Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 14 (14): 1662-1665, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.1662.1665

Design and Analysis of Generalized Predictive Control for Moisture Content Control in a Benchmark Paper Plant

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Abstract: The role of advanced control techniques for an energy intensive chemical process like paper industries is indispensable. The quality of the end product depends entirely on the efficiency and disturbance managing capacity of the control techniques. In this background the role of Model predictive control as a constraint handling as well as quality assuring tool has to be studied. In this study, two different model predictive controller techniques namely Dynamic Matrix Control (DMC) and Generalized Predictive Controller (GPC) is considered. The controllers are suitably designed for controlling the moisture level for a bench marked paper machine model. The servo performance of the DMC and GPC controllers under unconstrained environment is studied for and the results are tabulated in this study. The study reveals that the Dynamic matrix controller (DMC) provides better performance than the Generalized Predictive Controller (GPC).

Key words: Predictive control, dynamic matrix controller, MPC

INTRODUCTION

The quality of the study is based up on the moisture content present in the study. The control that has been imparted on the moisture content of the paper plays a vital role in paper manufacturing industries. The conventional controls like PID controllers were employed in early days. The advent of computers paved way for computer based controllers which were in fact more reliable and has more accuracy when compared to the conventional controllers. Extensive work has been carried out in implementing the computer based controllers in the paper manufacturing industries. Multivariable deadbeat algorithm is used by D'Hulster *et al*. (1983) to control the head box of paper machine. Matko and Schumann (1984) proposed self-tuning dead beat controllers. Dumont (1986) conducted a survey on advanced control strategies adopted in paper and pulp industries. Model predictive controller has been used in the paper manufacturing industries to achieve good control over the moisture content present in the study. Mercangoz and Doyle (2006) implemented Generalized Predictive Control to a paper benchmark model. Ramkumar and Ramakalyan (2009) implemented Dynamic Matrix Control (DMC) was has been implemented for the paper mill which controls the moisture of the study (Ramkumar and Ramakalyan, 2009). An overview of the MPC has been suggested by Rawlings (1999) and Mercangoz and Doyle (2006) developed model based control technique for paper mills. Ramkumar and Ramakalyan (2009) obtained the model for the paper plant. Qin and Badgwell (2003) addressed different control algorithms used in MPC. This study is aimed at analyzing the servo performance of two MPC techniques under unconstrained environment. The study is structured as follows. Generalized predictive controller is discussed in the second section. It is followed by simulation results and discussion and subsequently by conclusion.

MATERIALS AND METHODS

In this study, a FOPDT model of a paper plant is obtained by bump test (Ramkumar and Ramakalyan, 2009). The Generalized Predictive Controller (GPC) algorithm is developed in MATLAB. The FOPDT model obtained is controlled using a Generalized Predictive Controller (GPC) and the controller performance is studied. The performance of GPC is compared against the Dynamic Matrix Controller (DMC) implemented for the FOPDT model of the paper plant.

GENEREALIZED PREDICTIVE CONTROLLER

Model predictive controller (MPC) is a modern control technique which makes use of a model of the process to achieve the desired results. The striking feature of MPC is that it takes energy optimization and prediction of future events into account. Chow *et al*. (1995) and Clarke *et al*. (1987) proposed generalized predictive algorithm (GPC), which is used in MPC. The

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GPC makes use of Transfer function as well as State space model of the process for calculating the manipulated variables that has to be provided for the plant. In this study the transfer function of the process is converted to state space model to reduce the computational burden. The augmented matrix is presented by Wang (2009):

$$\begin{bmatrix}\Delta x(k+1)\\ y(k+1)\end{bmatrix}=\begin{bmatrix}F & O^T\\ HF & I\end{bmatrix}\begin{bmatrix}\Delta x(k)\\ y(k)\end{bmatrix}+\begin{bmatrix}G\\ HG\end{bmatrix}\Delta u(k) \quad (1)$$

Where:

$$\hat{F}=\begin{bmatrix}F & O^T\\ HF & I\end{bmatrix};\hat{G}=\begin{bmatrix}G\\ HG\end{bmatrix};\hat{H}=\begin{bmatrix}O^T & I\end{bmatrix}$$

$$O^T=\begin{bmatrix}0 & 0 & \dots & 0\end{bmatrix}$$

The future state equations of a state at an instant ‘k’ can be provided up to prediction horizon (N_P).The mathematical representation of the future state equations can be formed in a recursive fashion and it is given below:

$$x\ (k+1|k) = Fx\ (k) +G\Delta u\ (k) \quad (2)$$

$$x\ (k+2|k) = F^2x\ (k) +FG\Delta u\ (k) +G\Delta u\ (k+1) \quad (3)$$

At time instant ($k+N_P$), the state equation is given by:

$$x\ (k+N_P|k) = F^{NP}x\ (k) +F^{NP-1}G\Delta u\ (k) + F^{NP-2}G\Delta u\ (k+1) \dots .+ F^{NP-Nc}G\Delta u\ (k+N_c+1) \quad (4)$$

Similarly the output equation till prediction horizon (N_P) is given by:

$$y\ (k+1|k) = HFx\ (k) +HG\Delta u\ (k) \quad (5)$$

$$y\ (k+2|k) = HF^2x\ (k) +HFG\Delta u\ (k) +HG\Delta u\ (k+1) \quad (6)$$

$$y\ (k+N_P|k) = HF^{NP}x\ (k) +HF^{NP-1}G\Delta u\ (k) +HF^{NP-2}G\Delta u\ (k+1) \dots .+ HF^{NP-Nc}G\Delta u\ (k+N) \quad (7)$$

In general the output is mentioned as:

$$Y = Px\ (k) +H_x\Delta U \quad (8)$$

Where:

$$Y = [y\ (k+1)\ |k]\ y\ (k+2|k) \dots\ y\ (k+N_P|k)^T$$

$$\Delta U= [\Delta u\ (k)\ \Delta u\ (k+1)\ \Delta u\ (k+2) \dots\dots\ \Delta u\ (k+N_P+1)]^T$$

$$P=\begin{bmatrix}HF\\ HF^2\\ HF^3\\ \vdots\\ HF^{N_P}\end{bmatrix}$$

$$H_x=\begin{bmatrix}HG & 0 & 0 & \dots & 0\\ HFG & HG & 0 & \dots & 0\\ HF^2G & HFG & HG & \dots & 0\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ HF^{N_P-1}G & HF^{N_P-2}G & HF^{N_P-3}G & \cdots & HF^{N_P-N_c}G\end{bmatrix}$$

The cost function J has to be minimized with respect to the input, which in turn reduces the offset between the reference value and the measured output from the process. The cost function is given by:

$$J = (R_S-Y)^T (R_S-Y) + \Delta U^T\lambda\Delta U \quad (9)$$

Where:

$$R^T_S = [1\ 1 \dots 1]\ r\ (k)$$

The symbol λ represents scaling factor by which the speed of the response can be altered.

From Eq. 8-9 can be rewritten as:

$$J = (R_S-Px\ (k)^T (R_S-Px\ (k))-2\Delta U^T\Delta U^TH^T_x (R_S-Px\ (k)) +\Delta U^T\Delta H^T_xH_x+\lambda)\ \Delta U \quad (10)$$

To achieve zero offset between the reference and the actual output from the process, the cost function must be minimized with respect to minimum input effort applied to the process:

$$\frac{\partial J}{\partial \Delta U}=0 \quad (11)$$

The derivative of the cost function is given as:

$$\frac{\partial J}{\partial \Delta U}=-2H_x^T(R_s-Px(k))+2(H_x^TH_x+\lambda I)\Delta U$$

From Eq. 11:

$$\Delta U=(H_x^TH_x+\lambda I)^{-1}\varphi^T(R_s-Px(k)) \quad (12)$$

The ΔU contain inputs till prediction horizon (N_P). Out of which the first input is given to the plant and the response is obtained and for the subsequent time instants new inputs are provided.

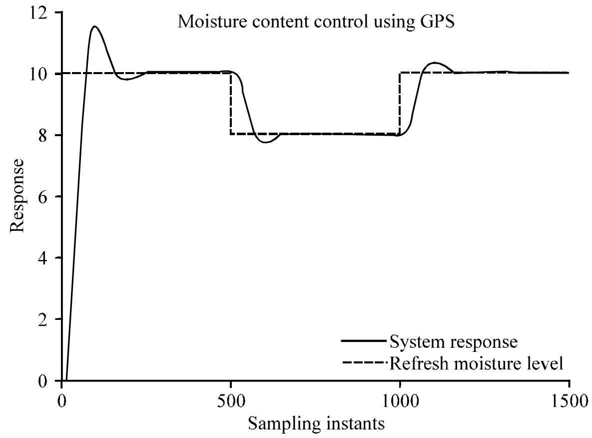

Fig. 1: Set point is presented in dotted line and the response is provided in continuous red color. The set point is 10 till 500 samples. The set point is 8 in between 501 and 800 samples and the set point is 10 from 801 samples to 1500 sample

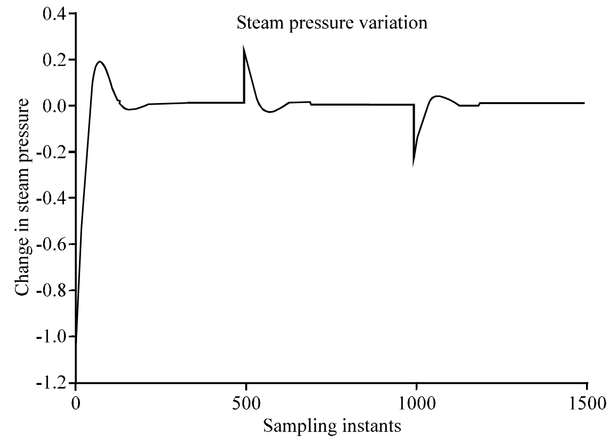

Fig. 2: Rate of change of steam pressure at each sampling instant as per the control action taken by the GPC

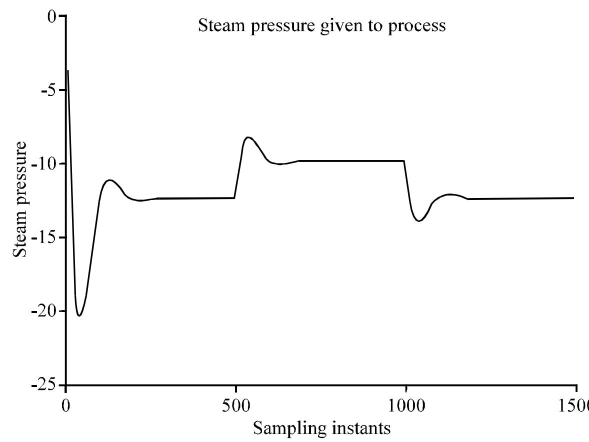

Fig. 3: Steam pressure generated by GPC algorithm at each sampling instants in response to the set point provided in Fig. 1

RESULTS AND DISCUSSION

The set point or reference moisture level is 10 for first 500 samples, the reference moisture level is 8 in between 501 and 800 samples and the reference level is 10 from 801st sample to 1500th sample. Figure 1 describes the response obtained by the FOPDT model of paper plant, controlled by GPC algorithm. Figure 2 describes the rate of change of manipulating variable i.e., steam pressure. The GPC algorithm manipulates the steam pressure very quickly and it enables the plant to reach the set point in a short period of time. The rise time of the FOPDT model is 80 sec in DMC controller (Ramkumar and Ramakalyan, 2009). Whereas the rise time of the same model is 64 sec by using GPC algorithm.

The controller output provided by the GPC algorithm is shown in Fig. 3. It can be noted from the figure that the steam pressure varies very rapidly in order to make the plant to reach the set point. The quick change in the manipulated variable i.e., steam pressure might cause the response of the plant to go beyond the set point. This type of scenario is called as overshoot. The response of the plant produces 1.5% overshoot in GPC algorithm, while there is no overshoot in the response of the plant which is controlled by DMC algorithm (Ramkumar and Ramakalyan, 2009). Further, the settling time of the plant gets increased due to overshoot. Due to overshoot experienced in the response of the plant using GPC algorithm, the settling time of the plant is 250 sec. While the settling time of same plant controlled by DMC controller is 90 sec (Ramkumar and Ramakalyan, 2009). A small amount of overshoot has caused a significant difference in the settling time of the process. Based on the results obtained, it is evident that GPC algorithm produces rapid control action than DMC controllers and it is not suitable for highly sensitive process.

CONCLUSION

In this study the dynamics of moisture content for a bench marked paper plant model were analyzed based on the performance of two types of algorithm of MPC namely GPC and DMC. Both GPC and DMC produced good control action in the presence of constraints and for the plant possessing negative gain. But when the servo performance of the controllers was compared, it has been found that DMC has an edge over GPC in enhancing the performance of the process.

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