Grey Prediction Control for Gas Turbine Power Generation System

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Abstract: With the rapid development of CCHP, the construction of Energy Internet, the mature mining technology for natural gas and the improvement of P2G technology, the proportion of gas turbine units for generating electricity is higher and higher. As the energy conversion hub of gas and electricity, the stability of gas turbine is of great significance to the safe, economical and reliable operation of power system. In order to improve its stability, this paper applied grey prediction to its speed control system, and a simulation model for gas turbine power generation system in the mode of island operation was built on the Matlab/Simulink. The simulation results have shown that grey prediction can reduce the overshoot and accelerate the response speed of the system under both the small and large disturbance, and it can enhance the robustness of gas turbine and improve the stability of gas turbine power generation system effectively.

Introduction

Gas turbine power generation is an important direction for use of new energy and a typical representative of distributed generation energy [1~3]. It is the key hub for energy conversion, and its dynamic performance is related to the safe, economical and reliable operation of power system. In order to make the gas turbine have a better dynamic performance, it is necessary to find an effective control method. In recent years, people pay more and more attention to grey prediction control. Grey prediction control use a set of data in different time which can reflect the past behavior of a system to predict the future behavior. It provides a new method for solving the uncertain problems with less data or poor information, so it is really real-time. Many kinds of uncertain problems (such as time-varying conditions and strong nonlinear) determine the grey characteristics in power system. Many scholars applied the grey prediction control to the power system and their works have proved that grey prediction can improve the stability of the system [4~7].

This paper took single shaft gas turbine model proposed by W.I.Rowen as the research object [8], applying the grey prediction control to gas turbine speed control system, and a gas turbine island power system model was built. The simulation results have shown that the grey prediction control can effectively improve the dynamic performance of the system.

Grey prediction control [9]

Grey prediction uses the known data to predict the future data of the system. The old data can be replaced by new data to adapt to the change of the system. Grey prediction is based on Grey Model, GM \((h, m)\), where \(h\) is the order of the equation, and \(m\) is the number of the variables. Grey prediction principle is as follows:

- Set a non-negative data column with a given point of \(n\)

\[
y^{(0)} = \{y^{(0)}_1, y^{(0)}_2, \ldots, y^{(0)}_n\}
\]

By a accumulating procession we obtain
\[ y^{(1)} = \{ y_1^{(1)}, y_2^{(1)}, \ldots, y_n^{(1)} \}. \] (2)

Where \( y_i^{(1)} = \sum_{k=1}^{i} y_k^{(0)} \), \( i = 1 \sim n \).

We can establish Grey Model GM (1,1) by the formula (1) and (2):

\[ y_i^{(0)} + az_i^{(1)} = b \quad (i = 1 \sim n). \] (3)

Where \( z_i^{(1)} = (y_i^{(1)} + y_{i-1}^{(1)}) / 2 \), and we can obtain \( a \) and \( b \) by least square rule

\[ [a \ b]^\top = (B^\top B)^{-1}B^\top \mathbf{y}_N. \] (4)

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

With whitening treatment, equation (3) can become

\[ \frac{dy^{(1)}}{dt} + ay^{(1)} = b. \] (5)

Its solution is

\[ \hat{y}_{i+p}^{(1)} = (y_1^{(0)} - \frac{b}{a})e^{-a(i+p-1)} + \frac{b}{a}. \] (6)

We can obtain the predictive values of \( y^{(0)} \) in inverse accumulation

\[ \hat{y}_{i+p}^{(0)} = \hat{y}_{i+p+1}^{(1)} - \hat{y}_{i+p}^{(1)}. \] (7)

Where \( p \) is the steps of prediction.

When the principle above is applied into a controller design, a series of data reflecting system’s characteristics in the past time will be collected at first. Then, we can obtain system’s future data by grey prediction method. Compared the predictive values obtained by formula (7) with the reference value, we can determine the advanced control value and take corresponding control policy to act on the object.

**Design for Gas Turbine Speed Control System in Grey Prediction**

**Model of Gas Turbine System**

Fig. 1 is the gas turbine model proposed by W.I. Rowen. The upper and lower limits of the fuel signal is 1.5~ -0.058. The temperature function of exhaust is \( f_1 = 950 - 700 (1-W_f) + 550 (1-\omega) \) and the function for output torque is \( f_2 = 1.3 (W_f-0.23) + 0.5 (1-\omega) \). Temperature control system is using actual values, and other systems are per-unit. Gas turbine control system mainly includes speed, temperature, acceleration, fuel and turbine compressor control systems. Rotor speed can be controlled by changing the fuel. The speed, temperature and acceleration control system all generate corresponding fuel reference, and the minimum fuel reference will be output by minimum selector.
The product of minimum fuel reference and speed as the input fuel signal of fuel system can make it action.

\[
F_{\text{min}} = \frac{\omega_{\text{ref}}}{\omega_{\text{s}}}
\]

\[
\omega_{\text{ref}} = 3.3s + 1 + 0.4699s
\]

\[
\omega_{\text{s}} = 1.2s + 1 + 1.5s + 1
\]

**Figure 1. Model of gas turbine system.**

**Design for Gas Turbine Speed Control System in Grey Prediction**

When we use grey prediction to control the gas turbine speed, as shown in Fig. 2, we need to take samples of the speed \(\omega\) at first, then we will obtain the forecast value \(\hat{\omega}\) by grey prediction. Compared with the reference value \(r\), we can control the deviation in advance to make the speed achieve the reference value as soon as possible.

**Simulation and Results**

Building the simulation model of gas turbine island power system as shown in Fig. 3. We take a micro gas turbine as an example. Micro gas turbines can generally produce the power in the tens of kW to hundreds of kW, and the medium voltage and frequency AC produced need to be sent into the power electronic devices to acquire the AC in 380V and 50Hz, which can supply the power load directly. In order to study conveniently, supposing that the generator sends out 380V, 50Hz AC, so as to eliminate the consideration of power electronic devices. The single shaft gas turbine should be driven by permanent magnet synchronous generator. In this paper, we use the common AC synchronous generator with the excitation voltage to replace it. System parameters are shown in Table 1. PID: \(K_P=6.5, K_I=4, K_D=0\). Gray prediction \(n=4, p=30\), and the sampling period is 0.01s.
Figure 3. Simulation model for gas turbine power generation system in the mode of island operation.

Table 1. Parameter of elements.

| Elements names       | Parameter symbols | Parameter names | Parameter values |
|----------------------|-------------------|-----------------|------------------|
| Synchronous generator| $S$               | Rated capacity  | 30 [kVA]         |
|                      | $V$               | Rated voltage   | 380 [V]          |
|                      | $f$               | Rated frequency | 50 [Hz]          |
|                      | $V_f$             | Excitation voltage | 1               |
|                      | $p$               | Number of pole-pairs | 1               |
|                      | $V$               | Rated voltage   | 380 [V]          |
|                      | $f$               | Rated frequency | 50 [Hz]          |
| Power load           | $P$               | Active power    | 10 [kW]          |
|                      | $V$               | Rated voltage   | 380 [V]          |
| Power load           | $f$               | Rated frequency | 50 [Hz]          |
|                      | $P$               | Active power    | 5 [kW]           |

In order to study the control effect of grey prediction, small and large disturbance are added to the system. The system will achieve a stable state at $t=20s$. The small disturbance is a mechanical torque disturbance with the strength of 0.1p.u. and the duration of 1.5s at $t=25s$, and the large disturbance is cutting the power load 2 at $t=25s$. The curves of generator speed and mechanical power under two cases are shown in Figures 4 and 5.

Figure 4. Response curves of system to small signal disturbance in grey prediction.
From Figure 4 and 5, we can know that the grey prediction control can improve the stability and accelerate the response speed of the system under both the small and large disturbance. In the small disturbance case, it can make the system return to the original steady as soon as possible. In the large disturbance, it can make the system reach a new steady state as soon as possible.

**Conclusion**

Considering the nonlinear characteristics of gas turbine power generation system, it is very suitable to use grey prediction method for its control. In this paper, the grey prediction was used to control the generator speed, and a gas turbine island power generation system model was built. The simulation results have shown that compared with the conventional control, the grey prediction control can effectively shorten the adjustment time, reduce the overshoot of the response curve, and improve the dynamic response of the system.

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