Multivariable Predictive Control System Design for Coordinated Control System

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Abstract
In the paper a novel scheme is presented, which deals with the thermal unit systems operating over wide range load change and time-varying characteristic. The algorithm is tested on a 300MW once-through re-heater coordinate control system, simulation results demonstrate the proposed scheme can obtain satisfactory control performance.
Keywords: PREDICTIVE CONTROL; MULTIVARIABLE; COORDINATED CONTROL SYSTEM

1. Introduction

Predictive control has a wide application in industrial practice for its excellent control performance and robustness [1-6] .

The consistency between output power and load demand of boiler-turbine unit reflects the energy supply and demand balance between units and external power grid, main steam pressure reflects the energy supply and demand balance relations between the boiler and steam turbine of generator unit , Coordinated control system is to deel with these two balance. the main task of boiler-turbine unit control is to make unit response speedly to load demand by controlling the steam turbine valve adjusting instruction and boiler combustion rate instruction, at the same time ,guaranteeing the main steam pressure is in the allowed range and the unit operating safely and economically under the rated parameters .

In the paper a novel scheme is presented based on a multivariable predictive control algorithm[7], which deals with the thermal unit systems operating over wide range load change and time-varying characteristic. The algorithm is tested on a 300MW once-through re-heater coordinate control system, simulation results demonstrate the proposed scheme can obtain satisfactory control performance.

2. The Mpc Control Law

The principle of predictive control is shown in Fig. 1. The prediction of the plant output is given by its state-space model,

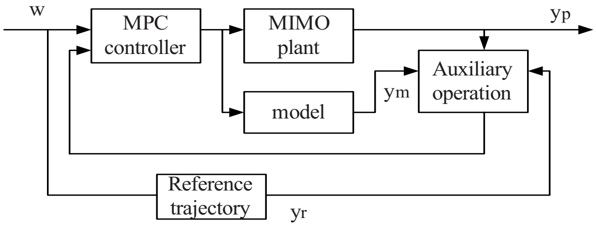

Figure 1. Principle scheme of MPC

where w is the set point of the reference trajectory, yr is the reference trajectory output, yp is the plant output, ym is the model output. The auxiliary operation involved time delays is described later.

The controlled plant is of multivariable with m inputs and m outputs and different delays of individual input-output pairs. Since the control is realized by means of a digital computer, sampled-data models will be used in the paper. The plant can be modeled by the transfer function matrix as follows:

$$y_p(k) = G_p(q)\cdot u(k) = \begin{bmatrix} g_{p_{11}}q^{-T_{11}} & g_{p_{12}}q^{-T_{12}} & \cdots & g_{p_{1m}}q^{-T_{1m}} \\ g_{p_{21}}q^{-T_{21}} & g_{p_{22}}q^{-T_{22}} & \cdots & g_{p_{2m}}q^{-T_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ g_{p_{m1}}q^{-T_{m1}} & g_{p_{m2}}q^{-T_{m2}} & \cdots & g_{p_{mm}}q^{-T_{mm}} \end{bmatrix}\cdot u(k) \quad (1)$$

where $u(k)$ and $y_p(k)$ are the vectors of the plant's inputs and outputs, respectively, while q is a shift operator. The integer parameters T_{ij} are the delays of the individual transfer functions. The exact model of the plant is not known during designing control law for a real system.

However, the approximated model can be obtained and described as follows:

$$y_m(k) = G_m(q)\cdot u(k) = \begin{bmatrix} g_{m_{11}}q^{-T_{11}} & g_{m_{12}}q^{-T_{12}} & \cdots & g_{m_{1m}}q^{-T_{1m}} \\ g_{m_{21}}q^{-T_{21}} & g_{m_{22}}q^{-T_{22}} & \cdots & g_{m_{2m}}q^{-T_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ g_{m_{m1}}q^{-T_{m1}} & g_{m_{m2}}q^{-T_{m2}} & \cdots & g_{m_{mm}}q^{-T_{mm}} \end{bmatrix}\cdot u(k) \quad (2)$$

The time delays in the plant will be circumvented by constructing an auxiliary variable that serves as the output of the plant without presenting delays, i.e., the so-called "undelayed" model of the plant will be introduced for the purpose. It is obtained by "removing" delays from the "delayed" model (2) and converting it to the state-space description:

$$\begin{aligned} x_m(k+1) &= A_m x_m(k) + B_m u(k) \\ y_m^0(k) &= C_m x_m(k) \end{aligned} \quad (3)$$

where $y_m^0(k)$ models the "undelayed" output of the plant.

The behavior of the closed-loop system is defined by the reference trajectory which is given in the form of the reference model. The control objective is to determine the future control action such that the predicted outputs coincide with the reference trajectory. The coincidence point is called a coincidence horizon and denoted by H. The prediction is calculated under assumption of constant future manipulated variables ($u(k) = u(k+1) = \cdots = u(k+H-1)$), the mean level control. The H-step ahead prediction of the "undelayed" plant output is then obtained from Eq. (3):

$$y_m^0(k+H) = C_m(A_m^H x_m(k) + (A_m^H - I)(A_m - I)^{-1} B_m u(k)) \quad (4)$$

The reference model is given as follows:

$$\begin{aligned} x_r(k+1) &= A_r x_r(k) + B_r w(k) \\ y_r(k) &= C_r x_r(k) \end{aligned} \quad (5)$$

where w stands for the reference signal vector. The reference model parameters should be chosen to satisfy the following equation

$$C_r(I - A_r)^{-1} B^r = I \quad (6)$$

which results in the unity gain of each channel so that the output can track the reference trajectory. For simplicity, we assume a first order reference model in this paper, hence, matrices A_r, B_r and C_r become diagonal. Furthermore, C_r can be chosen as I. In order to ensure the reference following in steady state, B_r has to be equal to $I - A_r$. The predictions of the reference trajectories are then written in the following form,

$$y_r(k+H) = A_r^H y_r(k) + (I - A_r^H)w \quad (7)$$

where

$$A_r = \begin{bmatrix} a_{r_1} & 0 & \cdots & 0 \\ 0 & a_{r_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & a_{r_m} \end{bmatrix} \quad (8)$$

The aim of the proposed algorithm is to find a control law that enables the reference trajectory tracking the "undelayed" controlled signal $y_p^0(k)$. To develop the control law, Eq. (7) is rewritten in the following form

$$w(k+H) - y_r(k+H) = A_r^H(w(k) - y_r(k)) \quad (9)$$

where a constant reference signal ($w(k+i) = w(k), i = 1,2,\dots,H$) is assumed, the reference trajectory tracking ($y_r(k+i) = y_p^0(k+i), i = 1,2,\dots,H$) is obtained,

$$y_p^0(k+H) = w(k+H) - A_r^H(w(k) - y_p^0(k)) \quad (10)$$

We let the objective increment vector Δ_p be equal to the model output increment vector Δ_m,

$$\Delta_p = \Delta_m \quad (11)$$

Δ_p is defined as the difference between the predicted reference signal vector $y_r(k+H)$ and the actual output vector of the "undelayed" plant $y_p^0(k)$

$$\Delta_p = y_r(k+H) - y_p^0(k) \quad (12)$$

Taking into account the reference trajectory tracking and (10), (12) can be rewritten as follows:

$$\begin{aligned}\Delta_p &= y_p^0(k+H) - y_p^0(k)\\ &= w(k+H) - A_r^H(w(k) - y_p^0(k)) - y_p^0(k)\end{aligned} \tag{13}$$

The variable $y_p^0(k)$ cannot be measured directly, however, it can be estimated from the available signals.

$$y_p^0(k) = y_p(k) - y_m(k) + y_m^0(k) \tag{14}$$

It can be seen from Eq. (11) that the delay in the plant is compensated by the difference between the outputs of the "undelayed" and the "delayed" model. If the perfect model of the plant is available ($G_m = G_p$), then $y_p(k) = y_m(k)$, the result is actually the output of the "undelayed" plant. If not, then, only the approximation can be obtained.

The model output increment vector Δ_m is defined by the following form:

$$\Delta_m = y_m^0(k+H) - y_m^0(k) \tag{15}$$

From (4), (10), (11), (13), (14) and (15), we have

$$\begin{aligned}u(k) = G_0^{-1}((I - A_r^H)(w(k) - y_p^0(k)) +\\ y_m^0(k) - C_m A_m^H x_m(k))\end{aligned} \tag{16}$$

where

$$G_0 = C_m(A_m^H - I)(A_m - I)^{-1} B_m \tag{17}$$

and the control law of MPC in analytical form is finally obtained,

$$\begin{aligned}u(k) = G_0^{-1}((I - A_r^H)(w(k) - y_p(k) + y_m(k)) +\\ (A_r^H C_m - C_m A_m^H)x_m(k))\end{aligned} \tag{18}$$

By taking into account (14), the control law from (18) becomes

$$\begin{aligned}u(k) = G_0^{-1}((I - A_r^H)(w(k) - y_p^0(k) + y_m^0(k)) +\\ (A_r^H C_m - C_m A_m^H)x_m(k))\end{aligned} \tag{19}$$

3. Control System of Coordinated Control System

3.1. Description of the Plant

The process of unit coordinated Control system is shown in Figure 2.

Where Ne is the power of generator(MW), Pt is main steam pressure of steam turbine(MPa), uT is steam turbine valve adjusting instruction(%), uB is boiler combustion rate instruction(t/ h) , $W_{NT}(s)$ is the transfer function from uT to Ne, $W_{NB}(s)$ is the transfer function from uB to Ne, $W_{PT}(s)$ is the transfer function from uT to Pt, $W_{PB}(s)$ is the transfer function from uB to Pt.

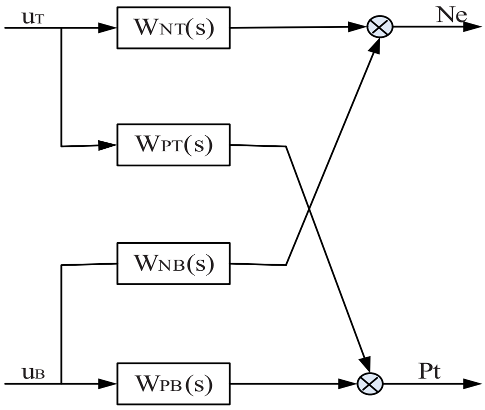

Figure 2. Multivariable coupling process of unit

Choose a 300 MW DC reheat unit as the study object. Assuming the model parameters are determined by load completely, and scales linearly with load, a variable parameter model in different load is obtained in essay [8]:

$$\begin{bmatrix} N_e \\ P_t \end{bmatrix} = \begin{bmatrix} W_{NT}(s) & W_{NB}(s) \\ W_{PT}(s) & W_{PB}(s) \end{bmatrix} \begin{bmatrix} u_T \\ u_B \end{bmatrix} \tag{20}$$

Where,

$$\begin{aligned}&W_{NT}(s) = (-5.924 + 10.607L)s[1 + (263.5 - 164.5L)s]\\ &/[1 + (16.7 + 33.3L)s + (74.7 - 16.7L)^2 s^2]\\ &[1 + (-0.6 + 4.7L)s]\end{aligned}$$

$$\begin{aligned}&W_{PT}(s) = (0.553 - 1.973L)[1 + (-3.3 + 6.1L)\\ &s / 1 + (160 - 90L)s]\end{aligned}$$

$$\begin{aligned}&W_{NB}(s) = (2.226 - 0.157L) \times [1 + (797.7 - 486.7L)s]\\ &/\{[1 + (389 - 240L)s]^2[1 + (20.4 + 2L)s]\}\end{aligned}$$

$$\begin{aligned}&W_{PB}(s) = (2.545 - 1.28L) \times [1 + (438.3 - 233.3L)s]\\ &/\{[1 + (261.3 - 133.3L)s]^2[1 + (11.03 + 0.67L)s]\}\end{aligned}$$

where, L is ratio of the actual output power and rated power,

L = N/ 300

3.2. Simulation Results

Case 1: Study of load tracking characteristics

In order to study tracking capability of the system, a 100% fixed operating point model is adopted as the object for simulation. As illustrated in Fig.3~Fig.4, +1 step disturbance is imposed to power loop, keeping main steam pressure stable, the responses of output and control variable are illustrated in Fig.3 and Fig.4 respectively.

The experimental results show that the the proposed control scheme has good load tracking ability.

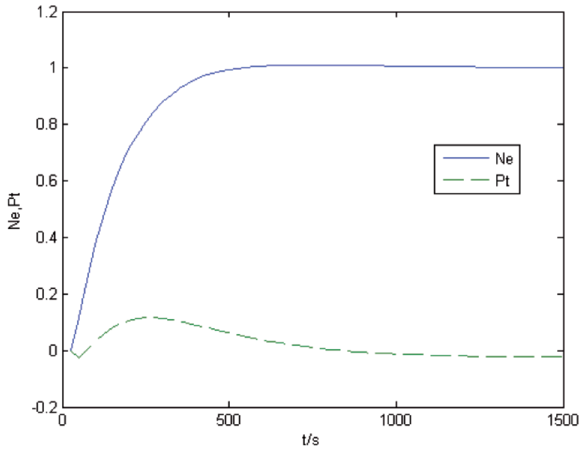

Figure 3. Output response of step disturbance in power loop

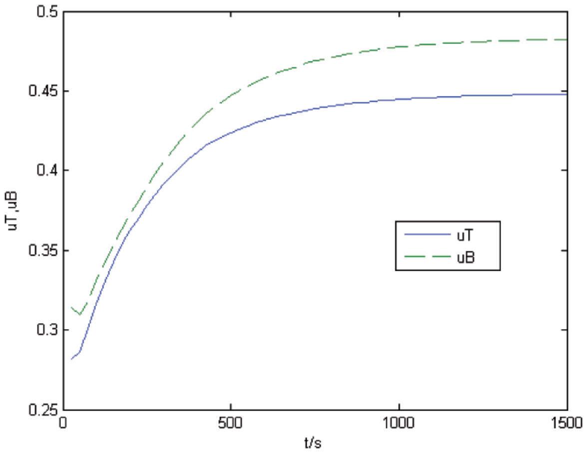

Figure 4. Control variable response of step disturbance in power loop

Case 2 A wide range load variation experiment

In order to meet the need of load control characteristics, a wide range load variation experiment is carried out below. supposing the system run stably, the load of the system then increases from 50% to 60% at 200s (the increasing ratio is 6%/min), after 1200s' stable running, the load increases to 70% at same ratio, then the load increases to 100% in same rule, and the output power increases 150MW in this process.

As illustrated in Fig.5, the parameter L increases from 0.5 to 1 in this process, so the object is time-varying, the results of the simulation is shown in Fig.6

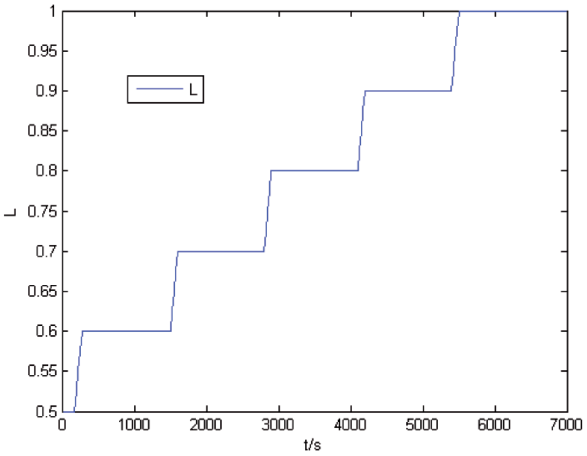

Figure 5. The parameter L

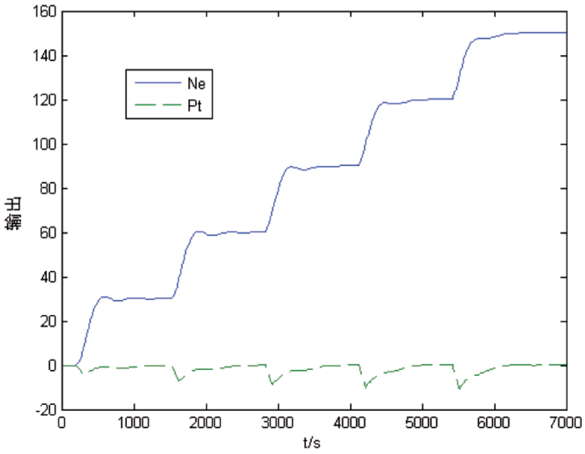

Figure 6. Output response of the system

The experimental results demonstrate the effectiveness of the proposed control scheme. While the operating condition varies in a wide range, the closed loop multivariable control system can also obtain a satisfactory performance.

Conclusions

In this paper, a multivariable control scheme for a 300MW DC reheat unit in a power plant is proposed based on predictive control strategy. The control law can be implemented easily for the multivariable systems with load varying in wide range. The experimental results demonstrate the effectiveness of the control system.

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Optimization Design of Mechanism Motion System Control Based on Simmechanics

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Abstract
Mechanism model is established by SimMechanics, CAD model is directly introduced into Simmechanics for modeling, Feedforward controller is established with the inverse kinematics provided by SimMechanics, A motor model is built with SimPowersystem, ideal drive and the actual motor drive is compared, Thereby the optimal design of system control is obtained.

Keywords: SIM MECHANICS, INVERSE KINEMATICS; FEEDFORWARD CONTROL

1. Introduction

Mechanism kinematics mainly study on relative motion of component: the displacement, velocity and acceleration change over time. The traditional analysis methods for mechanism kinematics mainly include graphic method and analytic method. Due to