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Dynamic model linearization of two shafts gas turbine via their input/output data around the equilibrium points

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ABSTRACT

The present paper deals with a linearization strategy of the non-linear model presenting a gas turbine with two shafts. Indeed, being able to describe and to explain the various phenomena involved and interacted in the dynamics of the turbines has a great impact in practice. Whereas; the modeling of the gas turbine using real data allows to approximate the variables of this nonlinear system based on a linearization approach. It is obvious that the advantage of this approach is to ensure the prediction and the monitoring of the gas turbine behavior to assess its optimized control. In this paper the obtained results based on real data of onsite measurements allow to understand and to analyze the phenomena interacting in the gas turbine system, and therefore the prediction of its dynamic behavior can be ensured.

1. Introduction

Currently, the development of mathematical models for the representation and approximation of nonlinear complex systems is a key issue in several disciplines of engineering science. Traditionally, modeling is seen as the double conjunction between understanding the nature behavior of a complex system and the appropriate mathematical treatment, which leads to the production of a usable model, for example in monitoring of these systems. The need for a deep understanding of the physical phenomena in industrial systems presents a major restriction on the practical level, when the concerned system is complex. Indeed, the implementation of the equations of the laws governing such systems usually leads to a complex model of knowledge where its implementation is difficult. In this case, the use of developed modeling techniques based on collected input/output system measurements is required [1–3,8,9,14,22,23,25–27,30].

The use of techniques issued from mathematical linear theories appears as the main alternative to address nonlinearities in industrial systems. This work proposes the use of these techniques to identify the complex problems of nonlinear systems applied to a gas turbine. It is well known that one of the main difficulties in modeling of industrial systems is the determination of the mathematical laws that describe these systems. However, obtaining a linear model simplifies the analysis of their dynamic behaviors, as well as the design of their control and surveillance strategies. Using a linearization method of a nonlinear model around an operating point aims to determine a linear description of the system around the equilibrium points, while keeping the mathematical properties of the initial system.

In this context, this work aims to develop a novel method for modeling nonlinear dynamic variables of a gas turbine, in order to achieve effective and equivalent linear approximation to their nonlinear models and to propose the nonlinear dynamic model identification around operating points obtained from real data. The use of this linearization system around an equilibrium point, or under certain assumptions (approximation of small deviations) allows to describe the nonlinear system by a linear mathematical model.

It is important to clarify that the gas turbine system has been studied and presented in several previous works, where the main works are cited here in this paper. Indeed, recently in 2016 Abdelhafid Benyounes et al. have studied the modeling of a gas turbine system based on fuzzy clustering algorithms using experimental data [2]. Hafaifa Ahmed et al. have presented a monitoring

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system of the gas turbine based on the acquisition of real data of onsite gas turbine vibration measurement [3], Nikolaus A. et al. have modeled the dynamics of flow with a probabilistic method [24]. Wei Sun et al. have the hierarchical modeling approach to characterize the dynamics of the drive system of a gas turbine [29].

In 2015, other authors developed a system for monitoring vibration in a gas turbine based on a parity space approach to increase the efficiency of the gas turbine [4]. Ahmed Zohair Djeddi et al. have proposed a model of reliability of this system based on hyperbolic tangent function [5,6]. Chisari Corrado et al. have made a static and dynamic identification using genetic algorithms applied to a turbine [12]. Jakub Cichowicz et al. have an energy and dynamic modeling for the evaluation of life cycle performance of a gas turbine [16]. Jiandong Duan et al. they modeled a micro gas turbine based nonlinear systems for the regeneration cycle in the turbine [17]. Ji-Zhen Liu et al. have proposed a dynamic model used for the design of controllers for turbine unit/boiler [19]. The aforementioned works are just the main important works that have been achieved within the research domain of gas turbine.

2. Gas turbine

A gas turbine is an internal combustion engine that uses gas energy from the air, by converting the chemical energy of fuel into mechanical energy, it is designed to extract as much as possible, the fuel energy. Indeed, the gas turbines are also called combustion turbines, they are used in a wide range of applications, including power generation, cogeneration, transmission of natural gas, as well as various applications of industrial processes [7,11,28]. These gas turbines are essentially composed of three main components: the compressor, the combustor, and the power turbine. In this article, a contribution is proposed to an important industrial theme by including linearization tools to determine reliable models for a gas turbine with two shafts. From data bases and operating history of this gas turbine, the linearization techniques were exploited from a nonlinear state model around an operating point, to determine the functions and variables that are involved in gas turbines.

2.1. Two shafts gas turbine

A gas turbine with two shafts has two independent turbines, the first turbine (high pressure turbine) is firmly connected to the compressor and drives, the second turbine (useful turbine) is not connected to the high pressure turbine; it produces the mechanical output power of the system as shown in Fig. 1.

The operating principle of this type of gas turbine consists in a first step, in a start procedure; the rotor of the HP turbine reaches 20% of the rated speed of the expansion turbine. The air drawn from the compressor is sent using pipes to the combustion chamber where fuel is charged under pressure with a high voltage spark igniting the fuel-air gas mixture. After ignition, the fuel injection of the fuel into the combustion chambers continues, creating a flame and increases the speed of the rotor of the HP turbine and compressor, consequently compressor discharge pressure is increased. The power turbine section produces the usable shaft output power for driving the load. Furthermore, it provides the power which is used to drive the compressor and all engine accessories.

The simple cycle is the basic operating cycle for most gas turbine with a thermal efficiency of 15%–42% which can be defined as the ratio between the useful energy supplied at the shaft and the input energy. The simple cycle gas turbines are typically used for shaft power applications without recovery of the heat of the exhaust gas. A major challenge of gas turbine modeling is the determination of the essential reactions which allows to describe its dynamic behaviors with the simplest possible equations to be exploited for the elaboration of the control laws of this machine. This work aims to determine linear models around the equilibrium points in a gas turbine with two shafts to show how the proposed modeling methods can be useful for the determination of gas turbine robust models.

3. Industrial applications

In this work, the linearization of the nonlinear dynamic model of the two shaft gas turbine type MS5002C is proposed Fig. 2. This gas turbine is used in a gas compressor station at Hassi Messaoud, south of Algeria. The linearization strategy adopted in this work allows to obtain linear models around operating points that can be used for the control or the supervision of this complex industrial system. The real experimental data obtained from the gas turbine system in site are used for the determination of linear dynamic model (LDM) of the presented system. The specific operating features of the studied gas turbine are respectively given in Table 1 and Table 2.

Fig. 3 shows the turbine power variation function of the ambient temperature and Fig. 4 presents the discharge pressure variation function of time. It is clear that when the pressure increases, the rotor of the LP turbine starts rotating and the speed of rotation of the two shafts increases until the operating speed.

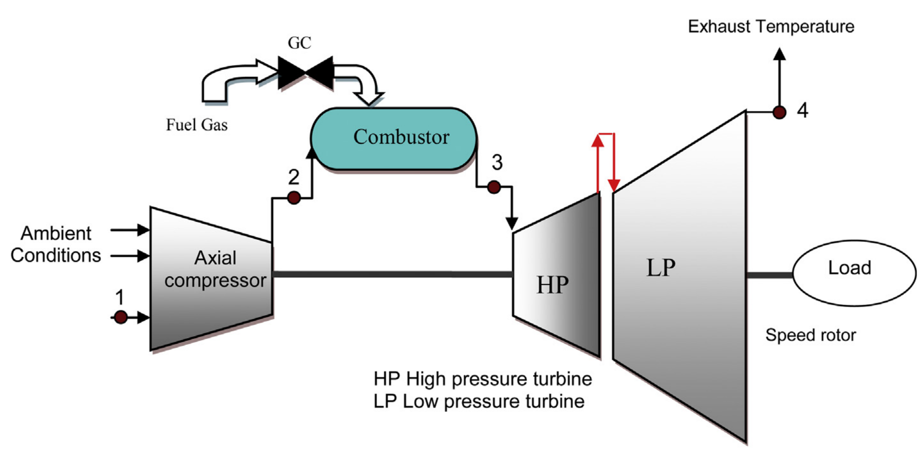

Fig. 1. The operating principle of the two shafts gas turbine.