Multi-Objective Robust Optimization of Energy Systems

W. Hu[1], N. Al-Qasas[2], M. Li[1], S. Al Hashimi[2] and S. Azarm[1]

[1]**Mechanical Engineering Department, University of Maryland, College Park, U.S.A.**
[2]**Chemical Engineering Department, The Petroleum Institute, Abu Dhabi, U.A.E.**

Abstract

Optimization problems in energy systems often involve multiple conflicting design objectives subject to multiple constraints and uncertainty in input parameters. One approach for solving such problems is to use Multi-Objective Robust Optimization (MORO). The goal in MORO is to obtain system solutions that are as best as possible in a multi-objective sense and at the same time their system performance is "insensitive" to uncertainty. In this paper, a new MORO approach is presented. We use both this new MORO technique and also a previously developed MORO technique to solve a distillation column problem. For this problem, it is found that the solutions obtained from these two MORO approaches are in agreement. More importantly, it is shown that the number of simulation calls required by the new MORO approach is an order-of-magnitude less than the previous MORO technique.

1. Introduction

The design and operational optimization of energy systems typically involves more than one objective. For these multiple objectives, which are at least partly conflicting, there exist tradeoffs among optimized system solutions. For example, for a distillation tower system in a petrochemical plant, the decision maker might want to optimize the system by minimizing its total ownership cost (or by maximizing net profit) and at the same time maximizing the purity of output products. These two objectives are conflicting which implies that along Pareto optimum solutions as the purity is improved the profit will have to be sacrificed and vice versa. Moreover, the design and operation of such systems often have to account for uncertainty in input parameters that exist due to uncontrollable external (e.g., environmental) and internal (e.g., operational) conditions. Uncertainty in input parameters can degrade system performance and thus has to be considered as part of a simulation-based optimization strategy for energy systems or by way of Multi-Objective Robust Optimization (MORO). In MORO, the goal is to obtain system solutions that are as best as possible in a multi-objective sense and at the same time system performance for each solution, in terms of multiple objectives and constraints, is "insensitive" to uncertainty.

Our previously developed MORO [1] was based on a two-level technique (i.e., two-level MORO) and required a large number of simulation calls. Here, we present some preliminary results for a new "single-level MORO" approach which requires a significantly fewer number of simulation calls compared to the two-level MORO.

2. Approach

In our new MORO approach, as in the two-level MORO [1], we assume that the uncertainty in input parameters is represented by an interval, with known upper and lower bounds. We define a feasibly robust design as the one that maintains satisfaction of constraints when the uncertain parameters vary within their interval. Similarly, a design is said to be multi-objectively robust if the variation of objectives is within an acceptable range. If a design is both feasibly and multi-objectively robust, we simply call it a robust design.

In the previously developed two-level MORO, the upper level problem solved for optimized design solutions while the lower level problem applied a robustness constraint. This iterative formulation in the two-level MORO between the upper and lower level problems can result in a large number of simulation calls. In order to handle MORO problems more efficiently, a single-level MORO approach is proposed here. In the single-level MORO, constraints are iteratively added to the optimization problem. These constraints are devised using a worst case value of parameters which collectively help identify robust solutions. Because the single-level MORO involves only one level, it is considerably more efficient than the two-level MORO.

3. Distillation Column Example

In this example, as shown in Figure 1, we have four design variables namely the number of stages in upper and lower sections N_1 and N_2, the reflux ratio R and the boil-up ratio V_B. All design variables are bounded from above and below. Uncertain input parameters are the feed flow rate F, purity of volatile component in feed stream X_F and the sale price of propylene PP. Our goal for the distillation column design is to identify a set of robust Pareto solutions that maximize both the profit and purity.

We use both the proposed single-level MORO and the two-level MORO to solve the distillation column optimization problem. For comparison, the deterministic optimization problem with the nominal value of parameters was also solved. It is found that the obtained Pareto solutions from the two MORO approaches are in general agreement, as shown in Figure 2. More importantly, the number of simulation calls required by the single-level MORO approach has been reduced by an order-of-magnitude (see the table to the right of Figure 2) compared to the two-level MORO.

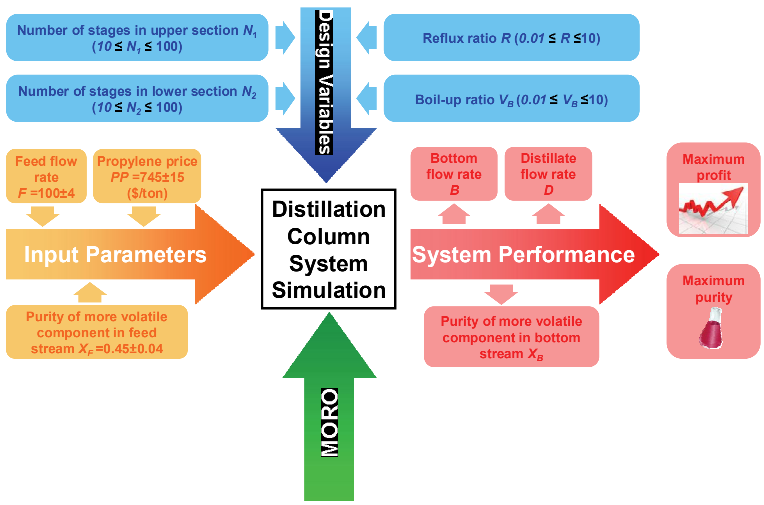
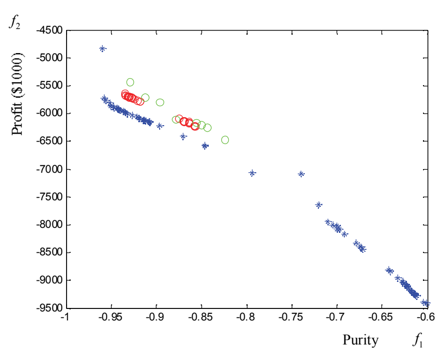


Figure 1. Distillation column example.



	Simulation calls
* Deterministic	1,282
o Two-level MORO	1,171,697
o Single-level MORO	112,880

Figure 2. Deterministic and robust results.

4. Conclusions

A single-level MORO is proposed for robust optimization of energy systems. A distillation column design example reveals the efficiency of the proposed single-level MORO approach compared to a previous two-level MORO technique. The proposed MORO is a generalized approach and applicable to a large class of energy system optimization problems.

5. References

1. Li, M., S. Azarm, and A. Boyars, "A New Deterministic Approach using Sensitivity Region Measures for Multi-Objective and Feasibility Robust Design Optimization," Journal of Mechanical Design, 128(4), 874-883, 2006.