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# The study of multi-model predictive control on hydraulic unit

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## ABSTRACT

Hydro-turbine governing system is a non-linearity, time varying non-minimum phase system, the control strategy of current don't meet and improve the control of quality and the requirements on large turbine units or isolate the unit control system with load of power grid, more advanced and more complex control strategy such as variable parameters of the PID, Adaptive control, Fuzzy control and so on have made further research study. In this paper, through studying the characteristics of water turbine regulation system, and the Multi-model DMC predictive control what is used to design the controller, in order to find a more suitable control strategy by the simulation.

## KEYWORDS

Hydraulic turbine; Governor; DMC predictive control; PID control.

DMC is the use of the controlled object phase jump response prediction model to describe the system is a non-parametric model, applicable to asymptotically stable linear system, for the unstable system, can be used in conventional control (PID) will stabilize and then use its DMC. With this feature [1],DMC can be used to predict the hydraulic control unit.

## THE DMC PREDICTION MODEL

Assuming a controlled object under control action unit step, the output response shown in Figure.1, if the system is asymptotically stable linear system, and set up the system after a period of *N* samples, the output tends to be stable, that is $y(NT) = a_N \approx y(\infty)\cdot$

The sampling values are:

$$a_i = y(iT) \quad i=1,2,\ldots,N \qquad (1)$$

In the formula *T*——Sampling period; *N*——Hits, Positive integer

Because the system is asymptotically stable, when *i*> *N* with the error *y* (*iT*) *y* (*NT*) has the same order of magnitude. So it can be controlled object unit step response of the first *N* limited sampling value $\{a_1, a_2, \cdots, a_N\}$ is used to describe the system dynamic characteristics, and the nonparametric model can be set up.

## MULTI-MODEL DMC[2]

### Prediction model

Taken as a parameter model plants get $\{a_1, a_2, \cdots, a_N\}$ non-parametric model, because of model unit operating conditions $y_a$ = 1.0 has reached the maximum, it can't step input signal. So it can take the unit operation condition in the relay trip $y_a$ = 0.5 to 0.9, after the system runs stably, the relay output $y_a$ = 0.1 step signal. Obtaining a total of five units open loop step response curve, as shown in Figure.2. Abscissa diagram for the time (in seconds),the vertical change rate for the corresponding rotational speed. Due to the step signal for $y_a$ = 0.1, so the need to obtain a non-parametric model $\{a_1, a_2, \cdots, a_N\}$ proportionally magnified 10 times treatment.

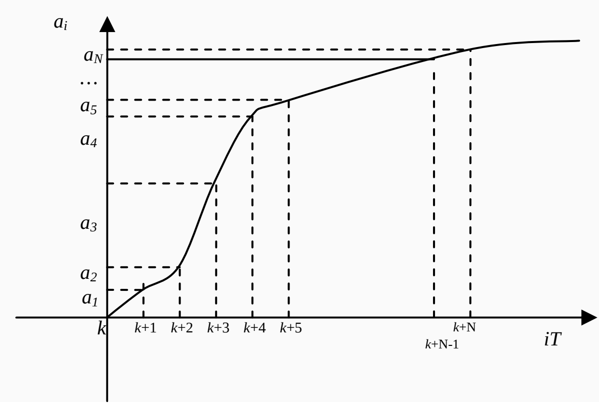

**Figure 1 : Step response characteristics of the system**

Known as shown in Figure.2, if want to get group of five curves $\{a_1, a_2, \cdots, a_N\}$ non-parametric model. As is the larger difference between the five sets of data, taking the relay model $\{a_1, a_2, \cdots, a_N\}$ of stroke was 0.9, the runtime model units in other conditions have bigger difference. Control effect is not shown in the relay trip of 0.9 of the control quality, the solution is to setting up multiple storage area, the different model $\{a_1, a_2, \cdots, a_N\}$ values are stored, according to the operation condition to select different parameters $\{a_1, a_2, \cdots, a_N\}$ .Assumes that the relay trip of the nonparametric model the dynamic coefficient matrix A1, A2,…,AN respectively, according to the operating conditions exist different $A_i$ .

When the relay device trip $y_{ai}$ , predicting the output model is:

$$\hat{Y}_k(k) = Y_0(k) + A_i \Delta U(k) \qquad i=1,2,\ldots,n$$

Control increment is: $\Delta u(k) = C\Delta u_M(k) = d^T\left[y_r(k) - \hat{y}_{P0}(k)\right]$

In the formula:

$d^T = C(A_i^T Q A_i + R)^{-1} A_i^T Q = [d_1 \cdots d_P]$ i=1,2,…,n

$C = [1 \quad 0 \quad \cdots \quad 0]$

Multi-model DMC system structure diagram as shown in Figure.3.

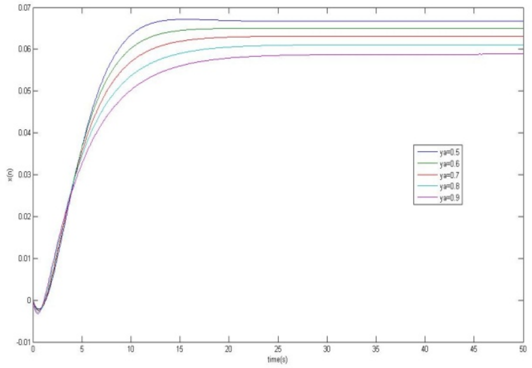

**Figure 2 : ydraulic units open loop step response model**

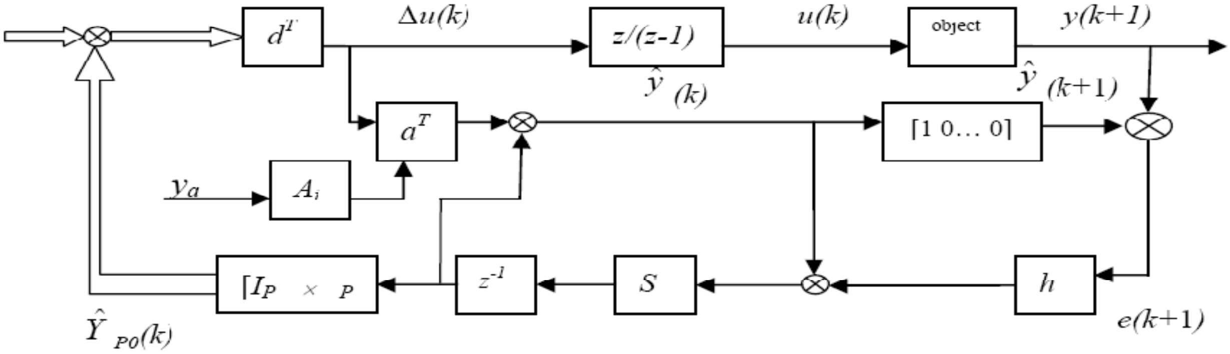

**Figure 3 : Multi-model DMC system structure**

## MULTI-MODEL PROBLEM

When the unit operation in different working conditions, model parameters are different. Especially in the two operation cohesion, the change of model is not stable, and this will affect system stability, so how to deal with the robust stability of the system model parameters into the key.

Bo-lin wang [3]for this model more variable gain control had a more detailed discussion.

Similarly nonparametric model function is used to approximate the dynamic coefficient matrix. Assuming a non-parametric model the dynamic coefficient matrix in different servomotor stroke yai $(1, 2, \cdots N)$ are $A_1, A_2, \cdots A_N$ ,corresponding with $\{a_{11}, a_{21}, \cdots, a_{N1}\}$, $\{a_{12}, a_{22}, \cdots, a_{N2}\}$, … $\{a_{1N}, a_{2N}, \cdots, a_{NN}\}$,each group of corresponding points of known points, when taking the i-th a coefficient of each group, the corresponding sampling time it is $\{a_{i1}, a_{i2}, \cdots, a_{iN}\}$,adopting the method of spline interpolation approximation. Since the cubic spline interpolation function compared with other polynomial function, it has better approximation smoothness and has simple calculation. So this article uses the cubic spline function to get the coefficient matrix [4].

Based on $\{a_{i1}, a_{i2}, \cdots, a_{iN}\}$ spline function can be obtained Si(ya),as long as know the relay device trip ya get in iT adopts corresponding ai value of the time. At this point you can use $A(\mathrm{y}_a)$ dynamic coefficient matrix to represent the nonparametric model [5,6,7]:

$$A(y_a)=\begin{bmatrix} S_1(y_a) & & \\ \vdots & \ddots & \\ S_M(y_a) & \cdots & S_1(y_a) \\ \vdots & & \vdots \\ S_P(y_a) & \cdots & S_{P-M+1}(y_a) \end{bmatrix} \qquad (2)$$

## THE SIMULATION CALCULATION SIMULATION CALCULATION

### A single DMC control model

Hydroelectric unit model in Appendix A and B taken as the controlled object, take a group of A1 (relay journey ya = 0.5) dynamic coefficient matrix as the nonparametric model, because of the unit step response in the 30s has been stable, the matrix coefficient$\{a_1, a_2, \cdots, a_N\}$ set N = 20,the time interval T = 1.5 s, because of the need to maintain stability of the speed, setting yr = 0, Q=diag(1 1 ⋯1),R =diag(1 1 ⋯1),Figure.4 is five kinds of 10% less in the cases of the output response of load characteristics and control output characteristics. It indexes such as Table 1.

### Multi-model DMC control

Corresponding units relay device trip 0.5, 0.6,…, 0.9 take the $A_i$ ,i =1, 2,…,5and at the same time, Figure.5 is the response of the output characteristics of the five conditions of minus 10% load, control effect can be seen very close.Fig.6 is the corresponding control output characteristics. ITAE index shown in Table 2,and the contrast can be seen, control quality single model DMC significantly worse than the occupy less memory ,in the unit operation condition change control quality has great changes [8].

### Multi-model DMC switch control

DMC direct multi-model switching control strategy. Switching DMC servomotor stroke model based on the value of ya .Still using the same hydraulic unit model, let servomotor stroke ya = 90%,that is a servomotor stroke output ya = 0.9.When the system is reduced 40% load, the relay trip also need smaller. Because the relay trip ya output decreased more than 0.1(It is certain, though not necessarily reduced proportionately),as the guide vane changes more than 10%,Hydraulic unit model also change. Because the model is based on DMC servomotor stroke every 0.1 from 0.5-0.9 to build a model, DMC control strategy relies also need to change the model, corresponding to changes in the model unit [9].

Compared to the system model from A5 to A2 or A1 changes, Figure.6 control characteristic is near the balance 10% change. Model the dynamic coefficient matrix of non-parametric model used has not changed so in their respective conditions to maintain good control effect [10].

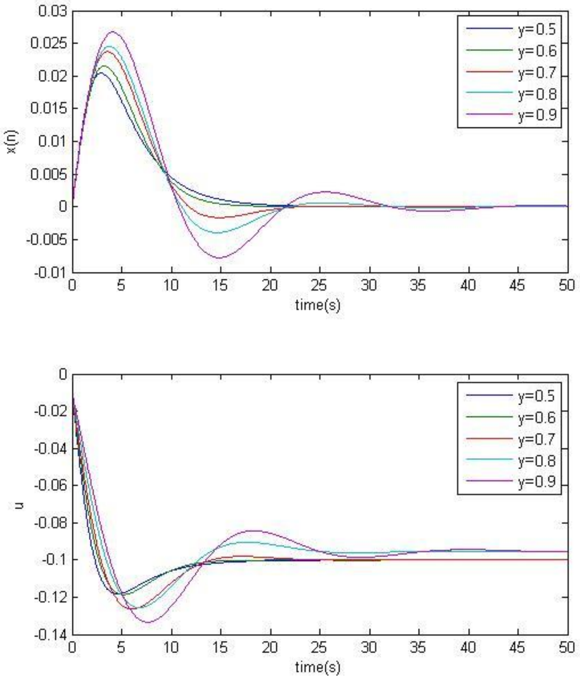

**Figure 4 : Five conditions under a single model DMC output response and control the amount of minus 10% load change characteristics**

**Table 1 : ITAE index under different conditions of single model DMC**

| Servomotor stroke $y_a$ | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
|---|---|---|---|---|---|
| ITAE | 0.1544 | 0.1231 | 0.1138 | 0.1096 | 0.1092 |

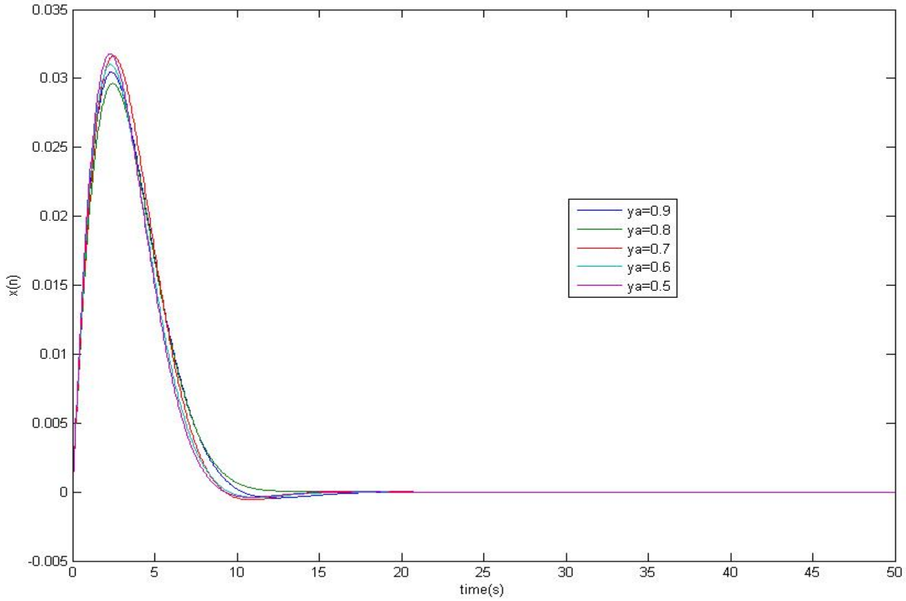

**Figure 5 : Five minus 10% under the condition of load response characteristics**

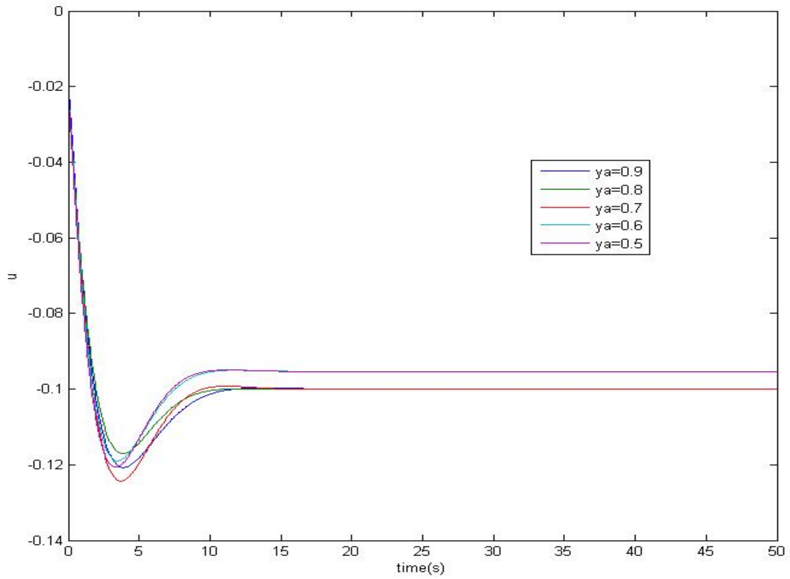

**Figure 6 : DMC conditions corresponding multi-model change control output characteristics**

**Table 2 : Multi-model DMC under ITAE index under different working conditions**

| Servomotor stroke $y_a$ | 0.9 | 0.8 | 0.7 | 0.6 | 0.5 |
|---|---|---|---|---|---|
| ITAE | 0.1092 | 0.1109 | 0.1102 | 0.1085 | 0.1088 |

Figure.7 ya = 0.9 is shown in an initial steady state, reducing 40% load speed change process, since the amount of change can be seen in more than 10%,model changes. Instability in the model conversion occurs at the boundary, and a larger speed fluctuation.

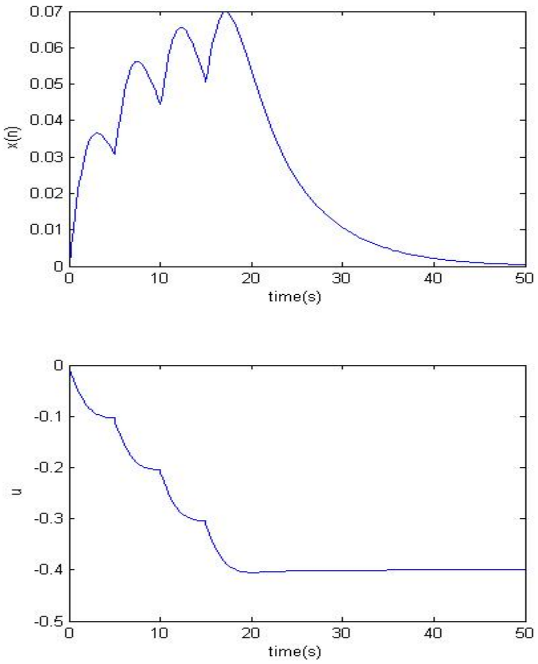

**Figure 7 : Control features multi-model conversion of DMC model**

By type (2) as a nonparametric model dynamic coefficient matrix of the model, department of servomotor stroke according to changes in the value of continuous change ya. Since the coefficient of variation is used spline interpolation, and therefore continuous time model switching. The simulation results can be seen, though in fine point is tiny disturbance, overall quality control and disturbance is less than 10% of the time is close to a single model .Continuous model of DMC control quality as shown in Figure.8,basic system reaches a steady state in the 30s.

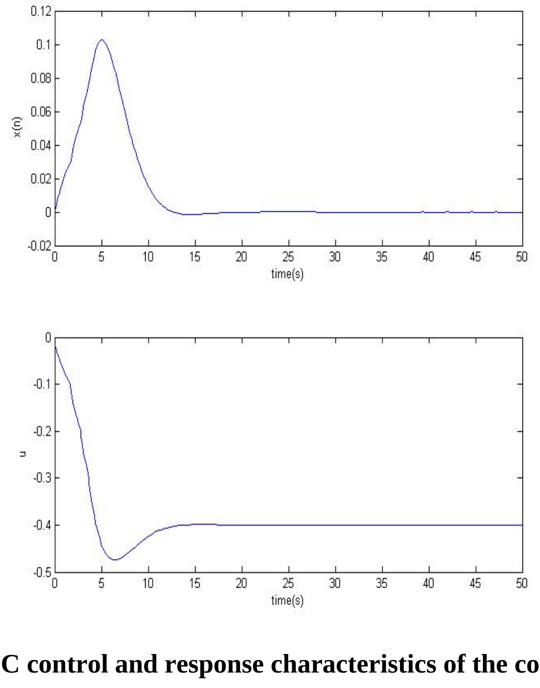

**Figure 8 : DMC control and response characteristics of the continuous model**

## ANALYSIS AND SUMMARY

DMC model predictive control for controlling the quality of a single dynamic system depends on the degree of matching the prediction model and the actual model, when the actual model and prediction model mismatch, even with feedback correction, it still can not achieve the optimal control performance. Therefore, the use of multi-model DMC can switch the corresponding model based on system changes, when switched to the model, a real-time online identification, real-time changing model, this kind of situation in the process of slowly time-varying may be a good choice. But in the case of fast time-varying, identification process may occur is not over, the new conditions have to start, real-time system identification can not be guaranteed. Therefore, the use of off-line and get the dynamic matrix coefficients stored in the memory, according to the position of running conditions, switching corresponding model, it can guarantee real-time systems. However, the use of matrix coefficients obtained by spline interpolation method, can fast continuously transform model, and avoid the fluctuation model when switching.

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