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Small Vertical Axis Wind Turbine Design Case study: 200 Watts for use on top roofs in Egypt

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Abstract: - Egypt is reach of sun and wind. Securing electrical energy for the new small communities by renewable resources is a good alternative instead of extending the national network to there, in addition to keeping clean environment. A numerical model was specially prepared for this study that utilizes double-multiple streamtube for estimating VAWT turbine efficiency. The model was verified against similar studies in literature. The model results was used for designing 200 Watts VAWT. That five standard NACA airfoils (NACA0012, NACA0015, NACA0018, NACA0021, and NACA0025) were tested for the proposed design to select the most suitable one for rated wind speed of 6m/s. Results showed that no great difference in behavior of the tested airfoils. NACA0021 showed slightly better results than NACA0025. Thicker airfoils (within limits) may be preferred for low wind speeds. Within the limitation of this study, NACA0021, and NACA0025 are too close to each other in power and steady torque for rated wind speed of 6m/s. While NACA0021 may be preferred for its higher power within wider range of tip speed ratios..

Keywords: - VAWT, Design, NACA airfoil, double-multiple streamtube, Egypt

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I. INTRODUCTION

Egyptian north coast and red sea coast are also promising zones for investment in power generation. While, the north coast communities obtain electricity supplies from the national network, the new and small communities along red sea cost are in need for electricity supplies, as it is relatively far away from the national network.

Renewable energy systems could have considerable rule in solving lake of electrical energy in Egypt in the near future. Urban wind turbines are fitting the needs in most areas of Egypt, especially with low average wind speed. Thus opportunities will be in the urban wind turbine areas of: 1) design; 2) manufacturing; 3) maintenance and low cost.

The yearly ranges of average wind speeds (Figure 1a) indicated that Egypt has moderate wind energy, and establishing wind power stations to generate electricity economically in large (Mega) scale is not applicable except to west of Suez Gulf, in addition to off sure (Figure 1b) average wind speed at the same zone is also economically for power stations [1, 2]. Due to the relatively high wind speed in comparison to the most areas of Egypt and lower cost of electricity generation from wind energy versus solar energy, mega scale wind power farms were built in Zafarana (located 120 kilometres south of Suez).

Two basic groups of wind turbines: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). Generally VAWTs are simpler in design, manufacturing and maintenance, while both types can be used as integrated system for connecting to an electrical network. The recent applications of VAWTs provide even better results than horizontal ones, as they use all the different directions of wind flow and are quieter in operation. VAWTs are divided into two catigories; (1) Savonius (Drag driven), and (2) Darrieus and H-rotor (Lift driven) [4] which is selected for this study.

Momentum theory is useful for initial estimations of power generation when extreme accuracy is not required, but it does “become invalid for large tip speed ratios and also for high rotor solidities because the momentum equations in these particular cases are inadequate” [5]. In such cases it may be more desirable to use vortex theory, cascade theory, or computational fluid dynamics using finite difference formulations. The Double Multiple Streamtube (DMST) model was developed as an extension to the single and multiple streamtube models, in order to increase the accuracy of the model, by evaluating the induced velocity at several points along the revolution of the turbine. The swept area of the blades is discretized into many parallel, independent streamtubes.

In this study, a VAWT will be designed for use in red sea communities where the yearly average wind speed varies from 5 to 7 m/s. Due to the extreme weather conditions, the wind turbine blades should be manufactured from materials can cope with Egypt's hot desert climate, sand storms and salty air in order to be placed on top roof of buildings (Figure 2). The study compares between different standard NACA airfoils to obtain the optimal design.

II. NUMERICAL MODEL

Airfoil characteristics (lift, drag, and moment coefficients "C_L, C_D, C_m") depend on Reynolds number and angle of attack will be interpolated from the tables of experimental data in literature [7].

2.1. Double Multiple Streamtube model [8,9]

Equating streamwise forces to the rate of change of momentum of air going through the turbine is the core concept of the momentum theory. The VAWT is represented as one or more streamtubes, each having a different disk velocity. The flowchart of the analysis method is illustrated in Figure 3.

Starting with assuming induction factor for each streamtube as; $a = 1 - u / V_\infty$ were u is rotor velocity (angular velocity) and relative velocity is defined by; $V_R = u \sin\theta / \sin\alpha$ where θ is the blade position angle. Calculate each tube wind speed $V_t = a * V_\infty$ and angle of attack (α) is defined as; $\tan\alpha = \dfrac{u\sin\theta}{u\cos\theta + V_t}$

From the available airfoil characteristics at Reynolds corresponding to V_t, lift and drag coefficients to be estimated then used to calculate sectional normal and tangential force coefficients for each streamtube (see Figure 4) as;

$C_t = C_L \sin\alpha - C_D \cos\alpha$ & $C_n = C_L \cos\alpha + C_D \sin\alpha$

Finally, calculate G function and its equivalent induction factor to iterate until convergence or to stop as;

$$G_{u,d}(a_{u,d}) = \frac{Bc}{8\pi r|\cos\theta|}\left[C_N\cos\theta + C_T\frac{\sin\theta}{\cos\delta}\right]\left(\frac{W_{u,d}}{V_{u,d}}\right)^2 \quad . \quad a_{u,d} = \frac{1}{1+G_{u,d}(a_{u,d})} \equiv F(a_{u,d})$$

The model preliminary tests showed very good agreement with literature [8, 9], prior to use it in comparing five standard NACA airfoils (NACA0012, NACA0015, NACA0018, NACA0021, and NACA0025). Where the proposed VAWT will has 0.9m radius, 1.27m height, and 0.25m blade chord length.

III. RESULTS AND DISCUSSION

For the proposed VAWT analysis using DMST, the wind velocity used in the analysis was ranged 4 to 9 m/s and the tip speed ratios (λ) were ranged 3 to 7. The total number of stream tube used for the analysis is 18 with $\Delta\theta = 10°$.

The induction factor "a" was calculated for all of the stream tube twice, one for half upstream of the turbine and the other half downstream of the turbine. The lift and drag coefficients for the selected NACA airfoils were imported to the model from Sheldal and klimas [7]. Since the momentum equation is not applicable beyond induction factor of "0.5" the Glauert empirical formula is used to calculate the thrust coefficient for $0.4 < a < 1.0$.

Figure 5 shows the coefficient of power (Cp) comparison between different airfoils. Where the Cp was obtained from the ratio of the modeled turbine power to the available wind power in the air. NACA0021 showed high Cp over wider range of tip speed ratios in comparison to the other one(s).

Figure 6 shows the steady state torque values at different wind speeds. The simulation result shows that the torque values are positive and increases with increase of wind velocity.

Symmetrical airfoils NACA0012, NACA0015, NACA0018, NACA0021, and NACA0025 are the conventional airfoil sections used in Darrieus type VAWTs. However, the main drawbacks with these types of sections are their minimum or negative torque generation at lower TSRs. Numerous attempts were made to improve self staring of VAWT by different scholars. These includes blade offset pitch angle, and blade lean forward (or yaw) angle [9]. Though the approaches were tend to contribute in the increases of starting torque, reductions in peak efficiencies and working on the operating range were some of the major problems.

IV. FIGURES AND TABLES

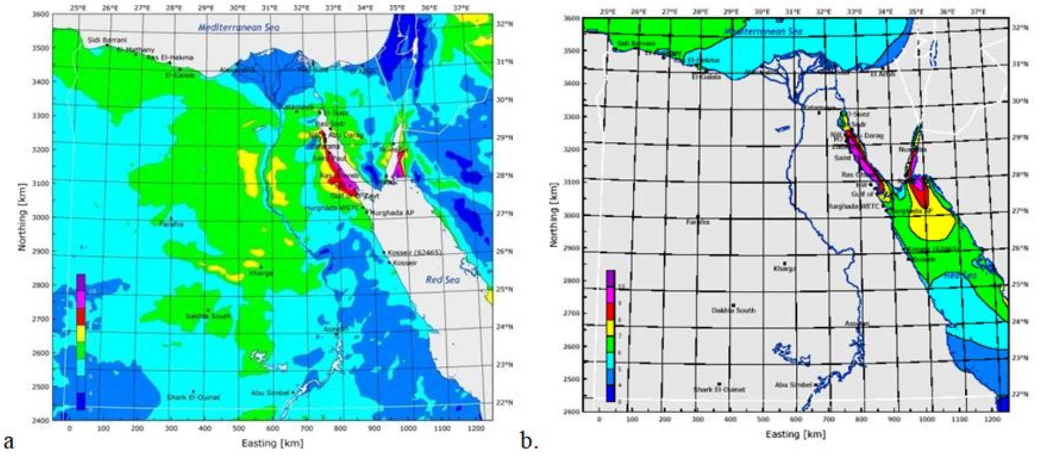

Figure 1: Annual mean wind speed allover Egypt (a) on (b) off shore at 50m height
Source [6]: http://www.geni.org/globalenergy/library/renewable-energy-resources/world/middle-east/wind-middleeast/wind-egypt.shtml (Wind Atlas for Egypt, 2006)

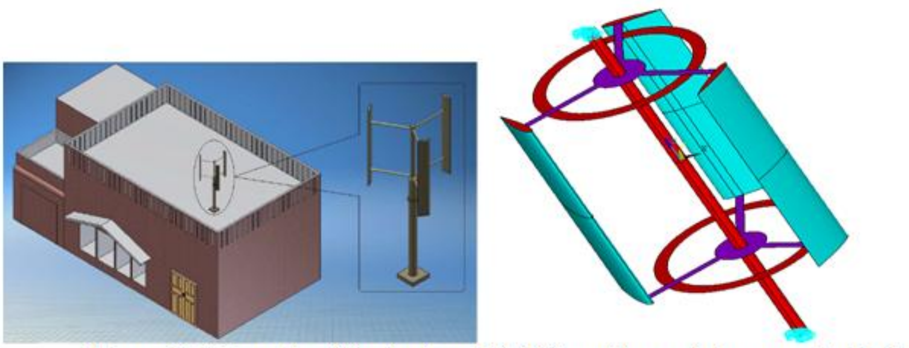

Figure 2: Schematic of the designed VAWT position and shape **capitalized.**

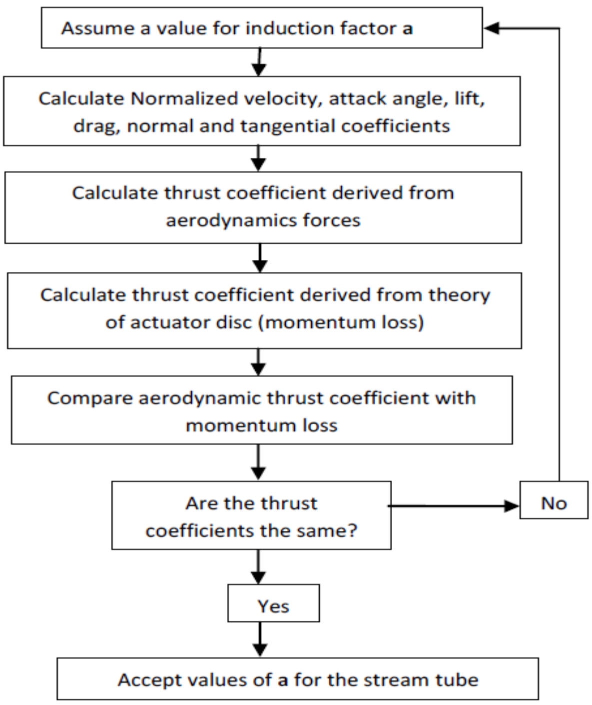

Figure 3: DMST model flowchart

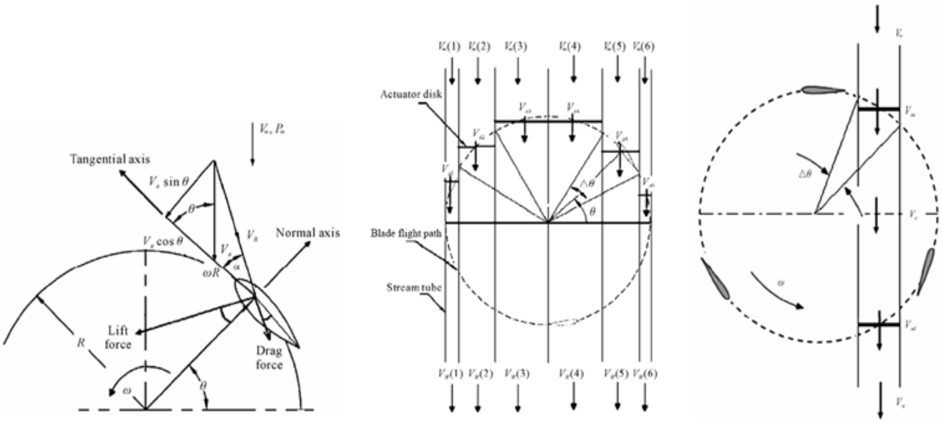

Figure 4: Schematics to clarify and define symbols used in DMST model

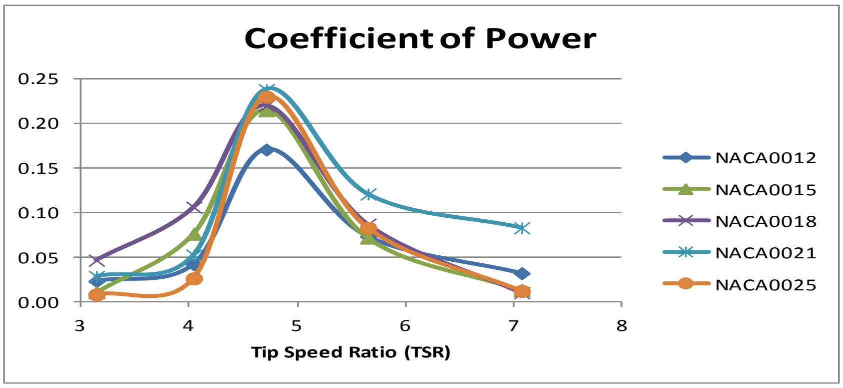

Figure 5: Coefficient of power versus tip speed ratio

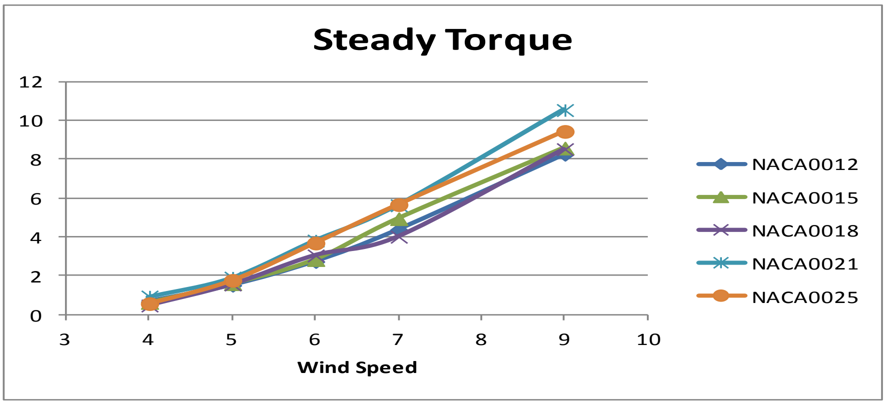

Figure 6: Steady torque comparison

V. CONCLUSION

This paper contributes to literature on the performance improvement of the VAWT at low wind speeds. VAWT with different NACA airfoil blades geometry based on fixed pitch three blades was analyzed using double-multiple streamtube model.

The power coefficients obtained shows that the turbine generates negative torque for the lower tip speed ratios. The maximum power coefficients show that all tested airfoils are in the normal range of turbine performance. While, NACA0021 showed relatively better performance than the other one(s).

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N/A.

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