Proceedings of the 24th UK Conference of the
Association for Computational Mechanics in Engineering
08-10 April 2016, Cardiff University, Cardiff

EVALUATION OF WIND POWER OUTPUT INTERMITTENCY THROUGH A SIMULATION METHOD

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ABSTRACT

One of the emerging issues with renewable energy technologies, such as wind turbines is the intermittent power output, in response to wind speed variation. Wind speed variation occurs at different timescales, each timescale having a different effect on the power output of the system. The key to understanding the intermittent power output is to understand the temporal dynamics of the systems output.

Vertical Axis Wind Turbine (VAWT) systems are becoming increasingly popular as they have a number of advantages over traditional wind turbines, such as reliability, ease of transportation and manufacture. The performance characteristics of a VAWT differ from that of a traditional horizontal axis wind turbine. Little work has been conducted on the performance of a low tip-speed ratio (0 – 1) VAWT systems in variable wind conditions.

In this study a non-linear, dynamic wind turbine model of a novel VAWT design is created to evaluate the wind power outputs at ms-sec time-scales. The effect that fluctuating wind patterns and the system topology will have on intermittency is of key interest in the study. A key outcome will be to understand the effect of changing particular parameters on power output fluctuations. A computationally inexpensive analytical model was created, from Newton’s laws of motion.

Keywords: *Wind Energy; Renewable Energy; Rotordynamics; Vertical Axis Wind Turbines*

1. Introduction

Wind variability is caused by wind speed variations as a result of changing climatic conditions. The classification of wind variability is based on spatial and temporal variations [1]. The time scale of the wind speed variation will have a different effect on the power system [1]. Microscale variations (ms - secs) which can be attributed to wind turbulence can cause power quality and frequency regulation problems when integrated into an electrical power system [1]. Rotor parameters can be altered to alleviate the negative effect of unsteady winds on the system output. Methods to understand and quantify the intermittent output of wind energy will be key to overcoming the technical issues associated with wind speed variation.

A suggested method of evaluating a wind energy systems response in unsteady wind conditions is the use of a dynamic simulation model. L.Ran *et al.* [2] studied the use of a dynamic simulation model of a horizontal axis wind turbine, to optimise the moment of inertia of the rotor, to alleviate output power fluctuations. Y. Hara *et al.* [3] used a similar simulation method to study the effect of moment of inertia in fluctuating wind conditions, deviating around an average wind speed value. T. Wakui *et al.* [4] used a similar model to develop a sensorless condition monitoring technique. A similar simulation technique was adopted in this study to investigate the effect of transient wind on the system.

2. Dynamic Simulation Model

The system model is simplified to include the rotational mass of the turbine and generator, coupled via a shaft with nominal stiffness and damping terms. A Standard model [5] for a double rotational mass was used to create a generic wind turbine model.

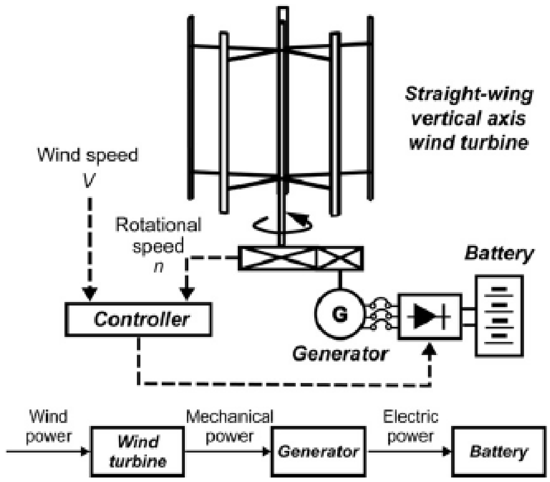

Figure 1: Schematic of the VAWT system model [4]

The equation of motion for a rotational mass is described in (1), where ω_T is the rotational speed of the turbine rotor in rad/sec, ω_G is the rotational speed of the generator in rad/sec, j_T is the moment of inertia of the rotor in Kg.m^2, t is time in seconds, $\dot{\omega}_T$ is the acceleration of the rotor in rad/sec^2 and Γ_T is the aerodynamic torque produced by the turbine in Nm. K and D are the stiffness and damping terms of the shaft, in N/m and N.s/m respectively. θ_T and θ_G are the angular displacement of the rotor and generator respectively in rads.

$$\dot{\boldsymbol{\omega}}_{\boldsymbol{T}} = \left(\frac{\mathbf{1}}{\boldsymbol{j_T}}\right)[\boldsymbol{\Gamma}_{\boldsymbol{T}} - \boldsymbol{D}(\boldsymbol{\omega}_{\boldsymbol{T}} - \boldsymbol{\omega}_{\boldsymbol{G}}) - \boldsymbol{K}(\boldsymbol{\theta}_{\boldsymbol{T}} - \boldsymbol{\theta}_{\boldsymbol{G}})] \quad (1)$$

The net torque value is taken as the net of the aerodynamic torque produced by the rotor and the load torque on the system. The aerodynamic torque is taken as an averaged, instantaneous torque value from CFD data [6], for a particular tip-speed ratio and wind speed. In the model this is taken as a lookup value from a 2D array of data. Previous authors have used Blade Element Momentum methods to generate aerodynamic torque data [4]. This data will be specific to a particular rotor, the dynamic model used is generic.

The numerical model involves integrating the equation of motion, over time, for a given wind speed profile. To integrate the equation of motion an initial value explicit Euler method was used, from the following equations:

$$\Delta\boldsymbol{\omega}_{\boldsymbol{T}} = \dot{\boldsymbol{\omega}}_{\boldsymbol{T}}.\boldsymbol{\Delta}\mathbf{t} \quad (2)$$

$$\boldsymbol{\omega}_{\boldsymbol{T}_{\boldsymbol{n}}} = \Delta\boldsymbol{\omega}_{\boldsymbol{T}_{\boldsymbol{n-1}}} + \boldsymbol{\omega}_{\boldsymbol{T}_{\boldsymbol{n-1}}} \quad (3)$$

The model consists of three main sections, the aerodynamic section, mechanical drivetrain section and the control load torque on the system. A number of control load torque regimes can be used. T. Wakui *et al.* [4] employed a constant tip-speed ratio load torque up until a power limit, then a constant speed torque mode was used. This is a typical control algorithm, which tracks the maximum power point at each wind speed up until a rated speed where a power shedding mode is utilised. A flow chart of the model method is shown in Figure 2 below

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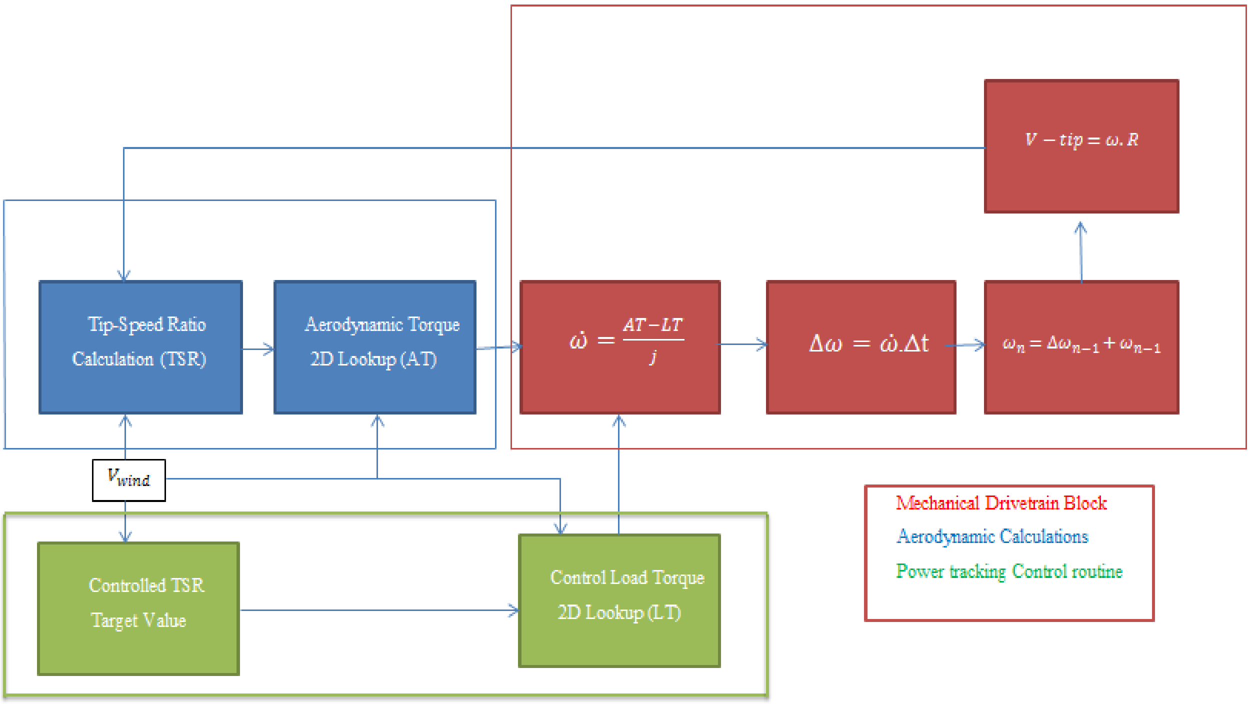

Figure 2: Outline of Dynamic Simulation Model

A number of unsteady wind conditions can be used in the model, high resolution (100 Hz) real wind data and a standard wind gust model prescribed in the British standard (BS EN 61400-2:2006) was used.

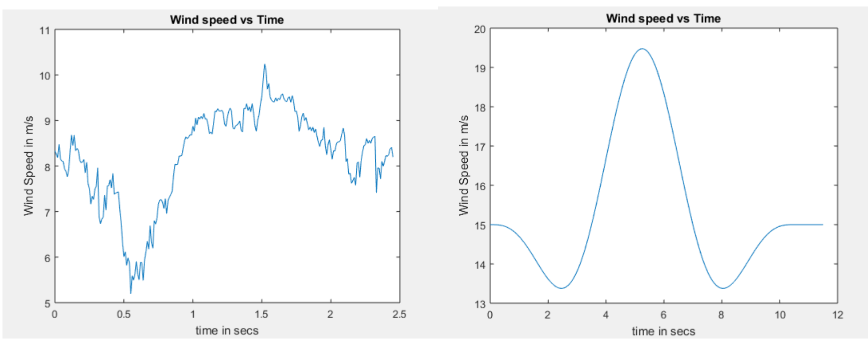

Figure 3: High Resolution (100 Hz) Sample of Wind Data (left), BS EN 61400-2:2006 wind gust model (right)

3. Conclusions

In this work a computational tool to test the effect of unsteady wind on a VAWT was created. The model can utilise a number of input wind conditions and control regimes for different rotors. This makes the model a useful tool for a parametric study of the rotordynamics in a number of wind conditions, at different timescales. The tool will be used for studying the power smoothing potential of the moment of inertia in unsteady wind conditions. Also the future work will look at coupling the VAWT model with other technologies such as wind pumping technology.

Acknowledgements

The author Amir Jalalian-Khakshour would like to acknowledge the funding from the EPSRC (EP/I015507/1) funded EDT MATTER - Manufacturing Advances Through Training Engineering Researchers, C-fec Ltd. and the European Social Fund through the Welsh Government.

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