Convexification, Modeling and Optimization of Complex Water-Energy-Resource Systems

By

Yingzong LIANG

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Examination Committee:
Prof. Sai Kit YEUNG, Chairman
Prof. Chi Wai HUI, Supervisor
Prof. Furong GAO, Prof. Richard LAKERVLED, CBE
Prof. Irene Man Chi LO, CIVL
Prof. Jinping LIU (External), South China University of Technology

Abstract

Increasing attention has been paid to the efficient design and operation of the water, energy, and resource systems that generate and supply essential products for human society. Much effort has been dedicated to optimize these systems, however, the systems’ complexity, such as large systems sizes and strong nonconvexity, has greatly hindered the optimization research. New mathematical framework and tools are needed, including those that will integrate modeling techniques, algorithmic methods and engineering heuristics, to tackle the challenges in optimizing these complex systems. Central to this dissertation is a detailed optimization study of these systems. New mixed-integer programming models are proposed for the optimal design and operation of the water-energy-resource systems facilitated by novel convexification techniques, algorithmic approaches and engineering heuristics.

This dissertation begins with the modeling and optimization of water systems. Chapter 2 addresses the nonconvexity resulting from the flow rate-head loss constraints of the investment minimization problem of water distribution systems. By convexifying the head loss constraints, we propose a convex model for the optimization problem that not only improves the solution efficiency but also ensures global optimization. Chapter 3 engages the simultaneous water and energy minimization problem of water allocation networks, of which the optimization is complicated by its nonlinear logical constraints and nonconvex constraints for water mixing. To handle these issues, the logical constraints are linearized, and engineering heuristics applied to reduce repeating heating and cooling efficient simultaneous water and energy minimization is achieved. The thesis then concentrates on the energy systems optimization with an industrial background of natural gas transmission and liquefaction. Chapter 4 extends the convexification method proposed in Chapter 2 to resolve the nonconvex flow rate-pressure drop constraints for natural gas transmission systems optimization problem. Chapter 5 proposes an effective framework for simultaneous multistream heat exchangers (MHEXs) and process optimization of natural gas liquefaction process. The framework avoids inefficient modeling of MHEXs, and embeds rigorous thermodynamics modules to achieve simultaneous optimization. Subsequently, the thesis forms a modeling and numerical study of resources systems and their effects on the environment from a perspective of agriculture. Chapter 6 presents a multi-objective optimization model for mixed crop-livestock farming systems to optimize their resource efficiency, economic profitability, and environmental sustainability. Finally, Chapter 7 summarizes the major findings of the research of water-energy-resource systems.