Research and Analysis of Nonlinear Predictive Model Identification Control Based on Pumped Storage Unit in Construction Site

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Abstract. In this paper, a generalized predictive control method for the speed control system of pumped storage units is proposed, which is suitable for different working conditions of the power generation direction of pumped storage units. Through a combination of mechanism modeling and data-driven model order and parameter reduction strategy to determine the time delay and order of the instantaneous linear prediction model of the speed control system of pumped storage unit. According to the operation state and control target of the unit, the design scheme of the generalized predictive control frequency regulation mode and the opening regulation mode are given respectively, and the dynamic analysis of the control process under different operation conditions is carried out according to the actual parameters of the speed regulation system of a single 300MW pumped storage unit of a pumped storage power station in Central China, which verifies the effectiveness of the control method.

1. Introduction
In this paper, a generalized predictive control method for the speed control system of pumped storage units is proposed, which is suitable for different working conditions of the power generation direction of pumped storage units [1-13]. Through a combination of mechanism modeling and data-driven model order and parameter reduction strategy to determine the time delay and order of the instantaneous linear prediction model of the speed control system of pumped storage unit. According to the operation state and control target of the unit, the design scheme of the generalized predictive control frequency regulation mode and the opening regulation mode are given respectively, and the dynamic analysis of the control process under different operation conditions is carried out according to the actual parameters of the speed regulation system of a single 300MW pumped storage unit of a pumped storage power station in Central China, which verifies the effectiveness of the control method [14-20].
Hydropower units are widely distributed in modern power system, which have extremely complex nonlinear characteristics of hydro mechanical electrical coupling. They play a key role in energy supply, peak load regulation and emergency reserve. The safe, stable and efficient operation of hydropower units is of great significance to improve the power quality and maintain the stability of the power system [21-33]. In recent years, with the large capacity units and pumped storage units widely put into operation, the hydropower units show the development trend of large capacity and complex structure, which makes the control of the unit regulation system more and more complex. In order to improve the control performance of the unit and the stability of the unit under complex operating conditions, it is necessary to study the advanced control theory and method of the regulating system of the hydropower unit [34-42].

The least square (LS) method is a widely used mathematical tool in the system parameter estimation [43-48], which has the advantages of easy understanding, fast convergence and concise program. According to the solution principle of the algorithm, LS can be divided into many forms, including batch least square (BLS), recursive least square (RLS), orthogonal least square (OLS), recursive factor recursive least square (ffrls) with forgetting factor, etc.

In this paper, a generalized predictive control method for the speed control system [49-56] of pumped storage units is proposed, which is suitable for different working conditions of the power generation direction of pumped storage units. Through a combination of mechanism modeling and data-driven model order and parameter reduction strategy to determine the time delay and order of the instantaneous linear prediction model of the speed control system of pumped storage unit. According to the operation state and control target of the unit, the design scheme of the generalized predictive control frequency regulation mode and the opening regulation mode are given respectively, and the dynamic analysis of the control process under different operation conditions is carried out according to the actual parameters of the speed regulation system of a single 300MW pumped storage unit of a pumped storage power station in Central China, which verifies the effectiveness of the control method.

2. Nonlinear predictive model identification control

The reference trajectory of the system output is represented by Equation (1):

\[
\begin{align*}
    y_{ref} (k) &= y(k) \\
    y_{ref} (k+i) &= \beta \cdot y_{ref} (k) + (1-\beta^i) \cdot \hat{y}_{set}; i = 1,2,...,N_p
\end{align*}
\]  (1)

In Equation (1): \( y(k) \) is the system output at time \( k \); \( \hat{y} \) is the given value of the system; \( \beta \) is the flexibility coefficient used to slow down the sudden change of the system control quantity and the track tracking process of the smooth track. Setting the flexibility coefficient for the given signal of the system output can reduce the excessive fluctuation of the control signal, but it also inevitably prolongs the response speed of the system. For the fast dynamic process of generator excitation system control, in the control process, it is generally necessary to make the system output track the given value quickly without sacrificing part of the control smoothness.

The cost function of predictive control for generator excitation system is given by Equation (2) considering output trajectory tracking, control increment limit and terminal state penalty.

\[
J = \sum_{i=0}^{N_p-1} \left[ \| \hat{y}(k+i) - \hat{y}_{ref}(k+i) \|^2 + \| \Delta U(k+i) \|^2 \right] + \| \hat{y}(k+N_p) - X_{ref}(k+N_p) \|^2
\]  (2)

Subject to the following:
\[ X(k+i+1|k) = f_d(X(k+i|k),U(k+i|k)) \]
\[ Y(k+i|k) = h_d(X(k+i|k)) \]  
(3)

\[ U \in [U_{\min}, U_{\max}] \]  
(4)

\[ \Delta U \in [\Delta U_{\min}, \Delta U_{\max}] \]  
(5)

\[ X(k+N_p) - X_{\text{ref}}(k+N_p) \in \Omega \]  
(6)

In the formula, operation \( \left\| X \right\|_2 = x^T \cdot A \cdot x \) is defined. \( R \in R^{m \times m}, P \in R^{r \times r} \) represents the weight matrix of system output, control input and terminal state penalty terms respectively; \( Q = \{ X \in R^{r \times r} \} \) represents terminal stability region.

### 3. Step of identification control
Because there may be model mismatch, random interference and other factors between the actual system and the prediction model, only using Equation (5) for state prediction will have some deviation from the actual situation. Therefore, in the sampling period of each controller, it is necessary to feedback and correct the state prediction value according to the real-time state information of the system. In this paper, the product of real-time system error and correction coefficient is used as the feedback correction method. The feedback correction formula is shown in Equation (7):

\[ y(k+i|k) = y(k+i|k) + he(k) \]  
(7)

In Equation (7), the deviation \( e(k) = y(k) - y(k|i|k - 1) \) of the system output at time \( k \). \( y(k|i|k - 1) \) is the step-by-step output prediction with feedback correction at \( k \) time; \( y(k|i|k + k) \) is the step-by-step output prediction without feedback correction calculated according to the prediction model at \( k \) time; \( h \) is the correction coefficient.

### 4. Simulation and Analysis
Taking the dynamic process of a 300MW pumped storage unit in a pumped storage power station in Central China as an example, without special instructions, the parameters of the controlled system and GPC controller are consistent. The first sampling period after the unit frequency reaches the switching frequency of closed-loop control is selected as the starting point of analysis, and the simulation time is 100s.

![Figure 1. Generalized predictive frequency regulation model control.](image)
Figure 2. Opening adjustment mode control.

Figure 3. Nonlinear predictive model identification control.

Figure 4. Model identification control 1.

Figure 5. Model identification control 2.
In Figure 1, 2, 3~7, through a combination of mechanism modeling and data-driven model order and parameter reduction strategy to determine the time delay and order of the instantaneous linear prediction model of the speed control system of pumped storage unit. According to the operation state and control target of the unit, the design scheme of the generalized predictive control frequency regulation mode and the opening regulation mode are given respectively, and the dynamic analysis of the control process under different operation conditions is carried out according to the actual parameters of the speed regulation system of a single 300MW pumped storage unit of a pumped storage power station in Central China, which verifies the effectiveness of the control method.

5. Summary
In this paper, a generalized predictive control method for the speed control system of pumped storage units is proposed, which is suitable for different working conditions of the power generation direction of pumped storage units. Through a combination of mechanism modeling and data-driven model order and parameter reduction strategy to determine the time delay and order of the instantaneous linear prediction model of the speed control system of pumped storage unit. According to the operation state and control target of the unit, the design scheme of the generalized predictive control frequency regulation mode and the opening regulation mode are given respectively, and the dynamic analysis of the control process under different operation conditions is carried out according to the actual parameters of the speed regulation system of a single 300MW pumped storage unit of a pumped storage power station in Central China, which verifies the effectiveness of the control method.
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