التحكم في زاوية ميل زعنفة التوربينة الريحية باستخدام التحكم التناسلي التكاملي التفاضلي (GA – PID) المعتمد على الخورزميات الجينية

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الملخص:

يتزايد الطلب على مصادر الطاقة المتجددة في جميع أنحاء العالم؛ لانها من المصادر المستمدة من الطبيعة ولا تسبب تلوثاً للبيئة ، يمكن تحقيق الحاجة إلى تنظيم القدرة المنتجة من هذه التربينات عن طريق تقنية ميل النصل المتغير وذلك من خلال تصميم تحكم جيد يضبط زاوية ميل ريشة توربينات الرياح (WT) للحصول على السرعة المناسة للتربينة الريحية ومن ثم الحصول على الطاقة الحركية المناسبة لتوليد الطاقة.

في هذه الورقة العلمية تم استخدام كلًّ من المتحكم التناسبي – التفاضلي – التكاملي المعتمد على طريقة نيكولاس وزيقلر(Ziegler-Nichols PID) التقليدية و المتحكم التناسبي–التفاضلي– التكاملي المعتمد في ضبطه على استخدام الخوارزميات الجينية (GA based PID) للتحكم في زاوية ميل زعنفة التوربينة الريحية.

تُستخدم حزمة برامج MATLAB / SIMULINK لمحاكاة ومقارنة تأثير التحكم التقليدي الذي تم ضبطه بواسطة طريقة نيكولاس وزيقلر مع وحدة التحكم القائمة على

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الخوارزمية الجينية للتحكم في زاوية ميل ريشة توربينة الرياح الدوارة في وجود اضطرابات الحمل وتغيير نقطة الضبط.

تُظهر نتائج المحاكاة أن المتحكم القائم على الخوارزميات الجينية (GA based PID) يعطي أداء أفضل في نظام التحكم ذي الحلقة المغلقة من المتحكم التقليدي الذي تم ضبطه بواسطة طريقة نيكولاس وزيقلر (Ziegler-Nichols PID).

Pitch Blade Angle Control for Wind Turbine Incorporating a Genetic Algorithms Based PID Controller Design

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Abstract:

The demanding for wind renewable energy source is increasing all over the world. Since it is non-polluting and economically viable. The need for regulating the amount of throughput with the variable blade pitch can be achieved with a good controller design that adjusts the angle of inclination of the wind turbine (WT) blade. In this work both the conventional Ziegler-Nichols PID and GA based PID algorithms are used to control the blade angle of WT.

MATLAB / SIMULINK software package is used to simulate and compare the effect of conventional PID control tuned by Ziegler & Nichols method with genetic algorithm based PID controller in controlling the turbine rotor blade angle in the presence of load disturbances and set point change.

The simulation results show that the GA based PID controller gives better closed loop performance than that of conventional PID controller tuned by Ziegler-Nichols method.

Keywords: Renewable Energy, Wind Turbine (WT), Genetic Algorithms, PID Controller, Ziegler- Nichols method.

1- Introduction:

Renewable energy power generation is based on capturing the energy from natural forces which is helps to minimise the pollution associated to conventional fuel that facing the humanity in this planet today.

The high demand for electric power with the limited supply of fossil fuels, there is a need to utilize natural resources.

There are three important renewable energy sources, namely geothermal energy, solar energy and wind energy. Wind energy is obtained by converting kinetic energy into mechanical energy, and then it is converted into electrical energy through a wind turbine generator [1]. Since wind is a very important source of energy, it is important to provide a method for predicting wind behaviour. The construction of the main components of WT, which are shown in Figure (1), are the blades, the nacelle, the tower and the main console [2]. The nacelle contains a gearbox, alternator, converter and transducer. The gearbox connects the shaft of the turbine blades and the shaft of the generator blades then the generated power is sent to the grid by a transformer [3].

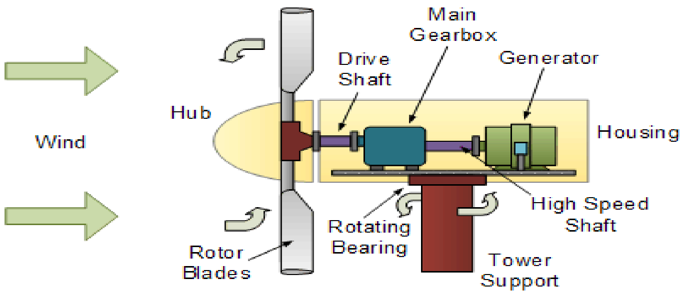


Fig. (1) Main parts of WT [2].

Therefore, the main objective of this work, is to control the WT speed by manipulating turbine pitch blade angle using intelligent genetic algorithms based PID controller and compare the performance of closed loop system with that of conventional PID controller.

This article is organized as the following: Section 2 the system model for a WT. Section 3 gives a brief review of the conventional PID controller, and its tuning using the Ziegler Nichols method. The genetic algorithms is briefly presented in Section 4. In Section 5, simulations were performed to demonstrate the performance of the closed-loop control system using both conventionally tuned PID controller and GA-based PID control design. Concluding observations and recommendations for future work are included in Section 6.

Wind Turbine System Model

WT model with closed loop control system [6] is shown in the Fig. (2).

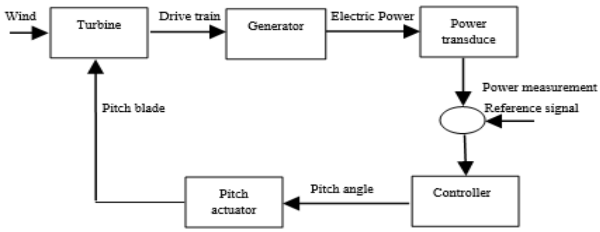


Fig. (2): WT model with feedback control system.

2.1 WT system with pitch control system

Pitch control strategy which is used in this work checks the turbine's power output several times per second using an intelligent controller. In this strategy, the pitch actuator is used to turn turbine blades along their longitudinal axis. In case of the output power is too high, a control signal is sent to blade pitch actuator (Stepping motor) to turn the blade slightly out of the wind stream, adapting the attack angle until the wind drops then these blades are turned back to the wind direction.

The actuator model describes a dynamic behaviour between a pitch demands, from the pitch controller and measurement of pitch angle are presented by the following equations [2]:

The change in pitch angle is given by:

$$\frac{\mathbf{d}ß}{\mathbf{dt}} = \frac{ß_{\mathbf{d}} - ß)}{\mathbf{T_B}}$$

$$\frac{\mathbf{T_B d}ß}{\mathbf{dt} + ß} = ß_{\mathbf{d}} \qquad (1)$$

$$\frac{ß}{ß_{d}} = \frac{\mathbf{1}}{\boldsymbol{s}.\boldsymbol{T}_{ß} + \mathbf{1})} \qquad (2)$$

$$\frac{ß}{ß_{d}} = \frac{\mathbf{1}}{(\mathbf{0.5}\boldsymbol{s}. + \mathbf{1})} \qquad (3)$$

Equation (3) represents the required transfer function.

Where,□ *d* is the reference of pitch angle , T_B is the stepping motor time constant which can be obtained from the initial WT's parameters as shown in Table (1).

Table (1): WT Initial parameters [2]

Parameters	**Value**
Power of generator, P_g	1000 KW
Generator speed W_g	1500 rpm
Turning speed of rotor W_t	20 rpm
Radius of WT blade , *R*	35 m
Reference of pitch angle,□ *d*	0 to 90 deg
Regulation of pitch angle accuracy	0.3 deg
Damping coefficient , B	2 N. m/ rad / sec
Inertia of Drive train , J_t	0.75 N.m2

2.1Model of WT drive train

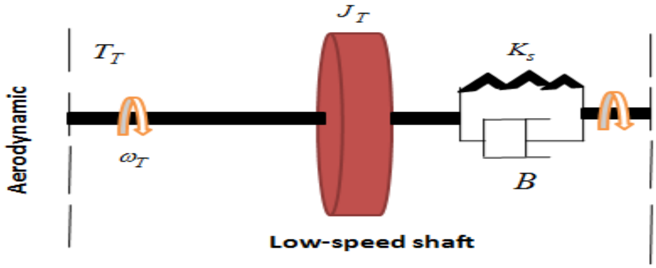


Fig. (3) WT Drive train mechanical model.

The mechanical model is presented to the drive in Fig. (3). Driveline dynamics are generated [2].

$$\frac{J_T d}{dt\,(W_T)} = T_T - (K_S \delta\theta + Bw\delta w)$$

$$\frac{d}{dt(\delta\theta)}\delta w = \qquad (4)$$

Using the second law of motion

$$\frac{jdw}{dt\ t} = T - Bw \qquad (5)$$

Applying Laplace Transform to eq. (5)

$$j.ws = T - Bw \qquad (6)$$

$$\frac{w}{T} = \frac{\left(\frac{1}{B}\right)}{\left(\left(\frac{J}{B}\right)S + 1\right)} = \frac{0.50}{(0.375S + 1)} \qquad (\ 7\ )$$

Where, W is the output value of WT and alternator shaft speed, J is the output value of WT and alternator shaft insufficiency, T is the WT output value and alternator shaft torque, B is WT damping coefficient.

Table (2) shows the modeling drive train parameters.

Table (2): Mechanical drive train modelling parameters [2].

Parameter	Description	Parameter	Description
J_T	WT inertia [kg.m2]	W_T	WT shaft speed [rad/sec]
J_G	Generator inertia [kg.m2]	W_g	Generator shaft speed [rad/sec]
K_S	Stiffness coefficient [N.m/rad]	θ_T	WT shaft angle [rad/sec]
B	Damper coefficient [N.m/rad/sec]	θ_g	Generator shaft angle[rad]
T_T	WT torque[N.m]	$1{:}n_{gear}$	Gear ratio
T_G	Generator electro-mechanical torque [N.m]		

1. PID controller tuning using convention approach

Ziegler and Nichols have introduced a useful methodology for controller tuning. It consists of a simple experiment with a controlled process and extracts some of its features. Once the experiment is completed, the method provides tables by which it is possible to calculate the controller parameters. The tuning tables were developed through numerous experiments which involved different processes. This design specification arises from empirical observations and has been used traditionally, but gives too oscillatory control systems. Ziegler and Nichols considered P, PI, and PID controllers in their method. In the experiment for the closed loop system, the process is controlled with a proportional controller in which its gain is gradually increased until the control system reaches stable oscillations on the stability y limit, whereas the integral and derivative controller values were set to zero. The value of the controller gain Kc is called the critical gain, and the oscillation period Tc is called the critical period. These two values serve as the basis for the calculation of the controller parameters as shown in Table (3). As the stable oscillations are reached, then the integral gain, Ki, is increased until any steady state error is corrected in sufficient time for the process. However, increasing Ki too much will cause instability. Finally, the derivative gain, Kd is increased until the close loop response is acceptably quick to reach its reference after a load disturbance. However, increasing Kd too much will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly.

Table (3): Control law settings [4].

Controller	K_p	T_i	T_d
P	$\frac{K_u}{2}$		
PI	$\frac{K_u}{2.2}$	$\frac{P_u}{1.2}$	
PID	$\frac{K_u}{1.7}$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

2. Genetic Algorithm Overview

Genetic algorithms have proven to be an effective and efficient way to improve control problems compared to classical optimization techniques [7]. GA begins with an initial set containing a number of encoded chromosomal sequences; each string represents the solution to the problem. The intercept operator is used on these strings to get a solution that inherits the good and bad properties of their parents' solutions. Each solution has a fitness value. The next generation will likely have solutions that have a higher fitness value. The mutation factor is applied to produce new properties that are not present in the current solution. This algorithm is repeated for several generations and finally stops when the individuals who represent the optimal solution to the problem are reached [7, 8].

The flow chart diagram of genetic algorithms is presented in fig. (4)

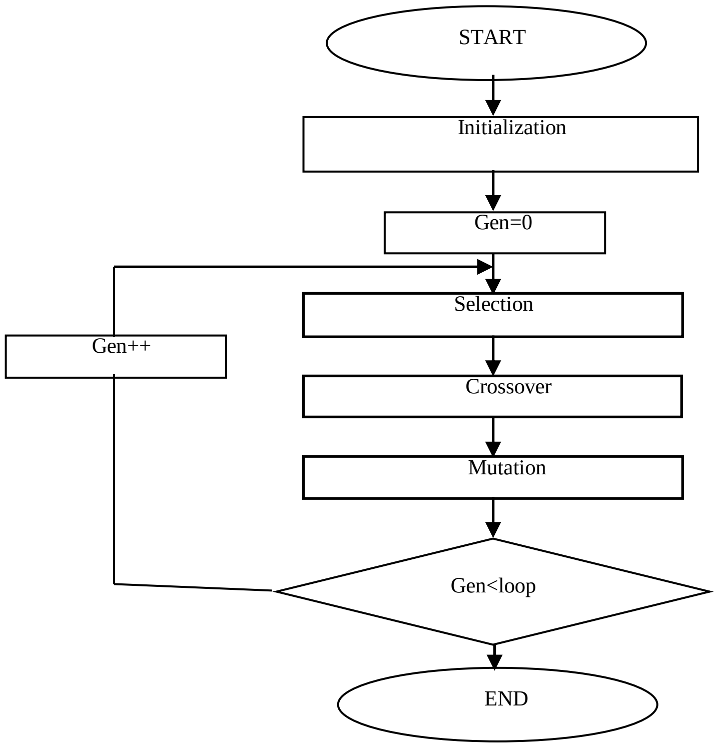


Fig. (4): Genetic Algorithms Engineering

In the above Fig. (4), the genetic algorithm routine is stated with selection operator, which is a process on how individual chromosomes are chosen for the genetic process, the purpose of **selection** is to define the members of a new generation from a current population in accordance with the chosen **fitness function** and the selection method. Parents are selected according to their fitness values for mating [9]. The subparts of two parent chromosomes is recombined using **crossover** operator to produce offspring. The crossover operator extracts common features from different chromosomes in order to achieve even better solutions. In order to achieve optimal solutions during the search space, the resulting offspring is subjected to a random changes on chromosome genes at a certain rate using **mutation** operator. However, the mutation rate has to be well chosen in order to avoid effecting the best convergence of the algorithm or obscure it [10].

There are various types of objective functions which can be used to evaluate fitness of each chromosome mainly the Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE) [11].

In this work, the MSE objective function is considered.

3. Simulation results:

In order to successfully use PID controllers, they need to be well-tuned using optimal tuning method. Many conventional PID tuning methods are introduced in process control. Some of these tuning methods are based on mathematical criteria Cohen –Con method, Trial and Error Methods and Experimental Method such as the Ziegler-Nichols method and Relay feed-back Method. Conventionally, the experimental Ziegler-Nichols method is widely used despite the requirement of a step input application with stopped process.

One of disadvantage of this method is a time consuming and it may not provide the good values of the PID parameters (KP, KI and KD) [5, 6].

For this reasons, it is highly desirable to enhance the capabilities of PID controllers by adding new optimization techniques. In this article genetic algorithm (GA) are used for achieving high efficiency and solving global optimization problems [8, 10].

In this section, the WT system presented by equations (3) and (7) is controlled by the classical Ziegler-Nichols tuned PID controller and the GA-based PID controller tuning method. This section is divided into three subsections (5.1), (5.2) and (5.3). In subsection (5.1) the classical ZN tuned PID controller is used, while the GA-based PID controller tuning method using MSE performance indicators is applied in subsection (5.2).In subsection (5.3) Investigating the effect of set point change and load disturbance on the performance of close loop system when GA base PID controller is implemented. In subsection (5.4) the simulation results are discussed. In all simulation experiments, the reference signal is assumed to be a unit step signal.

5.1Classical Ziegler-Nichols Tuned PID Controller

In this part, the classic Ziegler-Nichols tuning method is used. The obtained PID gain values K_p , K_i and K_d using this method are illustrated in Table (5). The step response of the closed loop system is shown in Fig. (5a). Whereas, the control input signal and the Bode diagram are shown in Fig. (5b) Fig. (5c), respectively.

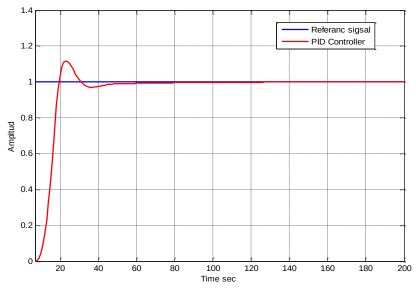


Fig. (5a): Response of the system with conventional Z-N tuned PID controller.

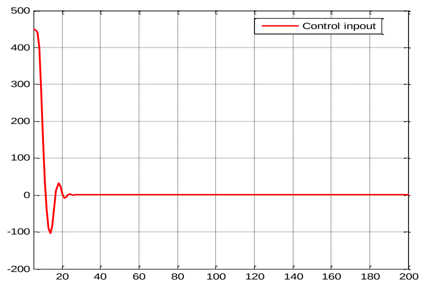


Fig. (5b): The input signal using conventional Z-N tuned PID controller

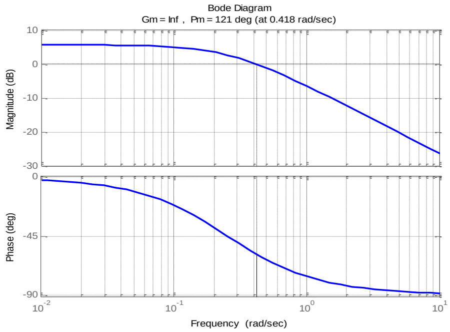


Fig. (5c): Gain margin and phase margin response using Z-N tuned PID controller

5.1GA based PID Controller tuning method using MSE objective function.

In this section the Genetic algorithms based PID controller is used to achieve a specified performance index (objective function). In this work the mean of the squared error (MSE) given by equation (8) is considered:

$$MSE = \int_0^t e(t)dt \qquad (8)$$

GA is used to adjust the parameters of the PID gain values to ensure optimal control performance under nominal operating conditions. Table 4 shows parameters of the genetic algorithm chosen for the purpose of tuning.

TABLE (4): GA Specifications

GA property	Value / Method
Population size	80
Function of fitness	MSE
Selection method	Geometric Selection
Crossover rate	Arithmetic
N. of crossover points	0.05
Mutation rate	Uniform Mutation
Mutation probability	0.01

The output and control input signals of a closed loop system using GA based PID controller are shown respectively in Fig. (6a) and Fig. (6b). The GA based PID controller parameters values K_p , K_i and K_d are shown in Fig. (6c). whereas, the Bode plot is shown in Fig. (6d).

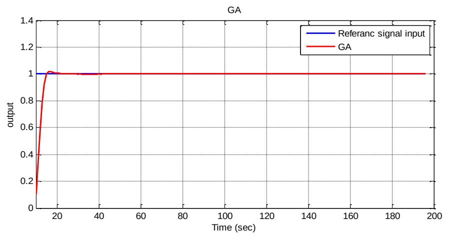


Fig. (6a): The output signal using GA based PID controller

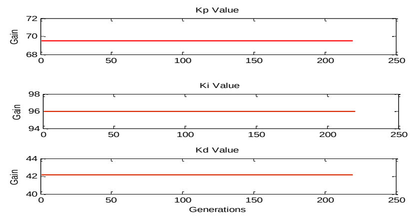


Fig. (6c): GA based PID controller gain values

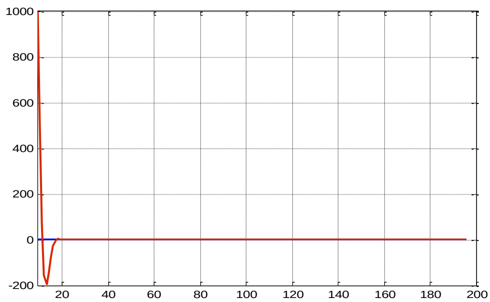


Fig. (6b): The control input signal

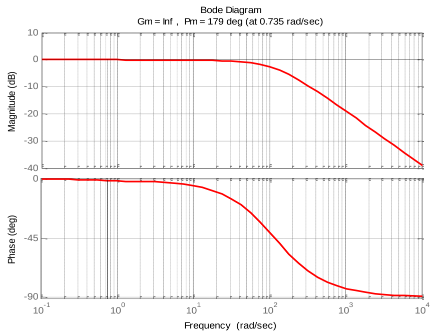
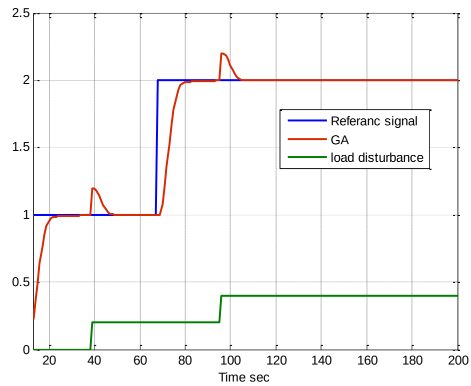


Fig. (6d): Gain margin and phase margin response

5.1 Investigating the effect of set point change and load disturbance on the performance using GA base PID controller

In order to see the effect of set-point change and load perturbation on the performance of the closed-loop system, step-point change at (t = 38s and 88 s) and step perturbation (20% of set-point) were artificially added to the system. The system output and control input signals are shown in Fig. (8a) and Fig. (7b).

It can be seen from Fig. (7a) and Fig. (7b) that the GA-based PID control can handle the set point change and can easily regulate the load perturbation to zero.



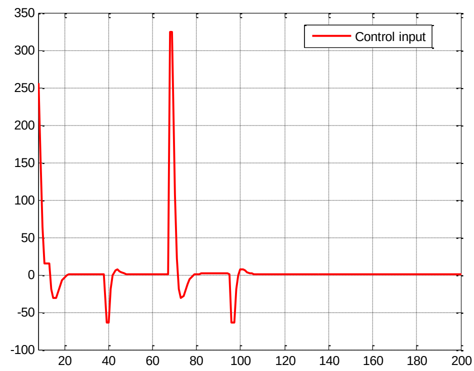


Fig. 7a. The output signal in the presence of load disturbance and set point change	Fig. 7b. The control input signal using GA based PID controller

5.4 Analysis of the Simulation Results

Table (5): Comparison of results

Controller	Kp	Ki	Kd	t_r	t_s	OP%	G_m	P_m
PID	23.50	20.4	2	0.18	1.07	11.6	Inf.	121
GA	68.45	51.23	13.18	0.060	0.102	0.219	Inf.	179

It can be seen from Fig. (5a), Fig.(5b), Fig.(5c) , Fig.(6a), Fig.(6b) and Fig.(6c) and the results shown in table (5) that the genetic algorithms-based PID controller with MSE performance index gives fast response with smaller peak compared to Ziegler-Nichols tuning method

It can be clearly seen from Table 5. It is also clear that all frequency response values (phase margin and gain margin) for all controllers are nearly identical. However, it is evident from Table 5 that using GA tuning method gives the lowest overshoot and lowest rise time values. Where the least settling time is obtained.

6. Conclusions and future work

In this paper, the mathematical model of the wind turbine pitch blade angle is formulated into simulation model using Matlab/Simulink software package. The gain values of the PID controller parameters which are obtained using both conventional and genetic algorithm has been implemented to control the wind turbine pitch blade angle.

It can be seen from simulation results shown in section (5), that the designed GA based PID has better response than response of the conventional method. The classical methods are good only for providing us with the pre-starting indication of what are the PID initial values. It is obvious from section 5 that, the GA based PID is much better in terms of the overshoot and the settling time than the conventional method. It is obvious from results that the designed GA based PID controller can handle set-point change and has the ability to suppress the step load perturbation to zero.

In order to further assess this design, the idea of implementing it in real time should be progressed. A further research can also be carried out to extend this work to include multivariable wind turbine behaviors into more generalized control design.

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