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Analytical Study of 'De-coupler' and 'Diagonal PID Controller' for the designing of a MIMO System

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***Abstract*--In the perspective of 'Control System' , the proper designing of controller for any industrial instrument is essential ormandatory to get a desired output response. There are versatile types of controller are used in the industrial level to get the output response according to our wishes. A controller is able to improve only transient response or Steady state response or it can improve both the responses. A special case of MIMO (Multiple input Multiple output) system is called TITO (Two Input two output) system. Here in this work,a new idea to design a controller has been proposed which is consisting of a 'De-coupler' and a 'Diagonal PID Controller'. This type of approach is also helpful to learn the exact designing of 'De-coupler' as well as'Diagonal PID Controller'.**

***Index Terms*--De-coupler, Diagonal PID Controller, TITO System, Optimization, TuningProcess**

I. Introduction

If We are using the product coming out from the large industries as soon as we get up in the morning. For Example- sugar used to make tea/ coffee is refined in the 'Sugar Mill' or any newspaper we read is printed from the paper industries or the necessary electric for running the motor of the toaster. Basically we all are somehow dependent to a large extent on the automation. Development of 'Control System' based modeling is one of the basic reasons for the fast growth or rapid development of the industrial automation. Some of them are complicated and some of them are very simple in nature.The PID controller has a fixed structure but still the concept old 'PID Controller' has been modified day by day for the advancements of the technology. The concept of tuning had also been introduced by the researchers to improve the response of the controller. But a poor tuning structure always deteriorates the performances of the plant and decreases the economic benefits of an industry. Therefore the automatic tuning process is always beneficial for the industrial application. It always includes the 'Identification' and 'Optimized designing' of the system. Apart from this, the automated system requires the sophisticated algorithm. There are a lots of research work related to the tuning process for SISO System but tuning process for MIMO System is unexplored till today. In this research work an attempt is taken to implement the suitable controller using the combination of 'De-coupler' and 'Diagonal concept PID Controller'. The main intension of this research work is to develop an 'Algorithm based Tuned Controller' for Two-Input and Two-Output system, incorporating the concept of 'De-coupler'

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II. A Short Literature Review

There are several types of feedback control are found in the application based process industries. The most popular type of the 'Feedback Controlis 'PID Control'. PID stands for Proportional – Integral – Derivative. So many researchers used different types of approach to design a feedback control. Åström,K.J. et.al.[1] talked about the application of the feedback PID Control in the industrial level. The relay-tuning method was proposed by the researchers. It is able to calculate the knowledge about a certain point on the 'Nyquist Plot' of a system. Relay introduced a limit cycle when the loop of the system is closed. The modeling of a reactor for chemical operation had been illustrated by the researcher Aris,R. et.al.[2]. Åström,K.J. et.al. [3], developed a control algorithm for the TITO (Two input – Two Output) system. It consists of two parts that are connected in series. The proposed method described a centralization process for the feedback control system. Using this process the dynamic behavior gives the better response. Still this process has not yet been applied due to some complicated control circuit. The process of decoupling is also demonstrated by the researchers. Againcomputerbased control system was described by some researcher Åström,K.J et.al [4]. Mainly program based control of tuning methods has been delineated in detail. The simplicity of the model comes from the fact that entire model was described by the linear difference equation with the constant coefficient. Distribution of the feed-forward path along with the command signal was explained very clearly in this research article. Bialkowski,W.L. et.al [5] described the shortcomings of the process control system in detail. The concept of 'Loop performance monitoring system' has been introduced in this research article. The researchers also highlighted different direction of the monitoring system.Bakosova,M et.al [6] represents a simulation based experiments of a tank reactor which is based on control analogy. In the steady state analysis it is observed that, the system attains so many steady states. As uncertainty is

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present within the system, the concept of robust output feedback logic had been implemented. Simulation process was used to test the stabilization process of the reactor. In the year of 1990, the researcher Bansode,P. et. al. [7] published a research article where the process of dynamic de-coupling strategies had been focused for the CSTR (continuous Stirred Tank Reactor) system. A critical look into the modeling and identification towards the nonlinear model using predictive control was elaborated by Bequette,B[8]. The strength and weakness of the fundamental modeling had also been described in this research article. A fantastic approach towards dynamical system and random walker was given by Desoer,C et.al. [9]. All possible control strategies for the complex dynamical system were discussed in this research article. Some typical types of non-trivial solutions are also highlighted in this paper. Enqvist,M. et.al. [10], shows how can we approximate non-linear modelinto a linear model. We have used this type of approximation in our research article.Hammer,J. et. al. [15] describes some useful technique to design a 'State-Feedback' controller for the nonlinear equipments. These nonlinear systems are continuous time in nature. The state space approach of the controllers has also been examined. It is found that, the controllers are stable in nature means asymptotic stable. The concept of autonomous controller was described with all necessary mathematical calculation. Hägglund,T et. al. [16] shows all possible difficulties and advantages of tuning rule given by the famous scientist Ziglar and Nicols in the era of 1940. For the multivariable control system, how nonlinear observer based control analogy works was delineated in the reference [17]. Kumar,N. et.al. [19] talked about the very popular 'MIT rule' to design a 'CSTR system'. Not only that, the simulation based analysis had also been depicted in the research article. Luyben,W. et.al.[20] illustrated the procedure of tuning of a 'SISO Controller'. The authors also describe the method to apply a SISO controller for the multivariable system. In the year of 2012, a novel method of de-coupling for the multivariable system including all types of external disturbances was invented by some researchers Liu,R et.al.[23]. The beauty of the design is that, all the parameters of the controller are independent to each other. A very typical type of example is illustrated in this paper that uses the novel method and also shows the better response with respect to the older design. For a TITO system, how the specification like 'Gain-Margin'or 'Phase-Margin' is assigned for the 'Decentralized type of PID Controller' was presented in reference [24]. The researcher Marinescu,B [25] described the concept of pole placement for the linear time invariant system where output is feedback to the input without disturbing the transient response of the system. Maciejowski,J. [26] works on the topological based design on the multivariable system where all kind of difficulties arises in the time of implementation are discussed with the help of suitable example. The process of connecting feedback is slightly different from the SISO system. The researcher Olatunji,O,M.[27] applied the concept of topologies in the simulation of CSTR model. Panagopoulos,H. [28] works on the optimization which is the final step of any type of control system to get desired output. Not only optimization, a comparative study between different types of optimization has also been depicted in this research article. Pottman,M et. al. [29] analyzed the multi-quadratic function with the help of identification process The abrupt behavior of the CSTR system was studied by the researcher Russo,L et.al. [30].

III. Problem Formulation

An Automation industry uses a thousand of methods for designing of controller.Each of them is usinga standard reference levelto make the system as an independently tuned system. But when a number of controllers are acting at a time, a chance of cross coupling may occur within the system that degrades the performance level of the entire system[11]. The only way to solve this type of typical problem is to use a 'Multivariable Controller'. The concept of 'De-coupler' is very important with respect to the designing of controller. Anyway, in case of TITO system, the problem related to the cross coupling also comes into play. Application of lots of TITO system is found in the process control industries which are having some additional properties also. Before going to the problem formulation, some typical types of assumption need to be maintained. The characteristics of the TITO system are very close to the linearly square nonsingular system means we are considering the system having equal numbers of input and output which are linear and stable in nature[12].Second assumption is this, if it is found that the system under experiment, is not linear must be linearized. In process industries, generally twoPIDcontrollers are used at a time with no special features. He basic block diagram is given in the following figure.

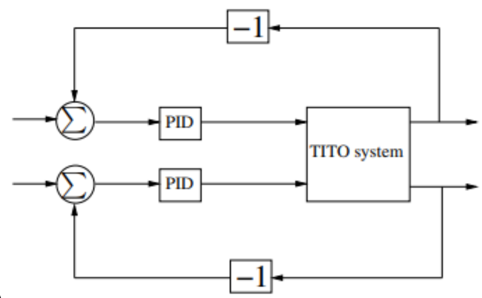

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Fig.1: Functional diagram of TITO System used in the process industries

In the above figure 1, there is no special part is contributed for the cross coupling rather each of the given input signal is paired with the corresponding output signal. This type of structure is not satisfactory or is not able to produces output according to our wishes as this type of structure causes oscillation within the system.

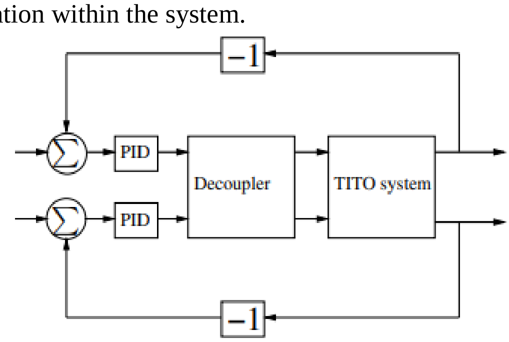

Fig.2 : 'TITO System' with 'De-coupler' for Process control Industries.

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Keeping PID controller in the structure is always advantageous as PID controller improves the transient section as well as the steady state part of the entire system[13] [14]. Figure 2 given below is close to our proposed design towards the MIMO system which is incorporating the concept of 'Decoupling'. But using of 'De-coupler' is not a new idea. The above figure 2 is including the concept of decoupling, but it is not a successful design as it is hard to operate or hard to automate. Apart from these, there are some special types of requirements that have to be fulfilled appropriately which is very difficult in case of implementation. Hence in this research article a new method of designing of a de-coupler used for the controller is explained in detail in the later section which is nothing but our main aim of this article.

IV. Specification Of The DesignPart

The basic requirement of the designing of any types of controller is the correct specification of the system. There may a deviation from the specification but small deviation is always preferred with respect to the design. It is sometime observed that to minimize the cost of the entire design, the design parameters are to be flexible. There is no such hard and fast rule, but tradeoff is needed between cost and robustness. Some common types of disturbances are always found in the system and considerations of those disturbances are mandatory on account of specification[31]. The primary constraints in the perspective of specification are the external disturbance, all time domain or frequency domain parameters, robustness of the design and cost of the design. Avery common type of closed loop system considering all sorts of external disturbances are displayed in the figure 3 given below.

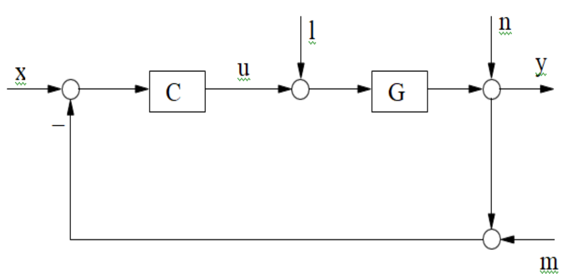

Fig. 3 :Appearance of the external disturbances with in a feedback control system.

In the above figure 3, all types of expected external disturbances are being included where output disturbances are represented by $'n'$and measurement disturbances are denoted by$'m'$. But it is assumed that, all are low frequency disturbances high frequency disturbances are not desired in the domain of nonlinear control system. Actually if high frequency noise signal is getting amplified then it may permanently destroy the actuator system or there is a chance of huge energy consumption within the system.Anyway, the transfer function considering the external disturbances $'n'$to the input control signal $'u'$is represented by the following equation and the transfer function considering the external disturbances $'m'$to the input control signal $'u'$is represented by equation number (1).

$$\begin{cases} T_{nu} = -C(I+GC)^{-1} \\ T_{mu} = -C(I+GC)^{-1} \end{cases} \text{.......}(1)$$

Due to the pole–zero similarity between two transfer function, they can be treated as single and having low frequency gain. Similarly the transfer functionsfrom$'m'$ and $'n'$ into $'l'$ and $'y'$ is given by equation number (2).

$$\begin{cases} T_{ny} = (I+GC)^{-1} \\ T_{my} = -GC(I+GC)^{-1} \text{.....}(2) \\ T_{ly} = -G(I+GC)^{-1} \end{cases}$$

All the disturbances regarding the output signal of the system$'y'$ should be minimized or small and must be bounded in nature.Stability is another aspect of designing any types of linear/nonlinear system. But without robustness stability analysis does not make any sense as controllers are always analyzed with respect to the robustness. Margin of stability is also calculated in case of process control system. Apart from these, there some special demands for automatic systems. Different controller has different mechanism for optimizing the relevant criteria. If a particular designed method is used as a decoupling circuit, it must be stable and simple as much as possible [18]. In this research article, a new method of automatic decoupling and tuning of PID Controller is proposed which is explained later. Optimization is another criterion with respect to the design specification means whether the proposed designed system is optimized or not? If the optimized is not carefully chosen for a system, the controller my not work proper properly.

V. Concept Of Proposed Method For De-Coupling

The basic concept of De-coupler for linearly stable and non-singular system (LSNSS)with proper explanation is given here in detail. Any types of MIMO system or a special type of MIMO system called TITO system is belonging to class of LSNSS system. To understand the basic theory of de-coupler, we draw a closed loop system in which $'G'$represent a matrix related to the 'LSNSS' , $'C'$represents 'Diagonal Transfer Matrix' and $'D'$represents the 'Linearly Stable Matrix' for the de-coupler circuit. Figure 4 given below is delineating the basic structure of closed loop decouple circuit.

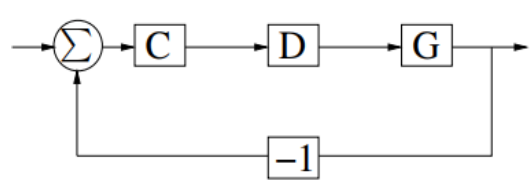

Fig. 4 :Decoupled closed loop system

Before going to the analysis of de-coupler, it is very important to know that why do we use a de-coupler system[32]. The main objective of any kind of de-coupler system is to decentralize the entire system in such a way that the system minimizes the amount of dynamics required for it. Not only that, it also reduces the delay of the system. Using de-coupler, an automatic control system will be benefitted more with respect to the other normal system. In this context

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it is better to mention that, we always choose a function $'D'$so that the multiplication of $'G' and\ 'D'$ is always a 'Diagonal Transfer Matrix' or 'DTM'. The de-coupler is used together with the controller. Thus the overall system is working as a low pass system that is able to eliminate the noise of high frequencies. Actually a PID system is itself a low pass system; therefore it makes the overall system low-pass in nature. But in this research work, the PID controller is used to control the de-coupling system and hence extra dynamical logic can be added. Furthermore tuning circuit is provided to make the system as an automatic control design.

VI. Process Of De-Coupling

The basic structure of the closed loop control system with de-coupling circuit has already been explained in the previous section. Two important thing related to the de-coupler is that, the $'GD'$matrix is always a diagonaland the de-coupler must not be a high pass system. The exact design procedure is demonstrated in this section. Before going to the design, some basic theory of matrix must be very clear to all of us. For example, the ad-joint of the matrix A is denoted by the term$[adj(A)]$, and then the following property must be maintained.

$A\,.\,adj(A) = adj(A).A = \det(A)\,.\,I$…..(3)

The initial step to design a de-coupler is to find the expression of the entire system. The proposition given below is badly needed to design a de-coupler.

$D = [adj(G).K]$….(4)

Initially consider that,$= I$, Then we may write from the equation(3),

$D = [adj(G)\ ]$…..(5)

Now the next target is to remove the biggest delay time of each de-coupler by multiplying the elementsof the column of de-couplermatrixby the factor $'K'$ which is diagonally spaced.Finally, poles and zeros which are common for the de-coupler have to be removed in a tricky way such that it behaves like a low pass filter[33][34]. We are taking an example to understand the entire process. Let the process is expressed by

$$G = \begin{pmatrix} \frac{s+4}{s^2+11.s+10}\,.\,e^{-2.6.s} & \frac{-(s+4)}{s^2+6.s+5}\,.\,e^{-2.8.s} \\ \frac{-(s+10)}{s^2+11.s+10}\,.\,e^{-1.3.s} & \frac{(s+10)}{s^2+11.s+10}\,.\,e^{-1.3.s} \end{pmatrix}\text{…..(6a)}$$

Similarly the de-coupler matrix is expressed by the following matrix.

$$D = \begin{pmatrix} \frac{s+10}{s^2+17.s+30}\,.\,e^{-1.3s} & \frac{-(s+4)}{s^2+6.s+5}\,.\,e^{-2.8.s} \\ \frac{(s+10)}{s^2+7.s+10}\,.\,e^{-1.3.s} & \frac{(s+10)}{s^2+11.s+10}\,.\,e^{-1.3.s} \end{pmatrix}\text{…..(6b)}$$

Thus the parameter $'K'$ is modified to the following expression.

$$k = \begin{pmatrix} e^{1.3s} & 0 \\ 0 & e^{2.6s} \end{pmatrix}\text{…..(7)}$$

Now the de-coupler matrix can be represented by the following expression.

$$D = \begin{pmatrix} \frac{s+10}{s^2+17.s+30}. & \frac{-(s+4)}{s^2+6.s+5}\,.\,e^{-0.2.s} \\ \frac{(s+10)}{s^2+7.s+10}\,. & \frac{(s+10)}{s^2+11.s+10}\,. \end{pmatrix}\text{.....(8)}$$

The above matrix implies the improvement of the de-coupler matrix with less time delay. We are taking another example where $'K'$ is modified to the following expression.

$$k = \begin{pmatrix} \frac{(s+2)}{(s+10)}e^{1.3s} & 0 \\ 0 & \frac{(s+1)}{(s+4)}e^{2.6s} \end{pmatrix}\text{…..(9)}$$

Considering this value of $'K'$, $'D'$is modified to the following expression.

$$D = \begin{pmatrix} \frac{1}{s+20}. & \frac{1}{s+5}\,.\,e^{-0.2.s} \\ \frac{1}{s+5}\,. & \frac{1}{s+10}\,. \end{pmatrix}\text{.....(10)}$$

The required dynamics to implement this structure is obviously less than previous one. Now we have also investigated the expression of the loop-coupler combination. The expression is given below.

$G.D = \begin{pmatrix} gd_{11} & 0 \\ 0 & gd_{22} \end{pmatrix}$, where the expression of $gd_{11}\ and\ gd_{22}$ is given below.

$$\begin{cases} gd_{11} = \frac{(s+4)}{s^3+26\,s^2+175.s+150}e^{-2.6s} - \frac{(s+4)}{s^3+11\,s^2+35.s+25}e^{-2.8s} \\ gd_{12} = \frac{-(s+10)}{s^3+12\,s^2+45.s+50}e^{-1.6s} + \frac{1}{s^2+17.s+30}e^{-1.3s} \end{cases}$$

…….(11)

Due to the complicated nature of the diagonal element, Normal PID Controller designing method is not suitable in this case. Hence an attempt is taken to design a new approach of design of a PID controller. Before going to design a PID controller, we have designed the 'Approximated designing De-coupler' [21].FOPDT model is selected as an example for the designing procedure as it is very famous for the process industries. The approximated model can be represented as

$$(s) = \begin{pmatrix} \frac{K_{11}}{T_{11}.s+1}e^{-s\,L_{11}} & \frac{K_{12}}{T_{12}.s+1}e^{-s\,L_{12}} \\ \frac{K_{21}}{T_{21}.s+1}e^{-s\,L_{21}} & \frac{K_{22}}{T_{22}.s+1}e^{-s\,L_{22}} \end{pmatrix}\text{…..(12)}$$

The 'Adjoin of G$'$ can be expressed as follows.

$$adj\,(G(s)) = \begin{pmatrix} \frac{K_{11}}{T_{11}.s+1}e^{-s\,L_{11}} & -\frac{K_{12}}{T_{12}.s+1}e^{-s\,L_{12}} \\ -\frac{K_{21}}{T_{21}.s+1}e^{-s\,L_{21}} & \frac{K_{22}}{T_{22}.s+1}e^{-s\,L_{22}} \end{pmatrix}\text{…..(13)}$$

The method is called approximated as common poles are removed. Not only that, the number of common poles can be increased also. In the above expression,$T_{ij}$is representing the time constant. The smallest time constant is given by T_S and the largest one is given by $'T_L'$. The large time constant can be approximated by the following expression.

$$\frac{1}{T_l.s+1} \approx \frac{1}{(T_s.s+1)(T_s - T_l).s+1}\text{……(14)}$$

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Now the pole given by $\frac{1}{(T_s.s+1)}$can be deleted from the above equation. So the approximation method can be summarized as follows.
i) Initiate a FOPDT model.
ii) Initiate the process with $'K' = 'I'$ and $'D' = adj(G)$
iii) Biggest delay timemust be eliminated.
iv)Final approximation is given below.

$$\frac{1}{T_l.s+1} \approx \frac{1}{(T_s.s+1)(T_s - T_l).s+1}$$

v) Common poles must be removed.

Now we are taking an example to illustrate the procedure to approximation. Let us take the transfer function

$$G = \begin{pmatrix} \frac{3}{9s+1}e^{-3s}. & \frac{2}{6s+1}.e^{-2.s} \\ \frac{1}{5s+1}e^{-4s}. & \frac{2}{7s+1}e^{-4s}. \end{pmatrix} \text{……..(15)}$$

Now again$'K'$ is selected as $'I'$and $'D'$is considered as [adj(G)][22].Therefore,$'G'$ can be written by the following expression.

$$G = \begin{pmatrix} \frac{3}{9s+1}e^{-3s}. & \frac{2}{6s+1}.e^{-2.s} \\ \frac{1}{5s+1}e^{-4s}. & \frac{2}{7s+1}e^{-4s}. \end{pmatrix} \text{......(16)}$$

Finally$'K'$ can be modified to be $K = \begin{pmatrix} e^{4s} & 0 \\ 0 & e^{2s} \end{pmatrix}$. Using this approximation, the de-coupler can be design as follows.

$$D = \begin{pmatrix} \frac{2}{7s+1}. & \frac{-2}{6s+1}. \\ \frac{-1}{5s+1}. & \frac{3}{9s+1}. \end{pmatrix} \text{.....(17)}$$

The above matrix clearly shows the improvement as it contains less time delay. We can do further approximation which is given below.

$$D = \begin{pmatrix} \frac{2}{(5s+1)(2s+1)}. & \frac{-2}{6s+1}. \\ \frac{-1}{5s+1}. & \frac{3}{(6s+1)(3s+1)}e^{-s}. \end{pmatrix} \text{.....(18)}$$

Now $'K'$ has again been modified which is given by the following expression.

$$K = \begin{pmatrix} (5s+1)e^{4s} & 0 \\ 0 & (6s+1)e^{2s} \end{pmatrix} \text{…..(19)}$$

Using this value of$'K'$, the de-coupler can be reframed and given below.

$$D = \begin{pmatrix} \frac{2}{2s+1}. & -2. \\ -1. & \frac{3}{3s+1}e^{-s}. \end{pmatrix} \text{.......(20)}$$

But there is a disadvantage of approximated model designing of the de-coupler. If we use approximated model of the de-coupler, exact decoupling is not possible which may causes an unstable design of the system taken into consideration.

VII. The Optimization Criteria

The integral absolute error can be defined by the following parameter called 'IAE' where as the simple integral error is defined by the term 'IE'. In the perspective of decoupling, both IE and IAE are very close to each other means we are able to approximate IAE with the IE. The IE can be realized by the following expression.

$$IE = \int_0^{\alpha} |e(t)|dt \text{……(21)}$$

Where e(t) is defined as a control error when step input is applied to the system. The other constraints related to the error are the sensitivity and complementary sensitivity function. They must be bounded within a certain time period. The sensitivity function can be realized in the complex plane by selecting two different radius circles. Again it is well known to us that the error IE is directly proportional to the inverse of the integral gain of the controller. It indicates that the direct minimization of IAE is possible. The upper boundary of any sensitivity function is the prerequisite for any type of'de-coupler design'. Let us suppose $'T_d'$ is the time constant for the derivative controller and $'T_i'$ is the time constant for the integral controller. If the controller has one pole at origin along with two filter poles, two filter zeros, then the zero is placed at a position in such a way that the following condition must be maintained.

$$z = \frac{1}{2T_d} \pm \sqrt{\frac{1}{4.T_d^2} - \frac{1}{T_d.T_i}} \text{……(22)}$$

If $'T_i'$ is less than $'4T_d'$, then the zeros are situated in the complex conjugate with the real part $\beta = -\frac{1}{2.T_d}$.

VIII. Proposed Algorithm For The Optimization Of De Coupler

The optimization is executed by means of exhaustive search. The big disadvantage of this search is that the complexity of the optimized algorithm is too high and hence the algorithm takes too much time for optimization. Let a parameter is defined by $'k'$. For every pair of T_d and T_i , there is a value of $'k'$ for which it provides the maximum value. For a stable process the value of the $'k'$ puts theNyquist curve on the edge and it encircles the point$(-1+j.0)$. The algorithm for doing this process is stated below.

Step 1 :Do some one time operation like "Load the process Model".

Step 2 :Define a parameter $'n_w'$ called frequency function vector point.

Step 3 :In the inner loop, T_d and T_i are gridded by the parameter $'k'$. This must be repeated at least for two times by the outer loop.For the first time, the loop is sparse the grid to find the intersection and for the second time it narrows the grid. A new parameter is $'n_0'$ is introduced to represent the number of loops running for the outer loop. The complexity depends on the loop running for the entire program.

Step 4 : The $'k'$ depends on the logarithmic fashion on $({K_{max}}/{K_{min}})$and $({K_{opt}}/{K_{min}})$

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Step 5 : The complexity is given by the following function

$$T_c \approx (n_0 c^2)\,(c_1 n_w (c_2 log\left({K_{max}}/{K_{min}}\right) + C_3 \log\left({K_{opt}}/{K_{min}}\right) + C_4 \frac{t}{dt} \text{...(23)}$$

In the above equation C_i represents the constant.

IX. Simulation Result

Now we are taking some examples to justify our proposed algorithm. Using the simulation results, we are going to establish our proposed work towards the decoupling technique. Let us take an open loop transfer function $G(s) = \frac{2s^2+5.s+1}{s^2+2.s+3}$. The Nyquist plot is given in the figure below.

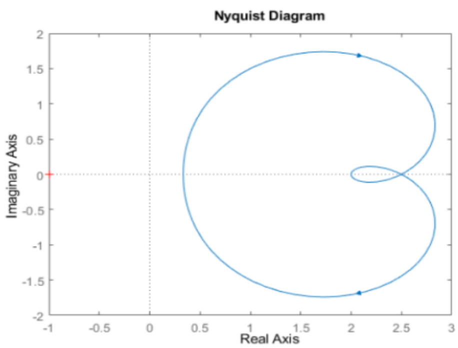

Fig. 5 :Nyquist Plot of the selected transfer function.

The grid used for the design is given by the following parameters. $\frac{1}{2T_d}$is divided into 15 grid point between .001 to 8000. From the above 'Nyquist plot', it has been observed that, the controller tries to find a way to bend the 'Nyquist plot' to the edge of the 'M Circle'. Let us take another complex dynamical system where $k = 1.2, T_i = 2.23, T_d = 1.3$.Using a low pass filter, the controller is filtered and then observe the position of polep $= (-20.8)$.

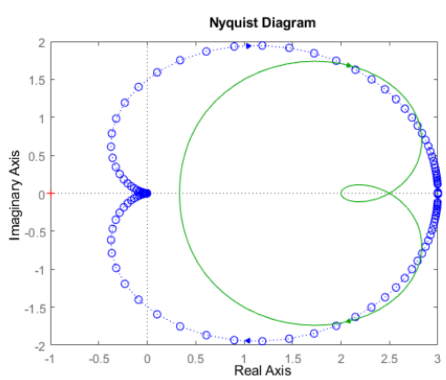

Figure 6 :Nyquist Plot of the selected complex dynamical system.

The above figure is the Nyquist plot of the complex dynamical system. The value of the $k = 1.4, T_i = 1.96, T_d = 1.13$ has been calculated from the above figure. Using the low pass filter, two poles are placed in the left half of the s plane. Hence the design is asymptotically stable.

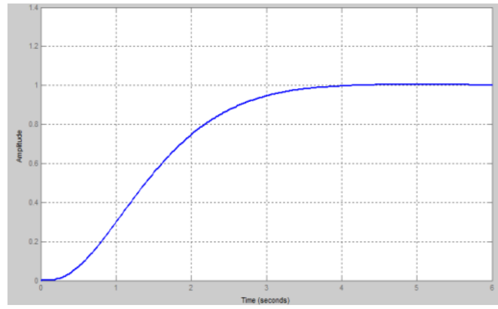

Figure 7 :Step response of de-coupled system.

In the above figure 7, the step response of the decoupled system is given from which it can be concluded that the system having passing through the decoupling process is stable under any types of external disturbances.

Controller parameters

	Tuned	Baseline
P	0	1
I	0.0021263	1
D		
N		

Performance and robustness

	Tuned	Baseline
Rise time	2.06 seconds	NaN seconds
Settling time	3.45 seconds	NaN seconds
Overshoot	0.401 %	NaN %
Peak	1	Inf
Gain margin	18.9 dB @ 3.27 rad/s	-19.9 dB @ 19 rad/s
Phase margin	69.3 deg @ 0.645 rad/s	-46.6 deg @ 60.3 rad/s
Closed-loop stability	Stable	Undefined

Table 1 : Response parameters of the system

In the above table 1, all the response parameters are enlisted. Gain margin and phase margin both are positive at a time. Hence the system is stable.

X. Conclusion

T The proposed method for the decoupling process along with the algorithm has been explained in this research article. From the simulation, it is clearly observed that the proposed method works for the simple system as well as for the complex dynamical system. The proposed algorithm is used to determine the parameters of the controller even for two parallel coupled processes having different dead zone. The problem related to the decoupling is analyzed in a generalized way while the designing of proposed 'diagonal PID Controller' is based on exhaustive search which is nothing but analgorithm. Both the designing are verified through proper simulation and all necessary simulations are provided here has also been explained step by step which will be very much helpful for the future research work.

XI. References

[1]K.J.Åström, T.Hägglund (2005).“Advanced PID Control”.ISA - The Instrumentation, Systems, and Automation Society, Research

Triangle Park, NC 27709.

[2] R.Aris,N.Amundson (2000). “An analysis of chemical reactor stability and control” Published in I. Chemical Engineering Science, Vol no. 7(8), pp. 121–131.

[3] K.J.Åström, K.H.Johansson, Q.Wang(2002). “Design of decoupled PI controller for two-by-two systems.” IEE Proceedings on Control Theory and Applications, Vol no. 149,pp. 74–81.

[4] K.J.Åström,B.Wittenmark, (1990).“Computer Controlled Systems—Theory and Design”. Prentice-Hall, Englewood Cliffs, New Jersey.

[5] W.L. Bialkowski, (1993).“Dreams versus reality: A view from both sides of the gap.” Pulp & Paper Canada 94:11.

[6]M.Bakosova, A.Vasickaninova, (2009). “Simulation of Robust Stabilization of a Chemical Reactor”.Published in ECMS Proceedings edited by J. Otamendi, A. Bargiela, J. L. Montes, L. M. DoncelPedrera, , pp. 570–576.

[7] P.Bansode,S.Jadhav (2015). “Decoupling based predictive control analysis of a continuous stirred tank reactor”. Published in Proc. of the 2015 International Conference on Industrial Instrumentation and Control (ICIC), , 816–820.

[8] B.Bequette (1990).“Nonlinear control of chemical processes: a review.”- Industrial & Engineering Chemistry Research Ind. Eng. Chem. Res., Vol no. 30, pp. 1391–1413.

[9] C.Desoer,Y.Wang, (1980). “Foundations of feedback theory for nonlinear dynamical systems.” - IEEE Trans. Circuits Syst. IEEE Transactions on Circuits and Systems, Vol no. 27(2), pp. 104–123.

[10]M.Enqvist andL.Ljung (2002). “Estimating nonlinear systems in a neighborhood of LTI-approximants.” Proceedings of the 41st IEEE Conference on Decision and Control,pp. 639–644

[11]G.C.Goodwin, ,S.F.Graebeand,M.E.Salgado (2001). “Control System Design. Prentice-Hall, Inc., Upper Saddle River, New Jersey 07458.

[12] A.Ghosh,S.Das (2012). “Decoupled periodic compensation for multi-channel output gain margin improvement of continuous-time MIMO plants.” Published in IET Control Theory &Applications,Vol no. 6(11):, pp. 1735–1740

[13]G.Gurumurthy , D.K.Das(2019).“An FO-[PI] λ controller for inverted decoupled two-input two-output coupled tank system,” Published inInternational Journal of Systems Science, vol. 50, Volno. 2, pp. 392–402.

[14]T.Hägglund, K.J.Åström (2002). “Revisiting the Ziegler-Nichols tuning rules for PI control.” Asian Journal of Control, Vol-4:4, pp. 364– 380.

[15] J.Hammer (2014).“State feedback control of nonlinear systems: a simple approach.” - International Journal of Control,Vol- 87(1):, pp. 143–160.

[16]T.Hägglund,K.J.Åström (2004).“Revisiting the Ziegler-Nichols step response method for PID control.” Journal of Process Control, Vol -14:6, pp. 635–650.

[17]M.Henson,D.,Seborg (1990)“Input-output linearization of general nonlinear processes”. AIChEJournal,Vol- 36, pp. 1753–1757.

[18] B.Jevtović,,M.Mataušek (2010).“PID controller design of TITO system based on ideal decoupler.” Published in Journal of Process Control, Vol- 20,pp. 869–876.

[19] N.Kumar, N.Khanduja(2013) “Mathematical modeling and simulation of CSTR using MIT rule.” Published in Proc of the IEEE 5 th India Intern. Conf. on Power Electronics.

[20]W.Luyben (1986). “Simple method for tuning SISO controllers in multivariable systems.”Published in Industrial & Engineering Chemistry Process Design and Development Ind. Eng. Chem. Proc. Des. Dev., Vol no. 25, pp. 654–660.

[21]S.Liu,D.Tian,T.Xue,Y.ZhangandZhang,S. (2019) “A Review of Industrial MIMO Decoupling Control,” - International Journal of Control, Automation and Systems, pp. 1–9.

[22]P.Lancaster(1969).“Theory of Matrices.” Published in AcademicPres, Inc., 111 Fifth Avenue, New York, New York-10003.

[23]R.Liu,G.Liu, M.Wu, (2012). “A novel decoupling control method for multivariable systems with disturbances.” Proceedings of 2012 UKACC International Conference on Control, pp. 76–80.

[24] D.Maghade, B.Patre, (2012). “Decentralized PI/PID controllers based on gain and phase margin specifications for TITO processes.” ISA Transactions, Vol no. 51, pp. 550–558.

[25]B.Marinescu (2010). “Output feedback pole placement for linear time-varying systems with application to the control of nonlinear systems.”Published in AutomaticaSinica, Vol no. 46, pp. 1524–1530.

[26]J.Maciejowski (1989)“Multivariable Feedback Design.” Addison-Wesley Publishing Company, Inc.

[27] O.M.Olatunji, M.J,Ayotamuno, (2014). “Simulation of A CSTR Model ForThevetiaPeruviana Oil Transesterification” Published in the Production of Biodiesel. International Journal of Electrical Engineering & Technology, Vol no. 5(7), pp. 103–114.

[28] H.Panagopoulos,K.J.Åström, andT.Hägglund, (2002). “Design of PID controllers based on constrained optimization.” IEE Proc. Control Theory Appl., Vol no. 149:1, pp. 32–40.

[29] M.Pottman, and D.Seborg, (1992). “Identification of non-linear processes using reciprocal multi-quadric functions.”Journal of Process Control, Vol no. 2, pp. 189–203.

[30] L.Russo,B.Bequette, (1995). “Impact of process design on the multiplicity behavior of a jacketed exothermic CSTR.”AIChEJournal,Vol no. 41(1), pp. 135– 147.

[31]S.Skogestad (2001): “Probably the best simple PID tuning rules in the world.” In AIChE Annual meeting, Reno, NV, USA.

[32] T.Schweickhardt ,F.Allgower, (2005).“Linear modeling error and steady-state behaviour of nonlinear dynamical systems. In Proc. 44th IEEE Conf. Decision Control, pp. 8150-8155

[33] V.Sujatha, R.Panda, (2013). “Control configuration selection for multi input multi output processes. Journal of Process Control, Vol no. 23(10), pp.1567–1574

[34]A.Uppal, W.Ray,A.Poore, (1974). “On the dynamic behavior of continuous stirred tank reactors.” Published in Chemical Engineering Science,Vol no. 29, pp. 967–985.

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