A Robust Practical Generalized Predictive Control for boiler super heater temperature control

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Key Words: Robust control, power-plant control, Control Application

Abstract-A practical method of robust generalized predictive controller (GPC) application is developed using a combination of Ziegler-Nichols type functions relating the GPC controller parameters to a first order with time delay process parameters and a model matching controller.

The GPC controller and the model matching controller are used in a master/slave configuration, with the GPC as the master controller and the model matching controller as the slave controller. The model matching controller parameters are selected to obtain the desired overall performance.

The effectiveness of the proposed control method is tested by simulation using a mathematical model of the boiler super heater temperature process.

1-INTRODUCTION:

Tight super heater steam temperature control is essential to improve lifetime, efficiency, and load following in power plants.

Low steam temperature reduces the efficiency of the thermal cycle. While high steam temperature is restricted by the strength and durability of materials used in super heaters. Tight Control of super heater steam temperature is important for the efficient and reliable operation of thermal power plants.

The standard method of controlling the boiler super heater outlet temperature is by the use of a water spray between the secondary super heater and the primary super heater.

Steam temperature is challenging due to nonlinear process model with a long dead time and time constants, and the boiler load and other disturbances.

A number of Advanced control algorithms have been considered in the literature for super heater temperature control[4][5][6][7],however the implementations of advanced control in the real world are still scare ,most of the existing power plants are still controlled by PID controllers.

The GPC (generalized predictive control) performs well when the system to be controlled is discrete non minimum phase unstable inverse plant model, since future process variables predictions are incorporated into the control law in such a way that the control action is less sensitive to time delay mismatches and non minimum phase systems.

A substantial amount of computation is necessary in order to implement a GPC controller. It is possible to reduce the amount of calculation needed by assuming that the projected control signal will remain constant after a few intervals. However even taking this into account, the necessary computational effort is still a real drawback to practical applications of this type of controller, a method has been proposed by E.F. Comacho and C.Bordons [1] to overcome this problem for first order process model by developing a set of Ziegler – Nichols type functions relating the GPC controller parameters to the process parameters, by using this set of functions the implementation of the GPC controller is simplified considerably.

However the process model is limited to a first order plus time delay process

A method is proposed in this paper, to facilitate the use of high order process models in the GPC controller design, by using a model matching controller as a slave controller in a master/slave configuration, with the GPC as the master controller.

The model matching slave controller closed loop transfer function is designed to be a first order plus time delay model, so the Ziegler – Nichols type functions relating the GPC controller parameters to the first order plus time delay model can be used.

The effectiveness of the proposed control method is tested by simulation using a mathematical model of steam boiler super heater temperature process.

2-THE PROPOSED CONTROLLER DESIGN METOD:

The control design process is divided into the following two distinct design steps.

2.1-THE GPC CONTROLLER DESIGN:

The GPC is obtained as a result of minimizing [1]:

$$J(N_1, N_2) = E\sum_{j=N_1}^{N_2} D(k)[y(k+j)-r(k+j)]^2 + \sum_{j=1}^{N_2-d} x(k)[\Delta u(k+j-1)]^2 \quad \ldots\ldots (2\text{-}1)$$

where y(k+ j) is an optimal j step ahead prediction of the system output , N_1 and N_2 are the minimum and maximum costing horizons respectively $D(j)$ and $X(j)$ are weighting sequences and $r(k+j)$ is a future set point .A substantial amount of computation is necessary in order to implement the GPC . It is possible to reduce the amount of calculation needed by assuming that the projected control signal will remain constant after a few intervals. However even taking this into account, the necessary computational effort is still a real drawback to practical applications of this type of controller [1].

This problem can be solved for a first order process model with time delay by using a set of Ziegler - Nichols type functions relating the GPC controller parameters to a first order model with time delay and unity steady state gain ,E.F. Comacho and C.Bordons [1] as follows:

For a first order with time delay plant given by

$$G_p(z^{-1}) = \frac{(1-p_1)z-1}{1-p_1^{\,z-1}} z^{-d} \qquad (2\text{-}2)$$

Where p_1= process pole

d = time delay

The multistage predictive controller for the first order process model is [1]:

$\Delta u(k) = l_1\hat{y}(k+d/k) + l_2\hat{y}(k+d+1/k) + l_3 r(k)$ ….. (2-3)

Where $\Delta u(\mathrm{k})$ is the control action increment.

Assuming the following:

$N_1 = d + 1$

$N_2 = d + N$

$D(j) = d + D^j$

$X(j) = X^j$

$D = 1$

$X = 0.8$

$N = 15$

l_1, l_2, l_3, is given by

$$l_1 = -0.845 - \frac{0.564\cdot p_1}{1.05 - p_1}$$

$$l_2 = 0.128 + \frac{0.459\cdot p_1}{1.045 - p_1}$$

$$l_3 = -l_1 - l_2$$

As it is clear from above the design of the optimal control can be eased to a large extent by using first order plus time delay process model However l_1, l_2, l_3 equations cannot be applied to a higher order models, to achieve this goal a model matching slave controller will be designed to have a first order process model with time delay closed loop response given by:

$$Gslave = \frac{(1-p)z^{-d}}{(1-pz^{-1})} \qquad (2\text{-}4)$$

Where p= the slave closed loop pole,

d = time delay

2.1 THE SLAVE MODEL MATCHING CONTROLLER DESIGN:

Consider a system defined by the equation:

$Ay(k-1) = Bu(k-1) + Ce(k)$ (2-5)

Where

$A = 1 + a_1 z^{-1} + \cdots + a_{na} z^{-na}$

$A = b_0 + b_1 z^{-1} + \cdots + b_{nb} z^{-nb}$

$C = 1 + c_1 z^{-1} + \cdots + c_{nc} z^{-nc}$

z^{-1} is the backward shift operator

$e(k)$= white Gaussian noise sequence with zero mean and variance

$y(k)$= plant output

$u(k)$ = plant input

With controller of the form:

$Fu(k) = Hr(k) - Gy(k)$ (2-6)

Where the polynomials F, G, H are given by:

$F = 1 + f_1 z^{-1} + \cdots + f_{nf} z^{-nf}$ (2-7)

$G = g_0 + g_1 z^{-1} + \cdots + g_{ng} z^{-ng}$ (2-8)

$H = h_0 + h_1 z^{-1} + \cdots + h_{nh} z^{-nh}$ (2-9)

Combining the controller and system equation yields the closed loop description, P.E. Wellsted and M.B.Zarrop [2]:

$(FA + BG)y(k) = BHr(k) + CFe(k)$ $(2-10)$

The closed loop poles are then assigned to their desired location, specified by the polynomial T by selecting F , G according to the polynomial identity [2].

$$FA + z^{-1}BG = TC \quad (2\text{-}11)$$

For a unique solution n_f, n_g should be selected as:

$$n_f = n_b$$

$$n_g = n_a - 1$$

Provided that A, B have no common zeros and $n_t < n_a + n_b - n_c$

The closed loop response is:

$$y(k) = \frac{HB}{TC} r(k) + \frac{F}{T} e(k) \qquad (2\text{-}12)$$

The pre compensator H is selected to achieve both low frequency gain matching and the cancellation of C from the servo pole set. The simplest choice is [2]:

$$H = C\left[\frac{T}{B}\right]_{z=1} \qquad (2\text{-}13)$$

Yielding the closed loop equation [2]:

$$y(k) = \left[\frac{T}{B}\right]_{z=1} \frac{B}{T} r(k) + \frac{F}{T} e(k) \qquad (2\text{-}14)$$

The desired pole set (the polynomial$T$) and a series compensator will be selected to improve the following:

1. Overall loop phase margin

2. Overall loop sensitivity to modeling error by reducing the following H_∞ norm.

$$S_m = \left| \frac{\dfrac{1}{1+H_L}}{\dfrac{H_C}{1+H_L}} \right|_\infty \qquad (2\text{-}15)$$

Where H_L, H_c are loop and the controller transfer functions.

By achieving the above mentioned design goals the overall controller robustness will be improved.

Thus the GPC controller design is simplified by applying the first order plus time delay model calculation formulas.

3. SUPER HEATER TEMPERATURE CONTROL DESIGN EXAMPLE:

The following super heater process model was used in the slave controller design H.Dangvan and D.Normancdcyort [3]:

$$G(s) = \frac{G_0}{(1+Ts)^3} = \frac{\Delta T_0(s)}{\Delta F_{sn}(s)} \qquad (3\text{-}1)$$

Where ΔT_o in volts is the super heater outlet temperature

ΔF_{sn} in m^3 / s is the spray water flow

G_o, T - are functions of the load level, as follows

load(MW)	T	G_0
60	115	1.29
80	84.1	1.36
100	61.4	1.32
115	57.1	1.18

By using the design method in section 2 , A controller was designed with a master GPC controller using equation (2-3), slave loop with a time constant of 226 seconds to achieve an overall loop phase margin of 49 deg, and an overall gain margin of 8 db, Fig (3-1) shows the servo performance, while Fig (3-2) shows the regulation performance compared to a tightly tuned PID controller at the same load level (115 MW).

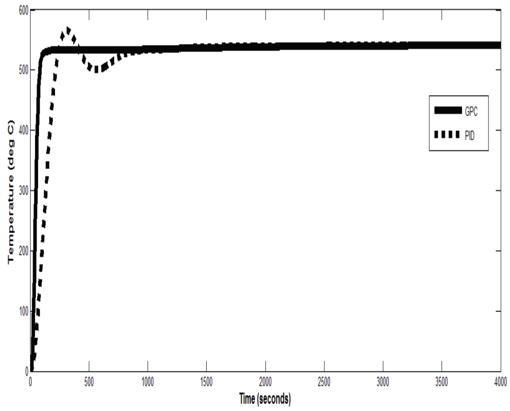

Fig (3-1)-servo performance

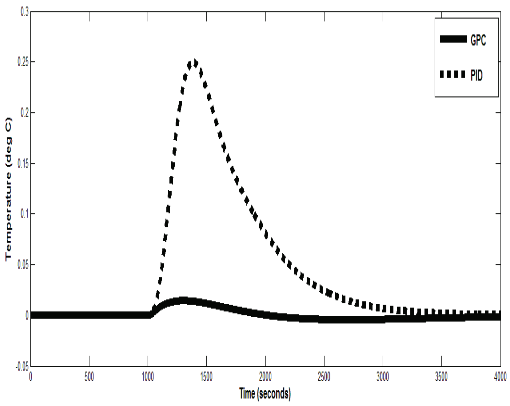

Fig (3-2)-regulation performance

4-<u>CONCLUSIONS:</u>

Historical development of thermal power plant control systems has led to the use of a distributed digital control system.

The use of distributed digital control system has improved process monitoring operation by using better man machine communication methods and permits the full automatic start - up and shut - down operation of the thermal power plant, thus it eases the operators task.

However although the distributed digital control system through its advanced calculation capabilities, permits the use of modern control system theory results in thermal power plant process parameters regulation, most operational distributed digital control system uses conventional PID control parameters regulation.

In our present work we have developed a simple and easy applicable GPC controller design method that avoids the complex calculations.

In order to test the effectiveness of the proposed control algorithm, a mathematical model was used to simulate steam boiler super heater temperature process.

Simulations indicates that the use of the proposed GPC controller design methods results in an improved regulation and servo performance compared to a tightly tuned PID controller.

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