Improved Many Machine Excitation Nonlinear Robust Controller Design

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Keywords: power system; nonlinear; excitation control; robust stability; backstepping method

Abstract. Electric power systems are one of nonlinear, multidimensional, dynamic and large scale systems. Once power systems lose stability, it would result in the consequence is very serious. With excitation control for multi-machine power system nonlinear model in this article, a series of stability control problems are studied by means of the improved backstepping methods, including excitation control. The nonlinear adaptive robust controller which can stabilize the system has been designed. The concise design method and excellent design strategy make the designed corresponding control scheme own extensive adaptability, which effectively improve the maintain system power angle and voltage stability.

Introduction

In real life there is a type of electric power system, including two or more than two which can match on the capacity of the power plant, after on the electrical distance is also a big system can match power lines approach transmission power. How to deal with the connection between each subsystem in the power system is a hot issue. Single machine infinite system of excitation control strategies for multi-machine systems may not be suitable [1]. In this case, the research on stability control problem of multi-motor transmission system is very necessary.

The paper focuses on the study of excitation control of multi-machine power system. The adaptive backstepping method is used to design multi-machine system nonlinear robust controller, and further improvement to the traditional adaptive backstepping method is also made, considering both the transient response, and controller gain in the feedback control law of recursive design process. In order to obtain faster convergence speed, the K class function is referred in the selection of virtual stabilization function. When time tends to go infinity, and the controller gain also tends to be traditional design of the adaptive backstepping method [2], in this way, the transient response speed would be improved significantly and the controller gain doesn't need to increase too much, The adjustable parameters in the K class function keeps the balance between the controller gain and transient response.

control objectives

Assuming generator adopts fast excitation mode, build a mathematical model of generator in the power system is as follows:

$$\begin{cases} \dot{\delta}_i = \omega_i - \omega_0 \\ \dot{\omega}_i = -\dfrac{D_i}{H_i}\left(\omega_i - \omega_0\right) + \dfrac{\omega_0}{H_i}\left(P_{mi} - P_{ei}\right) \\ \dot{E}'_{qi} = -\dfrac{1 + \left(X_{di} - X'_{di}\right) B_{ii}}{T'_{d0i}} E'_{qi} \\ + \dfrac{X_{di} - X'_{di}}{T_{d0i}} \sum\limits_{\substack{j=1 \\ j \neq i}}^{n} Y_{ij} E'_{qj} \cos\left(\delta_{ij} - \alpha_{ij}\right) + \dfrac{1}{T_{d0i}} V_{fi} \end{cases} \tag{1}$$

Among them, the one generator active power:

$$P_{ei} = E'^2_{qi}G_{ii} + E'_{qi}\sum_{\substack{j=1\\ j\neq i}}^{n} E'_{qj}Y_{ij}\sin\left(\delta_{ij} - \alpha_{ij}\right) \qquad (2)$$

Where, δ_i is the i electric potential generator system a node voltage vector $\bar{E}_{qi}$ and the angle between vectors $\bar{V}_{REF}$, said first rotor of generator operation angle, rad; ω_i is the i generator rotor angular speed, rad/s ; p_m is the i mechanical power units ; H_i is the i moment of inertia units, s; X_{di} is generator d-axis synchronous reactance, X_{di} is d-axis transient reactance; T_{d0i} is the i generator excitation winding time constant, s; D_i is the i damping coefficient generator; E'_{qi} is the i generator q-axis transient electric potential; E'_{qj} is the j generator q-axis transient electric potential; rad; G_{ii} and Y_{ij} is respective the i node conductance and mutual admittance between the i an $\delta_{ii} = \delta_i - \delta_j$ d the j node[3]; αi_j is the impedance Angle of complement. V_{fi} is the i generator exciting winding voltage as control variables.

To make it into a suitable form of backstepping, make $x_1 = \delta_i - \delta_{i0}$, $x_2 = \omega_i - \omega_{i0}$, $x_3 = E'_{qi} - E'_{qi0}$, Among them δ_{i0}、ω_{i0} and E'_{qi0} means corresponding to the initial value of the variable. As the known constant, make $k = \frac{\omega_{i0}}{H_i}$, $b_1 = X_{qi} - X'_{di}$, $b_2 = X_{di} - X'_{di}$; If the parameters D_i is unknown, $\theta = -\frac{D_i}{H_i}$ is unknown parameter, The (1) system can be further simplified as follows:

$$\dot{x}_1 = x_2 \qquad (3)$$

$$\dot{x}_2 = \theta x_2 + k\left(P_{mi} - \left(x_3 + E'_{qi0}\right)I_{qi} - b_1 I_{di} I_{qi}\right) \qquad (4)$$

$$\dot{x}_3 = -\frac{x_3 + E'_{qi0} + b_2 I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi} \qquad (5)$$

The control target of this paper is aimed at multiple machine excitation control system, by improving the backstepping method to solve the excitation control of multi-motor system. Nonlinear adaptive controller is designed to adjust the generator power angle and frequency to a domain of the steady-state operating point.

The design of nonlinera controller

The first step: for system (3), x2 will be regarded as virtual control, and K classes function will be elected when you pick up the stabilization function[4]. $x_2^* = -[\phi(|e_1|) + c_1]e_1$, $c_1 > 0$ is designed for a constant.Select, $\phi(|e_1|) = \frac{1}{2}e_1^2, x_2^* = -(\frac{1}{2}e_1^2 + c_1)e_1$,make $e_1 = x_1, e_2 = x_2 - x_2^*$, Then the system (3) can be expressed as:

$$\dot{e}_1 = e_2 - c_1 x_1 \qquad (6)$$

The Lyapunov function for the system (3) can be expressed as:

$$\mathrm{v}_1 = \frac{1}{2}e_1^2 \qquad (7)$$

It's time derivative $\dot{V}_1 = e_1\dot{e}_1 = e_1 x_2 = e_1(e_2 - c_1 e_1 - \frac{1}{2}e_1^3) = e_1 e_2 - c_1 e_1^2 - \frac{1}{2}e_1^4$.It is obvious that when e2=0, $\dot{V}_1 \le 0$ [5].

The second step: to augmented (7), forming a new Lyapunov function:

$$V_2 = V_1 + \frac{1}{2}e_2^2 \qquad (8)$$

There are:

$$\dot{V}_2 = \dot{V}_1 + e_2\dot{e}_2$$
$$= -c_1e_1^2 + e_1e_2 + e_2\dot{e}_2 - \frac{1}{2}e_1^4$$
$$= -c_1e_1^2 - \frac{1}{2}e_1^4 + e_2\begin{bmatrix} e_1 + \theta x_2 + k(P_{mi} \\ -(x_3 + E'_{qi0})\ I_{qi} - b_1I_{di}I_{qi}) + c_1x_2 + \frac{3}{2}x_1^2x_2 \end{bmatrix}$$

Take a new stabilization function:

$$x_3^* = \frac{e_1 + \theta x_2 + k(P_{mi} - (x_3 + E'_{qi0})\ I_{qi} - b_1I_{di}I_{qi}) + c_1x_2 + \frac{3}{2}x_1^2x_2 + c_2e_2}{kI_{qi}}$$
$$= \frac{e_1 + \theta x_2 + kP_{mi} + c_1x_2 + \frac{3}{2}x_1^2x_2 + +c_2e_2}{kI_{qi}} - E'_{qi0} - b_1I_{di}$$

$c_2 \geq 0$ is the design of constant. There is $\dot{V}_2 = -c_1e_1^2 - \frac{1}{2}e_1^4 + e_2(-kI_{qi}e_3 - c_2e_2) = -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2{}^2 - kI_{qi}e_2e_3$. It is obvious that when $e_3=0, \dot{V}_2 \leq 0$.

Step 3: define x = 1, then the formulas (8) augmented, forming a new Lyapunov function can be expressed as:

$$V_3 = V_2 + \frac{1}{2}e_3^2 \qquad (9)$$

There is

$$\dot{e}_3 = \dot{x}_3 - \dot{x}_3^*$$
$$= -\frac{x_3 + E'_{qi0} + b_2I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi} - \dot{x}_3^*$$
$$= -\frac{x_3 + E'_{qi0} + b_2I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi} - \frac{1}{kI_{qi}}[(1 + 3x_1x_2 + c_1c_2 + \frac{3}{2}c_2x_1^2)x_2$$
$$+(\theta + c_1 + \frac{3}{2}x_1^2 + c_2\ )(\theta x_2 + k(P_{mi} - (x_3 + E'_{qi0}) - b_1I_{di}I_{qi}))]$$

Then

$$\dot{V}_3 = -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 - kI_{qi}e_2e_3 + e_3\dot{e}_3$$
$$= -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 - kI_{qi}e_2e_3 + e_3(\dot{x}_3 - \dot{x}_3^*)$$
$$= -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 - kI_{qi}e_2e_3 + e_3(-\frac{x_3 + E'_{qi0} + b_2I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi} - \dot{x}_3^*)$$
$$= -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 - kI_{qi}e_2e_3 + e_3[-\frac{x_3 + E'_{qi0} + b_2I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi}$$
$$-\frac{1}{kI_{qi}}[(1 + 3x_1x_2 + c_1c_2 + \frac{3}{2}c_2x_1^2)x_2 +$$
$$(\theta + c_1 + \frac{3}{2}x_1^2 + c_2\ )(\theta x_2 + k(\theta x_2 + k(P_{mi} - (x_3 + E'_{qi0}) - b_1I_{di}I_{qi}))$$

$$\dot{V}_3 = -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 + e_3\{-kI_{qi}e_2 - \frac{x_3 + E'_{qi0} + b_2I_{di}}{T_{d0i}} + \frac{1}{T_{d0i}}V_{fi}$$
$$-\frac{1}{kI_{qi}}[(1 + 3x_1x_2 + c_1c_2 + \frac{3}{2}c_2x_1^2)x_2 + (\theta + c_1 + \frac{3}{2}x_1^2 + c_2\ )(\theta x_2$$
$$+k(P_{mi} - (x_3 + E'_{qi0}) - b_1I_{di}I_{qi}))]$$

Finally choose feedback control law can be described as follows:

$$V_{fi} = x_3 + E'_{qi0} + b_2 I_{di} + \frac{T_{d0i}}{kI_{qi}}[(1+3x_1x_2 + c_1c_2 + \frac{3}{2}c_2x_1^2)x_2$$
$$+(\theta + c_1 + \frac{3}{2}x_1^2 + c_2)(\theta x_2 + k(\theta x_2 + k(P_{mi} - (x_3 + E'_{qi0}) \qquad (10)$$
$$-b_1 I_{di} I_{qi}))] + T_{d0i}(kI_{qi}e_2 - c_3e_3)$$

$C_3>0$ is considered design constants. Then $\dot{V}_3 = -c_1e_1^2 - \frac{1}{2}e_1^4 - c_2e_2^2 - c_3e_3^2 \le 0$.

So assuming that $f(x_1) \neq 0$, The closed-loop error system (11) is asymptotically stable under feedback control law of formula (1).，When $t \to \infty$, $e_1 \to 0$, $e_2 \to 0$, $e_3 \to 0$.According to the definition of x_1、x_2、x_3、x_2^* and x_3^*, x_1 and x_2 will converge to zero, x_3 is also bounded[6].

$$\begin{cases} \dot{e}_1 = e_2 - c_1e_1 - \frac{1}{2}e_1^3 \\ \dot{e}_2 = -c_2e_2 - e_1 - kI_{qi}e_3 \\ \dot{e}_3 = -c_3e_3 + kI_{qi}e_2 \end{cases} \qquad (11)$$

simulation research

According to the design of the above results, the simulation of closed-loop system on the basis of nonzero initial conditions. Simulation parameters are as follows: $c_1 = c_2 = c_3 = 10$, $\delta_0 = \pi/3$, $\omega_0 = 314.159$, $E_{b1} = 50$, $E_{b2} = 50$, $E_{b3} = 50$, D=3,H=8, $P_{m0} = 0.9$, $I_d = 0.22$, $I_q = 1$, $E_{q0} = 0.4$, $X_q = 2.5$, $X_d = 2.5$, $X_d^{'} = 0.25$, $T_{d0} = 8$ .As shown in figure 1 is responding curves of angle error response curve simulation diagram, shown in figure 2 is responding curves of speed error simulation diagram [7].

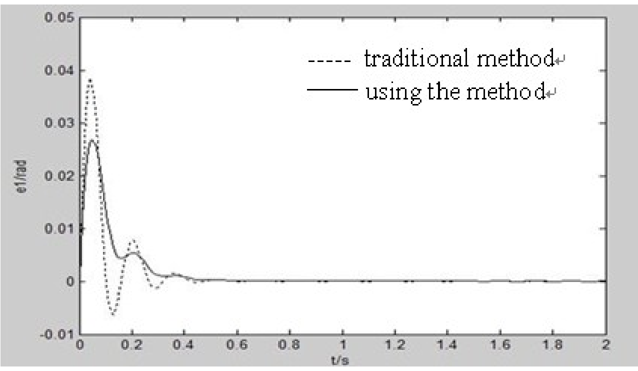

Fig.1. Responding curves of the Power angle error

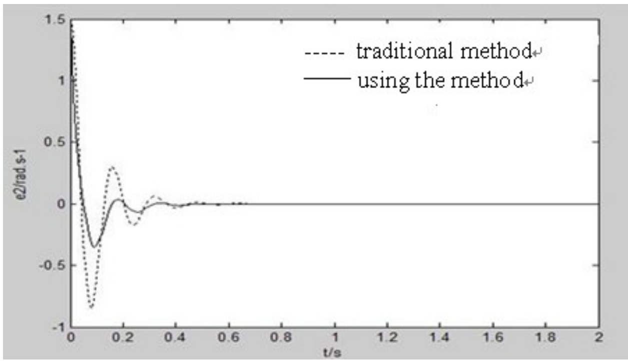

Fig.2. Responding curves of speed error response

From the state of the system response curve a conclusion can be drawn, the system convergence speed is quicken and it moves into a stable state in a very short period of time. Although as you can see from the figure. Although based on traditional adaptive Backstepping method is used traditionally to design the generator excitation controller and also can make the system stabilization[8], but the controller designed with the improved adaptive Backstepping method proposed in this paper, due to the introduction of the K class function, quickens system convergence speed.

Conclusion

For multi-machine excitation system, this paper has introduced the adaptive backstepping method, and the backstepping method is improved. In the recursive design of the feedback control law, when virtual stabilization function is selected, the K class function is introduced. With the result that when the error is bigger, the convergence rate of the system speeds up[9]. But with the increase of t, the error is reduced. Using improved backstepping method starting from the model description to design the controller, in the end, the particular form of the controller is obtained. Due to the design process without any linearization, the original system and the nonlinear characteristic of the system is retained completely [10]. At the same time, power network parameters is contained in the control law, Which contributes to the decentralized control. And the design process is simple, easy to be accept engineering personnel. At the same time, the simulation analysis shows that this kind of controller can improve transient stability of the system.

Acknowledgment

This work is supported by social science fund project of Liaoning province (L14BTJ002): Based on analysis of big data research the guidance of college students' learning and future employment

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