PARK, K.-S., ASIM, T. and MISHRA, R. 2013. Characteristics of a vertical axis wind turbine. In Proceedings of *26th Condition monitoring and diagnostic engineering management international congress 2013 (COMADEM 2013), 11-13 June 2013, Helsinki, Finland*. Birmingham: COMADEM International.

Characteristics of a vertical axis wind turbine.

PARK, K.-S., ASIM, T. and MISHRA, R.

2013

Effect of Blade Faults on the Performance Characteristics of a Vertical Axis Wind Turbine

K. S. Park, T. Asim, R. Mishra
School of Computing & Engineering, University of Huddersfield, Huddersfield, HD1 3DH, UK
kyoo-seon.park@hud.ac.uk, taimoor.asim@hud.ac.uk, r.mishra@hud.ac.uk

Keywords: Computational Fluid Dynamics, Vertical Axis Wind Turbine, Condition Monitoring, Torque Output, Tip Speed Ratio

Abstract

Due to the diminishing reserves of fossil fuels and increased pollution from exploitation of these fuels, the world is focusing on the renewable energy sources. Wind is being considered as one of the prime next generation energy sources. Considerable amount of research is being carried out on the innovative designs for maximizing the performance of wind turbines. Furthermore, a lot of research is being carried out on maintenance and condition monitoring of such systems to improve the design of these systems [1, 2, 6]. To predict likelihood of a fault in such systems a variety of fault situations are being examined either numerically or experimentally. Most of the available studies deal with the presence of a single fault in the blades/structure of the wind turbines such as missing blade, deformed blades, blades with slits etc. In the present study two different faulty conditions of the turbine blades have been investigated, both individually and in combination, in order to estimate the contribution of each fault on the performance output of a vertical axis wind turbine. The torque output is one of the most important performance parameters of a wind turbine which has been shown to be quite sensitive to the faults in the blades of the wind turbines [3, 4, 5].The results depict that the presence of faults on rotor blade/s adversely affects the torque output of a Vertical Axis Wind Turbine (VAWT) and its effects can be seen in variations in the amplitude of the torque output. The study further shows that Computational Fluid Dynamics can be used as an effective tool to evaluate and analyze the presence of faults in a vertical axis wind turbine and can be used as an add-on to novel model based condition monitoring systems.

Nomenclature

r	Radius of VAWT (m)
ω	Angular velocity (rads/sec)
v	Linear velocity (m/sec)
P	Power Output from VAWT (W)
T	Torque Output from VAWT (N-m)

1. Introduction

In the wake of the rise in the fuel prices globally, the research in the area of renewable resources has become ever increasing. Out of many the forms of renewable energy abundantly available throughout the world, wind energy has emerged as a potential candidate in overcoming the energy crises faced by the world today. The efficiency with which wind energy can be converted into useful forms of energy depends on the performance output from wind turbines. Wind turbines are the electro-mechanical systems which convert the kinetic energy of the wind into mechanical energy. Commonly these turbines are divided into Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs). Due to omni-directionality and low starting torques, VAWTs are more suitable for operation in urban environment [1 – 6].

Gareth et. al. [7] reports that the most important parameter of wind turbine is its Tip Speed Ratio (λ) and torque output (T). The tip speed ratio of a VAWT is defined as:

$$\lambda = (r * \omega) / v \qquad (1)$$

where r is the radius of VAWT's rotor, ω is the angular velocity of VAWT's blades and v is wind velocity. Torque output of the wind turbine has a significant impact on the total power output of the wind turbine. Power of a VAWT is a function of the rotational speed and the torque output of the wind turbine and can be computed from the following expression:

$$P = \omega * T \qquad (2)$$

where P is power output and T is the torque output.

Figures 1 and 2 shows the in-house built model of the VAWT analysed in the present study. Figure 2a shows the stator blades while figure 2b shows the rotor blades of the VAWT model. This VAWT model has been shown to perform better than conventional VAWTs in terms of its performance outputs. This study focuses on the condition monitoring of the presented VAWT model under various fault conditions of the rotor blades such as a missing rotor blade and a slit in the rotor blade which might occur due to impact of a foreign object with the VAWT. The air flow in the vicinity of the VAWT has been numerically analysed using Computational Fluid Dynamics (CFD) tools.

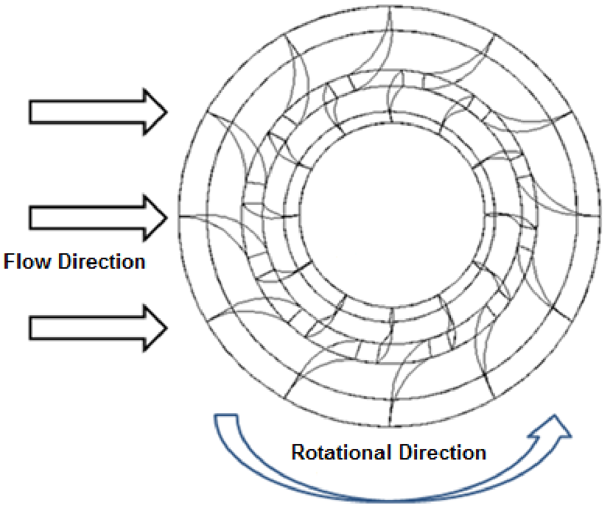
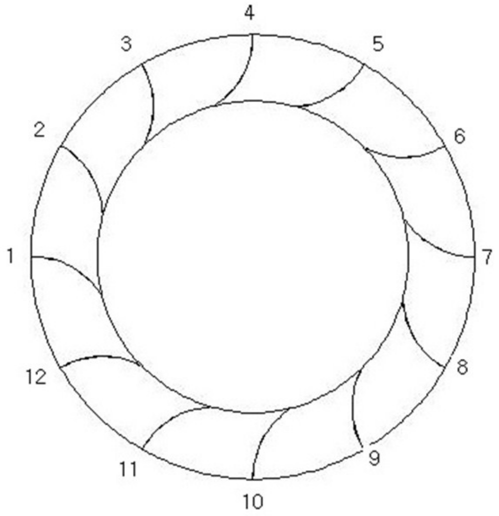
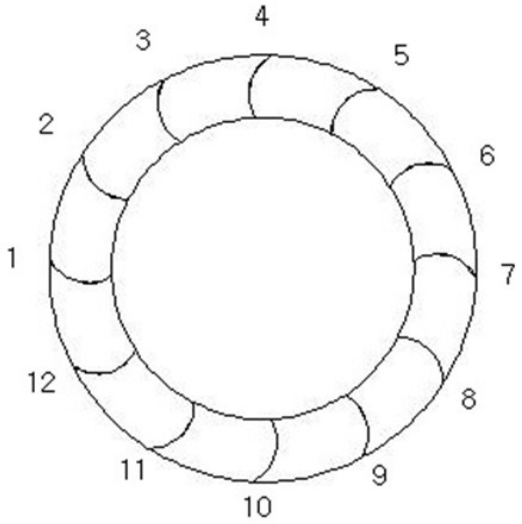


Figure 1 - 3D model of the VAWT



(a) Stator blades of the VAWT



(b) Rotor blades of the VAWT

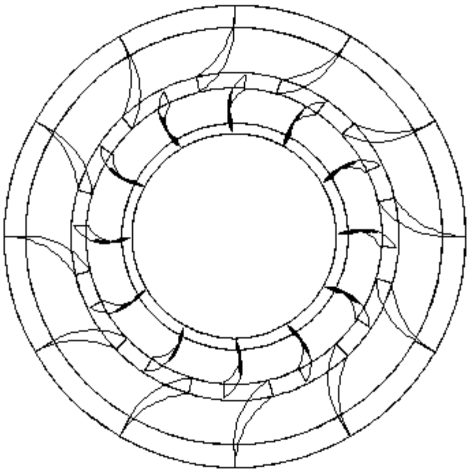
Figure 2 - Blade numbering of VAWT

2. Numerical Modelling

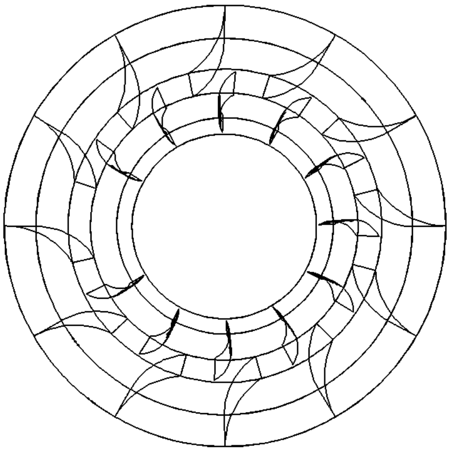
The VAWT model has been numerically analysed for various fault conditions of the rotor blades as mentioned earlier. The VAWT model consist of two parts, i.e. the stator blades having a diameter of 2m and height of 1m in height, and the rotor blades having a diameter of 1.4m and height of 1m. The VAWT model has 12 equally spaced stator and rotor blades respectively. Three different faulty conditions of the rotor blades have been analysed against a healthy condition of the VAWT model. Table 1 and figure 3 depict the details of these conditions.

Condition	Blade number having Defect
Healthy	N/A
50mm square slit	7
Missing blade	1
Missing blade & 50mm square slit	1 & 7

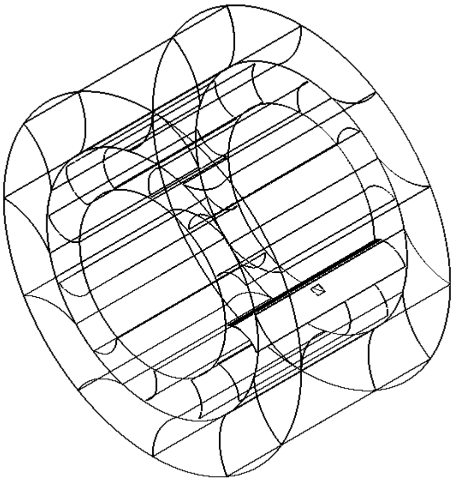
Table 1 - Various VAWT's Configurations



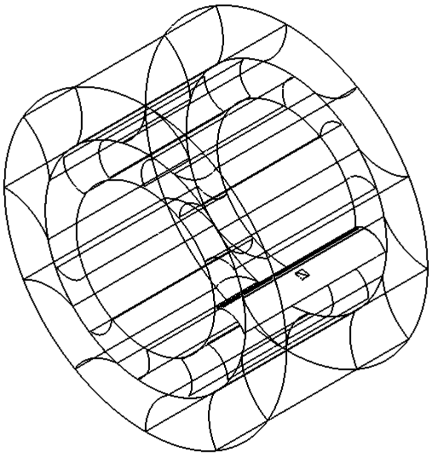
(a) Healthy



(b) Missing blade



(c) 50mm square slit



(d) Missing blade &50mm square slit

Figure 3 - Various VAWT's configurations.

A commercial CFD package has been used to numerically simulate the flow in the vicinity of the VAWT. The geometric details of the flow domain, encompassing the VAWT, have been shown in figure 3. 4m/sec of air flow velocity has been specified at the inlet boundary of the domain whereas the outlet of the flow domain is assumed to be at the atmospheric pressure. The other sides of the flow domain have been specified as stationary walls with no-slip boundary conditions. k-ε turbulence model has been shown to resolve the steady-state turbulent parameters in the flow domain with reasonable accuracy [7] and hence has been chosen for analysis in the present study. Sliding mesh technique as mentioned by Park et. al [1] has been used to rotate the blades with respect to the central axis of the turbine at an angular velocity of 1.143 rads/sec such that the TSR of the VAWT is 0.2. Three dimensional Navier Stokes equations have been numerically solved in an iterative manner to predict the flow structure in the vicinity of the VAWT for every 3^0 rotation of the rotor blades. During the initial revolutions of the VAWT, significant changes in the flow parameters have been observed due to numerical diffusion. The flow structure within the flow domain has been constantly monitored and the results obtained once the flow parameters become statistically steady.

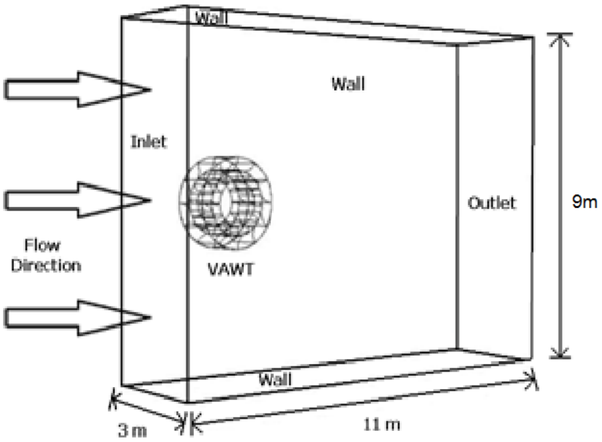


Figure 4 - Flow domain encompassing the VAWT

3. Results and Analysis

To analyse the effect of various performance outputs of the VAWT, numerical converged solution has been used.

3.1 Healthy condition

In order to analyse the flow parameters in the vicinity of the VAWT, figures 5 depicts the variations in the velocity of flow for healthy VAWT, It can be clearly seen that there exists a high velocity region at the entrance of the 1st rotor blade in case of healthy VAWT (circled). This information will be compared against the defective VAWT in the next sections.

The normalised torque output during one revolution of the VAWT has been observed to be cyclic as shown in figure 7. The average distribution of torque output is the same for all the blades. Highest peaks refer to the maximum torque output when the rotor blades are in line with the stator blades, making uniform passages for the flow of air (Figure 6 (a)). The maximum normalised torque output is 1.065. The lower peaks (circled in figure 7) correspond to that orientation of the VAWT when the rotor blades are in between two stator blades making two uniform passages for the flow of air. The minimum value of the normalised torque output from the healthy VAWT is 0.95 which corresponds to that orientation of the VAWT at which the rotor and stator blades make non-uniform passages for the flow of air (Figure 6 (c)).

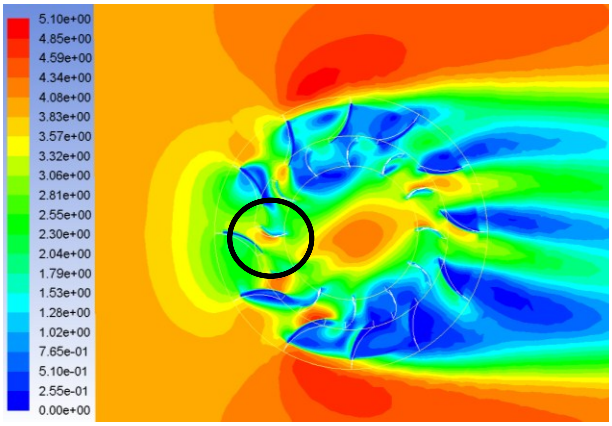
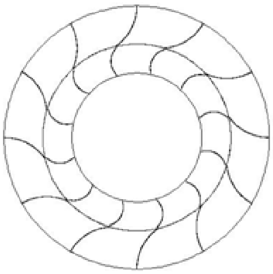
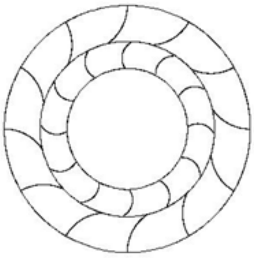


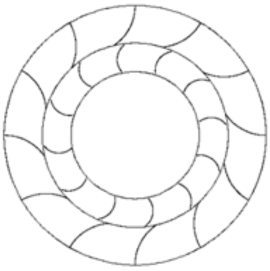
Figure 15 - Velocity variations in Healthy VAWT



(a) Orientation at higher peak



(b) Orientation at lower peaks



(c) Orientation at pits

Figure 6 - Blade’s orientations

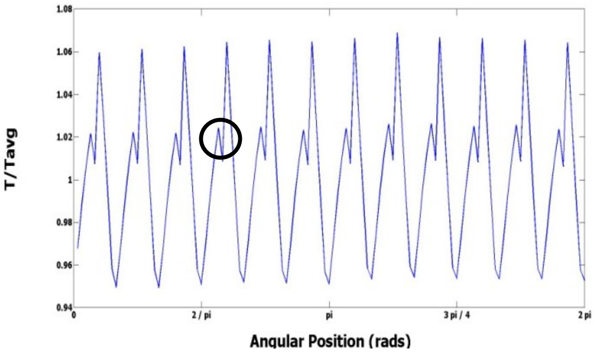


Figure 7 - Normalized Instantaneous Torque output from Healthy VAWT

3.2. 50mm square slit

Figure 8 depicts the normalized torque output for the VAWT having a 50mm square slit in one of its rotor blades. Although the torque variation is cyclic, the torque output values are slightly different from that observed for the healthy condition of the VAWT. The maximum torque output, as compared to healthy state, has increased by 0.1%. The minimum normalized torque output is 0.92, showing 5% decrease as compared to healthy VAWT. Figure 9 depicts the comparison between healthy and 50mm square slit VAWT conditions. The parts circled in the figure highlight the difference in the torque output from both the models. Hence, the presence of a single 50mm square slit in one of the rotor blades of the VAWT slightly increases the amplitude of instantaneous torque output from the VAWT.

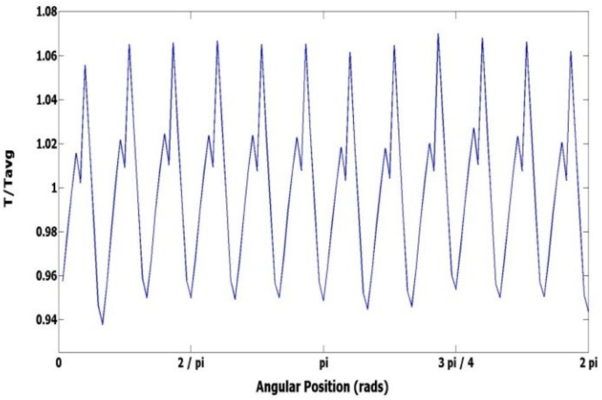


Figure 8 - Normalized Instantaneous Torque output from the VAWT with 50mm square slit

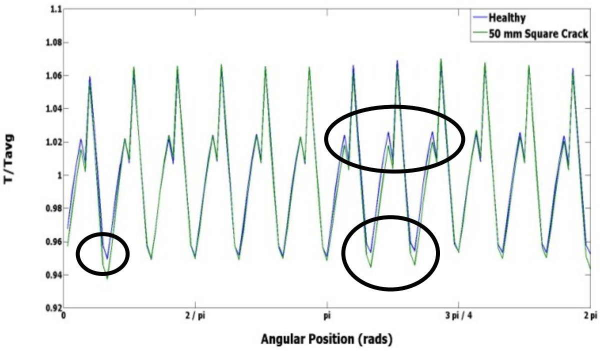


Figure 9 - Comparison of performance output from the Healthy and 50mm square slit VAWTs

3.3 Missing blade

Figure 10 depicts the normalised torque output from the VAWT when blade number 1 in Figure 2(b) is missing from the VAWT. The figure shows that the normalised torque output from the VAWT is no longer cyclic in nature and that the amplitude of the torque output has increased significantly; leading towards considerable degradation of the VAWT's performance due to severe vibrations. The average value of normalised torque output for in-line stator and rotor blades, which corresponds to higher peaks, is 1.249. Hence, there is an increase of 16.84% in the values of higher peaks and a decrease of 12.37% in the values of lower peaks on average as compared to the healthy condition VAWT. In comparison to the 50mm square slit condition of the VAWT, the fault in the VAWT, represented by a missing blade, has dominant effects on the performance output of the VAWT.

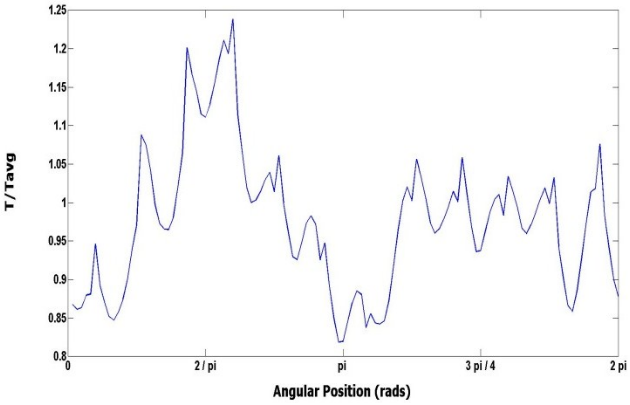


Figure 10 - Normalized Instantaneous Torque output from a missing blade VAWT

3.4 Missing blade & 50mm square slit

In order to effectively analyse the effect of the combined faults on the flow parameters in the vicinity of the VAWT, figure 11 depict the variations in the velocity of flow for the defective VAWT, where defective VAWT refers to the configuration having a combination of faults, i.e. missing blade and 50mm square slit. It can be clearly seen that for the defective VAWT model, the high pressure region around rotor blade 1 observed for healthy VAWT, is absent due to non-existence of the rotor blade. This considerably affects the performance of the VAWT.

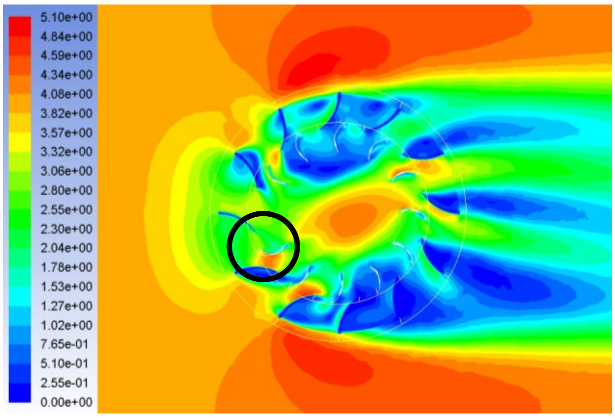


Figure 11 - Velocity variations in Defective VAWT

This effect has been further analysed in figure 12 which shows the normalised velocity w.r.t. the angular position of the rotor blades for both the healthy and the defective VAWT. The velocity V is the average velocity at the interface between the stator and rotor blades and it has been normalised with the inlet velocity for the flow domain i.e. 4m/sec. It can be seen that for the defective VAWT at the position shown in figure 11, the flow velocity is considerably lower at the front and rear faces of the VAWT; precisely the locations where the missing and the slit blades are present. Furthermore, as compared to the healthy VAWT, the flow velocity for the defective VAWT is lower in the core region, which is the flow passage between the missing blade and the slit blade.

In order to represent the pressure variations at the interface between the stator and the rotor blades, the variations of coefficient of pressure w.r.t. the angular position of the rotor blades for both the healthy and defective VAWTs has been shown in figure 13. It can be seen that the difference in the coefficient of pressure for both the healthy and the defective VAWTs is relatively small as compared to the differences shown in the normalised velocity in figure 12. Hence, Cp has not been able to detect the defects in the VAWT with significant difference.

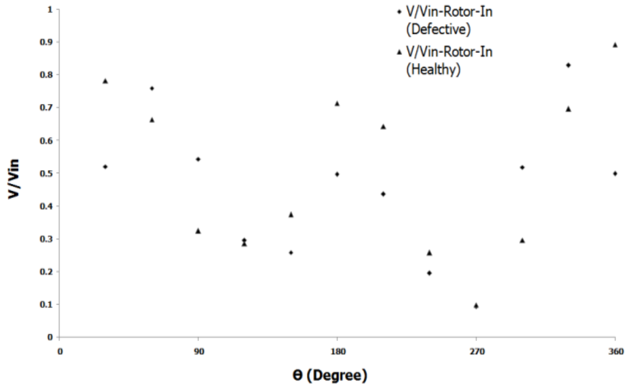


Figure 12 - Comparison of the Normalised Velocity at the Rotor Inlet for the Healthy and Defective VAWTs

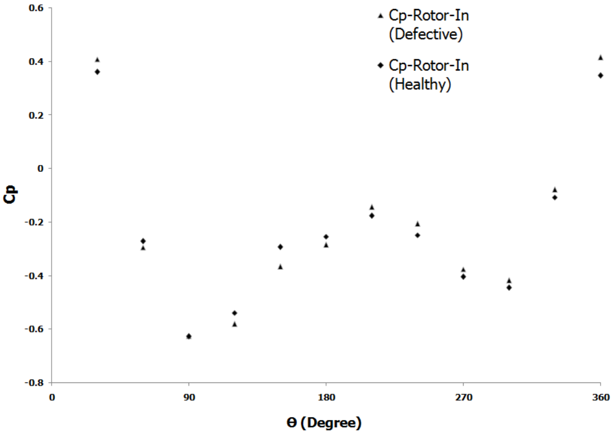


Figure 13 - Comparison of the Pressure Coefficient at the Rotor Inlet for the Healthy and Defective VAWTs

Figure 14 depicts the normalized torque output from the VAWT when rotor blade number 1 is missing from the VAWT and at the same time there is a 50mm slit in rotor blade number 7. The figure also presents a comparison with the missing blade VAWT model. It can be seen that the combined fault further degrades the performance output of the VAWT. Compared to the missing blade configuration, the peak torque has decreased by 0.88% and the minimum torque has decreased by 1.44%. Hence, the amplitude of the normalized torque output is higher for the combined fault, resulting in higher degree of vibrations in the VAWT.

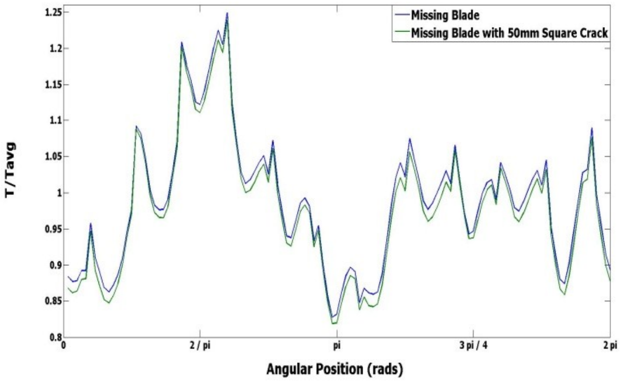


Figure 14 - Comparison of performance output from the missing blade and combined fault orientation of the VAWT

Instantaneous torque output for one complete revolution of the different configurations of the VAWTs at a tip speed ratio of 0.2 is shown in figure 15.

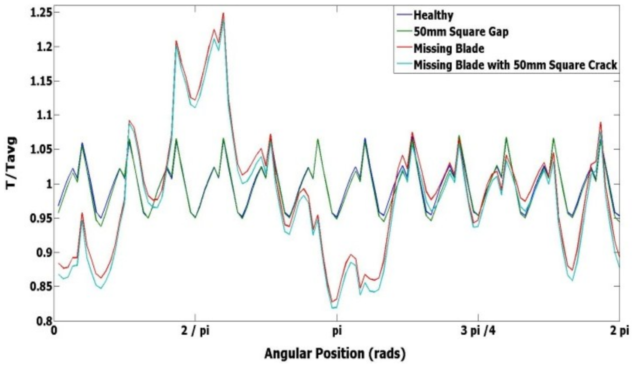


Figure 15 - Normalized Instantaneous Torque output from various VAWT configurations

Further analyzing the effect of the faults in rotor blades of a VAWT on the performance output, tables 2 and 3 presents the results for the average, maximum and minimum torque outputs from various configurations of the VAWT. It can be seen in table 2 that as the size of the fault in the rotor blade/s increases, the performance of the VAWT degrades. As compared to healthy condition VAWT, the average torque output has decreased by 0.3%, 1.16% and 2.4% for the slit, missing and combined faults in the rotor blades of the VAWT.

It can be seen in table 3 that the amplitude of the normalized torque output increases as the size of the fault in the VAWT increases. Hence, the VAWT with a small slit has the least, while the slit and missing blade combined has most effect on the performance of the VAWT. Increased amplitude of normalized torque output from the VAWT results in increased vibrations in the VAWT and hence degrades its performance.

Condition	Average Torque Output	% difference w.r.t Healthy
Healthy	11.178	
50mm square slit	11.144	0.308
Missing blade	11.048	1.167
Missing blade with 50mm square slit	10.910	2.400

Table 2 - Average torque outputs from various VAWT conditions

Condition	Max Normalized Torque Output	% difference w.r.t healthy	Min Normalized Torque Output	% difference w.r.t Healthy
Healthy	1.065		0.952	
50mm square slit		0.004	0.948	0.464
Missing blade	1.060	0.462	0.942	1.087
Missing blade & 50mm square slit	1.052	1.179	0.929	2.509

Table 3 - Torque outputs from various configurations of the VAWT

4. Conclusions

Different faults in the rotor blades of a VAWT have been generated and the VAWT models numerically simulated for the flow of air at a constant TSR. The results show that the presence of faults in a VAWT can be detected by using CFD tools. It has been concluded that the size of the faults have a direct relation to the degree of degradation in the VAWT's performance output. A small slit shows the least deviation in the performance of the VAWT as compared to the healthy condition, whereas, a combination of faults, such as a missing blade and a slit, shows the most deviation in the performance output. Furthermore, it has been shown that the normalized velocity of the flow at the rotor inlet can be used as an effective tool to detect the defects in the rotor blades of a VAWT.

5. References

[1] Park, K., Asim, T., Mishra, R., 2012, Computational Fluid Dynamics based Fault Simulations of Vertical Axis Wind Turbines, Journal of Physics: Conference Series, 364

[2] Park, K., Asim, T., Mishra, R., 2012, Simulation Based Approach to Predict Vertical Axis Wind Turbine Faults using Computational Fluid Dynamics, 1st International Conference on Through-Life Engineering Services, 5-6 November, 2012

[3] Park, K., Asim, T., Mishra, R., 2012, Computational Fluid Dynamics based transient

analysis of faulty conditions of a Vertical Axis Wind Turbine, FMFP-2012

[4] Shahzad, A., Asim, T., Park, K., Pradhan. S., Mishra.R., Numerical Simulations of Effects of Faults in a Vertical Axis Wind Turbine's Performance, e-maintenance2012.

[5] NRDC (Natural Resources Defence Council), Using the Clean Air Act to Sharply Reduce Carbon Pollution from Existing Power Plants. http://www.nrdc.org/air/pollution-standards/

[6] GWEC (2011). Global Wind Report. Available at: http://www.gwec.net/, accessed: 28 September 2012

[7] Colley, G., Mishra, R., 2011, Computational flow field analysis of a Vertical Axis Wind Turbine, International Conference on Renewable Energies and Power Quality (ICREPQ'11), Las Palmas de Gran Canaria, Spain, 13-15 April 2011