Design of adaptive PID for pitch control of large wind turbine generator

Jin-Sung Kim
Dept. of Control and Instrumentation Engineering
Korea University
Seoul, Korea
yawaya@korea.ac.kr

Jonghyun Jeon, Hoon Heo
Dept. of Control and Instrumentation Engineering
Korea University
Seoul, Korea
(swear24, heo257)@korea.ac.kr

Abstract— **Pitch control system plays an important role in large wind turbine generator (LWTG) because of the direction and intensity of wind is changing every moment. Therefore, the system of pitch control is difficult to be set up the tuning parameters of controller. Conventional PID controller is not suit for all operating point. Because, tuning parameters of conventional PID controller are not consistently changed. In this paper, a self tuning PID control method using reinforcement learning is proposed the pitch control of large wind turbine generator (LWTG). Actor-Critic learning is used to tune PID parameters in an adaptive way by taking advantage of the model-free and on-line learning properties of reinforcement learning effectively. Also proposed controller includes the improved integral control action. Therefore, the robust control of LWTG is studied utilizing the new adaptive PID (NAPID) controller in this paper. This structure is composed with new type of integral control action and Actor-Critic learning part. The improved integral control has concept of error window and weight function concept. The performance of newly proposed adaptive PID controller is compared with those of conventional ones via Matlab SIMULINK simulation.**

Keywords- Large wind turbine generator (LWTG); Actor-Critic Learning; pitch control; improved integral control; New adaptive PID (NAPID)

I. INTRODUCTION

Recently, researches have focused on large wind turbines, which are typically massive structures with enormous blade spans [1].With the enlargement of wind turbine generating capacity, it is vital to develop feasible, reliable and powerful control strategies in the wind energy conversion systems to achieve maximum power performance. When the wind speed is below nominal, the main concern is how to control the operational speed for turbine to extract maximum energy. On the other hand, when the wind speed is above nominal, the control objective is to maintain the stationary output power constant by means of pitch control. Compared with fixed speed wind turbines, variable-speed wind turbine can produce higher energy with lower component stress. Therefore, variable-speed wind turbine design has become field of increasing interest. [2, 3]

Many tuning methods of PID control can be shown in the literature. The Ziegler Nichols is a conventional one that is widely used, despite the requirement of a step test with stopped process. Once tuned the PID controller using the Ziegler Nichols tuning method a good but not optimum system response will be reached. The transient response can be even worse if the plant dynamics is changed. It must be noticed that numerous information of plants has its dynamics changed by environmental factors, e.g. temperature and pressure. To assure an environmentally independent good performance, the controller must have the ability to adapt to plant dynamic characteristics changes. [4, 5]

Here, the PID parameters are tuned on-line and adaptively by using the Actor-Critic learning method, which can solve the deficiency of realizing effective control for complex and time-varying systems by conventional PID controllers. In this paper, a new concept of adaptive PID controller based on reinforcement learning with the improved integral control for LWTG control is proposed.

The paper is organized as follows. The transfer function model, from pitch to tower fore-aft deflection including a time delay in the hydraulic pressure driven unit of wind generation system, is described in Section II. In Section III, new adaptive PID controller based on improved integral control part and self tuning PID control strategy using Actor-Critic learning is described. Also simulation results and conclusion are presented in sections IV and V respectively.

II. THE LWTG SYSTEM MODELING

The pitch operating mode included hydraulic pressure driven and electrical driven mode. Therefore, hydraulic pressure operating unit is occurred the dead time. These factors are caused by increase the complexity of plant. Considering the time delay, the required transfer function from pitch to tower fore-aft deflection following as [6, 7]

$$G_p(s) = \frac{a_2 s^2 + a_1 s + a_0}{b_4 s^4 + b_3 s^3 + b_2 s^2 + b_1 s + b_0} e^{-DTs} \tag{1}$$

Where, DT is the dead time parameter. And, a_0, a_1, a_2, b_0, b_1, b_2, b_3, b_4 means that the system parameter of the wind turbine. These values depend on the damping ratio and natural frequency of the wind turbine system. The above transfer

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function was evaluated for various turbine configurations and operating conditions [1]. This paper used a three type of large wind turbine generation system from the FAST. The FAST is an aforementioned aero-elastic wind turbine simulator. The considered systems are described below. [1, 8]

A. LWTG 1

Structure of LWTG 1 is rotor diameter = 70 m, tower height = 90 m, rated power = 1.5MW, And the operating conditions is wind speed = 15 m/s, pitch angle = 0°, q_{op}= [7.245e -2 3.207]^T and DT = 0.25. So the transfer function can be expressed as

$$G_p(s) = \frac{2.426s^2 - 4.6345s - 147.3}{s^4 + 4.857s^3 + 126.2s^2 + 266.4s + 3659} e^{-0.25S} \qquad (2)$$

B. LWTG 2

Structure of LWTG 2 is rotor diameter = 15 m, tower height = 25 m, rated power = 50kW, And the operating conditions is wind speed = 15 m/s, pitch angle = 0.75°, q_{op}= [1.97e -2 6.505e-2]^T and DT = 0.25. So the transfer function following as

$$G_p(s) = \frac{-0.2545s^2 - 0.0647s - 0.9384}{s^4 + 2.28s^3 + 878.5s^2 + 437.7s + 7.7\times10^4} e^{-0.25S} \qquad (3)$$

C. LWTG 3

Structure of LWTG 3 is rotor diameter = 27 m, tower height = 42 m, rated power = 275MW, And the operating conditions is wind speed = 15 m/s, pitch angle = 0°, q_{op}= [6.848e -2 8.915e-2]^T and DT = 0.25. So the transfer function can be define as

$$G_p(s) = \frac{-0.6219s^2 - 8.7165s - 2911}{s^4 + 5.018s^3 + 691.3s^2 + 1949s + 1.15\times10^5} e^{-0.25S} \qquad (4)$$

III. PROPOSED NEW ADAPTIVE PID CONTROLLER

The new adaptive PID is composed of new type of integral control part and Actor-Critic learning part. These parts are described in the following section.

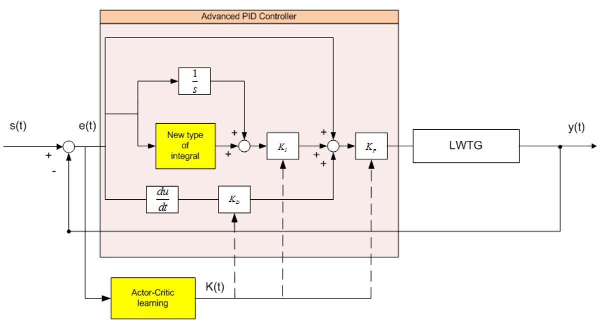

Figure 1. Schematic of new adaptive PID controller

A. New type of integral control part

Generally the integration region of I controller in conventional PID control scheme covers period 0 to present. However the integration region of proposed I controller in PID control scheme covers period from certain time in past to present. Following is design procedure for proposed new I controller.

(Ⅰ) Error data form $t-p$ to t be acquired. New integration region is shown in Fig.2 called window.

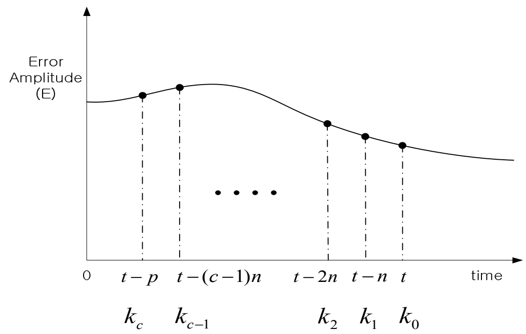

Figure 2. Schematic of new type of integral section

Where, t = present time (sec.), p = window size (sec.), n = sampling time (sec.), k = index of window element, $c+1$ = number of sampled error data ($=\frac{p}{n}+1$). The window size (p) and the sampling time (n) are tuning parameters. [9]

(Ⅱ) Weight values are obtained from weight function defined on time basis, which is obviously time dependent function. The procedure for that is explained below.

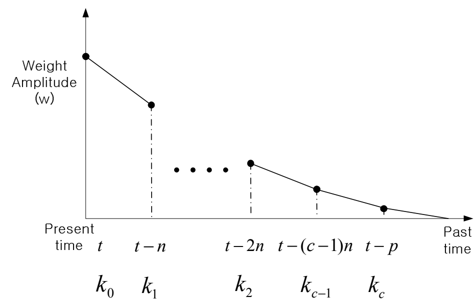

Figure 3. schematic of weight function in window

The weight function revealed in Fig.3 emphasizes that present error is regarded more important than the errors in the past. Also the type of weight function is determined depending on the characteristics of objective system under consideration. [9]

(Ⅲ) The weight values are imposed on collected error data. As a result mathematical expression for new I controller is derived as following (5)

$$I_{\text{Term}} = K_I \left[\left\{ \begin{array}{l} (w_{k_0}E_{k_0}) + (w_{k_1}E_{k_1}) + (w_{k_2}E_{k_2}) + \\ \cdots + (w_{k_{c-1}}E_{k_{c-1}}) + (w_{k_c}E_{k_c}) \end{array} \right\} + \int e(t)\,dt \right] \qquad (5)$$

Where, E = error, w = weight value, k = index of window element

(Ⅳ) The window shifts along with time from present to next sampling time. And then it returns back to step (I), so on.

B. Actor-Critic learning part

Actor-critic learning is TD method that has a separate memory structure to clearly represent the policy independent of the value function. The actor has plays a role of policy. And value function is used to the critic. The critic is evaluated the action made by the actor. Learning is always on policy: the critic must learn about and evaluation whatever policy is currently being come with the actor. The evaluation takes the form of a TD error. The TD error $\delta_{TD}(t)$ is calculated by (6).

$$\delta_{TD}(t) = r(t) + \gamma V(t+1) - V(t) \tag{6}$$

Where γ is discount factor between 0 and 1. And the r(t) is the reward signal according to the following equation.

$$r(t) = \alpha r_e(t) + \beta r_{ed}(t)$$
$$r_e(t) = \begin{Bmatrix} 0.01 & |e(t)| \le \varepsilon \\ -0.01 & otherwise \end{Bmatrix}, r_{ed}(t) = \begin{Bmatrix} 0.01 & |e(t)| \le |e(t-1)| \\ -0.01 & otherwise \end{Bmatrix} \tag{7}$$

Where, α and β are weighed coefficients. And the ε is a tolerant error band.

The Actor and critic part is made using the RBF network. These parts are described as follows.

First, the system error e(t) is converted into the state vector as $x(t) = [e(t), \vartriangle e(t), \vartriangle^2 e(t)]$.

The first layer is input layer. Each unit in this layer denotes a system state value x_i where i means that the input value index. The input vector $x(t) \in R^3$ forwarded to the next layer.

The second layer is hidden layer. The kernel function of the hidden unit of RBF network is adopted as a Gaussian function. The output of the j th hidden unit is

$$\phi_j(t) = \exp\left(-\frac{\|x(t) - \mu_j(t)\|^2}{2\sigma^2_j(t)} \right), j = 1, 2, ..., h \tag{8}$$

Where, the $\mu_j = [\mu_{1j}, \mu_{2j}, \mu_{3j}]^T$ is expected value. And the σ_j^2 is variance. The j means that j th hidden unit respectively, h is the number of hidden units.

The third layer is output layer. This layer consisted of the actor part and a critic part. The m th output of the Actor part is $K_m(t)$ can be calculated from the following equation

$$K_m(t) = \sum_{j=1}^{h} w_{mj}(t)\phi_j(t), m = 1, 2, 3 \tag{9}$$

Where w_{mj} is the weight value between the j th hidden unit and the m th Actor part

And the value function of the Critic part is V (t) can be expressed as

$$V(t) = \sum_{j=1}^{h} v_j(t)\phi_j(t) \tag{10}$$

Where v_j means the weight value between the j th hidden unit and the single Critic unit. [10]

Based on the TD error performance index, the weights of Actor and Critic are updated according to the following equations through a gradient descent method and a chain rule.

The weight values of actor and critic part are updated using the TD error given as

$$w_{mj}(t+1) = w_{mj}(t) + \alpha_A \delta_{TD}(t)\phi_j(t) \tag{11}$$

$$v_j(t+1) = v_j(t) + \alpha_C \delta_{TD}(t)\phi_j(t) \tag{12}$$

Where, α_A and α_C are learning rates of Actor and Critic.

Also, the Actor and the Critic are used the input and the hidden layers of kernel function. Therefore, the expected value μ_j and the variance σ_j^2 updated using the following:

$$\mu_{ij}(t+1) = \mu_{ij}(t) + \eta_\mu \delta_{TD}(t) v_j(t)\phi_j(t)\frac{x_i(t) - \mu_{ij}(t)}{\sigma^2_j(t)} \tag{13}$$

$$\sigma_j(t+1) = \sigma_j(t) + \eta_\mu \delta_{TD}(t) v_j(t)\phi_j(t)\frac{\|x(t) - \mu_j(t)\|^2}{\sigma^3_j(t)} \tag{14}$$

Where η_μ and η_σ are learning rates of expected value and variance respectively.

IV. Simulation Result

Numerical simulation is conducted to confirm the effectiveness of proposed method using the Matlab SIMULINK, whose results are presented in this section. The PID gain parameters of the conventional PID controller are set by using of PID Tuner of Matlab in off-line manner, which is listed in Table I. Setting parameters of conventional PID

Model name	**Proportional gain**	**Integral gain**	**Derivative gain**	**Type**
LWTG1	2.220e-16	-1.87e+16	0	Series
LWTG2	2.220e-16	6.01e+19	0	Series
LWTG3	2.220e-16	-2.37+16	0	Series

The parameters setting for the Actor-Critic PID (ACPID) and new adaptive PID (NAPID) are shown in Table II.

TABLE I. SETTING PARAMETERS OF ACPID AND NAPID

Parameter	**Actor-Critic PID**	**New adaptive PID**
n	0.01	0.01
ε	0.01	0.01
α	0.9	0.9
β	0.1	0.1
α_A	0.01	0.01
α_C	0.014	0.014
η_σ	0.01	0.01
η_μ	0.01	0.01
p	.	100
Weight func.	.	$\exp^{-1}$

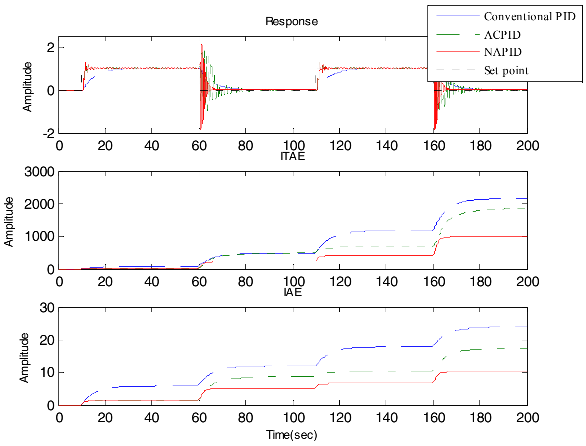

Figure 4. Performance comparison of tracking for LWTG1

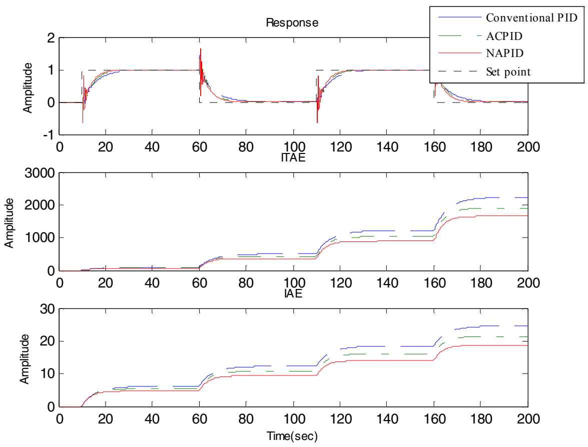

Figure 5. Performance comparison of tracking for LWTG2

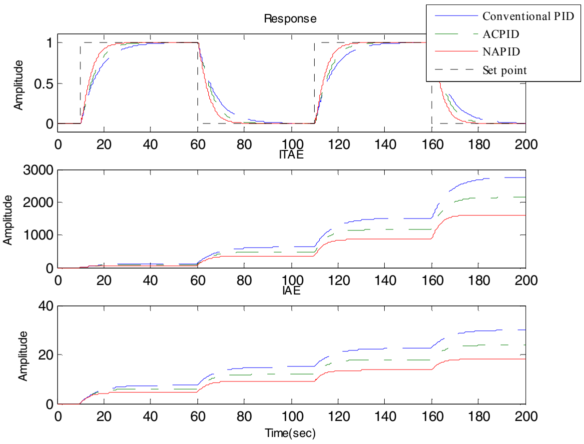

Figure 6. Performance comparison of tracking for LWTG3

V. CONCLUTION

In this paper, a novel new adaptive PID controller for pitch control of LWTG is presented which combines the new type of PID controller with Actor-Critic learning. As can be observed in the simulation results the newly proposed adaptive PID controller is successfully implemented and proved to be very effective one. Furthermore, research on the performance of disturbance rejection for the NAPID control is under way.

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