International Journal of Engineering & Technology, 7 (4.19) (2018) 502-506

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Online Validation of Relay based Identification and Controller Design with an Anti-Reset Windup for a Binary Distillation Column

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Abstract

Sequential auto-tuning based model identification is a closed loop approach, which has an extensive benefit compared to conventional methods because of user defined manipulated gain to the process within the verge of instability. Model parameters estimation of multi input multi output process is challenging because of existence of multivariable interaction among the variables. In this paper ideal relay is used as a sequential basis for binary distillation column in real time. Obtaining sustained oscillations in conventional methods is based on trial and error, benefit of relay is that oscillations can be generated as scaling of user defined gains. Predictive PI control algorithm is implemented. Results depicts the efficiency of methodology and importance of anti-reset term in the algorithm.

Keywords: *FOPDT; Sustained oscillations; Sequential relay; auto tuning; pade approximation*.

1. Introduction

Relay is an electrically operated switch. Relay feedback identification is employed in this process. Relay plays important role in mathematical modelling of physical process. Relay identification method is very convenient when compared to any other identification method. V. Sujatha and Rames C. Panda [1] presented new technique to model the off-diagonal closed-loop transfer function of 2-by-2 Multi Input Multi Output (MIMO) system in time domain using ideal as well as biased relay feedback tests. Swapnil Nema and Prabin Kumar Padhy [2] modelled two input and two output (TITO) process using hysteresis relay feedback method. Analytical expressions are derived using state space TITO matrix. Quadruple tank is used for real time experimentation. Different examples of proposed model were considered and compared it with nyquist plot and integral absolute error (IAE). V. Sujatha and Rames C. Panda [3] presented brief idea of interaction of loops in MIMO process and how to overcome this problem by using the control configuration selection among the loops. Eadala Sarath Yadav *et al.*, [4] has implemented relay based model identification using conventional, symmetric and asymmetric relays, design controller for respective models and implemented to online conical process.

Windup phenomena occurs when controller output exceeds the actuator input. Process variable acts as function of error (positive or negative) with respect to the setpoint, integral term in the controller will accumulates the gain (positive error) which should be compensated with its reciprocating gain (negative error). Therefore concept of anti-reset windup is implemented to eliminate this accumulation of error, integral needs to reset every time process variable crosses the set point. [5].

Figure.1 depicts decentralized control structure with anti-reset windup, where T_t is equivalent to integral gain T_i for the case of PI control structure.

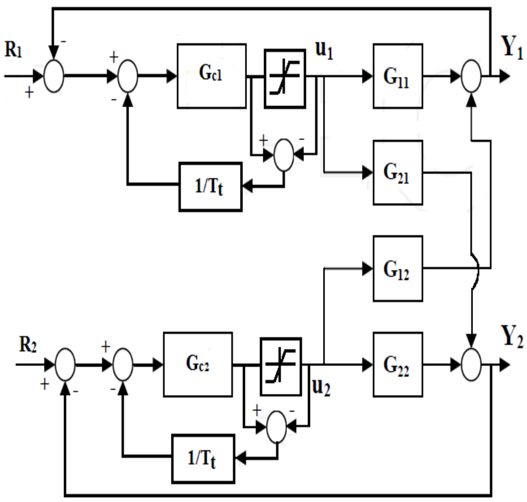

Fig. 1: Decentralized control structure with anti-reset windup

Interaction among the variables makes the control design more challenging in multi input and multi output process. Therefore, it is important to consider the effect of interaction on each variable on other. In this paper identification of the model is precisely modelled using sequential auto relay, where threshold limits are selected with the function of error. Modeling is done at certain region of operation. Controller design includes implementation of predictive PI control algorithm with and without anti-reset windup. This paper comprises of model identification in section.2 followed by control design and result analysis in section 3.

2. Methodology towards Plant Modeling

Wood and berry model is taken as reference model and parameters were obtained in relay. By following the concept of sequential auto tuning method each controller is designed in series.

$$G(s)=\begin{bmatrix}\dfrac{12.8e^{-s}}{16.7s+1} & \dfrac{-18.9e^{-3s}}{21s+1}\\ \dfrac{6.6e^{-7s}}{10.9s+1} & \dfrac{-19.4e^{-3s}}{14.4s+1}\end{bmatrix} \tag{1}$$

The sequential auto tuning method [6] is described in a few steps as follows:

a) Step-1

Decentralized two input two output structure has been considered, initially relay is given to the loop (Y1/R1) by eliminating secondary input loop and giving u2 as zero, shown in the Figure 2.

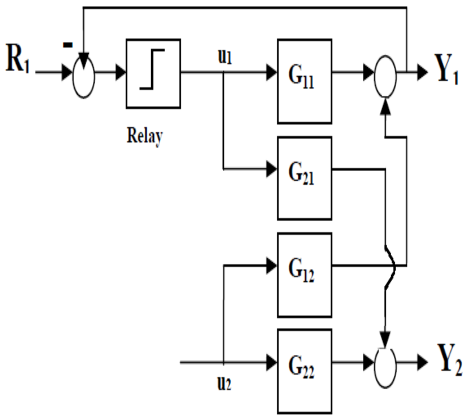

Fig. 2: Ideal relay in loop 1

Change in input generates oscillations at Y1, by making use of those oscillations ultimate gain and ultimate frequency can be calculated, thus by using Ziegler–Nichols closed loop tuning Gc1 is obtained. Therefore loop (Y1/R1) kept automatic using Gc1.

a) Step-2

Once Gc1 is designed, relay is given to loop (Y2/R2) as shown in the Figure 3. Similarly by using oscillations from Y2, Gc2 is designed and relay is shifted to loop (Y1/R1) again by keeping loop (Y2/R2) as auto mode

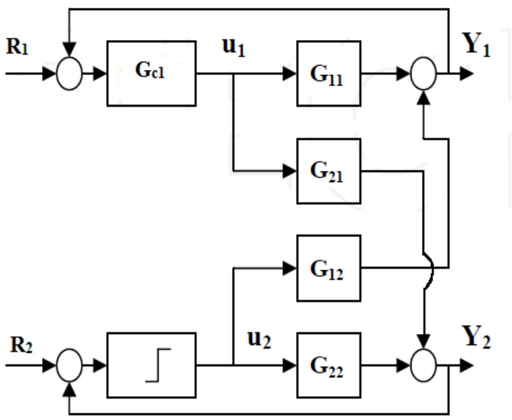

Fig. 3: Relay in loop 2 with loop 1 automated

a) Step-3

As relay is given to loop (Y1/R1) and loop (Y2/R2) is automated as shown in the Figure 4, oscillations are generated at Y1 and new Gc1 can be obtained. This procedure continues till the controller Gc1 and Gc2 converges. By using Ziegler–Nichols closed loop tuning we have found out Gc1 and Gc2 Controller is designed from ultimate gain and ultimate frequency After 3 to 4 iterations the Kc and Ki values converge at some values and these values are taken into considerations for designing the controllers. When loop 2 is automatic and relay feedback test for loop1 is shown in the Figure.4

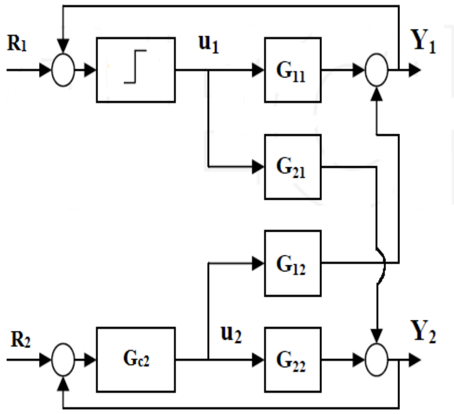

Fig. 4: Relay in loop 1 with loop 2 automated

For loop 1

$$G_{c1}=K_c+\frac{1}{s}K_i \tag{2}$$

For loop 2

$$G_{c2}=K_c+\frac{1}{s}K_i \tag{3}$$

In order to proceed we need to find out the closed loop transfer function and notation will be

$$G_{P11,CL}(s)u_1(s)=\left[g_{p11}(s)-\frac{g_{p21}(s)G_{c2}(s)g_{p12}(s)}{1+g_{p22}(s)G_{c2}(s)}\right]u_1(s) \tag{4}$$

$$G_{P22,CL}(s)u_2(s)=\left[g_{p22}(s)-\frac{g_{p21}(s)G_{c1}(s)g_{p12}(s)}{1+g_{p11}(s)G_{c1}(s)}\right]u_2(s) \tag{5}$$

$$G_{p12,CL}(s)u_2(s)=-\frac{g_{p12}(s)}{1+g_{p11}(s)G_{c1}(s)}u_2(s) \tag{6}$$

$$G_{p21,CL}(s)u_1(s)=-\frac{g_{p21}(s)}{1+g_{p22}(s)G_{c2}(s)}u_1(s)$$

(7)

Substitute in the controller values in the closed loop system we have got the transfer function G_{11} and G_{22} i.e (8) and (9)

New models obtained using wood and berry model as given below

$$G_{11cl}=\frac{6.39}{6.345s+1}e^{-9.46s} \tag{8}$$

$$G_{22cl}=\frac{-9.75}{5.33s+1}e^{-10.355s} \tag{9}$$

Equation (8) and (9) are obtained by using equation (4) and (7) respectively.

Similarly for the real process, model has been generated using input-output data through regression method [7]. New Model is estimated as shown in equation (10). Figure.5 represents the real time distillation column which is automated.

Fig. 5: Real time distillation column

$$G(S)=\begin{pmatrix}\dfrac{-0.436e^{-1.58s}}{1.85s+1} & \dfrac{0.035e^{-1.16s}}{0.262s+1}\\ \dfrac{-0.096e^{-0.989s}}{0.198s+1} & \dfrac{0.088e^{-0.76s}}{0.349s+1}\end{pmatrix} \quad (10)$$

$$G_{11CL}=\frac{-0.417e^{-0.0825s}}{1.7s+1} \quad (11)$$

$$G_{22CL}=\frac{0.083e^{-0.011s}}{0.32s+1} \quad (12)$$

By using equation (11) and (12) Predictive PI control has been design and implemented with closed loop [8].

3. Result Analysis

Wood and berry model is familiar and benchmark system. In this paper estimating new model parameters using sequential relay for wood and berry model reflected to validate the methodology of obtaining model for any other models.

The controller design for obtained model and validated those control parameters by performing closed loop test for wood and berry model. This approach is simple because control design can be done as same as the procedure done with single input and single output system (SISO). Another model for pilot plant distillation column using regression method shown in equation (10) which was re-estimated using sequential relay shown in the equations (11) and (12). Control design for equations (11) and (12) is carried out using predictive PI with and without anti-reset windup term is considered and implemented as decentralized structure to equation (10).

Simulation results for wood and berry system depicted in the Figure.6 with reference tracking of loop (Y1/R1). Steady state obtained at 400 sec for the step change of 90%. Figure.7 represents reference tracking of loop (Y2/R2). Steady state obtained at 500 sec for the step change of 80%. Actuator windup occurs when controller output exceed the actuator input. This effect can be reduced or eliminated by reseting integral term via reverese gain change to integrator. The error accumulation in integrator can be removed by introducing tracking time constant as the factor of saturation difference. Figure.9 shows the importance of using anti-reset term, it is observed for tray '1' in the Figure.8, when setpoint changed from 70 to 68 actuator action started at $3.05{*}10^5$ (Figure.9), even though process variable crossed setpoint at $2.5{*}10^5$. This means that time taken for the integrator to reduce the acumulation of error took $0.5{*}10^5$ sampling time.

Whereas in Figure.10 as controller is equipped with anti-reset term, as soon as process variable crosses the setpoint the error accumulation in the integrator will reset to zero. Therefore controller action depicted in the Figure.11 activates as soon as process runs beyond setpoint which helps the actuator to run in precise band of operation. Back calculation has been used for designing tracking time constant T_t [9].

$$T_t = T_i$$

Here tracking time constant acts as function of difference between saturated input and output or it can be taken as the difference between controller output and the value of process feedback.

3.1. Performance Analysis

Performance of the controller without and with anti-reset windup shown in Tables.1 and 2 respectively. It is observed that settling time rise time and peak time are reduced for the process with anti-reset windup controller. But there is overshoot and undershoot was better without anti-reset windup. As the objective of research is to reduce the effect of control action to obtain optimal response, the controller with anti-reset windup gives better performance than controller without anti-reset windup.

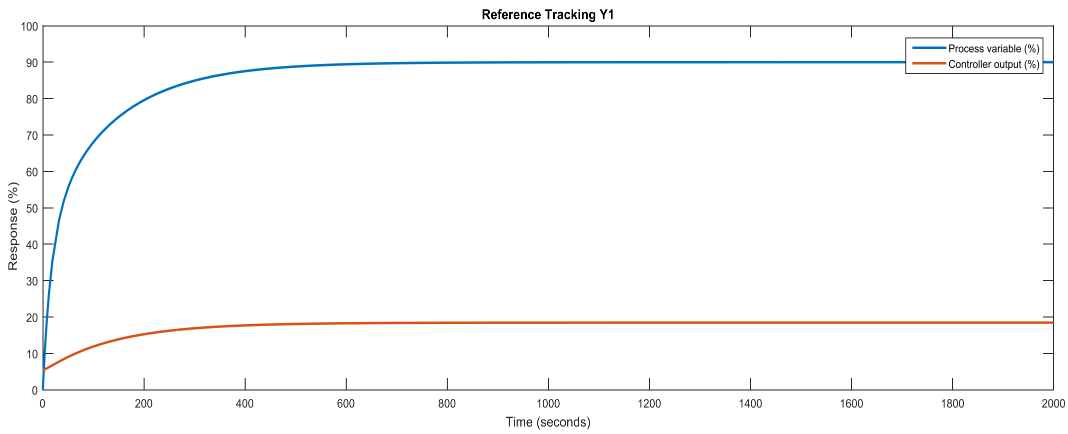

Fig. 6: Closed loop control response of Y_1

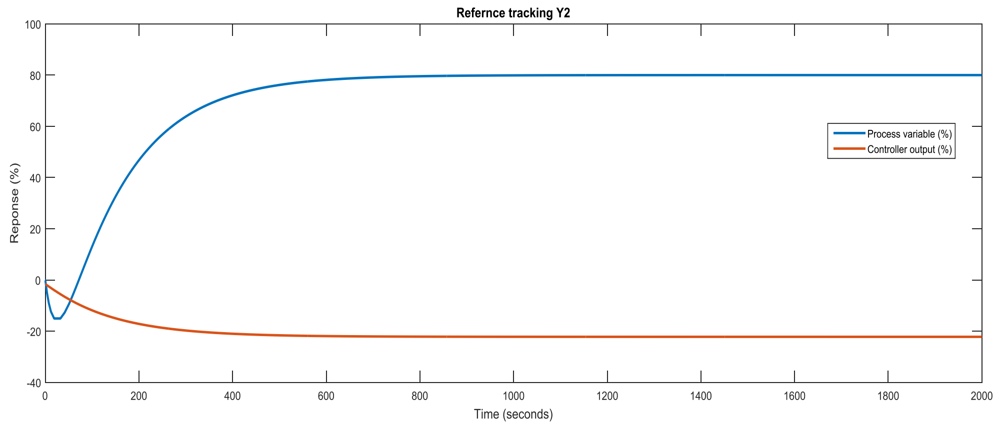

Fig. 7: Closed loop control response of Y_2

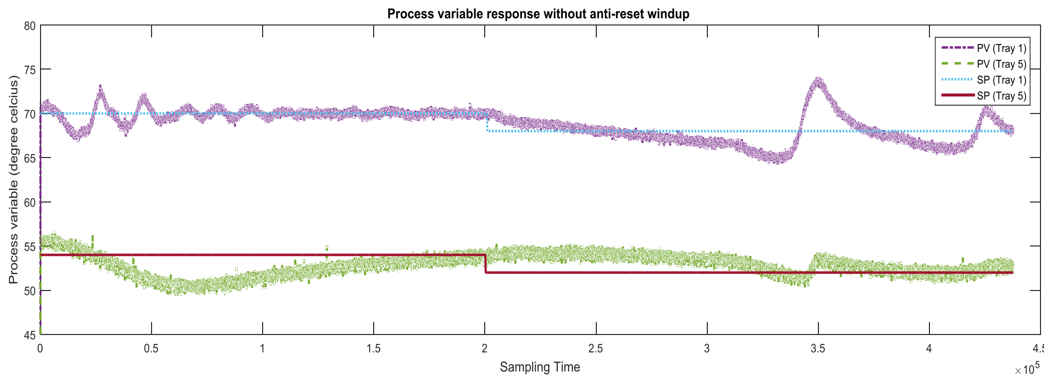

Fig. 8: Closed loop response without anti-reset windup

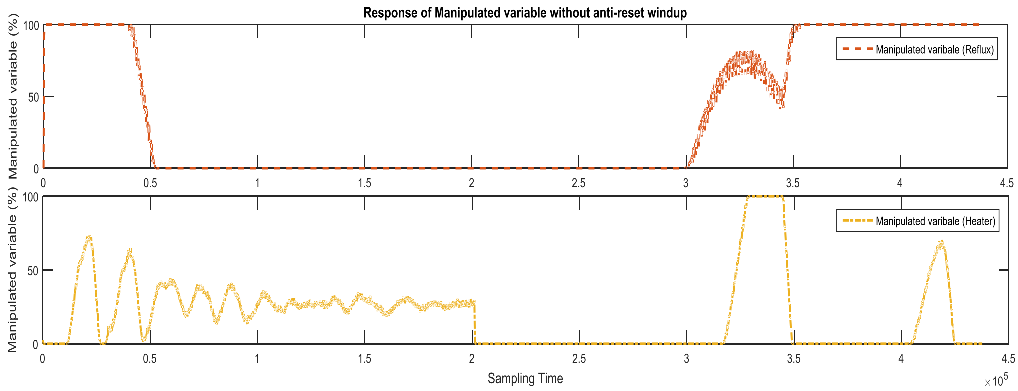

Fig. 9: Controller response without anti-reset windup

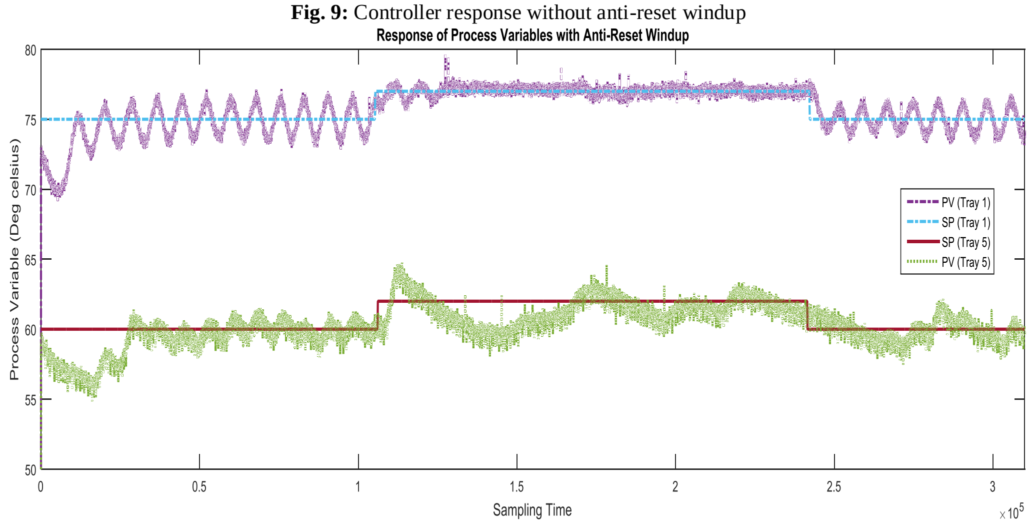

Fig. 10: Closed loop response with anti-reset windup

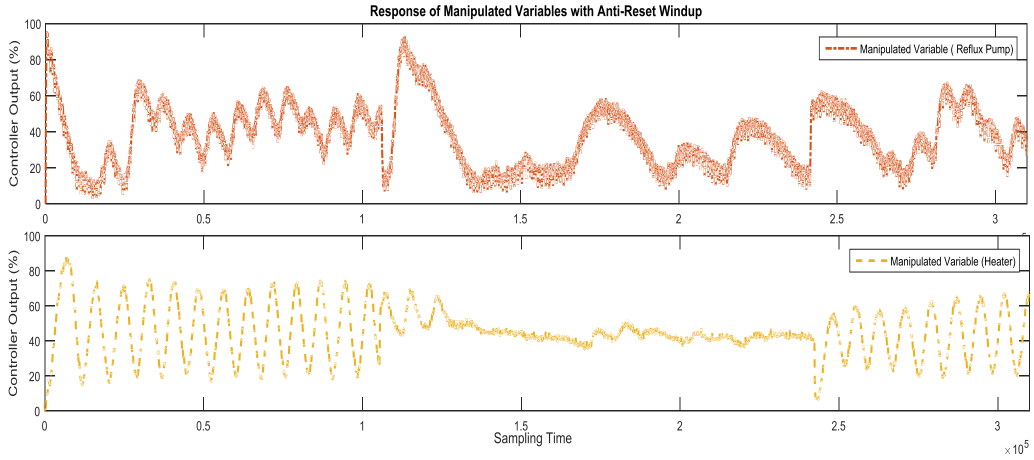

Fig. 11: Controller response with anti-reset windup

Table 1: Different performances of closed loop response without anti-reset windup

Trays	Set point	Peak Time/ Fall Time (Sampling seconds) *10^5	Rise Time (Sampling seconds) *10^5	Overshoot/ Undershoot (%)	Settling time (Sampling seconds) *10^5
T_1	70	0.32	0.1	1.5	0.5
	68	1.4	0.4	1.8	0.15
T_5	55	0.6	0.2	1.2	1.4
	53	1.5	1.1	1.1	1.2

Table 2: Different performances of closed loop response with anti-reset windup

Trays	Set point	Peak Time/ Fall Time (Sampling seconds) *10^5	Rise Time (Sampling seconds) *10^5	Overshoot / Undershoot (%)	Settling time (Sampling seconds) *10^5
T_1	75	0.365	0.11	1.73	0.11
	77	0.07	0.04	0.7	0.04
T_5	60	0.292	0.275	2	0.28
	62	0.07	0.05	3.7	0.12

4. Conclusion

Mathematical model has been identified for binary distillation column using sequential relay auto-tuning approach. Controller values are obtained using time period and amplitude of sustained oscillation generated by sequential relay for both the loops. The optimal values of controller are considered at the point where both the loop responses converges. By means of those controllers closed loop model is obtained using block reduction method. Predictive PI algorithm is implemented for the individual loop of obtained models and introduced anti-reset windup to the controller. The efficiency of the methodology has been validated by closed loop test for online binary distillation process. Controller response and performance analysis depicts effectiveness of Predictive PI algorithm with anti-reset windup and optimum conservation of energy for actuators has been realized.

Future Works: Authors would like to extend the work with advance control strategies like model predictive control, nonlinear model predictive control to increase the efficiency the actuators and produce optimal throughput.

Acknowledgement

The authors would like to thank Dept. of Instrumentation and Control Engineering, MIT, Manipal University for providing the experimental facility to carry out the research works and online library facilities. We would also thankful to Mr. Kiran Kumar and Ms. Asha Samanth, Technicians of Control System laboratory (Lab-2) for their technical support towards experimental works.

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