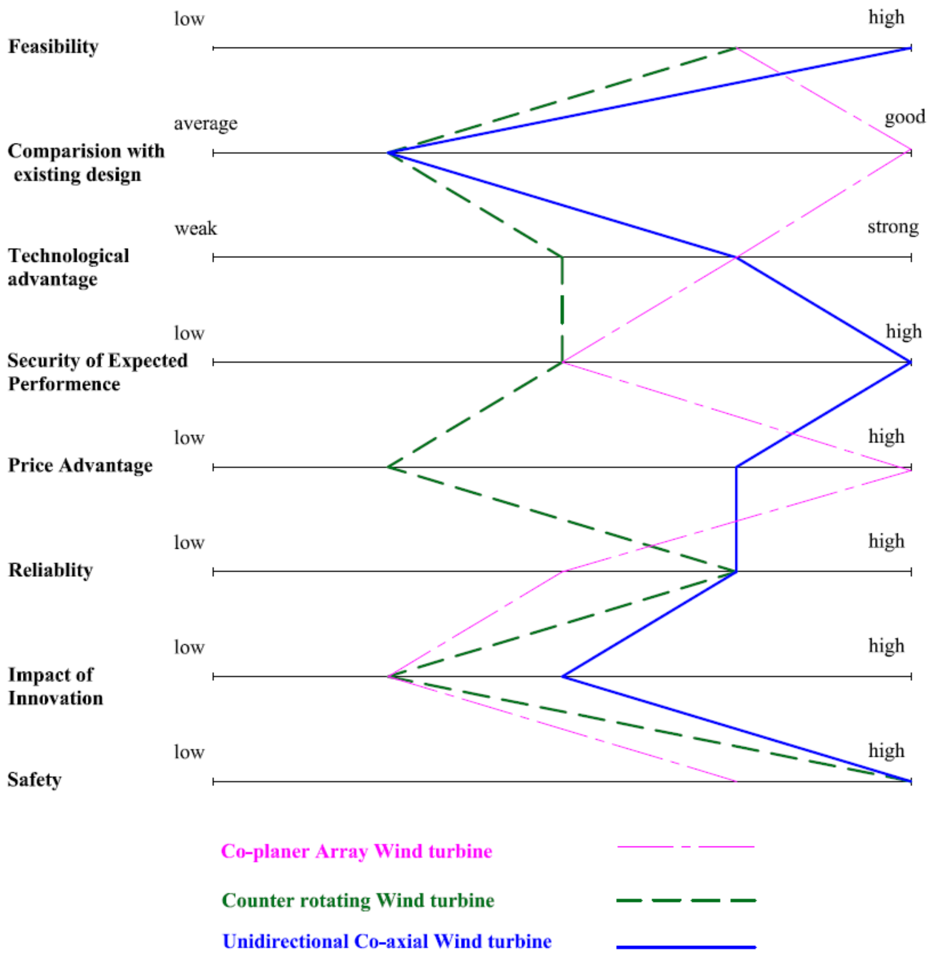


Fig.3 Comprehensive Assessment Model for multi rotor wind turbines based on Comparative scale

The criteria for complete evaluation of multi rotor wind turbines discussed in this work are analyzed theoretically in the preceding section. These wind turbines are comparatively assessed by using scale starting from low to high, average to good, weak to strong, etc and represented by Fig.3. This diagram provides a useful visual tool for researchers interested to work in this field to understand future of various multi rotor wind turbines. It will also guide them for selection of area for their research.

6. CONCLUSION

A new model developed for complete assessment of multi rotor wind turbine based on comparative scale delivers very useful guidelines for future research. It shows all three basic versions of multi rotor wind turbines i.e. co-planer multi rotor or array wind turbines, counter rotating wind turbines and unidirectional co-axial series rotor wind turbines are feasible. Array wind turbine and unidirectional co-axial series rotor wind turbines are reliable and has strong technological aspects. As cost effectiveness is based on number of small rotors, better price advantages can be obtained for array wind turbines. Security of expected power performance for unidirectional co-axial series rotor wind turbines is observed on higher side. Among compared three wind turbines unidirectional co-axial series rotor wind turbines shows encouraging rays.

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