Chapter 1

Introduction

This chapter provides background on multiobjective optimization of 2DOF controller parameters using evolutionary and swarm intelligence enhanced with TOPSIS for the problem of shell and tube heat exchanger system. Motivation for the research work and organization of thesis is provided at the end.

1.1 Background

Proportional Integral Derivative(PID) feedback controllers are widely used in industrial applications since its inceptions. The various methods are observed in the literature for tuning and design of PID controllers. It is observed that PID controller (called one degree of freedom (1DOF) control structure) is tuned either for disturbance rejection or set point tracking. The drawback with 1DOF control structure is that when the disturbance response is optimized, the set point response is found to be poor, and vice versa. Due to this reason, the classical research on the optimal tuning of PID controllers have shown two tables: one for the "disturbance optimal"parameters, and other for the "set point optimal"parameters [1],[2]. Two degree of Freedom (2DOF) feedback control structure can attain both the objective set point tracking and disturbance rejections simultaneously [3].

The process of heat exchanger is used at different temperatures and thermal contact to transfer thermal energy between two or more fluids, a solid surface and a fluid, or between solid particles and a fluid [1]. Although, varieties of heat exchangers are available in the market, shell and tube type of heat exchanger system is widely used in industry [2].

Heat exchanger system has two predominant conflicting disturbances one is due to flow variation of input fluid and second is due to temperature variation of input fluid. The prime goal in the process of heat exchanger is to keep outlet temperature of process fluid flowing through it at desire value in the presence of two major conflicting disturbances. Hence, 2DOF control structure is applied for the multiobjective optimization problem of shell and tube heat exchanger systems [8].

Controller tuning is a broad research area in which tuning rules are derived from the mathematical model of the system [4]. The problem of multiple objective optimization gives rise to set of multiple optimal solutions (known as Pareto optimal, or non-inferior, or non-dominated solutions), instead of single optimal solution. In the absence of information related to the problem it's difficult to determine which Pareto optimal solution is better than other. This demands as many Pareto optimal solutions as possible. Classical computational methods fail in tuning controller for the multiobjective optimization problems due to following reasons: (1) These methods can generate single solution from single run hence; several runs are required in order to generate Pareto set of solutions. (2) Convergence to optimal solution depends on chosen initial condition. (3) It requires differentiability of both objective functions and constraints. (4) These methods fail when Pareto front is concave or discontinuous [5].

Evolutionary and swarm based controller tuning is appealing investigators due to its efficiency to optimize parameters based on cost function, without any know-how about the process. Also, these algorithms work based on population of search instead of single search therefore, it provides parallelism [6]. Single objective optimization algorithm terminates upon obtaining optimal solution. In the case of multiobjective optimization, there are number of optimal solutions. The multiobjective optimization algorithms required modifications in simple evolutionary or swarm based algorithm. Multiobjective Genetic Algorithm (MOGA), Vector Evaluated Genetic Algorithm(VEGA), Niched Pareto Genetic Algorithm(NPGA), Nondominated Sorting Genetic Algorithm(NSGA), Nondominated Sorting Genetic Algorithm-II(NSGA-II), and Nondominated Sorting Genetic Algorithm-III(NSGA-III) are evolutionary based multiobjective optimization algorithms. Multiobjective optimization based on Pareto dominance [10], multi-swarm PSO known as VEPSO algorithm [11], Nondominated sorting PSO for multiobjective optimization [12], and Handling multiple objectives with PSO(MOPSO) [13] are well known swarm based multiobjective optimization algorithms. Performance of NSGA-II is so good, that it has become very prevalent in the last few years. It has become a benchmark with which other multiobjective evolutionary algorithms required to be compared [14]. NSGA-III is the extension of the NSGA-II algorithm for optimization of many objectives (more than four objectives) problems[15]. MOPSO algorithm has faster convergence rate compared to other algorithms in the category of PSO based multiobjective optimization algorithms [13]. Hence, NSGA-II and NSGA-III algorithms from the evolutionary category and MOPSO algorithm from the swarm intelligence category is selected to optimize 2DOF controller parameters.

The result of evolutionary and swarm intelligence based algorithm gives Pareto set of solutions under each evaluation criteria. Practically, user needs only one solution from the set of Pareto optimal solutions for particular problem. Generally, user is not aware of exact trade-off among objective functions. Hence, it is desirable to first obtain maximum possible Pareto optimal solutions and select best one using multi-criteria decision making technique. The various multi-criteria decision making techniques are MAXMIN, MAX-MAX, SAW (Simple Additive Weighting), AHP (Analytical Hierarchy Process), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), SMART (Simple Multi Attribute Rating Technique), ELECTRE (Elimination and Choice Expressing Reality) and many more [16],[17]. The major advantage of TOPSIS method is it's rational, easy to implement, and good computational efficiency. Hence, TOPSIS is proposed as a decision support tool to rank the optimal solutions and select the best rank optimal solution [18].

An evolutionary (NSGA-II and NSGA-III) and swarm intelligence (MOPSO) based algorithms enhanced with TOPSIS was employed to optimize five parameters of two degree of freedom (2DOF) controller for the problem of shell and tube heat exchanger system. The main objective in the process of heat exchanger system is to maintain outlet temperature of process fluid flowing through it at desired value in the presence of two predominant disturbances, flow variation of input fluid and temperature variation of input fluid. Three objective functions, one for set point tracking and two for disturbance rejections (flow variation of input fluid and temperature variation of input fluid both are in conflict) were deployed for the problem of shell and tube heat exchanger. Three test criteria IAE, ISE and ITAE function of error (set point tracking and disturbance rejections) and time were used for evaluation of objective functions. The Pareto set of solutions were obtained after optimizing all the five parameters of 2DOF controller. In order to obtain the comparative analysis of optimization algorithms (NSGA-II, NSGA-III, and MOPSO) all the Pareto optimal solutions were combined under three separate evaluation criteria IAE, ISE, and ITAE. TOPSIS a multiple criteria decision making method was used to rank the set of Pareto optimal solutions for reducing number of Pareto optimal solutions to a single solution. The best rank solution obtained for 2DOF controller parameters after applying TOPSIS on set of Pareto optimal solutions using evolutionary (NSGA-II and NSGA-III) algorithms were compared with swarm Intelligence (MOPSO) algorithm. To evaluate the performance optimization of 2DOF controller tuning, we compared the values of peak overshoot of step response, set point tracking error, disturbance rejection (both flow and temperature), settling time, and the percentage of solutions obtained from optimization algorithms. MATLAB software tool was used to implement the above algorithms.

1.2 Motivation

The majority of real world problems involve multiple conflicting objectives, this results in problem of multiobjective optimization. The solution of multiobjective optimization problem resorts to a number of trade-off optimal solutions. Classical optimization algorithms can obtain single solution in one simulation run hence; those algorithms are not suitable to solve multiobjective optimization problems. The controller parameter optimization in multiobjective optimization problem is one of the emerging topics at present. An evolutionary and swarm based controller tuning is appealing investigators due to its efficiency to optimize parameters based on cost function, without any know-how about the process. The work published in journals, conference papers, and seminars on controller parameter optimization has motivated to work in the direction to optimize parameters of 2DOF controller for the problem of shell and tube heat exchanger system. The motivation behind research work reported in this thesis was:

(a)Application of 2DOF controller to satisfy two conflicting objectives set point tracking and disturbance rejections for the problem of shell and tube heat exchanger system under three performance evaluation criteria IAE, ISE, and ITAE of the objective functions.

(b)To apply outperformed multiobjective evolutionary (NSGA-II and NSGA-III) and swarm (MOPSO) based algorithms to optimize five parameters of 2DOF controller using software tool MATLAB.

(c)Application of TOPSIS a multiple criteria decision making method to rank the set of

Pareto optimal solutions for reducing these to a single solution.
(d)Comparison of results using following performance criteria: (1) Minimization of peak overshoot of step response. (2) Reduction in flow and temperature disturbance. (3) Reduction of set point tracking error. (4) Reduction in settling time. (5) The percentage of solutions obtained from optimization algorithms under all three evaluation criteria IAE, ISE, and ITAE.

1.3 Organization of thesis

Thesis is organized in the form of eight chapters as under:
Chapter 1: The current chapter provides background about multiobjective optimization of 2DOF controller parameters using evolutionary and swarm intelligence enhanced with TOPSIS for the problem of shell and tube heat exchanger system. Lastly, motivation behind research work and organization of thesis is given.
Chapter 2: It provides brief about parameter optimization of 2DOF controller. The comprehensive survey of algorithms based on evolutionary and swarm intelligence including its methodological issues from the perspective of multiobjective optimization is provided.
Chapter 3: It provides theory of conventional 1DOF and 2DOF control structure, and equivalent transformation of 2DOF control structure. The description of heat exchanger contains types of heat exchangers available in the market, shell and tube heat exchanger system description, and derivation of system transfer function with 2DOF controller.
Chapter 4: It covers difference between single objective and multiobjective optimization, terminologies used in multiobjective optimization, theory of multiobjective optimization, and approach for solution of multiobjective optimization problem. The next section contains 2DOF controller parameter optimization method, formation of three objective functions, discussion on criteria for evaluation of objective functions, and process applying objective functions for multiobjective optimization problem.
Chapter 5: It contains method optimization of 2DOF controller parameters using multiobjective evolutionary optimization of NSGA-II and NSGA-III algorithms.
Chapter 6: It contains method optimization of 2DOF controller parameters using Pareto dominance based multiobjective particle swarm optimization (MOPOS) algorithm.
Chapter 7: This covers application of TOPSIS a multi-criteria decision making technique on Pareto solutions obtained using NSGA-II, NSGA-III, and MOPSO algorithms

and comparison of results.

Chapter 8: It provides discussion of the results, conclusions, and scope of future work.

Thesis ends with a complete Bibliography.