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Design of Decoupler and Performance Analysis of Distillation Column

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Abstract: This paper deals with the design of decoupler for TITO process to enhance its performance. MIMO process is where all the inputs and outputs are coupled to each other and therefore it is very difficult to control. In this type of process the interactions will be very strong and to eliminate such interactions among their loops, it is needed to design a decoupler. After designing of decoupler then the various control techniques have been done such as PID (proportional-Integral-derivative), MPC (Model Predictive Controller), MRAC (Model Reference Adaptive Control). The mathematical model of Wood and Berry distillation column is considered for the analysis. It is one of the most underestimated fields of chemical engineering and has been around for well over hundred years. Simulation results are done in MATLAB simulink and comparison analyses of various controllers are carried out. The valuation of diverse time domain parameters is done to establish that the adaptive control and Model predictive controller has diminutive overshoot and speedy response as compared to PID controller .The performance evaluation illustrates a good relationship between PID,MPC and adaptive controller.

Keywords: PID, Auto tuning, Decoupling, Distillation column, MPC, Adaptive.

I. INTRODUCTION

Multi input, multi output (MIMO) systems shows the process with more than one input and output which require multiple control loops. These multivariable systems can be complex with loop interactions that consequences in variables with unpredicted effects [1]. One of the example of MIMO systems is distillation column. It is the process of separation of two or more substances .This process is also an example of loop interaction, hence these interactions is necessary to be avoided as changes in one loop might cause destabilizing changes in another loop[4]. To do so, MIMO systems can be decoupled into individual SISO loops. Decoupling is done using various techniques that includes pairing of input –output which is made through perceptive guessing or by mathematical methods. One such mathematical method is Relative Gain Array (RGA) .To decouple two feedback loops, the decouples have to be designed and it is done by ideal decoupling method [15]. After the design of decouple suitable controller is chosen .In recent years many superior controllers have been discovered. The PI and PID are the most admired controllers of both in the dominion of the academic and industrial application [5]. The implementation of this controllers is easy. It helps to correct the error among the measured outputs and desired outputs of the process which improve the transient and steady state responses as much as possible.

Advanced controller such as MPC is used which is engender an online feedback control by using the open-loop optimization [14]. The prediction of the future plant response with help of a process model is the basic principle of MPC and it tries to minimize a set horizon objective function which is the sum of future predicted errors and control moves. Model Reference adaptive controller is designed. This controller consists of two components PID controller and adaptive Mechanism [19]. Thus this paper presents the simulated case study of distillation column of wood and berry model which is designed with decoupler with various controllers such as PID, MPC, MRAC. Lastly comparing all the performance simulation results like ISE, IAE, ITAE errors is done to prove the best controller.

II. DISTILLATION COLUMN

Process depiction

Distillation column is very often encountered in chemical processes for the separation of mixture into its individual components [8]. This column have number of trays and each tray has material and heat capacities . A weir on one side of the tray maintains a liquid level at suitable height on the tray.

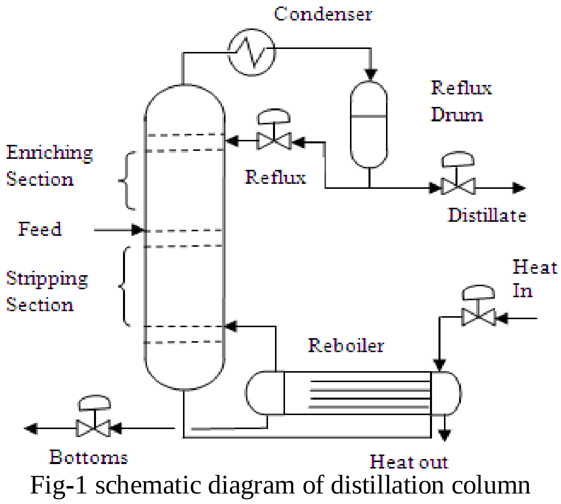

Fig-1 schematic diagram of distillation column

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Distillation column has 4N+10 variables and control variables are X_D (Distillate composition, mol fraction) , X_B (Bottoms composition), M_D (liquid holdup in reflux drums, mols), M_B (Liquid holdup in column base/ reboiler, mols) and pressure[14].

Distillation may be carried out either as a batch or as a continuous operation. A distinctive distillation column consists of reboiler, condenser, reflux drum etc and has one feed stream and two of the product streams. The top distillate is referred as Xd and bottom distillate is referred as Xb. Distillation column used in different applications in the fields of petroleum industries, chemical industries ,in food processing[7] .

III. PROCESS INTERACTIONS

Transfer Function Model (2 x 2 system)
The open loop input-output relationship can be written in the matrix form

$$\begin{pmatrix} Y1 \\ Y2 \end{pmatrix} = \begin{pmatrix} G11 & G12 \\ G21 & G22 \end{pmatrix} \begin{pmatrix} U1 \\ U2 \end{pmatrix} \quad \text{---(1)}$$

The identified MIMO process is Distillation Column (Wood and Berry model)

$$\begin{pmatrix} X_D(s) \\ X_B(s) \end{pmatrix} = \begin{bmatrix} \frac{12.8e^{-s}}{1+16.7s} & \frac{-18.9e^{-3s}}{1+21s} \\ \frac{6.6e^{-7s}}{1+10.9s} & \frac{-19.4e^{-3s}}{1+14.4s} \end{bmatrix} \begin{pmatrix} R(s) \\ S(s) \end{pmatrix} \qquad (2)$$

Process interactions may induce undesirable interactions between two or more control loops. Control loop interactions are due to the presence of a third feedback loop[2]. In order to design the decentralized controller, the suitable pairings between manipulated inputs and controlled outputs are chosen using (RGA) analysis to weaken the interactions.

IV. RELATIVE GAIN ARRAY

It provides two types of useful information such as measure of process interactions and Recommendation about the best pairing of controlled and manipulated variables. It requires knowledge of steady state gains but not process dynamics.

$$\wedge = \begin{bmatrix} \lambda & 1-\lambda \\ 1-\lambda & \lambda \end{bmatrix} (\lambda = \lambda_{11}) \qquad (3)$$

where,

$$\lambda = \frac{1}{1 - \frac{k12k21}{k11k22}}$$

$\lambda12 = 1 - \lambda11 = \lambda21$

Recommended controller Pairing
-It corresponds to the λij which have the largest positive value that is closest to one. –It is suggest not to select the Pairings which correspond to negative [3].
For identified wood and berry model the steady state matrix is

$$k = \begin{bmatrix} k11 & k12 \\ k21 & k22 \end{bmatrix} = \begin{bmatrix} 12.8 & -18.9 \\ 6.6 & -19.4 \end{bmatrix}$$

Therefore

$$\wedge = \begin{bmatrix} 2.009 & -1.009 \\ -1.009 & 2 \end{bmatrix}$$

Hence the recommended pairing is Y1 and U1 and Y2 and U2.

V. DECOUPLER AND CONTROLLER DESIGN

PID:-
Initially PID and PI controller is used and it is not tuned independently rather by decentrailized Relay feedback method the values of PID and PI is determined [17].
(PID)
P=0.01; 0.067;
I= -0.23;0.016;
D=0.008; -0.54;

Decoupling control strategy
Here we are using simplified decoupling technique [10]. In general the best disturbance rejection is not obtained by perfect decupling but that the best response is obtained by some tuning of the decoupler and feedback controller [9]. so decoupling matrix T is taken to decouple a process with a transfer matrix G[16] .Generally some elements of T is chosen and then feedback controllers are tuned. In simplified decoupling the common choice is that T11= T22= 1 and the off diagonal elements

$T12 = -\frac{G21}{G22}$ and $T21 = -\frac{G21}{G11}$

$$T = \begin{bmatrix} 1 & -\frac{G12}{G11} \\ -\frac{G21}{G22} & 1 \end{bmatrix}. \qquad (4)$$

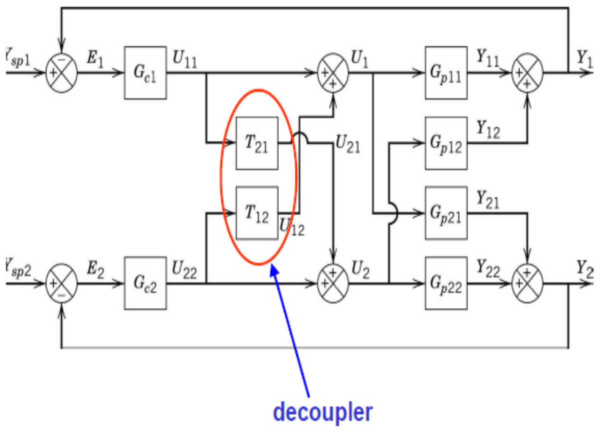

Fig 2- block diagram of 2x2 decoupler

VI. MODEL PREDICTIVE CONTROLLER

MPC is the one of the class of advanced control techniques is most often used in the process industries. It is indeed straight-forward for multivariable systems with time delays which finds its application in discrete domain and also in chemical industries. It has ability to handle constraints in a optimal fashion [14]. The basic idea behind MPC is that the authenticity allows the present time slot to be optimized, while keeping future time-horizon. The major principle of MPC is to determine a sequence of control moves so that the predicted response moves to the set point in an optimal manner. The determination of prediction and control Horizon comes under superposition principle and its calculation based upon the current and predicted measurement [14]. It is a model based approach. It is found to be giving the better response comparatively by the simple build-in process procedural.

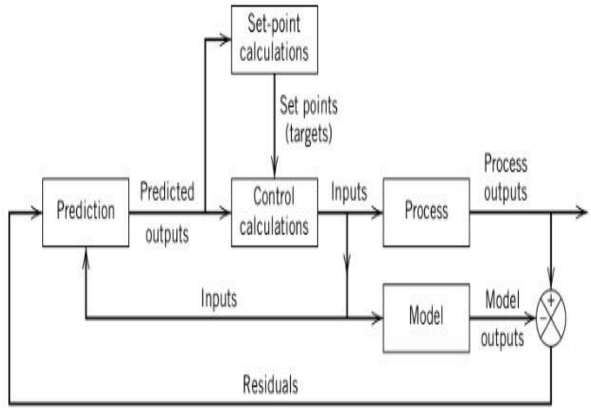

Fig-3 block diagram of MPC

VII. ADAPTIVE CONTROLLER

In this day adaptive controller is used as the most advanced controller in the field of any control field. The main two sub components of this controller are PID controller and athe adaptive Mechanism. Where the PID block is fixed , and by keeping the initial plant parameter the gains have been turned to achieve the total stability.

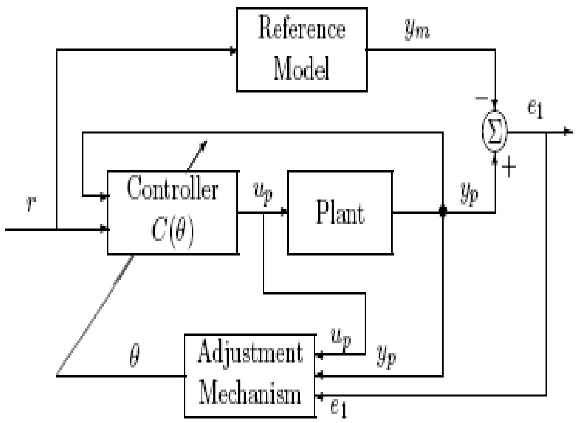

Fig- 4 The block diagram of MRAC.

Next comes the Adaptive Mechanism where its output (Θ) gets changed based on error (e) between plant output (Yp) and reference model output (Ym). How fast it can adapt (or change its output) depends on parameter called learning rate, gamma. Higher the value of gamma, faster it can adapt to any changes in plant. But there are some side effects also. Controller output (U) is calculated by: U = Uc * theta.

VIII. SIMULATION RESULTS AND DISCUSSION

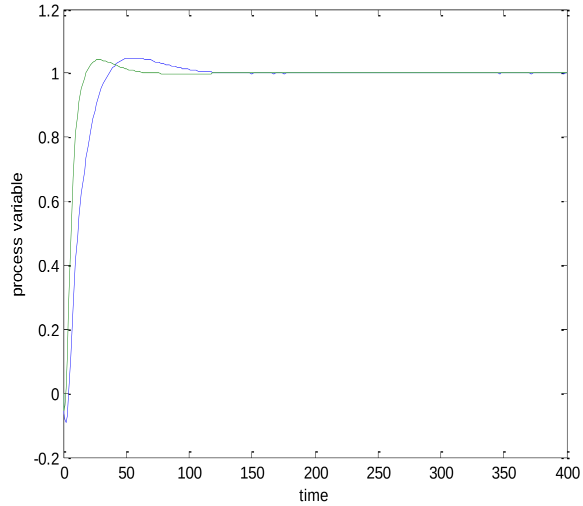

Fig-5 step response of a 2×2 distillation column system of decoupler and PID controller.(---Xb & ----Xd)

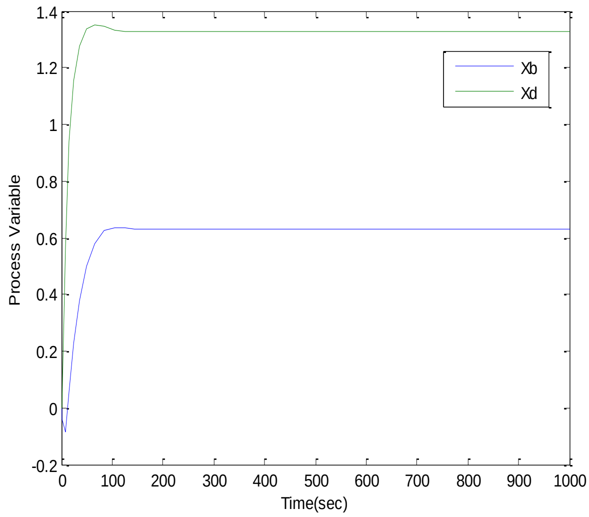

Fig- 6 response of distillation column of decoupler and MPC

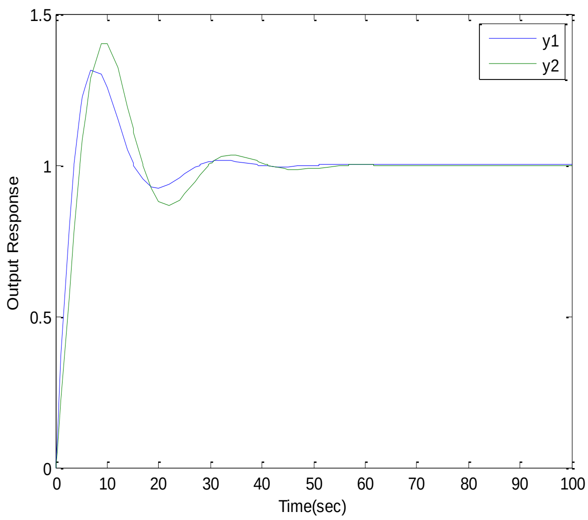

Fig -7 Response of 2x2 distillation column of decoupler and adaptive controller

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Table – 1 performance criteria Of PID , MPC and adaptive with decoupler.

Method	Setlting Time	controller	IAE	ISE	ITAE
PID	145	Loop 1	10.055	4.8790	113.736
	80	Loop 2	2.1042	1.8109	66.801
MPC	120	Loop 1	5.7002	3.0411	97.310
	130	Loop 2	2.2164	0.8901	64.335
Adaptive	40	Loop 1	3.1516	2.0544	65.331
	45	Loop 2	1.4419	0.627	52.617

IX. CONCLUSION

In this paper, a new control stratergy of combination of decoupler and adaptive controller was proposed for decentralized TITO wood and Berry Model. The analysis evidently explains that set-point in PID control is far from constrains whereas Mpc control is better than PID. Compare to other two controls, Adaptive set-point is closer to constraint. In this paper it was proved that MRAC tries to bring the process as close as possible to constraints without infringing them. Here the performance indices such as IAE(Integral Absolute Error),ITAE(Integral Time Absolute Error),ISE(Integral Square Error) based on integral error for a step set point are considered for comparison as they are generally accepted as a good measure for system performance. Hence it is concluded that the performance of MRAC with decoupler is better to compared with other two controls.

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