International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

Design and Analysis of Small-Scale Wind Turbine as An Alternate Power Source for Addis Ababa City Residents

Wubishet Degife[1], Jolan Baccay Sy[2]
[1]School of Mechanical and Chemical Engineering, [2]School of Electrical and Computer Engineering.
Wollo University, Kombolcha Institute of Technology
Kombolcha, Ethiopia

***Abstract*—Today, global warming is affecting the world and the globe is looking to tackle the gross effects by relying on green energy sources. Relying on renewable energy source has its own part to play and every small contribution have a meaning effect and role. This paper is about designing Small Scale wind turbine as an alternate power source for Addis Ababa city residents. In this paper, the airfoil based on the wind data of Addis Ababa has been designed using SWRDC source code, the power and torque coefficients has been calculated using MATLAB 2013 and finally it was able to design 25.418KWh power generating horizontal axis small scale wind turbine, and this is higher than the demand by a single house hold which is 20KWh. Therefore, it is found that the design remains applicable as an alternate energy source for the city residents.**

Keywords—Airfoil; Wind Turbine; Alternate Power; Power Coefficient; Renewable Energy; Torque Coefficient; Tip Speed ratio

I. INTRODUCTION

Kaldellis and his friend, said that wind energy exploitation dates back five thousand years ago, contemporary societies are based almost exclusively on fossil fuels for covering their electrical energy needs. They also stated that, during the last thirty years, security of energy supply and environmental issues have reheated the interest for wind energy applications [1]. That is why, Negus and his friends mentioned that, the human race's dependence on fossil fuels for energy generation has started to cause major changes in the environment. They also said that, Climate change is a universal issue and it is evident that our current energy schematic is not sustainable. Therefore, it will be a must issue to replace fossil fuels with renewable energy. Small wind turbines may be used for a variety of applications including on or off-grid residences, telecom towers, offshore platforms, rural schools and clinics, remote monitoring and other purposes that require energy where there is no electric grid, or where the grid is unstable [2].Thus, small scale wind turbine has the potential to be a key component in future energy portfolio as we begin to implement renewable energy[3].

Green energy or wind energy is one of the most important sources of renewable energy that easily available in nature. At the end of this decade, most of the countries are moving towards to install more wind turbine around the world, because of the increasing need of electric power without any pollution [4]. It has been said that, wind energy is rapidly emerging as one of the most cost-effective forms of renewable energy with very significant increases in annual installed capacity being reported around the world. The most common type of turbines used for electricity generation purposes is the Horizontal Axis Wind Turbine (HAWT) with low solidity ratio (ratio of blade area to swept area) and high tip speed ratio [5]. Wind power plants in this category are generally designed for small and individual customers such as households, farms, weather stations, road signalization, and advertising systems and SWTs offer a promising alternative for many remote electrical uses. Again, SWTs can be identified as beneficial, both as stand-alone applications and in combination with other energy conversion technologies such as photovoltaic, small hydro or diesel engines [6].

According to Fantu Guta and his friends In Ethiopia, the lack of access to modern energy services that are clean, efficient and environmentally sustainable is a critical limitation on economic growth and sustainable development. They said that, recognizing the critical role played by the energy sector in the economic growth and development process, the Government of Ethiopia (GoE) has embarked on large scale hydroelectricity projects, with a view to developing renewable and sustainable energy sources. The government of Ethiopia has currently injected a huge amount of money into energy infrastructure, i.e., electricity generation from hydro and from other renewable energy sources such as wind, solar and geothermal [7]. The successful in the implementation of wind turbines depends on several factors, including: the wind resource at the installation site, the equipment used, project acquisition and operational costs, one of the technologies to generate electricity on a small scale is the Small Wind Turbine (SWT) [8]. It has been said that, Small scale wind turbines are usually used on parks, suburban houses or in general places where there is no electrical grid(off-grid) or have grid electricity sustainability problems irrespective of wind conditions. Electricity output should be as much sustainable as possible for off-grid applications. Therefore, wind turbines for off-grid applications should be optimized for low wind speed so that electric is sustainable by lowest possible cut-in and rated speed [9]. According to Casini, 2015 the integration of renewable resources in buildings is a fundamental aspect of the 21st-century architecture in order to achieve zero energy buildings (ZEB), reduce the consumption of fossil energy and cut carbon emissions in urban areas. He also said that, small wind generators (200 W - 10kW) can be used as stand-alone systems or as grid connected systems, and both can be paired with other energy conversion systems, such as photovoltaics. With a height from 2 to 20 meters, small wind turbines can be placed on rooftops, on streets or in gardens, they have relatively little visual impact and are able to produce energy even from modest wind flows. In addition to that, small wind turbines may also be coupled to street lighting systems (smart lighting) [10].

II. METHODOLOGY

Design and analysis of small-scale wind turbine as alternate power source for Addis Ababa city is achieved by following standard methods.

A. Average Load Estimation

The life of the peoples in Addis Ababa city have wide range with very few reach peoples and too many poor peoples. According to Guta and his friends he averages daily energy consumption is about 20KWh which is around 833 watts [11]. Therefore, the design is targeting an average wind power of 900Watt.

B. Selecting the Best Type of Small-Scale Wind Turbine

After having detain investigation on existing wind turbines and their efficiency and performance. Horizontal axis small scale wind turbines are selected for this study.

C. Technical Analysis

For the technical Analysis SWRDC source code and MATLAB 2013 has been used. The SWRDC source code is developed by David Wood. The wind turbine performance analysis, optimized blades shape and baseline blades shape parameters are based on the source code.

D. Design Assumptions and Data Used

The following assumptions and data are used throughout this study, changing one parameter will change the result at the end.

Table 1: Design assumptions Data’s used

Rotor Radius	1	M
Hub Radius	0.1333	M
Number of Blades	3	
RPM	948	Rpm
Moment of Inertia of Generator	1	kg m^2
Resistive Torque	1	N m
Air Density	1.225	kg m^3
Kinematic Viscosity of Air	0.0000178	m^2 /s
Design Height	20	M
Design Windspeed (*DWS*)	8	m/s
Design Tip-Speed Ratio	8	
Design RPM	611.1549815	rev/min

III. RESULT AND DISCUSSION

A. Blade Geometry

The geometry plot contains all the relevant information about a candidate blade's geometry. Fig. 1, the curves are manipulated by control points and they define, the blade twist and chord distributions. The dimensional thickness, twist and the chord are decreasing as the non-dimensional radial position of the blade, r/R increases. From this, graph one can easily understands that the optimal Cp will be derived considering all the four relationships and the Cp Value is about 0.47 and this is shown in section III F.

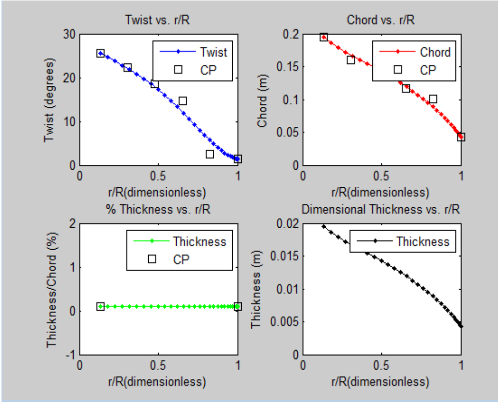

Fig. 1. Geometric Plot

B. Structural performance

A structural performance plot is shown in Figure 2, which includes five sub-plots: shell thickness, stiffness, bending moment, deflection, and 1st flap wise eigenmode, all versus the non-dimensional zed radial position of the blade, r/R. The shell thickness plot contains the dimensional and relative thickness of the shell. The dimensional shell thickness is in meters (black line) while the relative thickness is the dimensional shell thickness divided by the chord (green line). When the Cross-Section option in the Structural Data panel is set to be Solid, the relative shell thickness shown should be a straight horizontal line. This corresponds with the case when the shell is at the maximum thickness, thus creating a `Solid' blade. If the Structural Data panel is set to Hollow, the shell thickness represents the thickness required to maintain structural integrity of the blade.

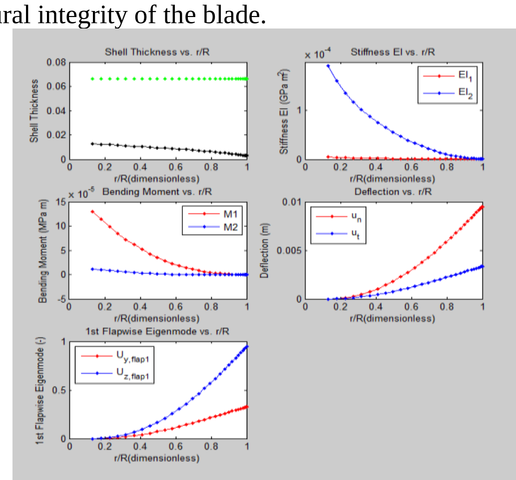

Fig. 2. Structural Performance

The stiffness plot depicts the stiffness along the first (EI1) and second (EI2) principal axes and depends strongly on the shell thickness. The stiffness in the edgewise direction will always be larger than in the flap wise direction. This is shown in Figure 2, where EI2 is much larger than EI1.

The bending moments along the first (M1) and second (M2) principal axes, the flap wise (Un) and edgewise (Ut) deflections, and the deflection shape of the first flap wise eigenmode, Uy, flap1 and Uz, flap1, are included in the structural plot.

C. Airfoil

After calculating and generating blade geometry, the airfoil of the turbine can be easily drawn, without missing a

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

single data. The design airfoil based on the analysis is shown in figure 3.

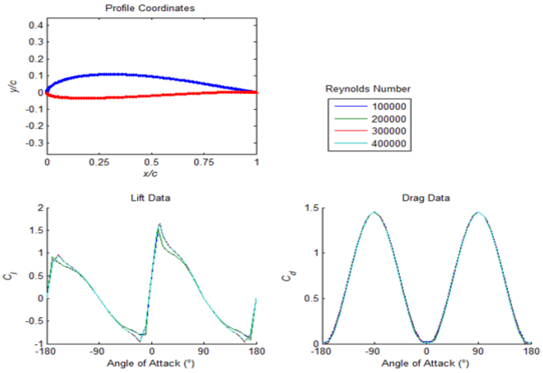

Fig. 3. Airfoil of the wind Turbine

The angle of attack relationship with the lift and drag coefficient has been calculated and from the curve we can understand that, the optimal angle of attack for the maximum lift occurs between 0-10 degrees, and in this degree ranges the drag coefficient drops, therefore the airfoil should operate in this range to harness the maximum possible amount of wind energy

D. *Cord Versus Radius*

For this specific design the chord ranges from 0.2 to 0.05 (Figure 4) having a decreasing curvilinear relationship with increase in radius. This means the aerofoiled maintains bit smooth curve transition from the base of the blade to the tip.

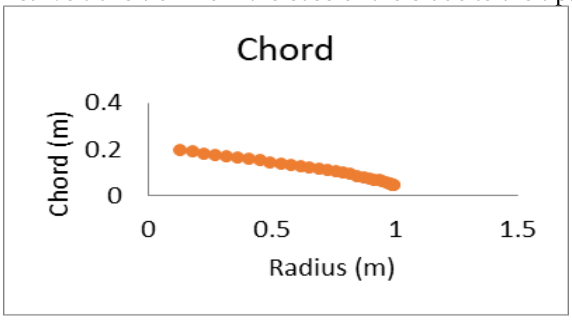

Fig. 4. Radius versus Chord

E. *Twist angle Versus Radius*

Care should be taken in designing twist angle because the power production and safety of the wind turbine depends on it. This design has a maximum twist angle of 25^0 (figure 5), as the radius of the blade increases twist angle decreases in different pattern as shown in the graph below. And, this permits the blade to harness a wind effectively.

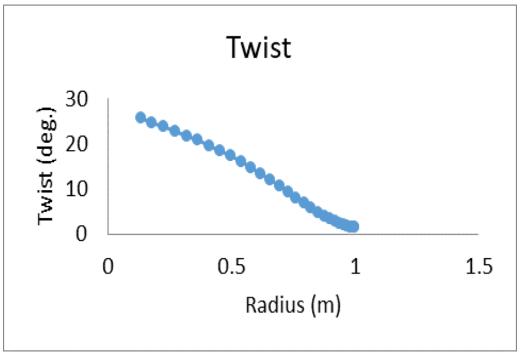

Fig. 5. Radius versus Twist Angle

F. *Power Coefficient Versus Tip Speed Ration*

From figure 6, the maximum power coefficient (4.3) is attained when the tip speed ratio is 4.7. Cp increases in parabolic form up to its maximum then drops down as the TSR increases furthermore. Therefore, the turbine should operate near the maximum tip speed ratio, if possible, at the maximum tip speed ratio.

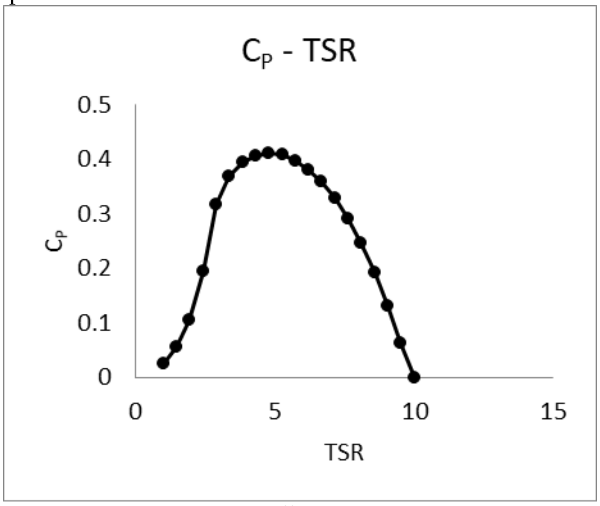

Fig. 6. Power Coefficient Vs Tip Speed Ratio

G. *Torque Coefficient Vs Tip Speed Ratio*

From figure 7, one can understand that the torque coefficient increases with increase in TSR up to the point where it hits its maximum about 5 TSR then as the TSR increases CT decreases. For a maximum power production, the coefficient of torque must be maximum and for this design the maximum coefficient of torque is about 6.2, this value permits the turbine to operate in the maximum efficiency possible.

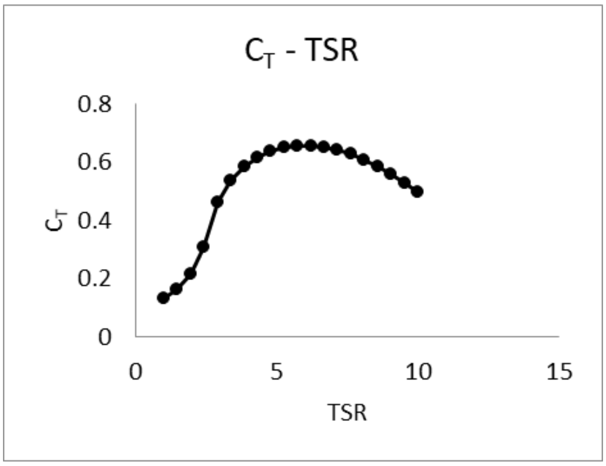

Fig. 7. Torque Coefficient Vs Tip Speed Ratio

H. *Design Power Output of The Wind Turbine*

Calculating and knowing he design power out of the designed wind turbine is very important as it is the main parameter that will be compared with the demand of the customers. The designed turbine is calculated using equation 1.

$$P = \frac{1}{2} C_p \rho A V^3 \qquad (1)$$

$$P = \frac{1}{2} * 4.3 * 1.225 \frac{kg}{m^3} * \left(\frac{\pi * 1^2}{4}\right) m^2 * \left(\frac{8m}{s}\right)^3$$

$$P = 1{,}059.1 \text{ Watt}$$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 06, June-2020

Converting this power output in to KWh, the power will be 25.418 KWh.

IV. CONCLUSION

In this study, the design and analysis of small-scale wind turbine as an alternate power source for Addis Ababa city residents has been completed, the average consumption of power in the city is about 20KWh and the design output is about 25.418KWh, which is more than the average consumption of power in the city and blindly it meets the demand as alternative power source. Form the design the maximum power coefficient (Cp) is 4.3, the maximum tip speed ratio (TSR) is 4.7, and the average wind speed is at 20m height is 8m/s. after performing the calculations and simulations the design is totally intended to meet the average demand of the city residents, and it is possible to say that installing small scale wind turbines for Addis Ababa city is very important as the city is suffering breaking of power many times a day.

REFERENCES

[1] J. K. Kaldellis and D. Zafirakis, “The wind energy (r)evolution: A short review of a long history,” Renew. Energy, vol. 36, no. 7, pp. 1887–1901, 2011.

[2] M. K. Chaudhary and A. Roy, “Design & optimization of a small wind turbine blade for operation at low wind speed,” World J. Eng., vol. 12, no. 1, pp. 83–94, 2015.

[3] M. Negus, J. Swanton, and B. Chilcoat, “Why Waste The Wind ? A Look into Small Scale Wind Energy,” 2014.

[4] V. Abraham, “Power Generation from a Moving Locomotive by Wind Turbine,” no. March, pp. 20–26, 2018.

[5] H. S. Patil, “Experimental work on horizontal axis PVC turbine blade of power wind mill,” Int. J. Mech. Eng., vol. 2, no. 2, p. 11.

[6] J. Bukala et al., “Small Wind Turbines: Specification, Design, and Economic Evaluation,” Wind Turbines - Des. Control Appl., p. 23, 2016.

[7] M. Mustafa, V. Sunil, and U. Bhasker, “Hybrid Power Generation By Solar Tracking and Vertical Axis Wind Turbine (Design and Analysis),” Int. Res. J. Eng. Technol., vol. 4, no. 8, 2017.

[8] R. V. RODRIGUES and L. A. ROSSI, “Performance of small wind turbines: simulation of electricity supply to loads connected to the public or isolated grid,” vol. 4430, no. 1, pp. 281–290, 2016.

[9] A. Xia and G. Hu, “Design and Analysis of Shrouded Small-Scale Wind Turbine for Low Wind Speeds Design and Analysis of Shrouded Small-Scale Wind Turbine for Low Wind Speeds,” 2018.

[10] M. Casini, “Small Vertical Axis Wind Turbines for Energy Efficiency of Buildings,” J. Clean Energy Technol., vol. 4, no. 1, pp. 56–65, 2015.

[11] F. Guta, A. Damte, and T. F. Rede, “The Residential Demand for Electricity in Ethiopia, Environment for Development (EfD): Discussion Paper Series,” no. April, p. 38, 2015.