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Optimization Design Blade Wind Turbine in Enhancing Power Based on Passive Control System

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Abstract: Control power on rotor wind turbine can be carried out by changing blade angle of attack through via pitch control and stall regulated method to produce much power and control power as well as protect wind turbine from high wind to operate in rated power. By using search-based design method to optimize design blade and Blade Element Momentum Theory (*BEMT*) to analyze aerodynamic performance for stall and pitch control power. Recent work demonstrates that some very significant effect can be achieved by using constant speed pitch control. Comparing of among ordinary blade and design blade of constant speed stall regulated and optimized show that enhancing power is nearly similar while design blade using pitch control give significant effect in enhancing aerodynamic performance of design blade. For average power, design blade constant speed pitch control has average power about 47970,77 Watt and constant speed stall regulated is 43855,41 Watt.

Keywords: Design Blade; Pitch Control; Power Coefficient; Stall Regulated; Rotor Power

Introduction

The use of renewable energy is now increasing (Muslimah et al., 2020; Maslikhah et al., 2022; Anggereini et al., 2023). As evidenced by the increasing use of renewable energy that be based technologies, it can be seen on application technologies such as solar panels, micro hydro, wind turbine, biogas and biomass (Wiratama, 2014; Li et al., 2018;). Wind turbines as a renewable energy-based technology has been widely operated to produce large-scale (mega-watt) electricity generated by wind farms in which rotor blade wind turbine have to be designed for extract maximal energy kinetic and its rotor blade is required to work at optimal shape of the blade during operation (Wiratama et al., 2016; Menezes et al., 2018).

Generally, to control blade during operation, classical power control system via pitch control and stall regulated are the common methods used to protect wind turbine operation and enhance as much as possible aerodynamic power production from the wind speed and as far as achieving rated power Samani et al. (2020) and in other side to limit produce power of rotor blade at below rated power (Wiratama et al., 2016; Macquart et al., 2017; Wiratama et al., 2023).

This paper compares of use of power controls via pitch control and stall regulated in optimization of design blade wind turbine that aimed to enhancing power at low wind speed and power regulated at high wind. Both of control power methods are based on controlling flow angle of attack at different wind speed and its functions have been widely applicated for medium and large-scale wind turbine (Wiratama & Maheri, 2014; Macquart & Maheri, 2015; Maheri 2020; Wiratama et al., 2021; Maheri et al., 2022).

In power control by using stall regulated control method, shape of blade has to be designed in stall condition in high wind speed and blade operation is without any pitching control system applied therefore stall regulated is simpler and pitch of blades are only once set-up and adjusted when wind turbine is installed. Optimization design blade using stall regulated have been investigated in the blade design. Maheri (2020) and Maheri et al., (2022) have carried out alternative

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approach into computing design blade by utilizing passive control system adaptive blade into the blade design calculation. The alternative approach into simulation design of adaptive blades uses the variable state design parameters concept and those investigations are use stall regulated for control power production. More deeply invetigation using stall regulated have been done by (Wiratama & Maheri 2014) and (Yuan & Tang 2017) which have investigated optimization design blade with flap for enhancing power based on the stall regulated control power. Many investigations found that stall regulated influence shape of power curve and its control power method does not provide the perfectly shape flat power curve when power production on top of rated wind speed.

In blade pitch control this control power has primarily been used to limit aerodynamic power on optimization design blade wind turbine when higher wind speeds operation. Pitch control power has been successfully utilized for this purpose (Chen et al., 2017; Habib et al., 2017). The investigation based on the approach and objective from those systems were quite varied with many researches involved in the investigation. Cheney & Speirings (1978) and Ward et al., (2019) investigated power control production with applied a device centrifugally loaded mass (a device system mechanical control) on an elastic arm as the system control rotor blade operation. A system mechanical control for regulating cyclically pitching blade for control load balancing had been worked in completely by (Ward et al.,2019). Dao et al. (2019) had developed a system adjusting pitch by using passive pitch control for controlling both of load control reduction and power regulation. The utilizing of all available blade loads to control power had been evaluated by (Ebrahimi et al., 2019) that was based on the effect pitch changes to regulate the rotor power output, the investigation aimed to get a flat power curve on higher wind speed condition. They reported that to achieve blade pitch position in the perfect adjusting position was quite problematic and that even the results less than perfect adjusting position became more challenge. Some investigations reported that to achieve perfect regulation these method approaches also depend on a quite substantial the influence of rotor blade rotations.

The comparison of a thorough results investigation of design wind turbine blade in enhancing the energy capture capability by using stall regulated and pitch control system give a confidence on the behavior of power control during wind turbine operation. The aerodynamic performance of blade design using Blade Element Momentum Theory (BEMT) will be analyzed. The investigation used the same methodology that presented in previously studies by (Wiratama, 2014) and (Macquart & Maheri, 2015) which are all of controlling parameters are found through solving an optimization problem, which can be formulated based on the investigation flap control systems and others utilizes control systems, (Macquart et al., 2017; Yuan & Tang, 2017; Habib et al., 2017; Maheri, 2020; Maheri et al., 2022).

Method

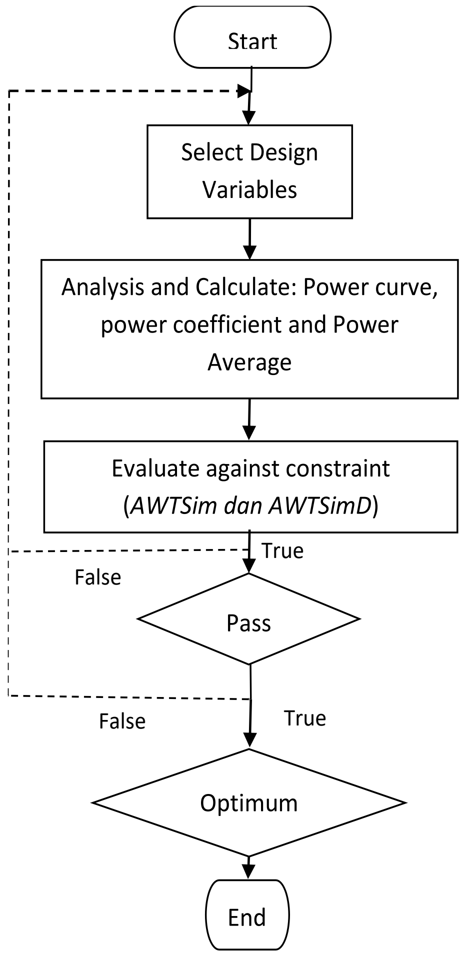

Figure 1. Flowchart tool to analyze and optimize design blade

The aerodynamic performance of rotor blade is influenced by some characteristics. To achieve better aerodynamic performance of design wind turbine some aspects have to be considered in effecting aerodynamic performance of design blade such as wind turbine rotor characteristics and characteristics of control system as well as operating condition.

By assuming blades have aerodynamic characteristics and a fixed shape of blade, this simulation design methods in theoretically deliver the optimal result shape of the blade. This simulation design methods, however, fail in optimal design of blades that equipped with controlling aerodynamic devices such as pitch and other controllers which influence the aerodynamic characteristics of blade. For such cases optimal aerodynamic shape of blade design is obtainable by using a direct search-based design method.

Therefore, to carry out simulation design blade, the control system behavior is also included in the simulation along with the aerodynamic behavior of the rotor blade wind turbine. This, however, is not practical as it requires having the control system designed prior to the blade. An alternative solution to this is to assume that the controller is capable of delivering the expected functions perfectly. This implies that the controlling parameter is always adjusted at its best possible value which leads to the best (goal) performance. Adapting this approach, the optimum (best possible) controlling parameter, which optimizes the performance measure(s) can be found via solving an optimization problem formulated.

For the passive control in case of stall regulated control power blade, the controlling parameter depends on wind turbine operating condition. A change in wind turbine operating condition by wind speed affects the flow kinematics around the entire of the blade either by changing in inflow angle for regulating power.

By modification control strategy for optimization design blade with flap for enhancing power based on the stall regulated control power (Wiratama & Maheri, 2014), simulation is carried out by Aerodynamic Wind Turbine Simulation Design (*AWTSimD)* package (Maheri et al., 2022). *AWTSimD* is a simulation package that is used to design wind turbine blade based on the search-based method. In *AWTSimD*, the control power system is simulated via solving an optimization problem. It is expected that the power control systems are efficient to delivering of the expected functions excellently. This indicates that the controlling parameter is managed at its best possible value, which brings to the best (goal) performance of design blade. Adapting this control strategy, the best possible controlling parameter, which optimizes the performance measure can be achieved through solving the optimization problem. The Aerodynamic Wind Turbine Simulator *(AWTSim)* package tool, as objective evaluator, is integrated with the Genetic Algorithm *(GA)* optimization module to form the blade design optimization tool. That is, each produced design candidate at the stage of initial population generation or as a result of crossover and mutation operations in *AWTSimD* and aerodynamic performance for each candidate is evaluated using *AWTSim*.

In this project, all of controlling parameters are found through solving an optimization problem, which can be formulated based on the investigation flap control systems and others utilizes control systems, (Wiratama & Maheri, 2014; Macquart et al., 2017; Maheri et al., 2022) and the optimization problem can be formulated as follows:

$$\max \quad P(q_i); \; i = \{1,2,\ldots,n_q\} \tag{1}$$

subject to

$$P \le P_{rated} \tag{2}$$

$$q_{i,l} \le q_i \le q_{i,u}\,; i = \{1,2,\ldots,n_q\} \tag{3}$$

In Equation (1), P is the rotor mechanical power at variation of range wind speed, q_i stands for the i-th controlling parameter limited to the interval $[q_{i,l},q_{i,u}]$. Number of independent controlling parameters, n_q depends on the rotor speed (constant speed or variable speed) (Wiratama & Maheri, 2014).

In order to select the best optimization method for optimization problem of Equation (1), it is needed to identify the type of this problem first. This is a constrained problem and therefore it needs an optimization method capable of dealing with constrained problems. The rotor power can be calculated and analyzed only through a numerical iterative procedure based on the Blade Element Momentum Theory (*BEMT* - Calculation) in the *AWTSim* tool that been validated for analysis design blade wind turbine (Wiratama, 2014).

Result and Discussion

The amount of enhancement aerodynamic performance of design blade via power and power coefficient due to constant speed regulated and pitch control as well as blade optimized using both control systems are shown in the through Figure 2 to Figure 7. As can been seen on the Figure 2 and Figure 3 the results show control system for stall regulated nearly similar result for given wind speed at low wind and high wind speed while Figure 4 and Figure 5 with pitch control system give significant effect in low wind speed compare to ordinary blade.

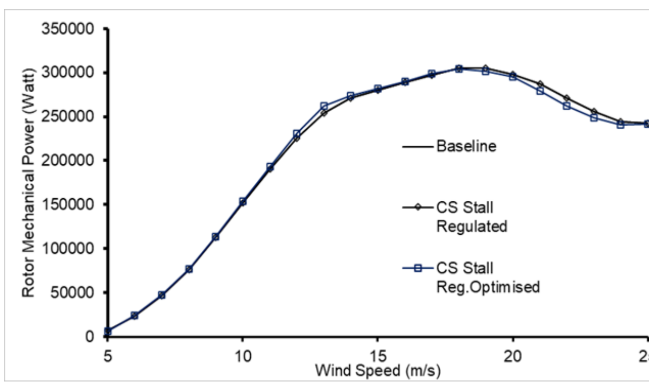

Figure 2. Result of power curve by using ordinary blade, constant speed stall regulated and blade optimized

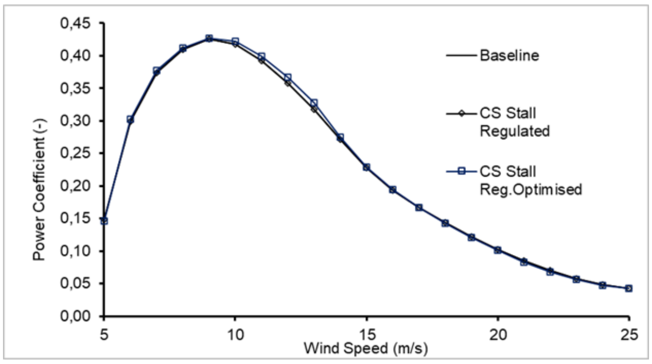

Figure 3. Result of power coefficient by using ordinary blade, constant speed stall regulated and blade optimized

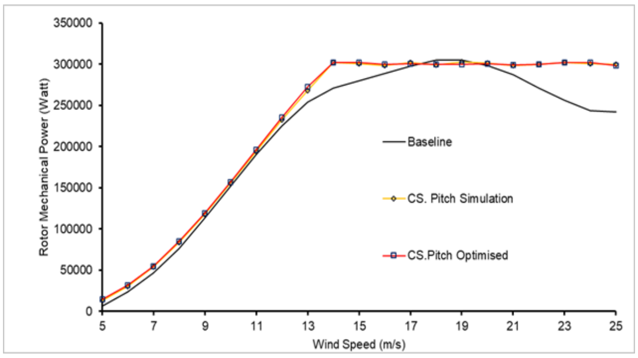

Figure 4. Result of power curve among ordinary blade, constant speed pitch control and blade optimized

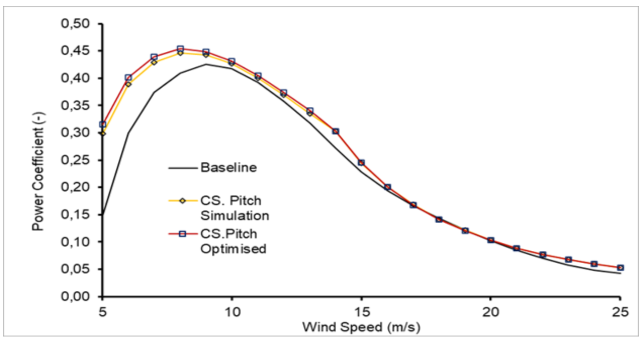

Figure 5. Comparison of result power coefficient by using ordinary blade, constant speed pitch control and blade optimized

As can be seen from Figure 4 and Figure 5 it can be observed that significant effect of increasing power of design blade in low wind speed because of increasing power coefficient when design blade using constant pitch control system and optimized blade have similar result for rotor power and power coefficient. As a function of rotor power the power coefficient increase at low wind speed which is aerodynamic performance of design blade based on the constant speed pitch control more suitable applied in low wind region and also this control system appropriate for design blade of small wind tur-bine because small wind turbine needs more rotor speed at low wind consequently, it is not rather simple be-cause wind turbine need electric to adjusted the pitch of the blades when the wind turbine is erected to achieve stall-regulation at appropriate wind speeds.

Through Figure 6 to Figure 8 with comparison among those control show that constant speed pitch control gives significant effect in low wind speed compare to ordinary blade. In this case, pitch control maintains the optimum blade angle to achieve power output or certain rotor speed.

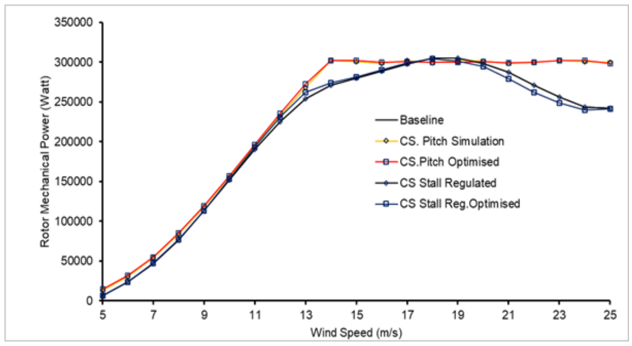

Figure 6. Comparison results of power curve for constant speed stall regulated speed and pitch control system

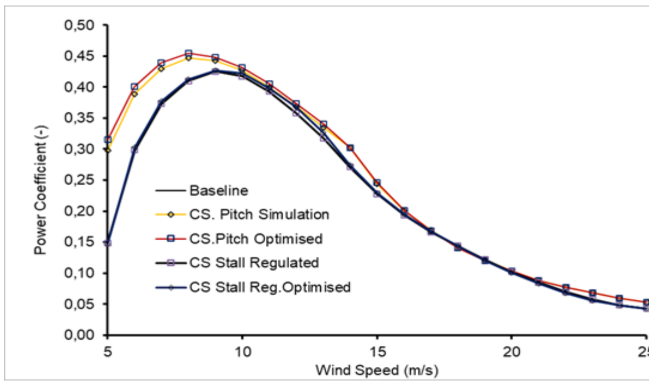

Figure 7. Comparison results of power coefficient for constant speed stall regulated speed and pitch control system

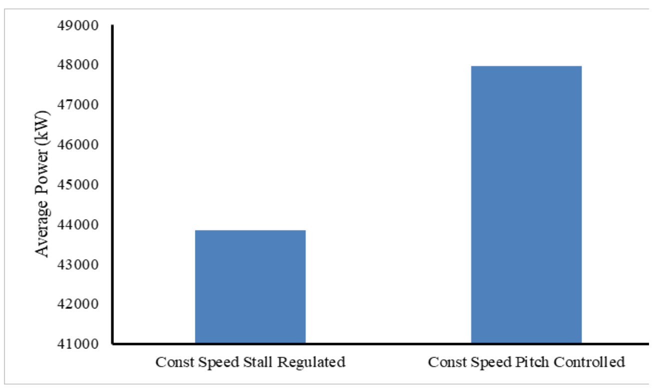

Figure 8. Comparison results average power based on design blade between constant speed stall regulated and pitch control system

From those figures comparing result of average power show that average power of design blade with constant speed pitch control is 47970,77 Watt while average power of design blade with constant speed stall regulated is 43855,41 Watt.

Conclusion

The presented research work allows the following conclusion for design blade for different control system as follow: The amount of enhancing of aerodynamic power for design blade with constant speed stall regulated and optimized compare to ordinary blade is nearly similar, moreover by using constant speed pitch control and blade optimized the amount of enhancing power and power coefficient are significant effect in low wind speed compare to ordinary blade. In addition, the average power of design blade with constant speed pitch control is 47970,77 Watt while average power of design blade with constant speed stall regulated is 43855,41 Watt.

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Conflicts of Interest
The author's interest in publishing this article is for research output needs in the form of publication in scientific journals as proof of the required performance. No conflict of Interest.

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