Performance Evaluation with Multivariable and Multiloop control for a class of square MIMO systems

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Abstract. Two approaches (centralized and decentralized) for designing a multi-input, multi-output (MIMO) tracing / regulating process are described within article. The vast popular of industrial process control applications are whist focused on multi loop controllers, ignoring the feedback control attainment with advantages of centralized multivariable controllers. Due to their single loop nature, the plant interactions that are merely in use keen on relation in the controller tuning process cannot be suppressed by decentralized controllers. In many situations, therefore it would be beneficial to delimit the detrimental consequences in pairing among inputs and outputs of the closed loop system under certain context. The centralized model predictive controllers (MPC) and decentralized / multi-loop PI controllers are designed. In terms of integral Absolute Error (IAE), Integral Square Error (ISE), and Integral Time-weighted Absolute Error (ITAE), the output of both controllers is then compared. The results of the simulation showed that the MIMO MPC is better than the other suggested control schemes. The projected central controllers minimize interactions superior than the multi loop controllers that have recently been published.

Keywords: MIMO, RGA, NI, PI, IMC, Phase and Gain Margin, MPC, Decoupling, Performance Indices

1. INTRODUCTION

MIMO system is having system parameters by interaction along with the input–output array values. All the industrial processes are having multiple interacting variables in nature. Decentralized control is used in the MIMO systems instead of multivariable control in most industrial processes, as the single loop control is straightforward to devise, simple to tune, incorporate and sustain [1]. The single loops PI/PID control is widely used in the literature to control MIMO systems with interaction using multiple single loop (SISO) PI/PID controllers [2].

The simple construction, effective tuning and the capability to achieve most of the control goals are the cause to use SISO PI/PID controllers for single loop control [3]. However the devise and tuning for the centralized distinct loop controllers is much supplementary complicated correlated to that of single-loop controllers because of interactions [8]. In MVC single loop controllers, the tuning of single loop should not execute independently, because the controllers communicate with each other. The performance and stability of the systems are often affected by Methods for controller configuration for a SISO system for single loop systems. Many methods are available for tuning the multi loop PI/PID controllers in technical papers and the literature. Mainly, it was divided into the following technique, (i) Detuning method, (ii) Sequential closed loop tuning, (iii) Optimum criterion method, (iv) IMC based tuning method, (v) Nyquist based tuning method, (vi) Fuzzy based PID tuning method, (vii) Heuristic based tuning methods, (viii) Integral error based tuning method, etc [9]. This method is not completely considered the interactions between the loops and also not ensures the guaranteed stability margins of the system for the retuned controller settings.
The major findings in the sequential loop method will be the requirement of the iteration procedure due to closing of certain loops will affects the already designed controller settings [18]. The relay auto tuning method requires minimum process information due to interaction effects, however tuning has to be repeated if the controller settings are not appropriate [13]. The Single Input Single Output controllers be designed separately within the limits of the stability and performance, due to their nature of tuning not considers the other loop dynamics [12]. This will degrade the performance of the system. Two Input Two Output systems is a simple example of multi loop systems, whether there is actual system of this nature / due to complexity of the system. A non-negligible relationship between its outputs and inputs has been decomposed into the Two Input Two Output process. [20–23]. For TITO systems, decentralized PID controllers with decouplers are most frequently preferred. [21, 22, 24–29].

Model predictive control (MPC) is one of the well established technique and it become the typical path in today's process industries due to capable of constrained multivariable control with interacting variables. The capability to covenant through degrees of interaction that might occur when there are more or less than outputs / although region limits are used for controlled variables is a key feature of MPC, which in practice is the certain condition. Mostly defined, MPC is to a control algorithm that specifically implements a usually non-square model of the process to forecast the managed plant's anticipated reaction and take suitable exploitation through the optimization technique. In the last 10-15 years, technology suppliers have made major efforts to enhance the application of the MPC products. [47].

2. GENERAL FORMULATION OF MIMO CONTROL

The multivariable control system has n number of manipulated parameters (u), n number of controlled parameters (y), the n number reference parameters (r), G is the system transfer function matrix and Gc(s) is a controller matrix and the structure of the equation is given in Equation (1) & (2). The closed control configuration of MIMO system is shown in figure 1.

\[
G_p(s) = \begin{bmatrix}
g_{11}(s) & \cdots & g_{1n}(s) \\
\vdots & \ddots & \vdots \\
g_{n1}(s) & \cdots & g_{nn}(s)
\end{bmatrix}
\]

and

\[
G_c(s) = \begin{bmatrix}
g_{c1}(s) & \cdots & 0 \\
\vdots & \ddots & \vdots \\
0 & \cdots & g_{cn}(s)
\end{bmatrix}
\]

respectively.

The PI controller is given by

\[
g_u(s) = K_p \left(1 + \frac{1}{\tau I_s}\right)
\]

And the process model is given by

\[
g_u(s) = \frac{K_p}{\tau s + 1} e^{-SL}
\]
3. RELATIVE GAIN ARRAY

The Relative Gain Array (RGA) is the most common and efficient method for input output pairing in MIMO system for control loop configuration. The RGA matrix have the elements, which represents the interaction between the input and output pairs. This is computed by:

$$\psi_{ij} = G_{ij}^{-1} G_{ij}$$  \hspace{1cm} (5)

Where $G = \text{System transfer function matrix}$, $\psi_{ij} = \text{Element of the RGA}$.

The pairing element should have around 1 in positive, which represents the interaction is moderate. The Niderlinski condition should be satisfied for the stability point of view, but this necessary but sufficient to verify the closed loop system stability. The Niderlinski condition (NI) is given by:

$$\text{NI} = \frac{\det G(0)}{\prod_{ij} g_{ij}(0)} > 0$$  \hspace{1cm} (6)

4. INTERNAL MODEL CONTROLLER

The structure of feedback control and internal model control is given in Figure 2. and, $G_p(s)$ is the system transfer function, $\tilde{G}_p(s)$ is the model of the corresponding transfer function, $G_i(s)$ is transfer function matrix which represents controller, $q(s)$ is the IMC controller, and $f_r(s)$ is the set-point filter. If the model of the process and process transfer function matrix is same mean there is no model error. The set point and disturbance output using IMC control law can be represented is given by:

$$y(s) = G_p(s)q(s)f_r(s)r(s) + \left[1 - \tilde{G}_p(s)q(s)\right]G_d(s)d(s)$$  \hspace{1cm} (7)

![Figure 2. Feedback control strategies.](image)

(a) Conventional feedback control. (b) Internal model control.

The representation of the process divided by using IMC parameterization as a minimum and non-minimum phase transfer function matrix,

$$\tilde{G}_p(s) = P_m(s)P_A(s)$$  \hspace{1cm} (8)

Here $P_m(s)$ is the minimum phase transfer function & $P_A(s)$ is the model of the non-minimum phase transfer function.

The $q(s)$ is calculated by: $q(s) = P_m^{-1}(s)f(s)$  \hspace{1cm} (9)
The internal model control filter \( f(s) \) is selected for improved performance is given by the equation:

\[
f(s) = \frac{1}{(\lambda s + 1)^n} \tag{10}
\]

Where \( \lambda \) is a tuning variable, this variable chosen compromise between performance and stability. The value of \( n \) preferably to be high adequate for the suitable IMC controller.

The IMC controller can be given by:

\[
q(s) = p^{-1}_m(s) \frac{1}{(\lambda s + 1)^n} \tag{11}
\]

Form these the controller transfer function derived as:

\[
G_c(s) = \frac{q(s)}{1 - G_p(s)q(s)} = \frac{p^{-1}_m(s)}{(\lambda s + 1)^n - p_A(s)} \tag{12}
\]

This equation not a standard format of PID type controller and also it is not physically realizable. The equation (12) modified by using Maclaurin series is given by:

\[
G_c(s) = \frac{1}{1 - G_p(s)q(s)} = \frac{1}{1 - \sum_{i=0}^{n} \frac{G_p(s)^i q(s)}{i!}} \tag{13}
\]

Where \( f(s) = G_c(s) \cdot s \)

The typical PID control algorithm is specified by

\[
G_c(s) = K_c(1 + \frac{1}{\tau_i s}) \tag{14}
\]

Comparing (13) with (14), the equations of proportional and integral controller settings are derived.

\[
k_{ii} = \frac{(G_{ii}(0) - n \lambda_i) K_{ci}}{(G^{-1}(0))_{ii}} \tag{15}
\]

\[
\tau_i = -\frac{(G_{ii}(0) - n \lambda_i) K_{ci}}{(G^{-1}(0))_{ii}} \tag{16}
\]

5. PHASE AND GAIN MARGIN

The Two Input – Two Output of the process is given by

\[
G(s) = \begin{bmatrix} g_{11}(s)e^{-\tau_{11}(s)} & g_{12}(s)e^{-\tau_{12}(s)} \\ g_{21}(s)e^{-\tau_{21}(s)} & g_{22}(s)e^{-\tau_{22}(s)} \end{bmatrix} \tag{17}
\]

The specified model \( G(s) \) is designed with decoupler matrix [21]. The design of the decoupler matrix following two scenarios measured.

Scenario 1: The off-diagonal matrix of \( G(s) \) has no Right Hand side Poles and diagonal matrix of \( G(s) \) has no Right Hand Zeros.

The decoupler is given by

\[
D(s) = \begin{bmatrix} v_1(s) & d_{12}(s)v_2(s) \\ d_{21}(s)v_1(s) & v_2(s) \end{bmatrix} \tag{18}
\]

Here, \( v_1(s), v_2(s), d_{12}(s) \) and \( d_{21}(s) \) as given in Equation. (18).

\[
v_1(s) = \begin{cases} 1, & r_{21} \geq r_{22}, \\ e^{(r_{21}-r_{22})}, & r_{21} < r_{22} \end{cases} \tag{19}
\]

\[
v_2(s) = \begin{cases} 1, & r_{12} \geq r_{11}, \\ e^{(r_{12}-r_{11})}, & r_{12} < r_{11} \end{cases} \tag{20}
\]
\[ d_{12}(s) = \frac{g_1(s)}{g_2(s)} e^{-(\tau_2 - \tau_{12})s} \]  

\[ d_{21}(s) = \frac{g_2(s)}{g_1(s)} e^{-(\tau_2 - \tau_{21})s} \]  

Scenario 2: The decoupler in the form of \( G(s) \).

With the GPM parameters, the subsequent equations can be formed.

\[ D(s) = \begin{bmatrix} d_{11}(s) & v_3(s) \\ v_4(s) & d_{22}(s) \end{bmatrix} \]  

\[ v_3(s) = \begin{cases} 1, & \tau_2 > \tau_{21}, \\ \frac{1}{g_1(s)} e^{-(\tau_2 - \tau_{12})s}, & \tau_2 < \tau_{21}, \end{cases} \]  

\[ v_4(s) = \begin{cases} 1, & \tau_1 > \tau_{12}, \\ \frac{1}{g_2(s)} e^{-(\tau_2 - \tau_{12})s}, & \tau_1 < \tau_{12}, \end{cases} \]  

\[ d_{11}(s) = \frac{g_2(s)}{g_1(s)} e^{-(\tau_2 - \tau_{12})s} \]  

\[ d_{22}(s) = \frac{g_1(s)}{g_2(s)} e^{-(\tau_1 - \tau_{12})s} \]  

\[ H(s) = G(s) D(s) = \begin{pmatrix} h_{11}(s) & 0 \\ 0 & h_{22}(s) \end{pmatrix} \]  

The \( H(s) \) decoupled elements are to be regulated by single loop PI / PID controllers. The higher order system is as well quite distinct through the FOPDT model [31]. The model can be represented as

\[ l_{ij} = \frac{K_i e^{-L_i s}}{T_{ij} s^2 + 1}, \quad i, j = 1, 2. \]  

\[ l_{ij}(0) = h_{ij}(0), \]  

\[ \left| l_{ij}(\omega_{ij}) \right| = \left| h_{ij}(\omega_{ij}) \right|, \]  

\[ \left| l_{ij}(\omega_{ij}) \right| = \left| h_{ij}(\omega_{ij}) \right|, \]  

From the equations (29) – (32) the PI controller settings are derived.

\[ K_i = h_{ij}(0), \]  

\[ T_{ij} = \sqrt{\frac{K_i^2 - \left| l_{ij}(\omega_{ij}) \right|^2}{\left| h_{ij}(\omega_{ij}) \right|^2}}, \]  

\[ l_{ij} = \pi + \tan^{-1}\left( -\omega_{ij} T_{ij} \right), \]  

The controller design method:

Standard loop requirements connected to frequency output are the gain and phase margins (GPMs) [33]. GPMs have often acted as essential robustness measures [34]. The PM is correlated with the damping of the device from classical control and can therefore also act as a quality measure [33]. The straightforward formula is derived for computing the PI / PID controller settings. These parameters are to ensure the user defined GM and PM provision.

Derived formulae to compute the PI / PID controller parameters settings are given below [35–37].

With the GPM parameters, the subsequent equations can be formed

\[ \arg \left[ l_{ii}(\omega_{pii}) k_{ii}(\omega_{pii}) \right] = -\pi, \]  

\[ A_{mii} = \frac{1}{\left| l_{ii}(\omega_{pii}) k_{ii}(\omega_{pii}) \right|^2}. \]
\[
\left| l_{ii}(j\omega_{gii})k_{ii}(j\omega_{gii})\right| = 1, \quad (38)
\]
\[
\phi_{mii} = \arctan \left( \frac{l_{ii}(j\omega_{gii})k_{ii}(j\omega_{gii})}{1} + \pi \right), \quad (39)
\]
Where \( A_{mii} = \) Gain margin in dB, \( \phi_{mii} = \) Phase margin in degrees, \( \omega_{gii} = \) Gain cross over frequency and \( \omega_{pii} = \) Phase cross over frequency. The Proportional gain is given by Eq. (40).
\[
k_{ii}(s) = k_{pii} \left( 1 + \frac{1}{T_{lii}s} \right), \quad (40)
\]
The integral time constant is given by Eq. (41).
\[
l_{ii}(s)k_{ii}(s) = \frac{k_{pii}K_{ii} (sT_{lii} + 1)}{sT_{lii} (sT_{lii} + 1)} e^{-T_{lii}s}, \quad (41)
\]
The Proportional & Integral values and also crossover frequencies computed numerically but not mathematically due to the existence of the tan inverse function for certain method and GPM requirements. To get the analytical solution, the arctan function is approximated and is given by the equation (42)
\[
arctan x = \begin{cases} 
\frac{1}{4} x, & (|x| \leq 1) \\
\frac{\pi}{2} - \frac{\pi}{4x}, & (|x| < 1)
\end{cases} \quad (42)
\]
Where, \( x \) is described in terms of multiplication of gross over frequencies with time constant. From the approximations the PI controller settings are given in terms of analytical equation (43-45).
\[
k_{pii} = \frac{\omega_{pii}T_{lii}}{A_{mii}K_{ii}}, \quad (43)
\]
\[
T_{lii} = \left( 2\omega_{pii} + \frac{4\omega_{pii}L_{lii}}{\pi} + \frac{1}{T_{lii}} \right)^{-1} \quad (44)
\]
Where \( \omega_{pii} = \frac{\omega_{mii}}{2} \frac{\pi}{2} \left( \frac{A_{mii} - 1}{A_{mii}} \right) L_{lii} \quad (45) \]

6. MODEL PREDICTIVE CONTROL

MPC algorithms consist of three key components: a controller with plant model, an optimization algorithm to evaluate control activities using an objective function with an optimization technique, and a predictor that predicts the plant performance / controlled variable's potential dynamic conduct. Figure: 3, illustrates the structure of a Model Predictive Controller (MPC). The model is formulated using the past and present values and on the projected finest future control behaviour, to forecast future plant outputs. Taking into account the cost function and the constraints, the optimizer calculates these actions. The key thoughts that appear in a predictive controller are
- Explicit use of a model to forecast system performance in future instants of time (control horizon)
- A control sequence measurement minimizing a certain objective function
- At every each instant of time the receding horizon is moved to the future outputs and inputs. It is associate with the purpose of the very first control signal of the progression computed at each instant of time.
Model Predictive control has various advantages over other methods of control. Here P is represents number of predictions in the horizon of prediction, while the number of control movements M is called the horizon of control. While each sampling moment calculates a series of M control movements, only the first step is actually enforced.

The LTI system model is given by:

\[ \Delta y = K \Delta u \]  \hspace{1cm} (46)

Here \( K \) = The steady state gain matrix, \( \Delta y \) = Change steady state output \( (y) \), and \( \Delta u \) = Change steady state input \( (u) \).

\[ \Delta y = y_{sp} - y_{OL(k)} \]  \hspace{1cm} (47)

\[ \Delta u = u_{sp} - u(k) \]  \hspace{1cm} (48)

To include the output feedback, then the steady model adapted as

\[ \Delta y = K \Delta u + [ y(k) - y(k) ] \]  \hspace{1cm} (49)

The optimum values, desired input and output, which minimize a quadratic output index, are calculated by a representation formulation for set-point optimization.

\[ \min_{u_{sp}} J = c^T u_{sp} + d^T y_{sp} + e_y Q_{sp} e_y + e_u R_{sp} e_u + S^T T_{sp} S \]  \hspace{1cm} (50)

Subject to meeting Eq.50 and the restrictions of inequalities on inputs and outputs:

\[ u_{min} \leq u_{sp} \leq u_{max} \]  \hspace{1cm} (51)

\[ \Delta u_{min} \leq \Delta u_{sp} \leq \Delta u_{max} \]  \hspace{1cm} (52)

\[ y_{min} - s \leq y_{sp} \leq y_{max} + s \]  \hspace{1cm} (53)

Where \( e_y = y_{sp} - y_{ref} \) \hspace{1cm} (54)

\[ e_u = u_{sp} - u_{ref} \]  \hspace{1cm} (55)

*Improve the tracing performance:*

The most important objective of the optimization is to compute the desired response and set point. It should be very closer to the reference set point and output. Depending on the relative value of the MVs, CVs, and restriction breaches, the weighting matrices \( Q_{sp}, R_{sp}, \) and \( T_{sp} \) should be selected.

*Choice of parameters for design and tuning:*

In a MPC controller, a number of design parameters need to be specified. Consider the challenges in the design issues and suggested values are discussed in this section.

*Parameters:*

1. Sampling Interval \( \Delta t \) and total length of the model horizon \( N \)
2. Control M and prediction P horizons
3. Weighting Matrices, \( Q \) and \( R \)
The desired future performance behaviour can be defined in various ways in MPC applications: as a guided value, upper and lower restrictions, an orientation trajectory, a funnel. (Qin and Badgwell, 2003). The guided trajectory and the funnel approaches each have a tuning factor that can be used for each output to modify the appropriate response speed.

7. CONTROL SYSTEM PERFORMANCE

The subsequent performance metrics are utilized for assessing the performance of the control system. [15].

1. Integral of the absolute value of the error (IAE)

\[ IAE = \int_0^\infty e(t) \, dt \]  

2. Integral of the squared error (ISE)

\[ ISE = \int_0^\infty [e(t)]^2 \, dt \]  

3. Integral of the time-weighted absolute error (ITAE)

\[ ITAE = \int_0^\infty t \, |e(t)| \, dt \]  

The variation among the set point and the output measurement is called the error signal \( e(t) \). Significant errors are penalized by the ISE criterion, while the ITAE condition penalizes errors to continue for lengthy periods of time. The ITAE is the chosen condition while the nearly everyone restrictive controller settings normally result in it. The most violent settings are given by the ISE criterion, although the IAE condition leads to generate controller values among the ITAE and ISE settings.

4. Total variation (TV)

The Total Variation is computed by using the manipulated variables moves with respect to previous moves.

\[ TV = \sum_{k=1}^{\infty} \left| U(k+1) - U(k) \right| \]  

The TV is a good indicator of the signal's smoothness and it should be thin. Instead of the settling time and the overshoot, TV is chosen because it can provide a reasonable solution given these typically contradictory time domain metrics. If it provides a fast and smooth reaction to input changes, a control system exhibits a high level of efficiency.

8. SIMULATION EXAMPLE

The multi-loop and multivariable controller design A simulation example shows the multi-loop and multivariable controller design process. Consider the Wood and Berry column of methanol-water distillation (1973) (Luyben, 1986):

\[ G(s) = \begin{bmatrix}
12.8e^{-8} & -18.9e^{-3s} \\
16.7s + 1 & 21s + 1 \\
6.6e^{-7s} & -19.4e^{-3s} \\
10.9s + 1 & 14.9s + 1
\end{bmatrix} \]  

Relative Gain Array (RGA) of the first output transfer function of the first input = 2.01. For the above mentioned system paired in the following way: \( y_1-u_1 \) & \( y_2-u_2 \), because the diagonal elements RGA is \( > 1 \) and off diagonal elements RGA is \( < 0 \).

The value of Niderlinski Index = 0.498, that is \( > 0 \). Due to the positive NI value the closed may be stable for above input and output pairings.

BLT: The biggest log modulus tuning technique must be perceived in the identical light as the traditional ZN SISO method. This offers suitable parameters will give an initial position for supplementary tuning and a benchmark for relative studies. The procedure for BLT tuning method is given below:

Step 1: Calculate the ZN settings for the given process transfer function matrix.

Step 2: Choose a factor \( F \) that is detonating a de-tuning factor and it is applied to all loops. \( F \) needs to be greater than one. The system is stable but slow set point and load reaction, the greater value of \( F \).
Step 3: A multivariate nyquist curve $W(j\omega) = -1 + \text{Det} [I + G_M(s)G_C(s)]$ is generated on the basis of the value $F$ and subsequent controller settings. The near this contour (-1, 0) is the, the closed loop system is more unstable. A biggest log modulus is the crest in the LCM design above the whole frequency spectrum, $L_{cm}^{\text{max}}$.

$$L_{cm} = 20\log_{10} \left| \frac{W}{1+W} \right|$$

(64)

Step 4: The factor $F$ is changed up to $L_{cm}^{\text{max}}$. $L_{cm}^{\text{max}} = 2N$ and $N = \text{Order of the system.}$

**IMC:** It is fine identified that in choosing the optimal closed-loop tuning parameter $\lambda$, there is always a trade off. By opting a narrow value of $\lambda$, quick response speed and strong disturbance rejection are preferred. However the broad significance of $\lambda$ favours stability and robustness. So option of $\lambda$ is based completely on the operator's familiarity inline the control system. It is opted that the initial value of $\lambda$ can be assumed to be slightly more than the process time delay, which can provide robust control efficiency based on several simulation studies. If not, once together the supposed and robust control output was reached; the value should be carefully increased. Here the time constant of the process is set as five.

**PGM:** The PI controller settings are computed from the PM and GM specifications. There is no need to solve the expressions by numerical techniques, formulas are derived to provide a reasonable approximation based on the PM and GM. These formulas enable the estimation of the PGM, which would be predominantly constructive in applying adaptive control where the PGM are computed robustly. The $G_p(s)$ and $G_c(s)$ denote the transfer functions of process and controller, with specific gain margins ($\text{mA}$) and phase margin ($\text{m\phi}$). In association with the diagonal transfer functions; the inputs and outputs of single loops control system are paired. To regulate the multivariable process $G(s)$, two single loop PI controllers are used with the margin of $\text{A_m} = 2$ and $\text{m\phi} = 20$.

$$G_c(s) = \text{diag} \left[ 0.57 \left( 1 + \frac{1}{20.9s} \right), -0.11 \left( 1 + \frac{1}{12.79} \right) \right]$$

(65)

For a more robust design the margins taken as $\text{A_m} = 3$ and $\text{m\phi} = 30$ for the two SISO loops.

$$G_c(s) = \text{diag} \left[ 0.383 \left( 1 + \frac{1}{21.67s} \right), -0.077 \left( 1 + \frac{1}{14.81} \right) \right]$$

(66)

9. **SIMULATION RESULTS**

| Tuning Method | Adjustment parameter | $K_c$ | $\tau_i$ |
|---------------|----------------------|------|--------|
| GPM           | Gm = 3               | 0.383| 21.67  |
|               | Gm = 3               | -0.077| 14.81 |
| IMC           | Lamda = 5            | 0.224| 17.2   |
|               | Lamda = 5            | -0.14 | 15.9  |
| BLT           |                      | 0.375| 8.29   |
|               |                      | -0.075| 23.6  |
TABLE II. COMPARISON OF PERFORMANCE INDICES FOR VARIOUS CONTROL SCHEMES

| Method     | Set-Point Tracking | Disturbance Rejection |
|------------|--------------------|-----------------------|
|            | ISE    | IAE   | ITAE  | ISE    | IAE   | ITAE  |
| MPC        | 1.31   | 2.07  | 104.44| 1.31   | 2.16  | 111.42|
| PI - PGM   | 17.53  | 36.22 | 3481.00| 123.22 | 143.34| 15939.00|
| PI - IMC   | 18.28  | 37.55 | 3460.00| 77.59  | 107.03| 11438.00|
| PI - BLT   | 19.88  | 47.34 | 4964.00| 172.94 | 192.94| 23328.00|

Figure 4. Simulation results of the W&B column for Set point response Loop1

Figure 5. Simulation results of the W&B column for Set point response Loop2
The outcome of the analysis demonstrated that the MPC controller was able to hold the deviation of the controlled variables much closer than the other PI controllers to the set points. The interactions are reduced by using decoupled PID controllers with single loop controllers. If the process model parameters not updated accurately the process response becomes sluggish and it highly difficult in real time implementation. In multi-loop and multivariable control systems, the proposed approach is straightforward and simple to implement. Model predictive control (MPC) is used to utilize like an extremely interacting system process based on its intrinsic decoupling scheme. The results of the simulation showed that the decentralized controller approach offers better output than the decentralized controller based on set-point and disturbance rejection mode performance indices. Finally, it is clarified that while MPC is not

10. CONCLUSION

The outcome of the analysis demonstrated that the MPC controller was able to hold the deviation of the controlled variables much closer than the other PI controllers to the set points. The interactions are reduced by using decoupled PID controllers with single loop controllers. If the process model parameters not updated accurately the process response becomes sluggish and it highly difficult in real time implementation. In multi-loop and multivariable control systems, the proposed approach is straightforward and simple to implement. Model predictive control (MPC) is used to utilize like an extremely interacting system process based on its intrinsic decoupling scheme. The results of the simulation showed that the decentralized controller approach offers better output than the decentralized controller based on set-point and disturbance rejection mode performance indices. Finally, it is clarified that while MPC is not
necessarily more or less robust than traditional feedback, robustness can be more easily modified. On a higher level, MPC is often used to provide set-points to the PID controllers running at the low controller hierarchy level. The MPC runs in a supervisory approach and the sampling interval longer compared to the lower-level sampling times of the PID controllers. It can be difficult to deal with due to at the MPC level because the bandwidth of the MPC loops is small.

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References

[1] Chiu MS, Arkun Y. Decentralized control structure selection based on integrity considerations. Industrial and Engineering Chemistry Research, pp. 29:369, 1990
[2] Vu TNL, Lee M. Multi-loop PI controller design based on the direct synthesis for interacting multi-time delay processes. ISA Transactions, Vol.49, pp.79–86, 2010.
[3] Ali A, Majhi S. PID controller tuning for integrating processes. ISA Transactions, Vol.49, pp.70–78, 2010.
[4] Sivaraman, P., A. Nirmal Kumar, and P. Prem. "Dynamic modeling and analysis of T-source electronic inverter using state space technique." Scientific Research and Essays 7, no. 38 (2012): 3269-3280.
[5] Luyben WL, Jutan A. Simple method for tuning SISO controllers in multivariable system. Industrial and Engineering Chemistry Process Design and Development, Vol.25, pp.654–660, 1986
[6] Hovd M, Skogestad S. Sequential design of decentralized controllers. Automatica, Vol.30, pp.1601–1607, 1994.
[7] P. Sivaraman & P. Prem (2017) PR controller design and stability analysis of single stage T-source inverter based solar PV system, Journal of the Chinese Institute of Engineers, 40:3, 235-245, DOI: 10.1080/02533839.2017.1303337 
[8] Wang QG, Huang B, Guo X. Autotuning of TITO decoupling controllers from step tests. ISA Transactions, Vol.39, Issue 4, pp.407–18, 2000.
[9] Tavakoli S, Griffin I, Fleming PJ. Tuning of decentralised PI (PID) controllers for TITO processes. Control Engineering Practice, Vol.14, pp.1069–80, 2006
[10] Pontus N, Hägglund T. Decoupler and PID controller design of TITO systems. Journal of Process Control, Vol.16, pp.923–36, 2006
[11] Jevtović BT, Matušek MR. PID controller design of TITO system based on ideal decoupler. Journal of Process Control. Vol.20, pp.869–76, 2010
[12] Åström KJ, Johansson KH, WangQG. Design of decoupled PI controllers for two-by-two system. IEE Proceedings: Control Theory and Applications, Vol.149, pp.74–81, 2002
[13] Mark L. Darby, Michael Nikolaou. MPC: Current practice and challenges. Control Engineering Practice, Vol.20, pp.328–342, 2012