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Grey prediction theory and extension strategy-based excitation control for generator

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ABSTRACT

The nonlinear characteristics and time-varying conditions of modern power system make the classic linear control method incapable of action, meanwhile the existing nonlinear control methods and the intelligent control technology cannot obtain satisfactory control effect. A novel excitation controller is proposed based on grey prediction technology and extension control strategy, which can improve the power system stability to a greater degree because it combines the former 'prior control' and the latter's advantage that does not require a precise mathematical model and the real-time performance is good. The simulation results on a single machine infinite bus power system and multi-machine system show that the grey prediction extension excitation controller has better control effect compared with traditional control mode and general extension control method.

Introduction

Excitation control system is an important part of automatic regulation system of generator, and it has a direct impact on the stability of power system. The control effect of excitation controller is relevant to the complexity of power system and control strategies taken by researchers. Due to the nonlinear characteristics and time-varying conditions of modern power system, the conventional PID excitation control method based on the classic linear control theory could do nothing. The introduction of PSS makes up for its shortcomings to a greater degree, but it still cannot obtain satisfactory control effect. In recent years, some methods on the basis of modern control theory, such as differential geometry control [1], variable structure control [2,3], adaptive control [4,5] and the Hamiltonian method [6], or intelligent methods represented by fuzzy control [7,8] and neural network control [9,10] are applied to the design of excitation controller or PSS. The stability of power system is improved greatly. However, these control methods either have a complex control law and a large online calculation, or their rule bank design is sophisticated and the training sample is difficult to obtain. Therefore, it is not easy to solve the real-time problem and the engineering practicability is poor.

In recent years, some new control methods proposed by Chinese scholars have attracted people's attentions, and the grey prediction control and extension control are the two most representatives. Grey prediction control uses plenty of data reflecting the different behaviours of system over the past different time to establish grey model, according to the principle of metabolism. Then it finds the development rule of system by using the built model, predicts the future behaviour of system, compares forecast results with a given reference, and pre-controls the deviation that may occurs later, is a kind of advance control of "Nip in the bud". Extension control is a new intelligent control method combining extenics with feedback theory. The basic idea is to process control problems from the perspective of information transformation, that is to say, using the conformity of control input information (correlation) as a basis to determine the control output correction quantity, thus enabling the controlled information to reach the qualified range. On the application of the grey prediction control technology and extension control method in the power system, the relevant experts and scholars have made some exploration and achieved gratifying results [11–17].

Extension control does not require an accurate mathematical model, and has good real-time performance. However, because of the inherent hysteresis of control system, extension controller like other "post" control methods, can't achieve the accurate control effect. In general, the grey prediction control, which is a kind of composite control method, combines grey prediction with a control strategy (such as PID control and fuzzy control) to pre-control the deviation that may occur. Among them, the grey prediction link can be seen as the auxiliary part, and its function is to preprocess input data of the main controller. Therefore, that it makes full use of their respective advantages through combining

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the grey prediction method with extension control technology, can obtain the better control effect. This paper will combine the two, used in the design of excitation controller of generator. The simulation results on a single machine infinite bus power system and multi-machine system show that the grey prediction extension excitation controller has better control effect compared with traditional control mode and separate extension control method.

Grey prediction method and extension control strategy

Grey prediction method

The foundation of the grey prediction method is the single variable first-order grey model GM(1,1). Following the principle of grey modelling and prediction:

Non-negative original data sequence is given as follows:

$$\boldsymbol{y}^{(0)} = \{y_1^{(0)}, y_2^{(0)}, \ldots, y_n^{(0)}\} \tag{1}$$

Many of them are irregular, random, and there are obvious swing. If we put a accumulated generating operation (AGO) into the original data, we can obtain new data sequence

$$\boldsymbol{y}^{(1)} = \{y_1^{(1)}, y_2^{(1)}, \ldots, y_n^{(1)}\} \tag{2}$$

where $y_i^{(1)} = \sum_{k=1}^{i} y_k^{(0)}$, $i = 1 \sim n$, n is the original data point.

The new data sequence is a monotone increasing curve, which indicates the volatility of original data are weakened and become more regular. So we can use a certain of function to fit approximation, and make a more accurate prediction of the later data.

Based on the type (1), (2), the grey model GM (1,1) is

$$y_i^{(0)} + a z_i^{(1)} = b, (i = 1 \sim n) \tag{3}$$

In the equation, $z_i^{(1)} = (y_i^{(1)} + y_{i-1}^{(1)})/2$; a is the development coefficient; b is the grey action; a and b are obtained according to the least square criterion

$$[a \quad b]^T = \left(\boldsymbol{B}^T \boldsymbol{B}\right)^{-1} \boldsymbol{B}^T \boldsymbol{y}_N \tag{4}$$

where $\boldsymbol{B} = \begin{bmatrix} -z_2^{(1)} & 1 \\ -z_3^{(1)} & 1 \\ \vdots & \vdots \\ -z_n^{(1)} & 1 \end{bmatrix}, \boldsymbol{y}_N = \begin{bmatrix} y_2^{(0)} \\ y_3^{(0)} \\ \vdots \\ y_n^{(0)} \end{bmatrix}$.

Whiten Eq. (3), and the equation is

$$\frac{dy^{(1)}}{dt} + a y^{(1)} = b \tag{5}$$

Its solution is

$$\hat{y}_{i+p}^{(1)} = \left(y_1^{(0)} - \frac{b}{a}\right) e^{-a(i+p-1)} + \frac{b}{a} \tag{6}$$

The forecasted value of $y^{(0)}$ can be obtained by serial-down

$$\hat{y}_{i+p}^{(0)} = \hat{y}_{i+p+1}^{(1)} - \hat{y}_{i+p}^{(1)} \tag{7}$$

In the Eqs. (6) and (7), p is prediction step length.

Extension control strategy

The extension controller consists of feature extraction, correlation calculation, measure mode recognition and control strategy. The structure of unit feedback control system using the extension control strategy is shown in Fig. 1, and the extension controller is in the dashed box.

(1) *Feature extraction:* The typical variables to describe the motion state of the system are known as the characteristic parameter. In general, we choose reference input r and the deviation e and the differential $\dot{e}$ of output y of system as characteristic parameters.

(2) *Correlation calculation:* In order to compute the correlation degree, we must firstly establish extension sets describing the characteristic state of control system. Therefore we need to establish the classical domain and extension field of characteristic parameters. Suppose the normal range (classical domain) of the deviation e and its differential $\dot{e}$ is respectively $[-e_{gm}, e_{gm}]$ and $[-\dot{e}_{gm}, \dot{e}_{gm}]$, and the range of maximum allowed(extension domain) is respectively $[-e_m, e_m]$ and $[-\dot{e}_m, \dot{e}_m]$. And the extension sets of characteristic parameters are shown in Fig. 2.

Suppose the origin of the characteristic plane $e - \dot{e}$ is $S_0(0,0)$, and defines $M_0 = \sqrt{e_{gm}^2 + \dot{e}_{gm}^2}$ and $M_{-1} = \sqrt{e_m^2 + \dot{e}_m^2}$. S $(e, \dot{e})$, any point in the plane $e - \dot{e}$, meets the correlation function

$$K(S) = \begin{cases} 1 - |SS_0|/M_0, & S \in R_{gy} \\ (M_0 - |SS_0|)/(M_{-1} - M_0), & S \notin R_{gy} \end{cases} \tag{8}$$

In the equation, $|SS_0| = \sqrt{k_a e^2 + k_b \dot{e}^2}$, R_{gy} is the classical domain of Fig. 2, k_a, k_b *is* the weighted coefficient, and they are decided by the characteristic state of control system. The correlation of any point S $(e, \dot{e})$ can be obtained by this equation.

(3) *Measure mode recognition:* We can recognize measure model according to the correlation degree of a point. Measure mode is divided into the following three kinds, respectively corresponding to the classical domain, extension field and non field.

i. Measure mode $M_1 = \{S|K(S) \geqslant 0\}$, says the characteristic state belongs to the classical domain. Then the characteristic parameter is in the control index range, and the bigger $K(S)$ is, the easier it is to control the system.

ii. Measure mode $M_2 = \{S|-1 \leqslant K(S) < 0\}$, indicates the characteristic state belongs to the extension domain. Characteristic parameter of this mode doesn't meet the control requirements, but we can transform the values of control variables to the range required. $K(S)$ reflects the degree of difficulty of control transformation in the control variables selected, and the more negative it is, the more amount of control quantity we need, which is more difficult to achieve the above transformation.

iii. Measure mode $M_3 = \{S|K(S) < -1\}$, show, in the control volume selected, the feature state of the system is greatly deviated from the classical domain, in a non domain. At this time, not by changing the values of control variables makes it transform to the range required, we need to transform the control variables.

(4) *Control strategy*: We can get the corresponding control strategy after identifying the current state of measure model of system. Inference rules are: If measure mode M_n, Then the control strategy D_n $(n = 1,2,3)$.

i. The measure mode M_1, as the characteristic quantity is in the control index range, we can use the classical PID control strategy. The controller output

$$u(t) = k_P e + k_I \int e dt + k_D \frac{de}{dt} \tag{9}$$

where k_P, k_I and k_D are respectively the proportional, integral and differential coefficient of the PID controller.

ii. About the measure mode M_2, we can use the extension control strategy. The controller output

$$u(t) = y(t)/k_c + k_e K(S)(-sign(e)) \tag{10}$$