Chapter XII
Evolutionary Multi-Objective Optimization in Energy Conversion Systems:
From Component Detail to System Configuration

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ABSTRACT

The research field on energy conversion systems presents a large variety of multi-objective optimization problems that can be solved taking full advantage of the features of evolutionary algorithms. In fact, design and operation of energy systems can be considered in several different perspectives (e.g., performance, efficiency, costs, environmental aspects). This results in a number of objective functions that should be simultaneously optimized, and the knowledge of the Pareto optimal set of solutions is of fundamental importance to the decision maker. This chapter proposes a brief survey of typical applications at different levels, ranging from the design of component detail to the challenge about the synthesis of the configuration of complex energy conversion systems. For sake of simplicity, the proposed examples are grouped into three main categories: design of components/component details, design of overall energy system, operation of energy systems. Each multi-objective optimization problem is presented with a short background and some details about the formulation. Future research directions in the field of energy systems are also discussed at the end of the chapter.

INTRODUCTION

Multi-objective evolutionary algorithms have a multiform spectrum of applications in the research field about energy systems. This chapter is an attempt to give an organized picture of the formulation and solution of multi-objective optimization problems in this field. The subject ranges from the design of component detail zooming out to various aspects about the design and operation of the whole system. Many applications of single-objective evolutionary algorithms have been proposed in the literature as well. They can be easily, and profitably, extended to multi-objective optimization problems by taking into account some other important objectives that have been neglected or incorporated in the considered single-objective function using weighting factors.

A short background of each topic is provided and some of the most recent and significant examples of applications are discussed, analyzing the context and the formulation of each problem. Some details are also provided about the codification of the decision variables, the evaluation of the objective functions, the multi-objective evolutionary algorithms used for the search of the Pareto optimal set and the most interesting features of the obtained results.

DESIGN OF COMPONENT DETAILS

Energy conversion systems feature a large variety of components performing different tasks, which usually involve the exchange or transformation of energy through operating fluids. When the focus is limited to a single component, several objectives related to the main process that takes place in the component can be considered to formulate multi-objective optimization problems. The nature of these objectives primarily involves energetic and economic aspects of the process, although several other objectives can be taken into account as well.

The main objective that is often considered in the formulation of optimization problems is a measure of the efficiency at which component task is performed. In a fan, for instance, the main component task is to transform the mechanical energy supplied by the rotation of impeller blades into a total pressure rise for the air that flows through the machine. The efficiency of this energy conversion process (the ratio between the desired output and the required input) cannot be 100% due to the aerodynamic and volumetric losses inside fan impeller and diffuser.

Two-objective optimization problems of particular interest can be set up when task performance index is taken into account as the second objective, since performance and efficiency are usually conflicting objectives. In the example of the fan, the two objectives would be the maximization of the air total pressure rise (task performance index) and the maximization of the efficiency of the conversion of impeller mechanical energy.

Other objectives that may be considered are the maximization of secondary task performance indexes (e.g., fan discharge static pressure in order to overcome the pressure losses in air ducts), the minimization of detrimental side effects (e.g., fan noise emissions) and the minimization of component or component detail sizes (e.g., the radial and/or axial room required by the fan unit). The minimization of costs (manufacturing, purchase, operating costs) obviously deserves, as always, a special place among the objectives that can be taken into account.

Multi-objective design optimization of components or component details can be exploited for an extremely wide spectrum of applications. Three examples are given in the following, about axial compressor blades, heat exchangers and horizontal-axis wind turbine rotors.

Optimization of Aerofoil Shape for Axial Compressor Blades

Axial turbomachinery design essentially deals with the definition of the geometrical parameters of a series of succeeding blade cascades, a problem in which the definition of blade section geometry plays a key role. In compressor cascades, the shape of blade profile is particularly critical because the flow (relative flow in rotating cascades and absolute flow in stationary cascades) decelerates in the blade channels (Figure 1). On the suction side, the adverse pressure gradient after peak velocity location may lead to flow separation,

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