Research and Analysis of On-Line Optimization Algorithm of Nonlinear Model Predictive Control Based on Hydropower Installation Field

Xiaoping Gou¹, Wanjun Zhang²,³,⁴, *, Feng Zhang⁴, Jingxuan Zhang¹, Jingyi Zhang², and Jingyan Zhang², f
¹School of Physical Education, Longdong University, Qingyang 745000, China.
²Gansu ZeDe Electronic Technology Company Limited, Gansu 741003, China.
³Lanzhou Industry and Equipment Company Limited, Gansu 730050, China.
⁴Xi’an Jiao tong University, 710049, Shaanxi, China.

*Corresponding author e-mail: wanjunzhang@xjtu.edu.cn

Abstract. Because of the strong nonlinearity of the controlled system, it cannot be expressed in the form of state space, and the calculation of nonlinear programming is large, so it is difficult to get the analytical solution. At present, it is generally solved by numerical method. The GPC stability theory based on state space analysis and internal model control is difficult to be applied in this case. In this paper, a fast algorithm of online optimization of nonlinear model predictive control based on the field of hydropower installation is presented. A fast algorithm control system of online optimization of nonlinear model predictive control is established and simulated by MATLAB. The simulation results show that the dimension of nonlinear programming solution in rolling optimization is effectively reduced and the feasibility of MPC is improved. Compared with single machine and multi machine systems, the model predictive control method is proved to have strong ability of generator terminal voltage maintenance and electromechanical oscillation damping.

Keywords: Hydropower installation field, nonlinear model predictive control, online optimization fast algorithm, research and analysis.

1. Introduction

GPC is applied to the speed control system of pumped storage unit, which realizes the frequency regulation and opening regulation of the speed control system under different operating conditions [1-3]. In order to fully consider the complex water machine electricity coupling characteristics of pumped storage power station in engineering practice, according to the actual structural parameters of water diversion system, mechanical and electrical parameters of pumped storage unit, this paper establishes a comprehensive simulation model of the speed control system of pumped storage unit, which is used to simulate the typical operation conditions and transition process of the actual pumped storage unit. The model is a highly nonlinear distributed parameter model, which can comprehensively represent the dynamic characteristics of pumped storage units. Due to the strong nonlinearity of the controlled system, it cannot be expressed in the form of state space, so the GPC stability theoretical analysis [4-6]
based on state space analysis and internal model control mentioned in this paper is difficult to be applied in this case. In order to deeply study the dynamic characteristics of the speed governing system of pumped storage unit and analyze the stability of the closed-loop control system, the nonlinear dynamic analysis method is introduced to analyze the dynamic stability of the speed governing system of pumped storage unit under the control of GPC from different angles through the mathematical tools such as the time domain of the system state [7-8].

Research on fast algorithm of online optimization for nonlinear model predictive control. In general, nonlinear MPC transforms rolling optimization into general nonlinear programming [9-10]. It is difficult to get the analytical solution because of the large amount of calculation in nonlinear programming [11]. It is of great significance to study a new on-line optimization algorithm for the application of nonlinear MPC in the regulation system of hydropower units [12].

In this paper, a fast algorithm of online optimization of nonlinear model predictive control based on the field of hydropower installation is presented. A fast algorithm control system of online optimization of nonlinear model predictive control is established and simulated by MATLAB. The simulation results show that the dimension of nonlinear programming solution in rolling optimization is effectively reduced and the feasibility of MPC is improved. Compared with single machine and multi machine systems, the model predictive control method is proved to have strong ability of generator terminal voltage maintenance and electromechanical oscillation damping.

2. Nonlinear predictive model identification control

The expression of system frequency track predicted in the time domain of k-time prediction is shown in Equation (1):

\[ \hat{f}_i(k + m|k) = f_i(k) + \sum_{j=1}^{\Delta} \hat{f}_i(k + j|k) \]  

(1)

Similar to \( P_m \) in GRC, \( f_i \) is a state variable in the distributed augmentation model. Therefore, the expression of frequency deviation increment of the prediction system in the prediction time domain in the \( k \)-time control region is shown in Equation (2):

\[ \Delta \hat{f}_i(k + m|k) = S_{\Delta f} \cdot A^r \cdot x(k) + \sum_{j=1}^{m} S_{\Delta f} \cdot A^{m-r} \cdot B L^T (j - 1) \cdot \xi (k) + \sum_{j=1}^{m} S_{\Delta f} \cdot A^{m-r} \cdot F \Delta \omega (k + j - 1|k - 1) \]  

(2)

In the (3) Formula, \( S_{\Delta f} \) is the selection matrix, which is used to filter out the rows related to the system frequency in matrix \( A \).

\[ \hat{f}_i(k + m|k) = f_i(k) + \sum_{j=1}^{m} S_{\Delta f} \cdot A^j \cdot x_i(k) + \sum_{j=1}^{m} \sum_{r=1}^{j} S_{\Delta f} \cdot A^{m-r} \cdot B L^T (r-1) \cdot \xi (k) + \sum_{j=1}^{m} \sum_{r=1}^{j} S_{\Delta f} \cdot A^{m-r} \cdot F \cdot \Delta \omega (k + j - 1|k - 1) \]  

(3)

The Formula (4) and (5) can be used to reduce the frequency deviation expression of the prediction system in the region as follows:
$$\begin{align*}
& \left( f_{\text{min}} - \zeta f_f \right) \leq \sum_{j=1}^{N_f} \sum_{i=1}^{N_r} S_{\Delta i} A^{i-1} B L^j (r-1) \cdot \xi(k) \leq f_{\text{max}} - \zeta f_f , m \in [1, N_p] \\
& \zeta f_f (k) = f_f (k) + \sum_{j=1}^{N_f} S_{\Delta j} A^{j-1} \chi(k) + \sum_{j=1}^{N_r} \sum_{i=1}^{N_r} S_{\Delta i} A^{i-1} F L^j \Delta \omega (k+r-1|k-1)
\end{align*}$$

(4)

In the formula: operation $\|x\|_d = x^T \cdot A \cdot x$. $Q \in R^{m \times m}$. $P \in R^{p \times p}$ represents the weight matrix of system output, control input and terminal state penalty terms respectively; $Q = \{X | X^T \cdot P \cdot X \leq \alpha\}$ represents terminal stability region.

3. Step of identification control

Therefore, the system frequency fluctuation constraint in control area $j$ is given by Equation (5). According to the expression of Laguerre function system prediction state quantity in time domain of $k$-time prediction given in Equation (5), it is easy to get that k-time prediction time domain terminal equation constraint $\xi(k)$ can be expressed as

$$A^{N} \cdot \chi(k) + \sum_{j=1}^{N} A^{N-j} - j \cdot B L^j (r-1) \cdot \xi(k) + \sum_{j=1}^{N} A^{N-r-j} F \cdot \Delta \omega (k+j-1|k-1) = 0$$

(5)

The corresponding constraints in Equation (5) are replaced by the constraint expressions of Laguerre function type in section, and then the decision variable $(k)$ of QP problem can be obtained by solving the optimization problem online. Then, the predictive control law sequence is calculated by Laguerre function fitting Formula (5). $M_0$ is the mpc-lfc real-time control law.

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, the parameters of the controlled system and GPC controller are not specified. 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.

In this paper, a fast algorithm of online optimization of nonlinear model predictive control based on the field of hydropower installation is presented. A fast algorithm control system of online optimization of nonlinear model predictive control is established and simulated by MATLAB.

![Online optimization of nonlinear model predictive control](image_url)
In Figure 1, 2, 3, Compared with single machine and multi machine systems, the model predictive control method is proved to have strong ability of generator terminal voltage maintenance and electromechanical oscillation damping.

**Fig. 2** On line optimization fast algorithm.

**Fig. 3** Nonlinear model predictive control algorithm.

**Fig. 4** Model identification control 1.
In Figure 4, 5, 6 and Figure 7, simulation results show that the dimension of nonlinear programming solution in rolling optimization is effectively reduced and the feasibility of MPC is improved. Compared with single machine and multi machine systems, the model predictive control method is proved to have strong ability of generator terminal voltage maintenance and electromechanical oscillation damping.

5. Summary
In this paper, a fast algorithm of online optimization of nonlinear model predictive control based on the field of hydropower installation is presented. A fast algorithm control system of online optimization of nonlinear model predictive control is established and simulated by MATLAB. The
simulation results show that the dimension of nonlinear programming solution in rolling optimization is effectively reduced and the feasibility of MPC is improved. Compared with single machine and multi machine systems, the model predictive control method is proved to have strong ability of generator terminal voltage maintenance and electromechanical oscillation damping.

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