CHAPTER 7

CONCLUSION

In this chapter major contributions from this research work are summarized for every chapter.

7.1 INTRODUCTION

In this chapter introduction to general MIMO systems, objective and scope of thesis and organization of thesis through different chapters are discussed. The majority of industrial plants are multivariable in nature having many output variables to be controlled and more than one input variable is coupled with outputs. Most of the chemical and bio-chemical processes are multivariable in nature. Interactions between inputs and outputs cause a manipulated variable to affect more than one controlled variable and hence MIMO processes are difficult to control. MIMO process refers to complex control configuration with Multiple Inputs and Multiple Outputs. To design a complex control system, configuration selection is difficult and a challenging process. Since the inferior configuration can dramatically reduce the control performance it is necessary to resolve interactions between different control loops. Hence, the objective of this work is to develop theoretical time series models for open-loop and closed-loop MIMO system and to calculate interactive measures using system/ signal theory and autotuning tools. The interactive transfer functions are formalized as multi-loop structure where the
process transfer functions are identified using relay feedback techniques. One of the specific objectives is to select the correct input-output pairing or control configuration selection and to synthesize advanced controller for multivariable system.

7.2 MULTIVARIABLE SYSTEMS

In this chapter process description of practical multivariable systems (ten distillation columns (Luyben, 1986) and liquid level control of coupled tanks control system) are discussed and defined with process transfer function matrix for further analysis and design. Some of these systems are concentration, temperature control of CSTR, Liquid level control of storage coupled tanks system and top-bottom product composition/temperature control of distillation columns, heat exchangers, flash drums, boiler drums, etc. Interactions are mainly contributed by off-diagonal elements of process transfer function matrix. Most of the controller design problem uses input output data or response of desired control loop. The response of undesired loop remains unnoticed or wasted due to off-diagonal elements of MIMO systems and carry important information regarding interactions, process dynamics and controllers.

7.3 INTERACTION MODELING USING RELAY FEEDBACK TEST

The state of art review on system modeling using relay feedback for both SISO and MIMO processes are presented in this chapter. A systematic approach is proposed to derive exact analytical expressions for ideal and biased relay feedback responses for off-diagonal closed loop interactive transfer functions in MIMO systems. The undesirable responses obtained from closed-loop interactive transfer functions of 2-by-2 and 3-by-3 MIMO systems are modeled without using approximation of time delay and validated
for case studies discussed in chapter 2. The results are provided in a closed form solution for the first time. A close look to these expressions reveals that it contains few segmental terms in the right hand side of equation. These segments show increasing number of terms containing exponential stabilizing (decaying) components giving rise to overall stable (oscillatory) response. These expressions are obtained from interactive closed-loop transfer functions that are formed from individual transfer function components (of FOPDT type with low D/τ ratio) of open-loop MIMO systems. The output relay responses are characterized by their D/τ ratio. Another MIMO system where liquid levels in two tanks are controlled by adjusting pump flow-rates, in real-time benchmark coupled tanks liquid level system, used to validate the relay response models of interactive transfer functions, tuning and estimation algorithms.

7.4 INTERACTION MEASUREMENT TECHNIQUES

In this chapter a brief state of art on interaction analysis is presented. Practical multivariable systems (ten distillation columns (Luyben 1986) and liquid level coupled tanks control systems are considered for analysis. Most of the available tools for interaction measurement techniques namely RGA, NI, SVD, MRI, DRGA, HIIA, PM and H₂ norm are used to calculate interaction and their values are tabulated for case studies to analyze interactions and thereby made use of control configuration selection.

The following interpretations are drawn for input-output pairing from the observation of values for 2-by-2 MIMO system (WB column), 3-by-3 MIMO system (OR column) and 4-by-4 MIMO system (A2 column). The diagonal pairing for 2-by-2, 3-by-3 and 4-by-4 MIMO systems are (y₁- u₁); (y₂- u₂), (y₁- u₁); (y₂- u₂); (y₃- u₃) and (y₁- u₁); (y₂- u₂); (y₃- u₃); (y₄- u₄). If the first element in the first column of RGA matrix is positive, RGA recommended diagonal pairing. If the NI value is positive, the closed loop
system with diagonal pairing is stable. From the directional sensitivity of the process SVD suggested diagonal pairing. MRI recommended the diagonal pairing since the minimum singular value was larger than one. DRGA suggested diagonal pairing since the measure corresponding to the paired variables is positive and closer to unity. HIIA, PM and H₂ norm proposed the diagonal pairing, since the elements in $\Sigma_{\Phi}$, $\Phi$ and $\Sigma_2$ are closer to unity. In the proposed method diagonal pairing is recommended since the minimum area is obtained with this pair.

RGA, DRGA suggests that the measure corresponding to the paired variables be positive and closer to unity as possible. The closed loop system with the specified pairing may be stable only if the value of NI is positive. SVD gives the information of principal gain and associated directions of i/o processes. MRI suggests that larger the value of minimum singular value the process is more resilient. Control configuration selection is done by choosing input-output pair corresponding to the largest element in each row of HIIA, PM and H₂ norm. Based on thumb rule for available tools of interaction measurement techniques, control configuration selection is done and discussed in chapter 4. The advantages of analyzing present interactive/undesirable transfer function over the other existing procedures are (i) it quantifies interactions (ii) it selects control configurations (iii) it also gives an account of looses in product/ utility through undesired yields that hints for retuning the loops to minimize losses (iv) it inherently estimates the closed-loop transfer function through eigenstructure realization algorithm.

The proposed method of interaction measurement is based on capturing the undesired dynamics and comparing the area under the curves by assuming diagonal and off-diagonal pairing and to find the correct input-output pair that gives minimum area under the curve. The proposed methods
are carried out for all 2-by-2 MIMO systems, coupled tanks control systems and one example of 3-by-3 MIMO and 4-by-4 MIMO systems.

7.5 CLOSED LOOP IDENTIFICATION

A state of art review on system identification for SISO and MIMO systems are presented upto date. The conventional methods of transfer function identification like least squares method and state space model identification like subspace methods are discussed in detail in this chapter. Sequential method of identification using relay feedback tests are carried out for 2-by-2 and 3-by-3 MIMO systems. Least squares and subspace methods are used to identify the process in open-loop and sequential identification technique is used to estimate the process in closed-loop. The model equations derived for 2-by-2 and 3-by-3 MIMO systems are useful to back calculate/identify the exact model parameters by applying boundary conditions. Also, the accuracy is justified by computation of multiplicative error. The data from undesired closed-loop containing information on interactions (loop) is used for identification of unknown process parameters. Parameter estimation algorithms using ultimate properties and landmark points are formulated to identify model parameters.

7.6 CLOSED LOOP STUDIES

Many research articles on design of multi-loop controllers are reviewed briefly in this chapter. PID controller for MIMO system is designed using centralized, decentralized and decoupler strategies and are implemented in the distillation column to study closed loop performance. The scope of the discussion is decentralized controllers for MIMO systems. The closed loop responses and its corresponding ISE values of decentralized PI controllers are designed using BLT and IMC methods and are compared in this chapter. The result shows that IMC design provides better performance than BLT design.
From the closed loop responses for set point tracking based on ISE values and the following conclusions are drawn for 2-by-2 MIMO systems. A multi-loop PI controller with IMC tuning is implemented for WB and WW columns and BLT tuning is implemented for VL and TS columns. Similarly, for 3-by-3 MIMO systems based on ISE values of closed loop responses, multi-loop PI controllers with IMC tuning is implemented for OR and T1 columns and BLT tuning is implemented for T4 column. Finally, for 4-by-4 MIMO systems, a multi-loop PI controller with IMC tuning is implemented for all DL, A1 and A2 columns in chapter 6.

A systematic approach is proposed to redesign the controller by monitoring the area under the closed-loop regulatory responses. The proposed methods of monitoring and redesign of controller is demonstrated effectively in real time coupled tanks experimental setup. For a particular coupled tanks system, optimum gain obtained is 5% when the disturbance is 10%. The control effort is calculated using this objective function which is found to be optimum that saved energy.