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OPTIMIZED MODELING, SIMULATION AND CONTROL OF A HORIZONTAL AXIS WIND TURBINE FOR LOW WIND SPEED APPLICATIONS USING MATLAB/SIMULINK

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ABSTRACT

Studies have demonstrated the feasibility of wind turbines in Malaysia, particularly during monsoon seasons, despite the region's low average annual wind speed. A dynamic simulation model of a wind turbine was developed in MATLAB/Simulink, specifically tailored for low-rated wind speed conditions, with the UTM wind turbine serving as the reference design. The model was used to simulate, evaluate, and optimize the dynamic responses of the UTM wind turbine control system—including supervisory control, generator torque control, and pitch angle control—under varying wind conditions. Using the Power Signal Feedback (PSF) method, the optimal Maximum Power Point Tracking (MPPT) control strategy for generator torque control was determined to be a 50%-35% MPPT reference power approach. This strategy entails maintaining 50% of the ideal mechanical power at maximum power points across Region 2 of the turbine's operating range, except at the rated wind speed point, where 35% of the ideal mechanical power was applied. Additionally, the pitch control system was optimized by adjusting the derating pitch angle array and refining a conventional PID controller. The improvements focused on enhancing power output stability, reducing overshoot, minimizing settling time, and decreasing steady-state error. The optimized PID gains were identified as Proportional (P) = 1000, Integral (I) = 1, and Derivative (D) = 150.

KEYWORD

Low rated wind speed horizontal axis wind turbine, MATLAB/Simulink, power signal feedback (PSF), torque, pitch control, conventional PID controller, renewable energy

INTRODUCTION

The University of Technology Malaysia (UTM) research team has successfully deployed a 30 kW, 25-meter diameter Horizontal Axis Wind Turbine (HAWT) in Nusajaya, Iskandar Puteri, Johor Bahru, marking a significant step in advancing Malaysia's renewable energy capabilities. While the initial turbine design was based on analytical calculations, the team recognized the critical need for a dynamic simulation model to further refine performance predictions and optimize real-world operation. The research objectives are: a) To evaluate the dynamic responses of low rated wind speed wind turbine control systems towards varying wind speeds in terms of power generation, supervisory control, pitch control, and generator torque control through MATLAB/Simulink simulations; b) To optimise the Maximum Power Point Tracking (MPPT) strategy based on Power Signal Feedback (PSF) method for improved generator torque control; c) To determine the optimum derating pitch angle and conventional PID controller gain for UTM wind turbine. A localised Simulink simulation model for low wind speed wind turbines was developed based on modifications on the MATLAB built-in wind turbine model (MathWorks, 2025).

The model covers the detailed simulation of wind conditions, full system of an onshore upwind HAWT including turbine rotor, control system, gear train, power generator and power grid, as in Figure 1. The dynamic responses of the developed model were assessed based on time series output signals of several crucial parameters such as power generation, pitch angle, generator torque, and turbine operational states, with respect to varying wind speeds. The simulation outcomes of each simulation were illustrated in Figure 2.

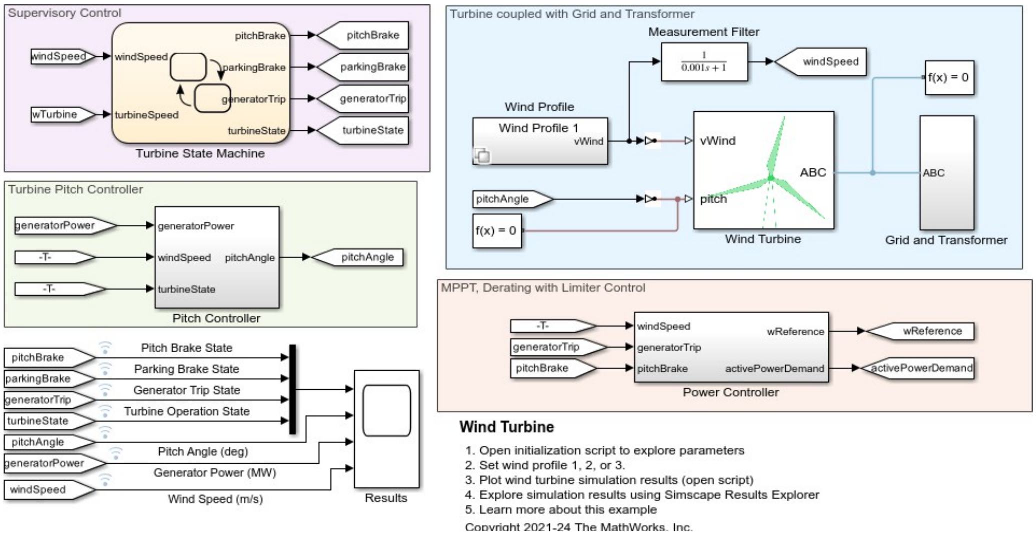

Figure 1: Simulink wind turbine model overview

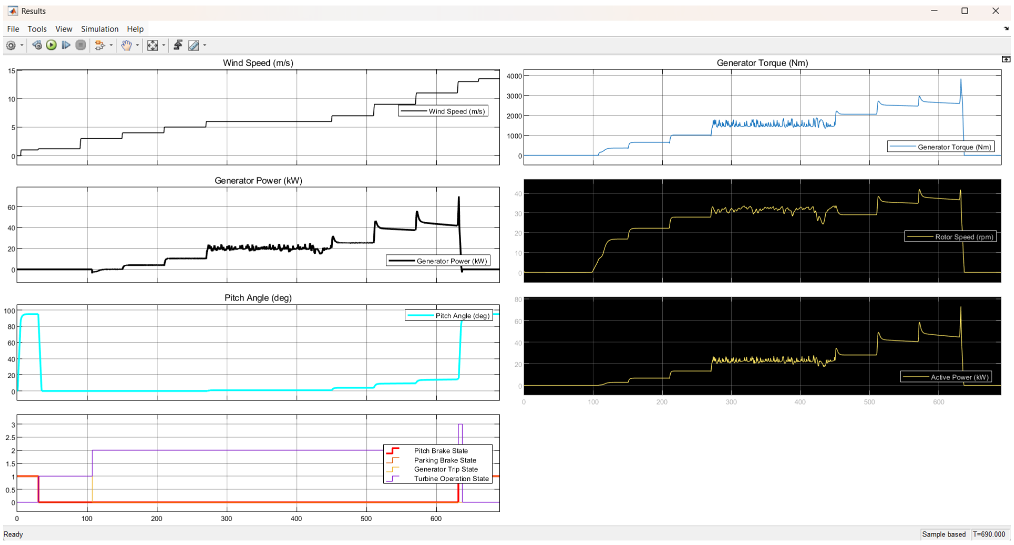

Figure 2: Simulation outcomes generated through Simulink

MATERIAL AND METHODOLOGY

A wind turbine model was first adopted from the MATLAB documentation to develop a simulator for UTM wind turbine. This model uses a Simulink block from Simscape Driveline library, as shown in Figure 6. The generator modelled is a doubly fed induction generator (DFIG) with low fidelity to improve the simulation time (MathWorks, 2025). The model utilises stateflow to simulate the supervisory control of wind turbine, where the operational readily switches between park brake state (state 0), start-up state (state 1), generating state (state 2), and pitch brake state (state 3) depending on the current wind speed input. Uni-directional wind inputs were expressed in the form of time series signal and fed into the model during the simulations. Initial input parameters were obtained based on data and specifications of UTM wind turbine.

The generator torque control was performed through a Maximum Power Point Tracking (MPPT) strategy, known as the Power Signal Feedback (PSF) method. The PSF method uses a look-up table to linearly interpolate the pre-determined MPPT reference power and MPPT reference generator speed at each MPPT wind speed points.

For generating state, pitch angle stays minimum in region 2, while PI controller and Derating pitch control are implemented to control the pitch angle in region 3. The equation governing the pitch angle control of this model is:

$$\beta = \beta_{min} + K_p \Delta P + K_i \int \Delta P \ dt + K_d \frac{d\Delta P}{dt} + \beta_{derating} \quad (1)$$

Where βmin is the minimum pitch angle, K_p is proportional gain, K_i is integral gain, K_d is derivative gain, ΔP is the difference between power generated and rated power (P_{gen} – P_{rated}), which is only applicable when the difference is positive (region 3), $\beta_{derating}$ is the derating pitch interpolated from a look-up table. $B_{derating}$ was optimised through iterations as the simulation outputs of each simulation can be readily obtained using the model.

Performance criteria were formulated as in Table 1, and reference values were taken from past research (Hamoodi et al., 2018; Ren et al., 2016; Poultangari et al., 2012; Hassan et al., 2012; Evans et al., 2018), to determine the rough range of optimum K_p, K_i, and K_d. After obtaining some prior knowledge based on the simulation outputs, a few iterations were done to deduce the optimum gains. The performance criteria accounted for 3 cases representing 3 levels of drastic wind change, to ensure the robustness of PID controller developed under various wind conditions. The overshoot percentage, settling time, and steady state error for every PID value sets tested were computed and written into an ExCEL file through MATLAB.

Table 1: Performance criteria for PID optimisation

Criteria	3m/s to 7 m/s	3 m/s to 10 m/s	3 m/s to 12.9 m/s
Overshoot	<10 %	<50 %	<100 %
Settling time	<7 seconds	<7 seconds	<10 seconds
Steady state error	< 2 %	<2 %	< 5 %

RESULT AND DISCUSSION

The MPPT parameters were inputted as arrays to be linearly interpolated through look-up tables. The initial MPPT reference power was equivalent to 90% of the ideal mechanical power (90% due to generator efficiency). Nevertheless, the wind turbine failed to generate any appreciable power across a wide range of wind speeds, from 1.21 m/s to 7 m/s. This indicates that the rotor blades failed to accelerate and produce an increasing torque. As a solution, the MPPT reference power was reduced to 65% of the ideal mechanical power. The values were obtained through repeating decrement of the reference power to identify the threshold to be free of rotor stall due to rapidly changing wind speeds.

While using 65% MPPT reference power for all elements in the array, the power generated at rated wind speed is capped at 20 kW. When the model was tested with constant wind speed inputs of 4.5 m/s to 6 m/s, the generator torque and rotor speed did not achieve the desired magnitude, indicating the current MPPT reference power was still too aggressive for this wind speed range. Two strategies were proposed, such as 65%-50%-35% MPPT reference power and 50%-35% MPPT reference power. Comparative studies were carried out to determine which strategy is a better option, in terms of the responses of both strategies towards constant and abruptly changing wind speeds, and power generation at specific wind speed points (Table 2).

Table 2 results prove that 50%-35% MPPT generates slightly more power than 65%-50%-35% MPPT across the range. Therefore, 50%-35% MPPT is a better option for maximising the power generation. Besides,a few iterations were performed to deduce the best derating pitch angle array. After performance analysis of a 18 set of PID gains, the optimum PID data set was deduced to be K_p = 1000, K_i = 1, K_d = 150, as it perfectly satisfies the requirements in Table 1.

Table 2: Comparison between two strategies for power generation at specific points

Wind Speed Point (m/s)	65%-50%-35% MPPT Power (kW)	50%-35% MPPT Power (kW)
1.4	-0.072	0
1.6	0.077	0.228
1.8	0.286	0.473
2.0	0.407	0.657
2.2	0.757	1.004
3	2.487	2.443
3.5	4.298	4.348
4	6.661	6.725
4.5	9.426	9.446

CONCLUSION

A Simulink simulator for UTM wind turbine is successfully developed through the modifications of the MATLAB/Simulink built-in wind turbine model. The model is localised to better suit the applications in low wind speed regions like Malaysia. This model enables the simulations of wind turbine operations under different wind conditions and generate time-series signals of important parameters in performance evaluation.

The developed simulator embodies its values in the optimisation of generator torque control as it provides a convenient platform for the optimisation task. In the end, the best strategy is deduced to be 50%-35% MPPT. The finding shows that low rated wind speed wind turbine has a displaced maximum power point as in De Kooning (2015). The optimum derating pitch angle set works together with the optimum PID gains of K_p=1000, K_i = 1, K_d =150 to ensure the constant 30 kW power generation across region 3, prevent high voltage spike, improve the response time, and eliminate the power mismatch during steady state.

The Simulink simulator developed is specifically designed to model all wind turbines with low rated wind speed, instead of solely representing the UTM wind turbine. It can be used to simulate other design solutions for low wind speed applications.

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