Chapter 14
Modelling and Simulation Approaches for Gas Turbine System Optimization

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ABSTRACT

This chapter deals with research activities that have been carried out so far in the field of modelling and simulation of gas turbines for system optimization purposes. It covers major white-box and black-box gas turbine models and their applications to control systems.

1. INTRODUCTION

The rapidly growing knowledge-based industry has been always looking for creative and bright ideas. Mechatronics, as a multidisciplinary field of engineering, is one of those innovative phenomena that has contributed many advantages to our industrial society. It represents a unifying paradigm that integrates, permeates, and comprehends fundamental and modern engineering (Habib, 2006). Mechatronics combines a variety of engineering disciplines including mechanics, electronics, computer science, systems design, and control to fulfill the challenges of modern technology and the demand for innovation (Habib, 2008). It has been a powerful solution to many sophisticated problems in complex industrial systems such as Gas Turbines (GT).

Gas turbine is considered as an internal combustion engine which uses the gaseous energy of air to convert chemical energy of fuel to mechanical energy. Although the story of gas turbines has taken a root in history, it was not until 1930s that the first practical GT was developed by Frank Whittle and his colleagues in Britain for a jet aircraft engine (Kulikov & Thompson, 2004). Gas turbines were
developed rapidly after World War II and became the primary choice for many applications. That was especially because of enhancement in different areas of science such as aerodynamics, cooling systems, and high-temperature materials which significantly improved the engine efficiency. Then, it is not surprising if gas turbines have been increasing in popularity year by year.

Today, gas turbines are one of the major parts of modern industry. They have been playing a key role in aeronautical industry, power generation, and main mechanical drivers for large pumps and compressors. They have the ability to provide a reliable and continuous operation. The operation of nearly all available mechanical and electrical equipment and machinery in industrial plants such as petrochemical plants, oil field platforms, gas stations and refineries, depends on the power produced by gas turbines.

Figure 1 shows the main components of a single-shaft gas turbine engine; including compressor, combustion chamber (combustor), and turbine. The set of these components is called engine core or Gas Generator (GG). Compressor and turbine are connected by the central shaft and rotate together.

As the figure shows, air enters the compressor at section 1 and is compressed through passing the compressor. The hot and compressed air enters the combustion chamber (combustor) at section 2. In combustor, fuel is mixed with air and ignited. The hot gases which are the product of combustion are forced into the turbine at section 3 and rotate it. Turbine drives the compressor and the GG mechanical output, which can be an electricity generator in a power plant station, a large pump or a large compressor.

2. GAS TURBINE CYCLE

Gas turbines work based on Brayton cycle. Figure 2 indicates a typical standard Brayton cycle in temperature-entropy frame (Tavakoli et al., 2009). As it can be seen from the figure, the actual processes in the compressor (1-2) and turbine (3-4) are irreversible and non-isentropic. Points 2s and 4s show the ideal situation, when these processes are assumed isentropic. Neglecting pressure loss in the air filters and the combustion chamber, processes 2-3 and 4-1 can be considered isobar (Tavakoli et al., 2009).

Considering Figure 1 and Figure 2, basic thermodynamic equations for the main parts of a single-shaft gas turbine can be written as follows (Al-Hamdan & Ebadi, 2006). For the compressor:

$$ T_{02} = T_{01} + \frac{T_{01}}{\eta_c} \left[ \frac{\gamma_{ar}}{\gamma_{ar} - 1} \right] - 1 \] $$

(1)

Figure 2. Typical Brayton cycle in temperature-entropy frame (Tavakoli, et al., 2009)