Design Control System of Pitch Angle Wind Turbine Horizontal Axis based Imperialist Competitive Algorithm (ICA)

Engineering

Ali Musyafa	Engineering Physics Department, Faculty of Industrial Technoogy, Sepuluh Nopember Institute of Technology, Indonesia & Kampus ITS. Jl. AR.Hakim , Surabaya Indonesia, (60111) * Corresponding Author
Akhmad B. Fauzi	Engineering Physics Department, Faculty of Industrial Technoogy, Sepuluh Nopember Institute of Technology, Indonesia & Kampus ITS. Jl. AR.Hakim , Surabaya Indonesia, (60111)

ABSTRACT

Wind Energy Conversion Systems (WECS) is one of the alternative energies developed from the use of small-scale wind wurbine.WECS capacity is less than 10 kW. Indonesia winds changing and relatively low. To overcome these problems required the control system of wind turbine pitch angle. In this study designed a control system of wind turbine pitch angle based imperial Competitive Algorithm (ICA). The control system is expected at varying wind speeds, can provide rotor angular velocity remains stable and working at optimum area. ICA is a novel evolutionary algorithm to optimize a system inspired from competition rule (imperial Competition). Optimization for ICA-based control system designed using ITAE (Integral Time Absolute Error) as the objective function in determining the PID control parameters. The results showed ICA-based PID control responds well to all set point tests, and the test results set point 10 peps provide the best response when compared to a higher set point. With Kip, Kid, and Kid sequentially 1:49, 3:13 and 0:03 gave the maximum overshoot (maximum overshoot) 11:30% with down time (settling time) for 1.85 seconds and quantitatively ITAE=0.42 for 10 seconds.

INTRODUCTION

The development of wind power technology in Indonesia is growing rapidly due to the energy crisis and efforts to develop alternative energy business. Development of alternative energy that is towards the development of conventional electrical energy electrical energy based on renewable energy. Wind Energy Conversion Systems (SKEA) consists of a wind turbine, generator, power electronics, network systems and small-scale wind control systems. Wind turbine capacity is less than 10 kW [1]; this turbine is suitable for Indonesia, which has a wind speed change. Energy low and variable power generated by wind turbines rely on mechanical power derived from the kinetic wind energy input. The several variables that affect the amount of mechanical power turbines which are coefisiency power (Cp). Value of the power coefficient is influenced by wind speed, pitch angle, and the speed of the turbine rotor.

In order to get the optimum power required at the wind turbine control system. Design of control system that controls the pitch angle of the wind turbine. Pitch angle of the turbine control system is controlling the angle of the turbine blades to produce the rotor angular velocity remains stable and are in optimal working. In this paper, we have designed a control system based on imperial pitch angle Competitive Algorithm (ICA). ICA method is a method of evolutionary optimization algorithms inspired by the latest imperialist competition [6]. Optimization (ICA) is able to provide the optimal control parameter values with the search value in the form of values of PID control parameters Kp, Ki, and Kd-based optimal imperialist competition.

MATERIALS AND METHODS

Wind turbine performance is affected by the power generated by the wind speed wind turbine bervariasi. The power shown by the following equation.

$$P = \frac{1}{2}C_p(\lambda, \beta)\rho_{air}A_r v^3 \qquad (1)$$

Based on the equation (1), wind turbine power is directly proportional to the amount of air density, broad sweep of the turbine rotor, wind speed and power coefficient (Cp). Power coefficient is influenced by the amount of Tip Speed Ratio (TSR) of wind turbines. TSR () is a variable which indicates the ratio between the speed of rotation around the blade and wind speed [1-2]. R is the length of the blade, is the speed of the rotor, and v is the wind velocity. TSR and the power coefficient are influenced by the pitch angle (β), Cp (λ, β). Cp maximum will be obtained if the position of the pitch angle is at the right position and the right tip speed ratio. Cp maximum wind turbines will generate maximum power.

TABLE - 1 PARAMETRE OF WIND TURBINE

Parametre	Value
Wind Speed	4.8 m/s
Beta (pitch angle)	10.5 degre
Rotor Speed	68.96 rpm
Long of Blade	1.0 m
Momen Inersia of rotor	1.297 kg m^2
Air Density	1.25 kg/m^3

Based on Table 1, which shows some of the
Tip Speed Ratio Based on the equation, the maximum power of the wind turbine can be obtained by assuming that one value constant and used as desired set point, and the turbine blade radius (R) is constant, then Cp only depends on the wind speed (v) and angle pitch (β), the pitch angle will be a controlled variable as a result of reaction varying wind speeds, in order to obtain the desired value of the power turbine. Pitch angle corresponding to various wind speed and its relationship with the rotor speed has been done by previous studies [x] and will be used as the basis for research.

Imperial Competitive Algorithm (ICA) is a new evolutionary algorithm to optimize a system inspired from competition rule (imperial). This algorithm was introduced by Atashpaz-Gargari and Lucas in 2007.ICA using the evolutionary process of socio-political conditions as a source of inspiration optimization strategy [6]. The optimization process is usually done with an optimization function to find the optimal solution value. Competitive imperialist algorithm can be described with the following steps [6],

Initialization Kingdom (Initial Empire):

This stage will be set up in advance of an empire consisting of imperialist and colony. ICA began by forming an array of variable values wich be optimized. Algorithms such as the GA, the array is called a "chromosome", then at the ICA known as state or "country". A state is 1 x Novar array. This array is shown as the following equation,

Country = $[p_1, p_2, p_3, \ldots\ldots p_{Nvqr}]$ (2)

Variables (P1, P2, P3, ..., PNvar) is a number of variables to be optimized Nvar, the cost of each country can be determined by evaluating the cost function at each of the optimization variables, the following equation,

Cost = f(country) = f $[p_1, p_2, p_3, \ldots\ldots p_{Nvqr}]$ (3)

Optimization algorithm begins by creating a form of population Country Country.Able two types, namely imperialist and colony. To form the initials of the empire, the division of the colony should be based on the strength of the imperialist.

Colonies movement towards imperialist An Empire:
This stage, the State imperialist start to improve or enhance their colony by moving all the way to approach the imperial colonies, colonies as far as x approaches imperial units, where the value of x is uniformly distributed random variables. So the value of x, we get the following equation,

$$x \sim U(0, \beta x d) \qquad (4)$$

Value β is a number that is more than 1 and d is the distance of the colony and the imperialist. Value of β> 1 will result in the colony moves closer to the imperialist viewed from both sides.

Exchange Position Imperialism and Colonies:
This stage, while moving closer towards an imperialist, a colony will reach the area or position that the price is lower than the imperialist. At this stage of imperialist moves towards the position of the colony and vice versa. The algorithm will continue by imperialists who move to a new position and start colony closer to that position.Total Power of the Kingdom: This stage, determined the total price of the overall strength of the kingdom or empire is primarily influenced by the strength of the imperialist states but the strength of the colony also has a negligible effect because of the small though. Total Cost shown by the following equation.

T.C$_n$ = Cost (Imperalist$_n$) + ξ mean{cost(colonies of empire$_n$)}

                                                   (5)

Competition Imperialist: This stage, is the basic philosophy of the process of imperialist competition, all the kingdom (empire) trying to have a colony of another kingdom and their control. This imperialist competition will gradually decrease the strength of the weak and the kingdom will increase the strength of the more powerful empire. As illustrated by taking a few colonies (one colony) on the weakest kingdom, then made a royal competition where will have it. Based on their total strength (empire), in this competition, each kingdom has the possibility (likelihood) to take and have the weak colony. So that the weakest colonies will not always owned by the most powerful kingdom, but the kingdom that will most likely have it.

Elimination Kingdom of The Weakest : This stage, which is helpless kingdom will collapse and the imperialist competition, their colonies will be distributed to the other kingdoms. Criteria for determining the weakest empire can be defined different. But in most implementations of ICA algorithm assumes and analogize kingdom is said to be powerless kingdom lost all its colonies. And this kingdom will be eliminated or removed. Furthermore, all the weak kingdom will fall and eliminated, so that only one of the most powerful that will control all the colonies, with the last stage of this condition and the cessation of imperialist competition algorithm.

In this study, the control system is designed using a PID control, the modeling of the wind turbine is based on linear modeling of

wind turbine obtained from several references [4-5-7]. Modeling was performed using several parameters the results of research on the relationship with the pitch angle of the rotor speed of the turbine and the search for the optimal pitch angle that produces the maximum rotor speed varying ranges of 2.8 m / s - 7.5 m / s. wind turbine used is prototype turbine small-scale wind blade type non-uniform S83n NREL Airfoil with three blades (blade) [3].

The parameters used in the modeling of wind turbines in this study, obtained the transfer function of the wind turbine as;

$$F_T(s) = \frac{\Delta\omega(s)}{\Delta v(s)} = \frac{6.051s}{0.01s^3 + 1.002s^2 + 0.1816s} \qquad (6)$$

Pitch angle control system design based imperialist competition algorithm (ICA) can be described by a block diagram of the optimization.
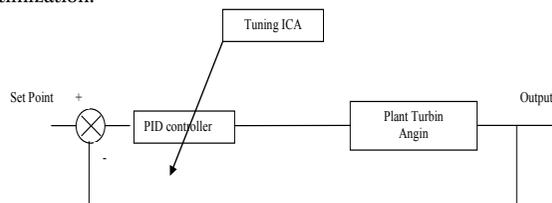

Figure 1. Block Diagram of Control System base ICA

Based on Figure 1 above, algorithm-based control systems imperialist competition (ICA) designed a control system using PID control. Value of the control parameters Kp, Ki, and Kd optimized with ICA algorithm, thus providing value solutions for the optimal control parameters of the control system are designed. ICA will tune the value of Kp, Ki, Kd by giving advance limit value of Kp, Ki, Kd are to be obtained. The process is based on the optimization objective function in the form of a minimum value of Integral Time Absolute Error (ITAE). ITAE is an index of the performance criteria are based on the price and the time integral of absolute error, the following equation ITAE.

$$ITAE = \int_0^\infty t|e(t)| dt \qquad (7)$$

Where t is time, and e is an error, the error is the difference between the outputs with the input of control system simulation. ICA-process based control system design with Simulink and Matlab 7.12.0 (R2011a). Parameters used in the optimization process optimization ICA algorithm as follows,

TABLE – 2 ALGORITHM PARAMETRE OF ICA

Parametre	Value
Jumlah Negara	50.00
Jumlah imperialis awal	5.00
Jumlah koloni	45.00
Dekade	50.00
Kecepatan Revolusi	0.30
Asimilasi (β)	2.00
Sudut Asimilasi (γ)	0.50
Zetta (ξ)	0.02
Kp	$0.5 \leq Kp \geq 1.5$
Ki	$1 \leq Kp \geq 5$
Kd	$0.01 \leq Kp \geq 0.1$

CASE STUDY
Performance testing base set point done with the three conditions set point which represents the variation of wind turbine rotor rotational speed, rotational speed of the rotor in the form of pulse value pps (pulse per second), pps is the number of pulses generated by the turbine rotor speed transmitter circuit for

one second that is received by the control digital. Pulse per second (pps) is used to calculate the rotational speed of the turbine in units of cycles per second or cycles per minute, it a value of 1 is equivalent to 3 rpm. Set point pps value is a signal step size is adjusted to the desired value pps. Three set point values are 10 pps, 20 pps and 40 pps, each of which represents a third for low, medium, and high speed.

Each set point did 10 times as much data retrieval data retrieval using the ICA optimization. So that there is a comparison of the results for each of the first time data acquisition and taken the best response for each test set point based on quantitative data based on the minimum value ITAE, and qualitative data based on the maximum overshoot, and settling time criteria 2% of the response given. The maximum overshoot is the maximum surge while trying to reach the set point response. Settling time is the time required response has entered ± 5% or ± 2% of the steady-state response.

Based on Figure 2 shows the results of testing 10 pps response as much as 10 times the retrieval of data, ICA optimization system produces the same response but differ in yield maximum value of its overshoot and settling time. The ICA optimization provide the best solution in the form of the value of the control parameters Kp, Ki, and Kd at each retrieval of data based on its objective function, ITAE minimum (best cost) that can be obtained by ICA at 12:42. Data collection was almost 10 times the minimum value ITAE entirely consistent, with the exception of the 4th data to experience the difference with his ITAE minimum value of 0:44. Based on quantitative analysis of minimal value ITAE and qualitative analysis on the resulting system response obtained. With parameter values on the optimal PID control set point value 10 with Kp = 1.49, Ki = Kd = 3:13 and 0:03. The response gives the maximum overshoot and settling of 11:30% 1.85 timely second. System response generated by the optimal PID parameters.

Figure 2. Respond of set point 10 pps

Based on Figure 2, the results of testing the response seen 10 times 20 pps retrieval of data, ICA optimization system produces the same response but differ in yield maximum value of its overshoot and settling time. Based on Table 4, the optimization ICA provide the best solution in the form of the value of the control parameters Kp, Ki, and Kd on ITAE minimum (best cost) that can be obtained by ICA at 0.85. Data capture as much as 10 times the minimum value consistent ITAE. Based on quantitative analysis of minimal value ITAE and qualitative analysis on the resulting system response, the value of the optimal PID parameters control the set point value of 20 with Kp = 1.44, Ki = 3.43 and Kd = 0.05 level. The response gives the maximum overshoot and settling of 12:05% time 1.67 seconds. The following system response generated by the optimal PID parameters.

Based on Figure 3, the results of testing the response seen 10 times 40 pps retrieval of data, ICA optimization system produces the same response but differ in yield maximum value of its overshoot and settling time.

Figure 3. Response of set point 20 pps

Optimization ICA provide the best solution in the form of the value of the control parameters Kp, Ki, and Kd on ITAE minimum (best cost) that can be obtained by ICA at 1.70. Data capture as much as 10 times the minimum value consistent ITAE. Based on quantitative analysis of minimal value ITAE and qualitative analysis on the resulting system response. The value of the optimal PID parameters control the set point value of 40 with Kp = 1.5, Ki = Kd = 5:00 and 0:06. The response gives the maximum overshoot and settling of 14:38% time 1.98 seconds. The system response generated by the optimal PID parameters.

Based on Figure 4, the results of each set point response test given during the time of 10 seconds for each simulation, the control system has been designed to give a good system response at all set point test, and deliver the best results on the test set point 10 pps, when compared with the set point others, because it gives the maximum value of 11:30% overshoot and settling time (2%) with a value of 1.85 seconds ITAE at 12:42. whereas at 20 pps set point response has a maximum yield of 12:05% overshoot and settling time (2%) 1.67 seconds with ITAE value of 0.85, and the set point 40 pps, which has resulted in a response by 14:38% maximum overshoot and settling time (2%) 1.98 seconds with ITAE value of 1.97.

Figure 4. Response of set point 40 pps

At the set point 20 pps and 40 pps, the control system which has a maximum response overshoot the set point greater in trials that were higher this is because at the same time, the resulting error is large enough so that the resulting value on set point ITAE 20 pps and 40 pps more large when compared with the smaller set point.

ICA is able to provide the value of the control parameters Kp, Ki, and Kd on certain thresholds, so that the ICA is one method of optimization heuristics (heuristic optimization) that can be used to tune (tuning) parameter control with a method of optimization strategies based on the evaluation function in the study the use Integral Time Absolute Error (ITAE). This optimization study of method has been made in iteration. This iteration method is done by creating a metric measuring 50x50x50 which represents the number of data in the form of the value of Kp, Ki, and Kd with the same restrictions on ICA and performed optimization iteration process 50 times, then the results of the iteration process is done using the image plotting plotting slice existing function on mat lab. Slice is a volumetric three-dimensional plotting facilities, the purpose of this is done is based on the value of knowing the distribution function (equation) the same objective with the ICA form ITAE calculate the value of Kp, Ki, and Kd particular, so that we obtain information ITAE minimum and maximum values of the data and the regional value of Kp, Ki, and Kd can be seen visually. The results of plotting slice optimization results using the method of iteration for each test set point 10 , 20 and 40 pps.
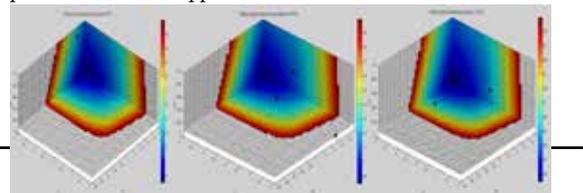
(a)   (b)   (c)

Figure 5. (a,b,c) Plotting slice on the test set point 10 PPS, 20 PPS and 40 PPS.

Based on Figure 5, the minimum value of optimization results ITAE iteration method setpoint10, 20, and 40 pps respectively on the value of 0:42, 0.85, and 1.70 with a value of Kp = 1.5, Ki = 5, and Kd = 0:01, the value of the minimum spread on local ITAE blue. For dots scattered black in the picture is plotting the value of Kp, Ki, and Kd obtained from the ICA optimization setpoint10, 20, and 40 pps. By spreading the value of Kp, Ki, and Kd is given by the ICA optimization, control parameters are the minimum area, in the area that produces the minimum value ITAE.

CONCLUSIONS
Based on the testing at various set point, the control system designed using a PID optimized using ICA is able to provide the value of the PID control parameters, based on the minimum value of the objective function ITAE (Integral Time Absolute Error). Judging from a quantitative analysis of minimal value ITAE systems and qualitative analysis based on the maximum settling time overshoot given. ICA-based PID control system is designed to work well on all test set point, and the test set point 10 pps, the control system is designed to provide the best results ITAE smaller value is 0:42, and produce a response that has a smaller maximum overshoot, i.e. 11:30% and the settling time of 1.85 seconds.Based on the results of optimization using iterative methods, optimization ICA as a method of optimization, is able to provide solutions that approach the optimal value based on the minimum value of objective function (ITAE).

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