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Condition Based Monitoring of Vertical Axis Wind Turbines using Computational Fluid Dynamics

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ABSTRACT

Scarcity of fossil fuels and a rapid escalation in the fuel prices around the world recently has lead the search for alternative energy sources. Out of the available energy sources, wind is being considered as the prime next generation energy source. The fundamental principle of wind turbines is to convert the wind energy into first mechanical and then into electrical form. The relatively simple operation of such turbines has stirred the researchers to come up with innovative designs for global acceptance and to make these turbines commercially viable. Furthermore, the maintenance of wind turbines has long been a topic of interest. On-line health monitoring of wind turbines is essential to maintain continuous operation of wind turbines. The present work focuses on the difference in the outputs of a vertical axis wind turbine (VAWT) under different operational conditions. A Computational Fluid Dynamics (CFD) technique has been used to monitor various blade conditions of a VAWT. The results indicate that there is significant degradation in the performance output of wind turbines as the number of blades broken or missing from the VAWT increases. The study predicts the faults in the blades of VAWTs by monitoring its output.

Keywords: Computational Fluid Dynamics, Vertical Axis Wind Turbine, Torque, Power

INTRODUCTION

The need for sustainable energy sources becomes greater due to the continued depletion of the fossil fuels. To harness such types of energy, wind turbines are now seen as the most logical choice due to their well-established performance credentials along with relatively short payback period.

Various kinds of wind turbines include horizontal axis and vertical axis wind turbines. The axis of rotation of horizontal axis wind turbines is parallel to the ground whereas the axis of rotation of the vertical axis wind turbines is perpendicular to the ground.

The main advantage of vertical axis wind turbines is their capability to operate at lower wind speeds and hence is considered more favourite for operation in urban areas in comparison with horizontal axis wind turbines. The other advantages of vertical axis wind turbines include low noise being generated and their simple design which can harness energy at all wind angles (Walker, 2009, BTM Consultants, 2008 and Lemming, 2009).

Gareth et. al., 2011, mentioned the important performance parameters for wind turbines. These parameters are torque output, power output and the tip speed ratio (TSR). The tip speed ratio of a VAWT is defined by:

$$\lambda = (r*\omega) / V \tag{1}$$

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:

$$P = \omega * T \tag{2}$$

Wind farms need to operate at peak performance without interruption or degradation in their output. In order to achieve this, an on-line monitoring system needs to be developed, based on CFD, such that it can accurately detect any kind of fault/s being generated within the vertical axis wind turbines. Extensive research is being carried out to effectively use CFD as an on-line health monitoring tool for VAWTs.

MODELLING AND SIMULATION

The model of the vertical axis wind turbine (VAWT) used for analysis is shown in fig. 1. It consists of 12 rotor blades and 12 stator blades each. The diameter of the stator is 2m while that of the rotor is 1.4m. Operation of a simple VAWT is shown in fig. 1. In these types of wind turbines, the stator remains stationary while the rotor revolves under the action of the incoming flow.

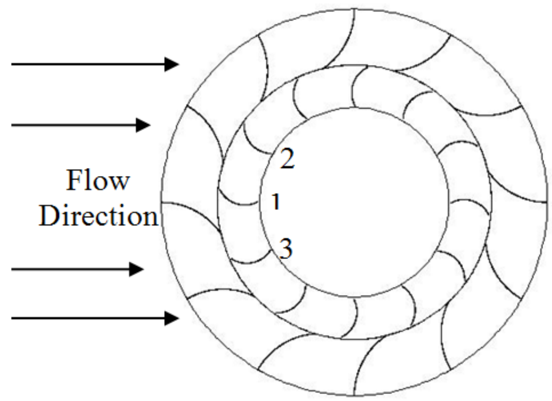

Fig. 1 Healthy state VAWT model

The first configuration is termed as healthy state and is shown in fig. 1. In this configuration all the blades of the VAWT are in their original shape and position. In order to introduce faults in the VAWT, the rotor blade/s have been assumed to be missing from the VAWT. The details of all the configurations that were taken into account are summarised in table 1.

Table 1 Various configurations of the VAWT

Condition	Missing Blade/s
Healthy	N/A
One blade missing	1
Two blades missing	1 and 2
Three blades missing	1, 2 and 3

Due to limited computational resources, only a two dimensional model as shown in fig. 1 has been taken into account for the analysis. It is assumed that due to symmetry of the flow within the VATW, a two dimensional model will behave with reasonable accuracy under operation. Unsteady Navier-Stokes equations have been solved numerically for a turbulent flow of air at a speed of 4m/sec towards the VAWT. In order to obtain a wide range of data, tip speed ratios of 0.1 to 0.9 have been considered for analysis. These tip speed ratios are achieved by altering the rotational speed of the rotor blades. It has been found that the Sliding mesh technique is capable of capturing those complex flow phenomena which are very difficult to capture with other techniques. The equations have been solved using iterative method such that each time step corresponds to 3º rotation of the rotor blades. Second order spatial and temporal schemes have been specified for better convergence and accuracy of the results. The torque output from the VAWT/s has been monitored throughout the iterative process. For transient simulations, the solution needs to attain a statistically steady state before any data could be obtained. In the present work, the model becomes statistically steady after four revolutions of the VAWT. The data is collected only in the fifth revolution.

RESULTS AND DISCUSSION

Torque and power outputs for the different VAWT configurations have been recorded and normalised with average torque and power respectively for one revolution of the VAWT. Data at various tip speed ratios has been presented here.

- **Instantaneous Torque**

Instantaneous torque output for one complete revolution of the different configurations of the VAWTs for tip speed ratios of 0.1 to 0.9 is described hereafter. The objective is to analyse the torque output of healthy and faulty VAWTs in order to realize whether CFD is capable of detecting faults in the blades of the VAWTs.

Figure 2 depicts that at TSR = 0.1, torque output from a healthy VAWT is fairly uniform and steady w.r.t. the angular position of the blades of the VAWT, whereas for defective VAWTs, the torque outputs are non-uniform and depend considerably on the angular position of the blades of the VAWT. It can be seen that from an angular position of about 270˚ to 30˚ the difference in torque outputs from all the different conditions of the VAWTs is very small. In between 30˚ and 270˚ angular position of the blades, the torque outputs from the faulty VAWTs are significantly deviated from the healthy condition VAWT.

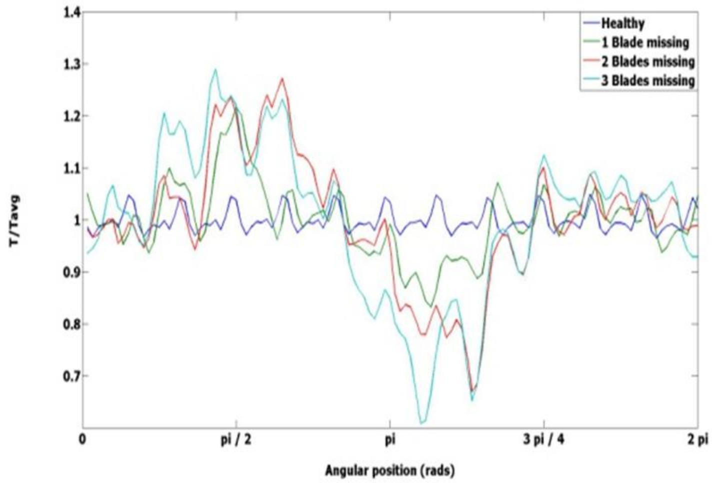

Fig. 2 Instantaneous torque output at TSR = 0.1

The reason for such a deviation is the angular position of the faulty/missing blade/s w.r.t. the incoming flow. As mentioned by Park et. al., 2012, there exists a low pressure region in the stator blades of the VAWT at these angular positions which contribute to degradation in the torque output from the faulty VAWTs as compared to the healthy state VAWT.

Figure 3 shows the normalised torque output for one complete revolution of the VAWTs at TSR of 0.2. It can be seen that the amplitude of deviation of the torque outputs from the faulty VAWTs has reduced as compared to TSR = 0.1. The least deviation is for one blade missing condition of the VAWT and the most for three blades missing condition.

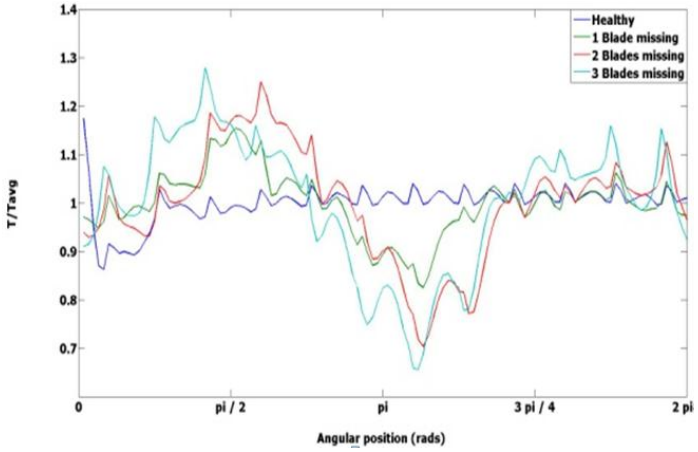

Fig. 3 Instantaneous torque output at TSR = 0.2

From figs. 4 to10, it can be seen that the deviations further reduces until all the conditions of the VAWTs produce a uniform torque output. It is noteworthy to mention that although the pattern of torque output becomes uniform and steady with increasing TSR, the instantaneous torque output from the faulty VAWTs also change.

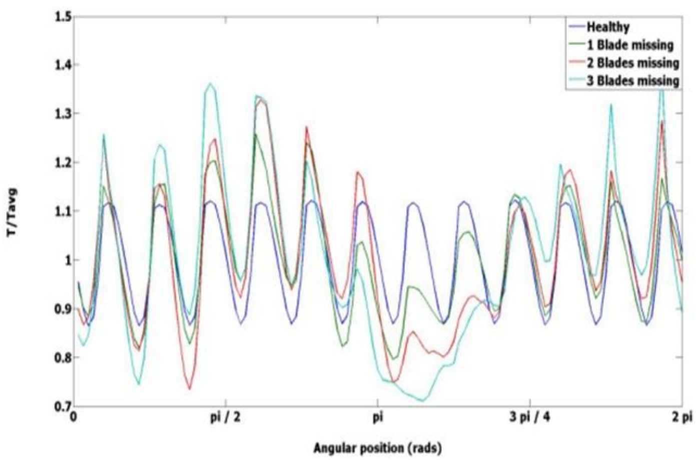

Fig. 4 Instantaneous torque output at TSR = 0.3

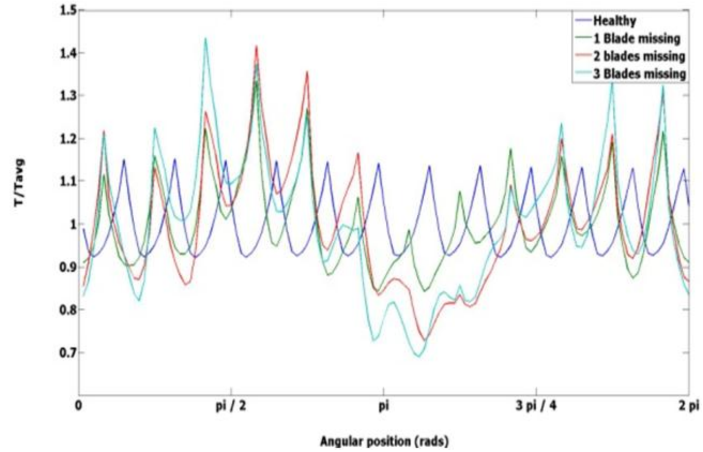

Fig. 5 Instantaneous torque output at TSR = 0.4

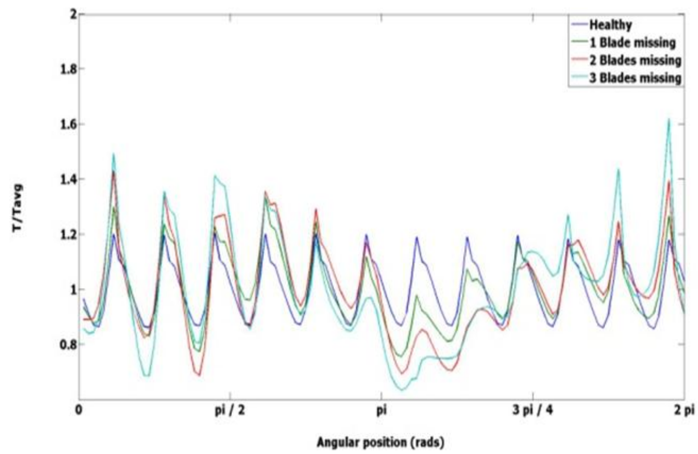

Fig. 6 Instantaneous torque output at TSR = 0.5

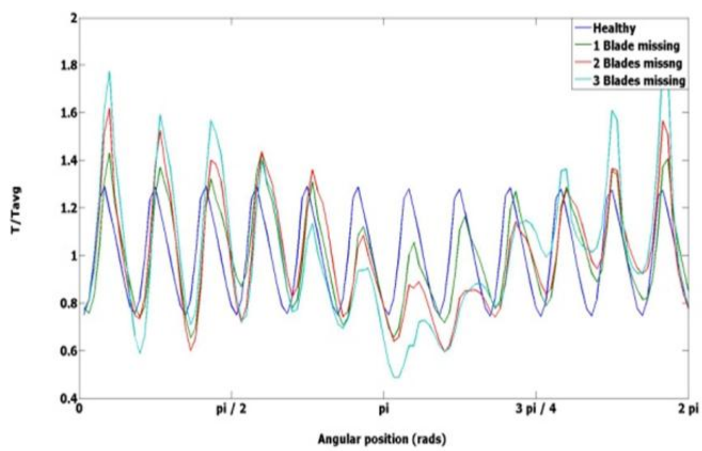

Fig. 7 Instantaneous torque output at TSR = 0.6

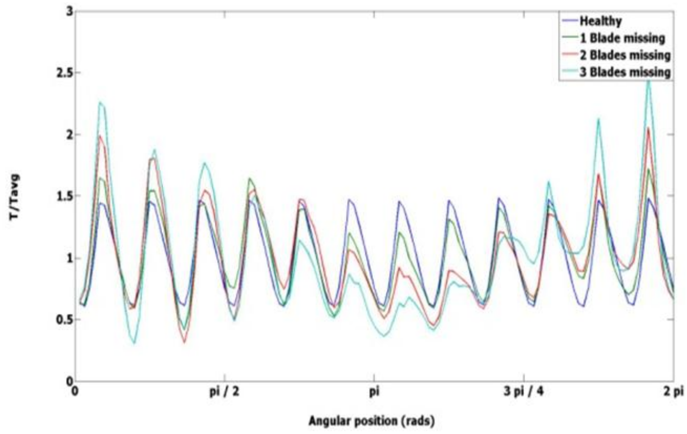

Fig. 8 Instantaneous torque output at TSR = 0.7

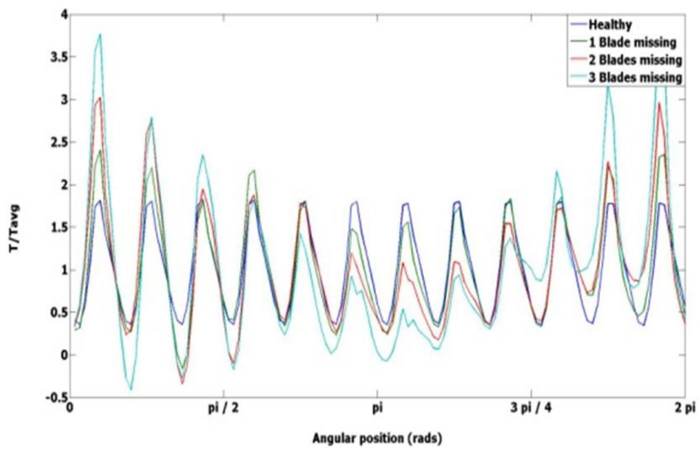

Fig. 9 Instantaneous torque output at TSR = 0.8

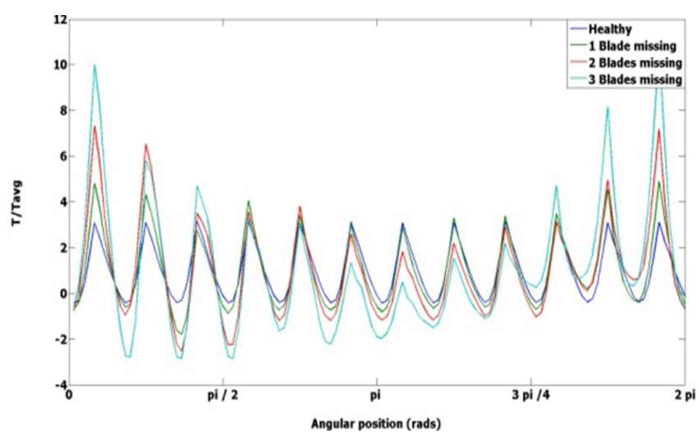

Fig. 10 Instantaneous torque output at TSR = 0.9

Table 1 summarises the average torque and power outputs from the various configurations of the VAWTs for different TSRs. It can be seen that as TSR increases average torque output decreases. Furthermore, at the same TSR, as the number of missing blades increases, average torque output decreases.

Furthermore, the highest power output is achieved at TSR = 0.5 and it reduces for other TSRs. Additionally, at the same TSR, the power output decreases as the number of missing blades increases from the VAWT.

Figure 11 and 12 depict the variations in average torque and power outputs w.r.t. tip speed ratio. It can be seen that the average torque decreases with increasing TSR while it also decreases with increasing number of missing blades from the VAWT. Furthermore, it can be seen in figure 12 that average power output increases from TSR of 0.1 to 0.5, while it decreases from TSR of 0.5 to 0.9.

Again, the average power form the various VAWTs is highest for the healthy condition of the VAWT and lowest for the maximum number of missing blades. The current study has shown that computational fluid dynamics based performance investigations of VAWTs can be used as a reliable tool for on-line monitoring of the wind farms.

Table 2 Average torque and power outputs from various VAWT conditions at different TSR

Tip Speed Ratio	Condition	Average Torque Output	Average Power Output	Percentage decrease in average torque output w.r.t healthy condition
(λ)		(Nm)	(W)	(%)
0.1	Healthy	18.492	10.559	
	One blade missing	18.083	10.325	2.2
	Two blades missing	17.272	9.862	4.5
	Three blades missing	16.661	9.514	3.5
0.2	Healthy	13.991	15.992	
	One blade missing	13.984	15.983	0.1
	Two blades missing	13.625	15.573	2.6
	Three blades missing	12.942	14.793	5
0.3	Healthy	13.45	23.002	
	One blade missing	13.42	23.062	0.22
	Two blades missing	12.883	22.051	4.3
	Three blades missing	12.43	21.306	3.5
0.4	Healthy	11.373	25.999	
	One blade missing	11.216	25.64	1.4
	Two blades missing	10.743	24.558	4.2
	Three blades missing	10.258	23.451	4.5
0.5	Healthy	9.347	26.705	
	One blade missing	9.145	26.129	2.2
	Two blades missing	8.768	25.05	4.1
	Three blades missing	8.363	23.892	4.6
0.6	Healthy	7.247	24.851	
	One blade missing	7.086	24.297	2.2
	Two blades missing	6.683	22.916	5.7
	Three blades missing	6.332	21.707	5.3

0.7	Healthy	5.32	21.28	
	One blade missing	5.071	20.285	0.047
	Two blades missing	4.746	18.982	0.064
	Three blades missing	4.405	17.621	0.072
0.8	Healthy	3.57	16.317	
	One blade missing	3.195	14.606	0.105
	Two blades missing	2.925	13.371	0.085
	Three blades missing	2.583	11.807	0.117
0.9	Healthy	1.849	9.508	
	One blade missing	1.513	7.783	0.182
	Two blades missing	1.205	6.2	0.204
	Three blades missing	1.006	5.175	0.165

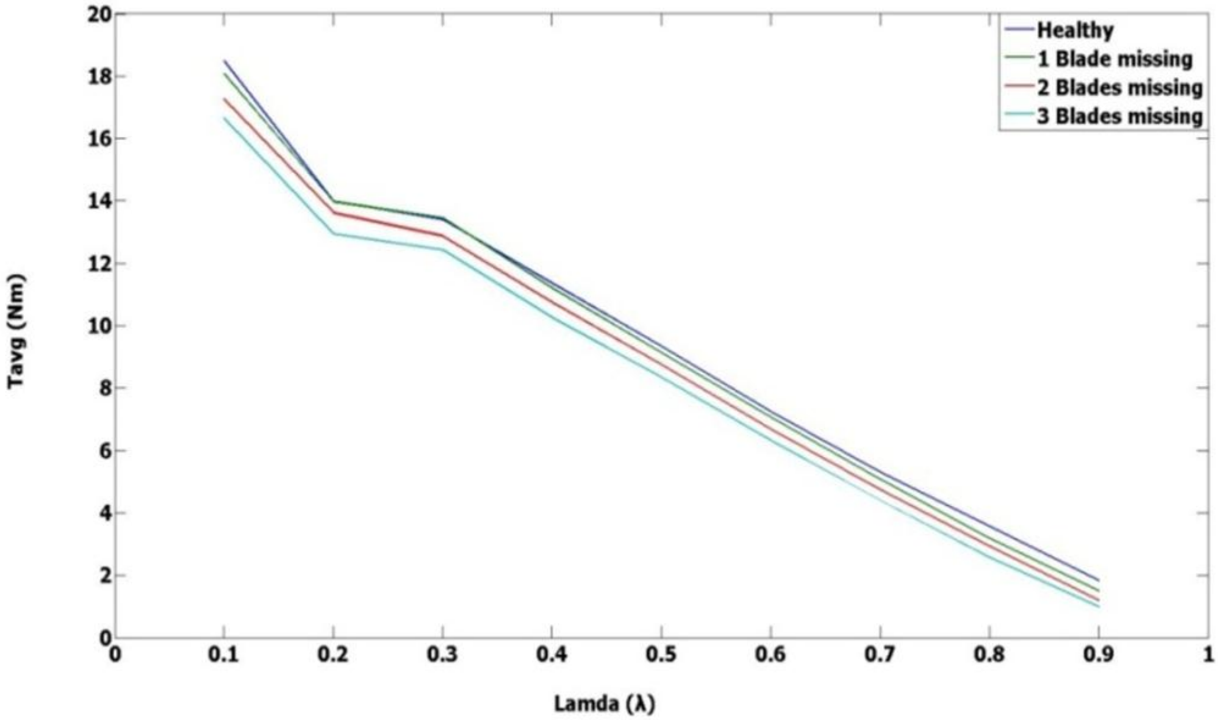

Fig. 11 Average torque outputs at various TSRs

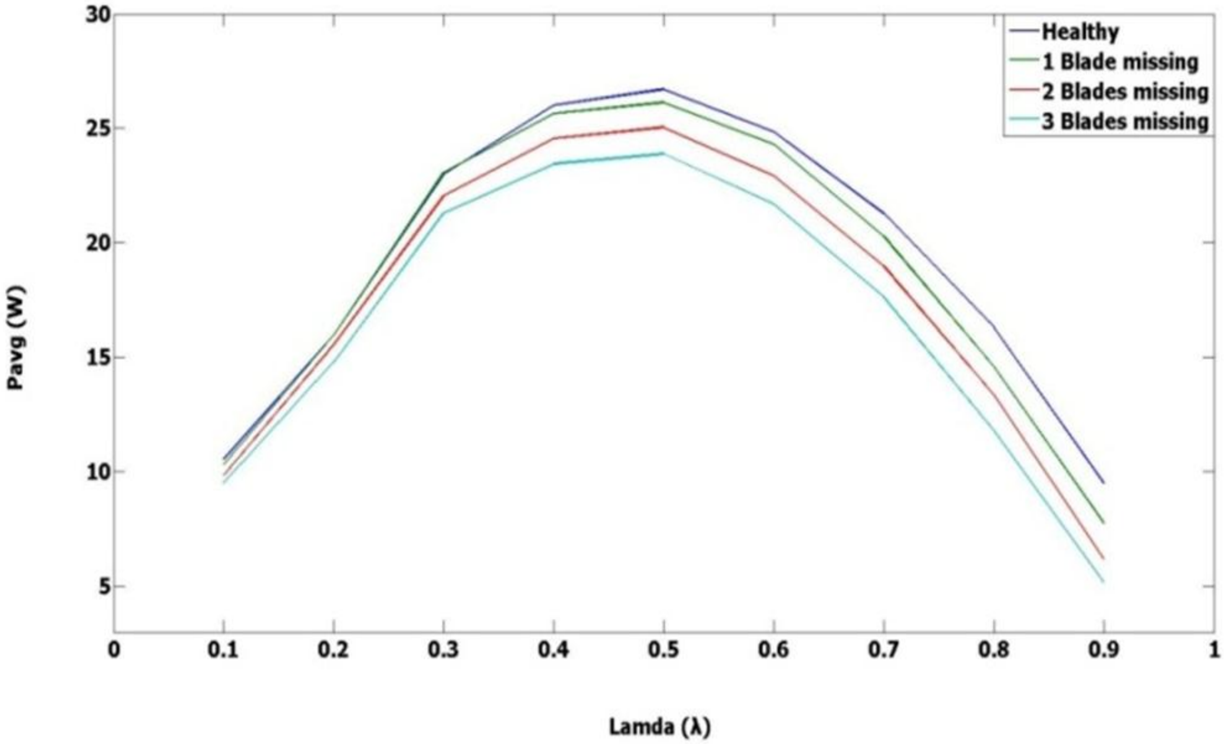

Fig. 12 Average power outputs at various TSRs

CONCLUSION

Various faults in the VAWT were introduced and the models were numerically solved for different tip speed ratios. It has been concluded that the presence of faults in the VAWT degrades the performance of the VAWT by decreasing its torque and power outputs. These faults give rise to vibrations in the VAWT which are a serious threat for the structural health of the VAWT. Investigations at various TSR has shown that the torque output from the VAWT decreases with increasing TSR while power output shows an upward facing cusp at TSR = 0.5.

REFERENCES

Consultants, B.T.M., 2008. World market update 2007

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

Lemming, J.K., 2009. Future wind energy technology and CO2 perspectives

Walker, J., 2009. Renewable energies: How far can they take us?

Park, K.S., Asim, T. and Mishra, R., 2012. Computational Fluid Dynamics based Fault Simulations of a Vertical Axis Wind Turbine, Journal of Physics: Conference Series (364)