ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

Paring, RGA and System Stability in Distillation Column

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Abstract: In this work the RGA of MIMO were obtained to try the loops that provide minimum interaction in an exceedingly distillation column. Wood and Berry 2X2 and Ogunnaike and Ray 3X3 were taken as case studies: the procedure is to figure the RGA by first obtaining the matrix at s=0, this implies the system is at its steady state. From the matrix obtained the inverse was calculated, from the inverse the backward was created and therefore the RGA was calculated by multiplying components of backward by components of the matrix, from RGA the loops that gave minimum interaction were given. The loops elite were subjected to stability analysis victimisation Niederlinski index, the basis locus analysis, point and nyquist plots that were premeditated victimisation MATLAB software system, they found to be categorically stable

Keyword: MIMO, RGA, Controller, Stability.

1- Introduction

There is extensive research about the logical solutions of the problem of distillation control for multivariate. From an industry point of view, it is possible to increase the profit and adjust the hydrodynamics of the distillation column by controlling the distillation [1][2].

If a binary mixture of components A and B is separated, it is squared relative to that pair of product streams. For typical distillation, the mixture is fed into the column as a saturated liquid, to the central feed vessel f as shown in Figure 1, showing the molar flow (mol/min), F and the molar part of half of A, C_f. If a binary mixture of different components A and B, square measure to be separated into a pair of product streams exploitation typical distillation, the mixture is fed into the column as a saturated liquid, onto the feed receptacle f as shown in Figure 1, with both molar flows shown (mol/min), and F_f molar fraction of half A, C_f. Part A, C_f follows, forming the upper part of the vapor. As for the upper steam stream, it is completely cooled and then condensed one by one, and then flows into the flow cylinder. We cool the upper steam with cooling water. The fluid flowing from the reflux cylinder is the portion pumped upward at intervals from the column (upper vessel, N) corresponding to the molar flow rate, the reflux stream partially removed as a result of the distillation at a molar flow rate of F_D, observing all-word readable coding By computer, the distillation sheath is preferred to retain liquid at intervals between the reflux cylinder and the X_D molar portion of component A of the preferred distillation. Hence, X_D is the formula for each reflux and drip as shown in the overhead vapor part A, C_f. The overhead vapor stream is cooled and each one is condensed, then it flows into the reflux drum. The technique to achieve an overhead vapor cooling is by cooling the water. Reflux drum liquid is part pumped-up up back at intervals the column (top receptacle, N) with the molar rate of flow, metal (reflux stream) and is part removed because of the distillation product with a molar rate of flow F_D, with computer readable wordbook the liquid holdup at intervals the reflux drum and X_D for molar fraction of component A at the best of the column. it's clear that X_D is that the composition for the reflux and distillation as shown in figure1. [1][2]

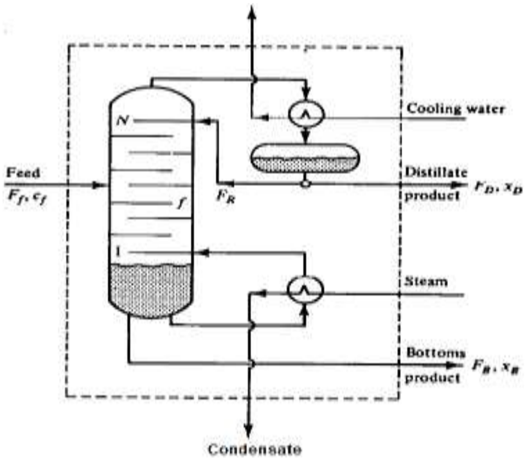

Figure1: Binary distillation column

Published studies showcased several techniques which supported analysis of the characteristic equations of the closed-loop transfer operate square measure bestowed which may be used with efficiency to work out loop stability [12][13]. Different techniques are also very popular for analyzing the steadiness of the characteristic equation. These techniques embrace the subsequent [3][4]:

a) Niederlinski Index

b) The Root. Locus Analysis

c) Bode Plot

d) Nyquist plots

Niederlinski Index

The Niederlinski Index (NI) is one of the techniques for analyzing and evaluating stability [14] [15]. This technique is considered very effective as it will not eliminate the pairs of unhelpful and influential variables. The best systems that can be applied and adopted are the Multiple Input Multiple Output (MIMO) systems.

The technique is unique as it it's wont to eliminate unfeasible pairings of variables at an early stage within the style. The controller settings only apply when an integral action is being used in all loops. The settings of the controllers do not have to be known, but it applies only when integral action is used in all loops [16][17]. As it only uses the steady state gains of the process transfer function matrix. [3][4] [7][8].

In the case where the index is negative, the system will be unstable for any of the controller settings. On the other hand, in the case of the index is positive index, the system may be stable or not, the Niederlinski index is:

$$\mathrm{NI} = \frac{\mathrm{Det}[\mathrm{K_P}]}{\prod_{\mathrm{J}=1}^{\mathrm{N}} \mathrm{K_P}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where:

$K_P = G_{M(0)}$ = matrix of steady state gains from the process open loop.

G_M transfer function.

K_{PIJ} = diagonal elements in steady state gain matrix.

Many reasonable management systems measure multiple variables. Each processed variable can have an input signal that acts to influence a number of controlled variables. An example of this is the output signals that interact between the different input and output loops [6] [9]. For this reason, comparisons were made between multivariate systems and single-input output cases. We proposed a multivariate system to be one of the powerful tools. Hence, this research sheds light on the importance of determining the degrees of interaction in addition to reducing the interaction effect through the correct input-output pairs. We get these differential features through interaction measures [10] [11]. Many management systems of sensible importance square measure multivariable. In such systems, every manipulated variable (input signal) could influence many several controlled variables, such as (output signals) as they inflict the acting interaction between the different input and / output loops [6][9]. For this reason, in comparison of a management of multivariable systems to a single-input single-output case was made, and we found a multivariable system to be a more powerful tool. Hence, it this paper highlights the is usually rather additional powerful compared to the single-input single-output case. it's therefore of nice importance to quantify the degree of interaction as well as the n thus correct input and /output pairs that which minimize the impact of the interaction is formed, for this dedicated interaction measures are employed [10][11].

Interactions in multivariable systems

Since this research works on the comparison of both systems, Single Input Systems (SISO) and Multiple Input and Multiple Output (MIMO) systems, we found that the most preferred systems are Multiple Input and Multiple Output (MIMO) systems.

Relative-Gain Array and the Selection of loops:

The interaction between control loops is significant factor and affects the goodness of a control system [18][19]. For this reason, management arrange to couple the manipulated variables with the controlled outputs in such the simplest way on minimize the interactions persist for any attainable pairing; we'll design a special system that decreased the interaction.

2- Previous Studies

Distillation column model [3]:

i. The Wood and Berry (WB)

The 2X2 process is presented by wood and berry (1973). The study was performed on a basket type reboiler.

ii. Ogunnaike and Ray (OR).

Ogunnaike studied a 36-tray, 2-m diameter industrial distillation. It separates a multi-component that has been evaporated and partially separated into two streams [21] [22]. The column downstream is left as a liquid which is later separated into two products.

Column separating a partly vaporized multi-component into two streams [21][22]. The bottom stream leaves the column as a liquid and is later separated into two products.

3- Methodology

2X2 Process of Distillation Column

Wood and Berry (WB):

The Wood and Berry distillation column is a 2X2 system with the following open loop process transfer functions [5].

$$G_M(s) = \begin{bmatrix} X_D(s) \\ X_B(s) \end{bmatrix} = \begin{bmatrix} G_{M(11)} & G_{M(12)} \\ G_{M(21)} & G_{M(22)} \end{bmatrix} \begin{bmatrix} R(s) \\ S(s) \end{bmatrix} \text{ ……………..…2}$$

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

Where:

X_D is the distillate composition.

X_B is the bottoms composition.

R is the reflux flow rate.

S is the steam flow rate.

Gain matrix k_p : setting s=0

$$K_P = G_{M(0)} = \begin{bmatrix} 12.8 & -18.9 \\ 6.6 & -19.4 \end{bmatrix} \text{………..…4}$$

$$K_P \text{ inverse } = \begin{bmatrix} 0.1570 & -0.1529 \\ 0.0534 & -0.1036 \end{bmatrix} \text{ ....5}$$

$$K_P \text{transpose} \begin{bmatrix} 12.8 & 6.6 \\ -18.9 & -19.4 \end{bmatrix} \text{ ………6}$$

Arrange the four relative gains into a matrix form, which is known as the relative-gain array.

$$\text{RGA} = \begin{bmatrix} 2.01 & -1.01 \\ -1.01 & 2.01 \end{bmatrix} \text{ …………7}$$

$$\text{RGA} = \begin{array}{cc|c} R & S & \\ \hline 2.01 & -1.01 & X_D \\ -1.01 & 2.01 & X_B \end{array}$$

Selection of loops:

For a process with two outputs there are two different loop configurations. We can use the relative gains to select the configuration with minimum interaction between the loops [9][23].

The recommended coupling is found to be opposite of the Wood and Berry distillation column case:

Couple X_D with R and X_B with S.

Then from the definitions of the relative gains, we concluded that:

$$\frac{X_D(s)}{R(s)} = \frac{12.8e^{-s}}{16.7s+1} \text{ …………………….. 8}$$

$$\frac{X_B(s)}{S(s)} = \frac{-19.4e^{-3s}}{14.4s+1} \text{ ………………….... 9}$$

Situations with relative gains outside the range 0 to1 create difficult control problems.

Notice it is found that the distillate composition X_D, is controlled by manipulating the reflux R and bottoms composition X_B is controlled by manipulating the steam rate S, as shown in figure2

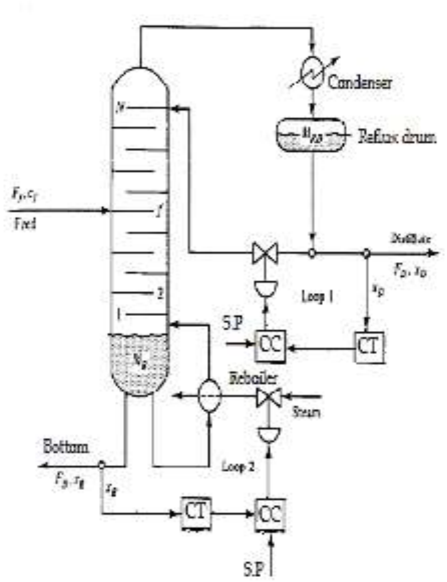

Figure2: Design of control loops with RGA for Wood and Berry model.

The Niederlinski index for the Wood and Berry column.

$$K_P = G_{M(0)} = \begin{bmatrix} 12.8 & -18.9 \\ 6.6 & -19.4 \end{bmatrix} \text{……..…}10$$

$$NI = \frac{\mathrm{Det}[K_P]}{\prod_{j=1}^{N} K_P} = \frac{(12.8)(-19.4)-(-18.9)(6.6)}{(12.8)(-19.4)} = 0.498\text{………………………………... }11$$

Since NI is positive, we can say that the system is stable for a closed-loop system with a definite coupling.Since the NI is positive, the closed loop system with the specified pairing is stable.

3X3 Process of Distillation Column

The Ogunnaike and Ray (OR) distillation column is a 3X3 system with the following open loop process transfer function [3]:

$$G_M(s) = \begin{bmatrix} X_T(s) \\ X_P(s) \\ X_{RL}(s) \end{bmatrix} = \begin{bmatrix} \frac{0.66e^{-2.6s}}{6.7s+1} & \frac{-0.61e^{-3.5s}}{8.64s+1} & \frac{-0.0049e^{-s}}{9.06s+1} \\ \frac{1.11e^{-6.5s}}{3.25s+1} & \frac{-2.36e^{-3s}}{5s+1} & \frac{-0.012e^{-1.2s}}{7.09s+1} \\ \frac{-34.68e^{-9.2s}}{8.15s+1} & \frac{46.2e^{-9.4s}}{10.9s+1} & \frac{0.87(11.61s+1)e^{-s}}{(3.89s+1)(18.8s+1)} \end{bmatrix} \begin{bmatrix} RL(s) \\ F(s) \\ RF(s) \end{bmatrix} \text{…………………………………….....}12$$

Where:

Change in tray temperature X_T.

Change in column pressure X_P.

Change in reflux drum level X_{RL}

Change in reboiler load RL.

Change in distillate vapor rate F.

Change in reflux flow RF.

$$K_P = G_{M(0)} = \begin{bmatrix} 0.66 & -0.61 & -0.0049 \\ 1.11 & -2.36 & -0.012 \\ -34.68 & 46.2 & 0.87 \end{bmatrix} \text{………}13$$

$$K_P \text{ inverse } = \begin{bmatrix} 2.9724 & -0.6035 & 0.0084 \\ 1.0899 & -0.8018 & -0.0049 \\ 60.6127 & 18.5177 & 1.7462 \end{bmatrix} \text{…..}14$$

$$K_P \text{transpose} = \begin{bmatrix} 0.66 & 1.11 & -34.68 \\ -0.61 & -2.36 & 46.2 \\ -0.0049 & -0.012 & 0.87 \end{bmatrix} \text{………...}15$$

Determination of the RGA is by multiplying elements of the transpose by elements of the matrixK_P.

$$RGA = \begin{bmatrix} 1.96 & -0.66 & -0.30 \\ -0.67 & 1.89 & -0.22 \\ -0.29 & -0.23 & 1.52 \end{bmatrix} \text{………....}16$$

For a process with three outputs there are three different loop configurations. We can use the relative gains to select the configuration with minimum interaction between the loops [20][22].

The recommended coupling is found to be to opposite of the Ogunnaike and Ray distillation column case:

Couple X_T with RL, X_B with F and X_{RL} with RF.

Then from the definitions of the relative gains, it is concluded that: $\frac{X_T(s)}{RL(s)} = \frac{0.66e^{-2.6s}}{6.7s+1}$ …………………......17

$\frac{X_P(s)}{F(s)} = \frac{-2.36e^{-3s}}{5s+1}$ ………………..……18

$\frac{X_{RL}(s)}{RF(s)} = \frac{0.87(11.61s+1)e^{-s}}{(3.89s+1)(18.8s+1)}$……………..19

Notice that the pairing assumes change in control tray temperature X_T is controlled by manipulating the reboiler load RL, that the column pressure X_P is controlled by change in distillate vapor rate F and change in reflux drum level X_{RL} is controlled by change in reflux flow R_F as shown in figure 3:

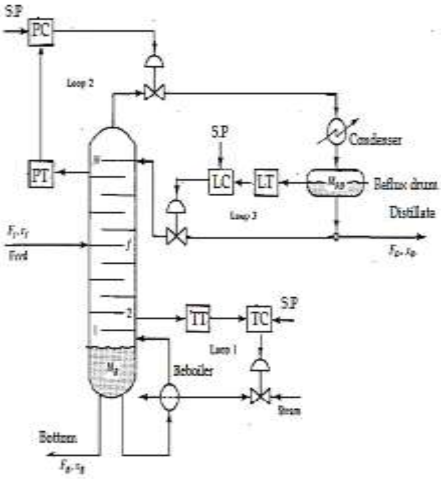

Figure 3: Design of control loops with RGA for Ogunnaike and Ray model.

The Niederlinski index for the Ogunnaike and Ray (OR) column is:

$\mathrm{Det}[K_P]=-0.5291$ ………………..……. 20

$\mathrm{NI} = \frac{-0.5291}{(0.66)(-2.3)(0.89)} = 0.4006$…….. 21

Since the metallic element is positive, the closed-loop system system with the desired pairing is stable.

4- Stability Analysis:

Stability analysis of the distillation column for 2X2 and 3X3 models are made by root locus, bode and nyquist plots. As shown in figures 4, 5 and 6.

For 2X2 Process of Distillation Column

MATLAB configurations are:

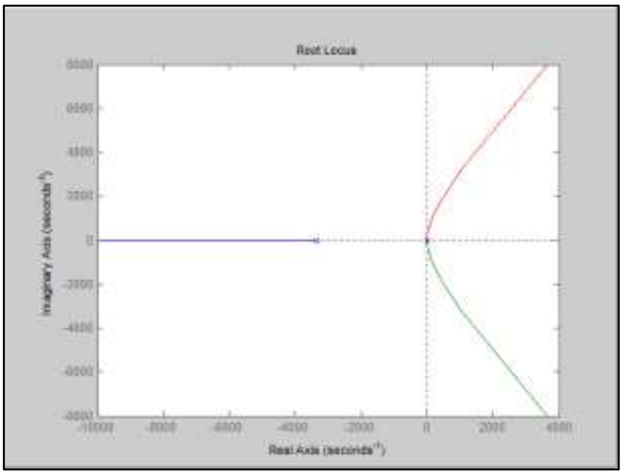

Fig 4: root locus plot.

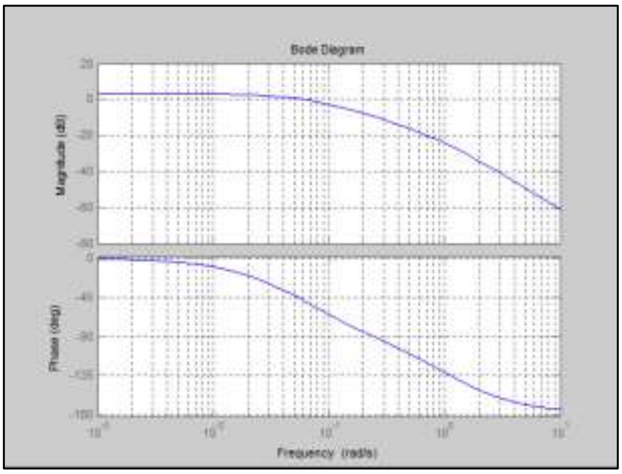

Fig 5:Bode plot.

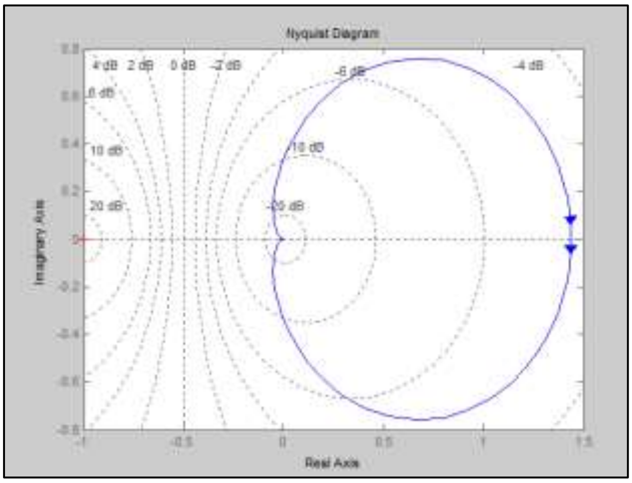

Fig 6: Nyquist plot.

The same procedure is repeated for the other four loops with the results that all loops are stable.

5- Conclusions:

Other loops combination 2X2 of Wood and Berry (WB) and 3X3 of Ogunnaike and Ray (OR) were treated similarly. The results in figures 4,5,6…. etc show that the systems are unconditionally stable. RGA can easily be used to select loops with minimum interactions; they are the tools to be applied wherever complex control MIMO systems are applied.

6- References:

1. Stephan Opoulus, G “Chemical Process Control an Introduction to Theory and Practice” Prentice Hall, India, 1994.
2. St´ephane Dudret, Karine Beauchard, Fouad Ammouri and Pierre Rouchon,” Stability and Asymptotic Observers of Binary Distillation Processes Described by Nonlinear Convection/Diffusion Models”, American Control Conference, Fairmont Queen Elizabeth, Montréal, Canada 2012.
3. Luyben, L. L” Process Modeling, Simulation and Control for Chemical Engineering”. McGraw Hill Publishing Company, New York, 2007.
4. Dale, E, Edgar, T.F and Duncan, A.M “Process Dynamic and Control. John Willey and Sons, New York, 1998.
5. Ogata, K., Discrete-Time Control Systems, Second Edition, Prentice-Hall, Englewood Cliffs, NJ, 1994.
6. J. L´evine and P. Rouchon, “Quality Control of Binary Distillation Columns Via Nonlinear Aggregated Models,” Automatica, vol. 27, no. 3, pp. 463– 480, 1991.
7. S. Khowinij, M. A. Henson, P. Belanger, and L. Megan, “Dynamic Compartmental Modeling of Nitrogen Purification Columns” Separation and Purification Technology, Vol. 46, No. 1-2, pp. 95–109, 2005.
8. S. Bian, M. A. Henson, P. Belanger, and L. Megan, “Nonlinear State Estimation and Model Predictive Control of Nitrogen Purification Columns,” Industrial and Engineering Chemistry Research, Vol. 44, No. 1, pp. 153–167, 2005.
9.
10. H SHIMODAIRA. "Time-Series Prediction", Expert Systems, 2002.
11. Himanshu Kumar, Raghav Kumar, Jyoti Yadav, Asha Rani, Vijander Singh. "Genetic Algorithm Based PID Controller for Blood Pressure and Cardiac Output Regulation", 2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), 2016.
12. J. Sanchis, M. Martínez, C. Ramos, Jose V. Salcedo. "Principal Component GPC with Terminal Equality Constraint", IFAC Proceedings Volumes, 2002.

13. Ghazal Karami, Majid Amidpour, Bijan Heidari Sheibani, Gholam Reza Salehi. "Distillation Column Controllability Analysis Through Heat Pump Integration", Chemical Engineering and Processing: Process Intensification, 2015.
14. Björn D. Tyréus. "Multivariable Control System Design for an Industrial Distillation Column", Industrial & Engineering Chemistry Process Design and Development, 1979.
15. "Practical Distillation Control", Springer Nature, 1992.
16. Sujatha, V., and Rames C. Panda. "Control Configuration Selection for Multi Input Multi Output Processes", Journal of Process Control, 2013.
17. Rames C., V. Sujath. "Chapter 7 Identification and Control of Multivariable Systems – Role of Relay Feedback", InTech, 2012.
18. Liu, Qie, and Qibing Jin. "Multi-loop PI/PID Controllers Design for Disturbance Rejection Based on Non- Parametric Effective Model and Non-Convex Optimisation", IET Control Theory and Applications, 2014.
19. P. Regina. "Comparative Study of Sliding Mode and Relay Enhanced PI Controllers for MIMO Systems", Technological Developments in Education and Automation, 2010.
20. William L. Luyben. "Method for Evaluating Single-End Control of Distillation Columns", Industrial & Engineering Chemistry Research, 2009.
21. Reza Katebi. "Robust Multivariable Tuning Methods", Advances in Industrial Control, 2012.
22. Yu Haoli. "Confirmation of Control Valve Stiction in Interacting Systems", The Canadian Journal of Chemical Engineering, 08/2009.
23. Chongguang Cao, Jiamei Li. "A Note on the Group Inverse of Some 2 x 2 Block Matrices Over Skew Fields", Applied Mathematics and Computation, 2011.