Concept design and numerical analysis of hybrid solar–wind turbine

Ackshaya Varshini K S 1*, Alenkar K Aswin 1, Rajan. H 1, K S Maanav Charan 1

1 School of Mechanical Engineering, Vellore Institute of Technology, Chennai Campus, Tamilnadu, India.

Abstract. A wind turbine is a device that converts wind energy to electrical energy. External factors such as wind speed and direction shift, as well as turbine blade design considerations, cause a significant amount of energy to be wasted throughout the conversion process. Considering all these losses, a turbine's average efficiency is roughly 45 percent. The blades of a wind turbine are one of the most crucial factors in determining the turbine's efficiency. The design and geometry of the blades have a direct impact on performance since it determines how much kinetic energy from the wind is converted into mechanical energy. Many concepts and technologies are being used to improve the efficiency of wind turbines while lowering their maintenance costs. Wind turbines based on their axis orientation are classified as vertical axis and horizontal axis. Vertical axis wind turbines are not as widespread as their horizontal-axis counterparts due to their lower efficiency. In this study, we will use a Savonius vertical axis wind turbine to investigate a way of enhancing its efficiency by installing solar panels on its vertical blades and determining the best performance angle at which the turbine should be kept achieving maximum efficiency. Computation fluid dynamic analysis and thermal and structural analysis has been performed to check the efficiency of the designed blade. As a result, an optimized wind turbine design has been developed.

1. Introduction

With the growing need for energy and depleting fossil fuels, the focus has shifted to renewable energy resources. Many countries have started to install facilities that use renewable energy sources for power generation [1]. The importance of renewable energy resources has increased with the severe exploitation of fossil fuels for power generation. People now investigate alternative energy sources for power production. In comparison to other renewable energy sources – wind energy accounts for the largest share in total energy production [2]. Wind Turbines are used to convert the kinetic energy of wind into electrical energy. In recent decades, wind turbines have become increasingly essential, contributing to 650 GW of wind power being produced around the world [3].

A wind turbine’s efficiency is averagely rated at 45 – 50 % [4]. The efficiency of a wind turbine depends on three factors – wind speed, air density, and blade radius. According to a study, for every 10% increase in wind speed, the energy generated by a wind turbine will increase by 20% to 30% [5]. Only at maximum wind speed and density will the turbine provide the highest efficiency. This leads to the most serious issue with wind turbines: inconsistency in energy generation. To maintain the turbine's efficiency high, a more reliable technique for continuous electric flow must be introduced.

Combining different energy sources for continuous energy generation is one such attempt. Wind turbines are of two types – horizontal and vertical axis wind turbines [6]. The horizontal axis is the most popular model and is used everywhere due to its better efficiency than the vertical-axis wind turbines which are less efficient [3]. But vertical axis wind turbines take up less space and require less

*Ackshaya Varshini K S – ackshayavarshini ks2018@vitstudent.ac.in
maintenance. These contrasting characteristics of the vertical axis wind turbine, make it both a boon and a bane. Thus, overcoming the lower efficiency problem in this turbine shall make it both prudent and commercially viable.

Vertical axis wind turbines are of two types – Darrieus wind Turbine, which uses lift forces to turn a shaft, and the Savonius wind turbine, which uses direct wind forces to push cups [7]. Savonius wind turbines are one of the most basic drag-type turbines, with two or three scoops. However, even at optimum conditions, the efficiency of this type of turbine is only 35% [8], which is quite low. Thus, here we aim to overcome this problem of lower efficiency of the wind turbine by installing solar panels. Solar Panel is an assembly of photo-voltaic cells mounted in a framework for installation. Solar Panels tend to have an efficiency of 18 – 20 % [9]. They can be fixed anywhere – where the sunlight could reach the panels. Thus, usage of solar panel is comparatively easier. As wind turbines are exposed to sunlight – if solar panels are placed on these turbine blades, the efficiency of the hybrid solar – wind turbine could be increased. The installation shall be ensured to make the net efficiency of the hybrid turbine higher while it remains aerodynamically stable. ANSYS analysis was done to simulate the model and obtain the results.

2. Methodology

Savonius turbines are simple vertical axis wind turbines whose gearbox is near the ground, and the primary rotor shaft is in a transverse position [8]. The Savonius turbines have efficiency lesser than the horizontal axis wind turbines making them not suitable for use. But they have their advantages such as the area required to set it and maintenance costs are less. So, more amount of Savonius turbines can be set up in each area. Thus, if the efficiency of the turbines were to be increased – Savonius Turbines could be feasible and commercially viable. These are mostly employed in areas where the wind direction changes frequently [8]. Hence, the blades of the turbine typically have a big surface area.

If solar panels were to be mounted on these turbine blades, it could help increase the net efficiency of the wind turbine setup. While wind turbines and photovoltaic systems are not steady sources of energy on their own, and they tend to over-and under-produce electricity due to their reliance on specific weather conditions. Thus, not just increasing the efficiency, but ensuring that the solar – wind turbine hybrid system is reliable is also the goal.

Solar Energy is the way of producing electricity using photovoltaic systems which harness radiation emitted by the sun. These solar arrays or panels are simple to install and attach to structures and objects [10]. These are typically installed on the ground and require a significant area of land to generate electricity on the magnitude of MW. Adding a solar panel to this turbine blade will not only boost the turbine's output but will also take up no additional space. The efficiency of the energy produced by solar panels is affected by the type of solar cell employed and the angle at which it is installed. The angle at which the panels must be installed is determined by the location's longitude. The attached panel must be as light as possible, as the larger the mass, the lower the wind turbine efficiency. This modified Savonius turbine can generate electricity by harnessing both the kinetic energy of the wind and the light energy of the sun through solar panels installed on the rotor blades. These turbines are especially useful in areas with a fluctuating amount of wind energy and frequent changes in wind direction. The turbine's efficiency is reduced because of this irregular and turbulent flow. While the added weight in mounting a solar panel on its blade reduces the amount of energy produced by wind energy, it does help harness energy from the sun. The amount of net energy produced per wind turbine can be enhanced in this way. As solar energy is independent of wind speed or direction, even during stagnant conditions of wind the turbines may generate energy utilizing solar panels and photovoltaic cells. Thus, increasing the net efficiency of a single turbine. Figure 1 demonstrates the process occurring in the hybrid solar–wind turbine.
2.1 Design Generation
The design of the wind turbine and solar panel was developed in SolidWorks Software. SolidWorks is a CAD software used by engineers to develop various designs. The parts of the Savonius Model of Wind Turbine and the Solar panel with varied layers were designed here.

2.1.1 Construction of savonius wind turbine
While designing the turbine three ratios were taken under consideration. The overlap ratio (e:d) = 0.15; Aspect ratio (D: h) = 1; Endplate parameter (D₀ : D) = 1.1 [11]. Table 1 depicts the necessary dimensions for the wind turbine design.

| Dimension                  | Value (m) |
|---------------------------|-----------|
| Blade Diameter – d        | 2         |
| Turbine Diameter – D      | 3.7       |
| End Plate Diameter – D₀   | 4.07      |
| Height of Turbine – h     | 3.7       |
| Thickness of blades – t   | 0.02      |
| Overlap Distance – e      | 0.3       |

Figure 2. Design of Savonius Wind Turbine  
Figure 3. Vertical View of Wind Turbine

Figure 2 displays the various dimensional parameters taken into consideration while designing. While Figure 3 shows the vertical view of the Savonius Wind Turbine.

2.1.2 Construction of solar panel
The following dimensions were considered to design the Solar Panel.
Breadth = 67cm; Length = 107 cm; Height = 4.2 cm
Figure 4 – 4 – depicts these various layers of the Solar Panel. Table 2 depicts the thickness and certain properties such as – thermal conductivity, specific heat capacity, and density of the layers.[12]. Figure 5 – 5 – shows the 60 photovoltaic cells applied in the design. The Solar Panel was developed in SolidWorks with six layers – glass covering, EVA - 1 – Ethylene Vinyl Acetate, Solar Cell, EVA – 2, Black Plate, and Aluminium frame [13].

**Table 2. Material Properties and Sizes of each layer in Solar Panel**

| Material Layer | Thickness (cm) | Specific Heat Capacity (J/kg°C) | Density (kg/m³) | Thermal Conductivity (W/m°C) |
|----------------|----------------|-------------------------------|----------------|-----------------------------|
| Aluminium Frame | 2 | 996 | 2707 | 204 |
| Black Plate | 0.01 | 1250 | 1200 | 0.2 |
| Solar Cell | 0.04 | 677 | 2330 | 148 |
| EVA | 0.05 | 2090 | 960 | 0.35 |
| Glass | 0.3 | 500 | 3000 | 1.8 |

2.2 Assembly
Once the designs were developed for the Savinous Wind Turbine and Solar panel – they were assembled in SolidWorks Assembly. As the aim was to obtain the maximum efficiency of the combined solar panel – wind turbine, two assemblies were generated.

2.2.1 Assembly – 1
In this assembly, the two solar panels were placed such that one end of each panel is attached to the other panel and the other end is attached to the blade. The design is symmetrical thus shall be replicative of the same in any other dimension or direction. The pairs were placed 0.6 m apart from the stator surface. Figure 6 shows the solar panel placement at 0.6 m distance from stator surface. The inclination provided to the panels is at 65 degrees to provide maximum exposure to sunlight. All the panels are placed tangentially to the blade to maintain the positions while rotating.

2.2.2 Assembly – 2
In this assembly, the two solar panels are placed parallel to one another, and they are coincident with each other. Whereas the other two panels are placed at an angle of 65 degrees to the previous panels. Figure 7 depicts the design where the solar panels are placed at 65 degrees to the previous panels. These four panels are placed exactly in the centre of the blade.
2.3 Simulation

ANSYS version 2020 R1 was used to analyse the velocity and pressure distribution of these assemblies. ANSYS is a CFD – Computational Fluid Dynamic tool used to analyse the performance of a model. ANSYS can be integrated to work with another engineer-employed software program with the addition of CAD – Computer-Aided Design and FEA – Finite Element Analysis connection modules. For simulating the turbine blade, CFX Modules were used. These modules are specially developed to test turbines with a rotor-stator setup. Thus, using this module the stability of the turbine, the velocity, and pressure impact for each assembly was studied.

To simulate the solar panels, ANSYS Transient Thermal was used. While simulating the panel, the change in heat flux from time to time led to the formation of the temperature gradient, which impacts the overall performance of the model. Thus, the transient thermal behaviour of the panel was analysed, essentially to find the out-of-scope deviation from the normal condition.

2.3.1 Procedure utilized to simulate the wind turbine assemblies:
The models were imported to ANSYS for simulation. On importing the assembly, the interface for inlet, outlet, and open interface must be determined. The analysed geometry was exported, this geometry is imported, and the blades are excluded, and stator geometry was set up with all inlets, outlet, and open conditions. After this, meshings were done for both the geometries. A CFX Module was set up and both meshings were linked to it. After applying the boundary conditions in the CFX Module, the results were interpreted [14]. Table 3 depicts the boundary conditions for Wind Turbine Simulation.

| Condition        | Value  |
|------------------|--------|
| Ambient Temperature | 35 °C  |
| Velocity of Air  | 7 m/s  |
| Inlet Pressure   | 1 atm  |
| Revolutions      | 90 rpm |

2.3.2 Procedure utilized to simulate the solar panel:
The geometry was imported into the Design Workbench of the ANSYS Transient Thermal Module. The material properties for each layer of the solar panel model were defined in the Engineering Data such as thermal conductivity, specific heat, and density as mentioned in Table 2. Subsequently, in Geometry – every layer of the solar panel was named. In Model – the mesh was generated – considering Physics Preference as CFD and Solver Preference as Fluent [15]. The initial temperature was then fixed at 35°C. Radiation of 1000 W/m² was applied to the panel and wind velocity was applied between setup 1 and 2 to obtain the coefficient of convective heat transfer [15]. Based on Newton’s Law of Cooling, the value of the convective heat transfer coefficients was
obtained [16]. After finishing set the environment condition, the simulation results of the solar panel model were obtained in a form of a contour plot.

3 Results and Discussion

On completion of the design of wind turbine, followed by the simulation in ANSYS, the following results were obtained, which were discussed in detail.

3.1 Results for Assembly – 1

It can be inferred from the above plots that velocity near the solar panel region is high compared to the rest of the blade. Figure 8 depicts the velocity contours for Assembly-1. This indicates that the atmospheric velocity is affecting only the solar panel and the rest of the model is undisturbed and stable. The magnitude of velocity near the panel region is 12 m/s. The pressure contour is very simple and there are no peaks observed in any region of the blade or the panel. Figure 9 depicts the pressure contour for Assembly-1. Therefore, pressure is not disturbed when placing solar panels on the surface of the blade.

As velocity is one of the major factors that affect the efficiency of the solar panel, the solar panel is simulated to this velocity to find the temperature difference in them.

3.2 Results for Assembly – 2

It can be observed that in this model also the only region affected by the velocity component is the solar panel region. Figure 10 depicts the velocity contour of Assembly-2. But compared to the last setup, this one has fewer impacts, and the magnitude of velocity is less compared to 1st setup. The magnitude of velocity near the panel region – 7 m/s. The pressure contour is very simple and there are no peaks observed in any region of the blade or the panel. Figure 11 depicts the Pressure Contour for Assembly-2. Therefore, pressure is not disturbed when placing solar panels on the surface of the blade.
As velocity is one of the major factors that affect the efficiency of the solar panel, the solar panel is simulated to this velocity to find the temperature difference in them.

3.3 Result for Solar Panel Analysis

Assembly – 1

Figure 12 depicts the Steady State Thermal for Solar Panel in Assembly – 1. It can be inferred from the contour that the temperature observed is around 131.5 °C. This huge temperature will affect the solar panel and will reduce its efficiency to a greater extent. The more the temperature of the panel, the less the efficiency.

Figure 12. Steady State Thermal for Solar Panel in Assembly – 1

Figure 13 depicts the Steady State Thermal for Solar Panel in Assembly – 2. In this contour, the temperature observed is 93.7 °C. This directly implies that the temperature of the panel is less compared to the temperature of the solar panel from the 1st setup.

Figure 13. Steady State Thermal for Solar Panel in Assembly – 2

Figure 14 Graph between Surrounding Velocity and Maximum Velocity observed in Turbine Blades. When the surrounding temperature increases, the velocity impact on the turbine blade also increases. It is observed that the highest velocity impact is found in Assembly 1 and a moderate amount of velocity impact is observed in Assembly 2. More the velocity impact, less efficiency of the wind turbine and more the surface temperature of the solar panel, hence less energy generation from the solar panel.
Figure 14. Graph between Surrounding Velocity and Maximum Velocity observed in Turbine Blades

Figure 15 depicts the graph between time and temperature of the solar panel. The highest surface temperature can be observed in the solar panel of setup 1 while there is a reasonably less temperature observed on the solar panel of Assembly 2. A high amount of energy can be generated when the surface temperature of the panel is less. Therefore, setup 2 solar panels will generate more energy than the other.

Figure 15. Graph between Time and Temperature of the Solar Panel

Thus, amongst the analysis done for the hybrid turbine and the solar panel it was observed, the Assembly – 2 is more feasible. The graphs depict that Assembly – 2 shall have a low velocity impact and shall generate more energy due to lower temperature of the solar panel. In Assembly – 2 temperature impact is lesser in comparison to the other setup. The efficiency of the solar panel must be high to ensure that it increases the net efficiency of the solar – wind turbine. If the temperature received by the panel is higher, it decreases the efficiency of the panel. Thus, using the combined setup in Assembly – 2 is seen to increase the efficiency drastically as the temperature is 40°C lesser than the temperature in Assembly – 1. Similarly, the results from the turbine analysis show that the velocity and pressure contours – for Assembly – 2 are defined better. The pressure of the turbine remains undisturbed by the addition of the solar panel. This is essential to ensure that the regular working of the wind turbine remains undisturbed,
and the efficiency isn’t further reduced. Thus, Assembly- 2 is the preferred model as it is both aerodynamically stable and commercially prudent.

4 Conclusion

The efficiency of the wind turbine is the core of its usage. With a world growing for more efficient and prudent use of energy sources, the hybrid solar–wind turbine offers hope to be both efficient and economical. The increased efficiency could encourage more users to embrace this turbine in larger proportions. This could in turn lead to the creation of additional energy – power required all around the world. The efficiency of the same is confirmed in ANSYS simulation – where the setup seems to perform better than the alternative possibilities. It was also observed that in this position – the solar panels would be under lower temperature exposure – which could ensure their efficiency could remain high. While this model seems experimentally viable, theoretically there could exist a possible scope for further exploration. The production and economic viability of the turbine could pose a possible issue for its commerciality. Since the hybrid solar–wind turbine is a combination of both the models – the problem in one of them could pose a significant problem to the other process occurring as they are interconnected. Similarly, the model’s restriction – to environmental setup shall pose a backseat for its viability. The purchase could be only made when the requirements for both the processes are met – which are – enough sunlight and a decent wind velocity. In the absence of either of them, the expected efficiency of the turbine shall remain unmet, and solar – wind turbine could underperform.

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