Gas Turbine Power Generation Systems

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Contributor: Omar Mohamed

This paper reviews the modeling techniques and control strategies applied to gas turbine power generation plants. Recent modeling philosophies are discussed and the state-of-the-art feasible strategies for control are shown. Research conducted in the field of modeling, simulation, and control of gas turbine power plants has led to notable advancements in gas turbines' operation and energy efficiency. Tracking recent achievements and trends that have been made is essential for further development and future research. A comprehensive survey is presented here that covers the outdated attempts toward the up-to-date techniques with emphasis on different issues and turbines' characteristics. Critical review of the various published methodologies is very useful in showing the importance of this research area in practical and technical terms. The different modeling approaches are classified and each category is individually investigated by reviewing a considerable number of research articles. Then, the main features of each category or approach is reported. The modern multi-variable control strategies that have been published for gas turbines are also reviewed. Moreover, future trends are proposed as recommendations for planned research.

Keywords: gas turbine ; power plant ; mathematical modeling ; intelligent modeling ; system identification ; predictive control ; intelligent control

1. Introduction

Modeling and control of gas turbine (GT) power generation systems are very important and are interrelated disciplines to study and improve the GT performance and efficiency. Understanding GT dynamics before actual installation or existing GT units cannot be achieved without sufficiently accurate models. GTs have occupied a privileged position among other power generation technologies for many reasons, including: high reliability; higher efficiency, especially when integrated with combined cycle; flexible operation; and regular availability [1][2]. The advances in GT operation and efficiency have occurred either from progress in GT control system philosophies [3] or introducing new designs [4]. GTs can be found in applications including engines used in aircraft and gas turbines used in power generation plants [5][6]. Due to the differences in the practical objectives between aircraft gas turbines and power generation gas turbines, the review presented here is dedicated to gas turbine power generation plants (GTPGP) used in power systems, whether they are studied on their own open cycle or as a part integrated to steam cycle in combined cycle gas turbine (CCGT) power plants. Therefore, for organizational and directive research reasons, the models for aircraft gas turbines are not included in this survey. Throughout our reading of the published research in this research area, the survey papers were found to be too general, and more specific review is needed [7][8][9][10]. The reviews in [7][8] summarized the GT modeling up to 2008 and 2011, respectively, with rather short explanations, whereas the survey in [9] is a general survey of thermal power plant simulations. Recent reviews on gas turbines diagnostics have been published in [10][11], however, those surveys have reported the methods of GT diagnosis and do not focus on modeling-based control theory and dynamic performance studies. The survey in this paper rather focuses on the models-based control and dynamic performance studies for gas turbine generation units. There is an urgent demand to reorganize the most recent and state-of-the-art methods of developments in GTPGP modeling and control, classify them properly, and discuss how they are cognitively connected with what had been previously published. The contribution of this paper is then to provide a more updated and a comprehensive survey about dynamical modeling of GTPGP from control point of view and the feasible methods of control that can be integrated to the GT unit with compliance of operational restrictions. The survey is beneficial for reporting the state-of-the-art techniques and attempting to extract future trends in the field. The survey is organized as follows: The modeling part has been divided according to the modeling philosophy and compared against each other. Moreover, the study outlines the feasible control strategies of gas turbine generation systems and discusses the future opportunities in the field. The survey offered in this paper shall be confined to GTs used in power generation or GTPGP for two main reasons: firstly, to understand and justify the dramatic growth of GTs in electricity sector as a power system resource and its positive influences on the power grid performance, such as grid stability and continuity of service; and secondly, the survey will simplify the way to investigate more feasible and safe operation strategies for compliance of grid codes specified by the system authority in different countries, which is a very specialized requirement in power plant engineering.

2. An Overview on Gas Turbines Power Plants and the Purposes of Their Dynamical Modeling

Gas turbines are widely used for propulsion and power production applications [12][13][14]. Consequently, for all industrial applications of GTs, modeling procedures and control methodologies are widely reported in the literature. Proper operation strategies are the key objectives to be fulfilled by process simulation and control. The essential parts of a typical gas turbine are shown in Figure 1, which are a compressor, a combustor or combustion chamber, and the turbine. Figure 2 shows the entropy–temperature (T–S) diagram of a typical GT unit. The air that is necessary for firing is fed by the compressor (control volume 1–2). In the firing chamber, the fuel/air mixture is combusted (control volume 2–3). Ideally, the control volume 1–2 contains isentropic process whereas control volume 2–3 is an isobaric process. The burnt gases are expanded in the turbine as an isentropic process (control volume 3–4) which produces the required mechanical work which is sufficient to drive the rotor of the synchronous generator (SG). Finally, in (1–4), the heat is rejected with fixed pressure. Gas turbine usually exists as a part of combined cycle unit in which the gas exhausted from the gas turbine is harnessed by the heat recovery steam generator (HRSG) to supply a high energy steam to the steam turbine (ST). The electrical power is delivered by the synchronous generator.

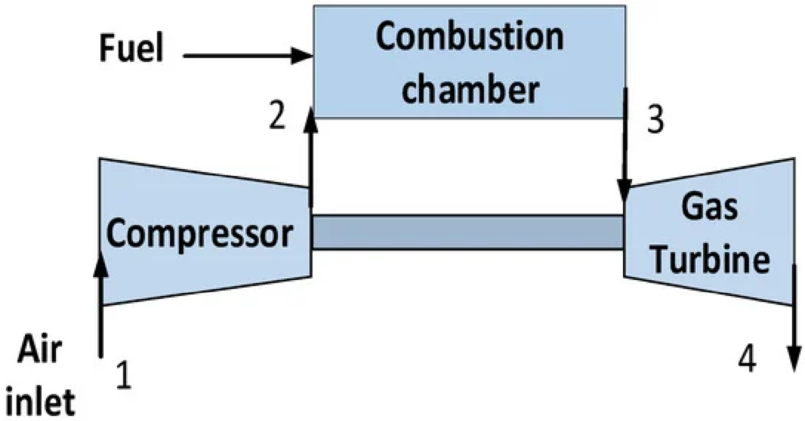

Figure 1. Main components of gas turbine unit.

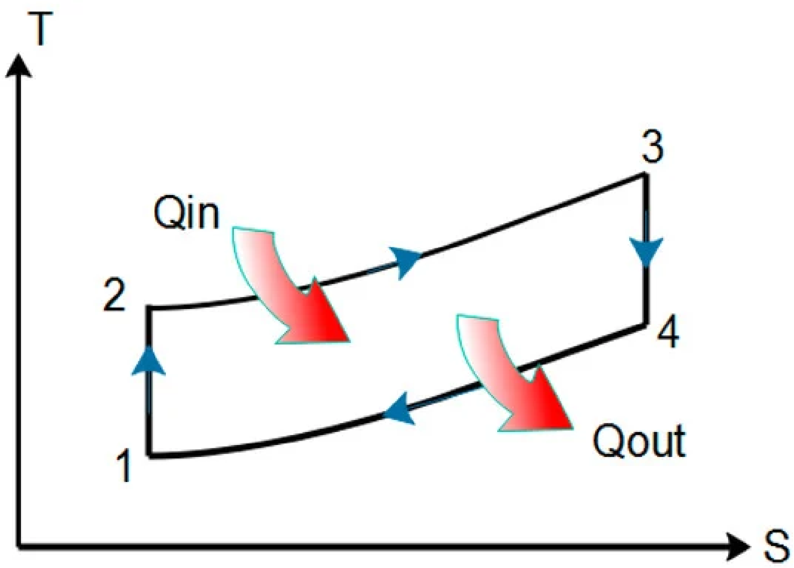

Figure 2. Temperature–Entropy (or T–S) diagram.

There are many goals and objectives for the modeling of GT or CCGT, including:

- Simulators for training purposes [15][16][17][18].
- Conditions monitoring and fault diagnosis [11][19][20][21].
- Upgrading the performance by control system analysis [3][22][23][24][25][26][27][28][29][30][31][32][33][34][35][36][37][38][39][40].
- Stability Studies (large signal and small signal stabilities) [22][23][24][25][26].

Apart from these modeling objectives, and to grasp the trends of the modeling literature of GTs, the modeling survey can be classified in a better and clearer manner as follows:

- Physical models based on the physical laws and parameters identification by data sets.
- Empirical models with predefined structure, which are based on operational data sets.
- Simplified mathematical models which are mostly transfer functions derived from system physics and identified to fit the plant manufacturer responses.

The next section reveals the significant differences between the models within each sorting.

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