Energy xxx (2016) 1–13

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Dynamic modeling of an industrial gas turbine in loading and unloading conditions using a gray box method

Abdollah Mehrpanahi, Gholamhasan Payganeh*, Mohammadreza Arbabtafti

Faculty of Mechanical Engineering, Shahid Rajaee Teacher Training University, Tehran, Iran

ARTICLE INFO

Article history:
Received 4 August 2016
Received in revised form
3 November 2016
Accepted 4 December 2016
Available online xxx

Keywords:
Industrial gas turbine
Dynamic modeling
Gray box method
Operation line

ABSTRACT

Using industrial gas turbines is on the rise because of their flexibility and structural diversity in different conditions and different industries. One of the multi-axial turbines produced in Iran is MGT-30 and there is an extensive program for their use in power generation and oil and gas industries. In this paper, dynamic modeling and analysis of the behavior of this type of turbines in the loading and unloading conditions are considered. Modeling was done by combining the thermodynamic equations and the equations derived from the values of some key parameters in two scenarios. In the first one, modeling was done based on the plant performance line and the model outputs were set according to the input disturbance to the system. In the second scenario, off-design conditions were achieved by adjustable parameters based on the system's physical condition. In addition, the application of the disturbances' effect of changing the type of fuel and ambient temperature on the ideal system's performance was investigated. Validation of the model for LPT exhaust temperature, PT's power and adaption of compressor's operation line was also carried out. Furthermore, the results of the model adaptation with Qeshm power plant on actual system conditions were provided.

1. Introduction

Gas turbine is one of the most fundamental equipment in various industries. In recent years, efforts have been increased to enhance and upgrade the technical and economic characteristics in the power generation plant in Iran. Industrial turbines have the potentiality to be used for cogeneration systems and enhance the efficiency of production. This equipment can also be used in industries such as oil, petrochemicals, etc. One of the industrial turbines being produced by MAPNA Group Company and used in Iran is MGT-30. Special characteristics of these turbines such as flexibility, low power and acceptable thermal efficiency have led to their use in power generation plants and gas compressor stations.

In order to study gas turbines' behaviors during load changes or analyze the effects of input changes in system behaviors in the cases such as controller design, condition monitoring systems or fault diagnosis, accurate models are needed. Appropriate software model enjoys high speed which can obtain system's outputs accurately. To provide such a model in the field of gas turbines, several methods have been offered. One of the first models in this regard is the Rowen model and its completed version, which were introduced in 1992 [1,2]. In the following years, this philosophy was employed to design other models. One of the valid proposed models is IEEE which was proposed by deMello et al. based on thermodynamics equations [3]. The advantage of this model is related to the use of thermodynamic equations with more details and accuracy in the results [4]. Based on the high efficiency of Rowen model regarding the production of gas turbines' dynamics, many studies have investigated dynamic models based on this method [5–11]. Models which include maps are mostly used in dynamic or performance behavior analysis and, in most cases, one compressor on a gas turbine has been investigated [12–18]. Researchers have produced models using different strategies of map production for single- and two-shaft gas turbines and have employed approaches such as convergence method (by operation point convergence loops) [19–22], geometric methods (mesh grid of map zone) [12,13] or equations methods (tune-able equations for matching) [23–27]. Among the mentioned research, analytical solutions and achieving performance points in three-shaft turbines have been investigated in several papers [20–22,27].

For the dynamic modeling of three-shaft turbines using compressor maps, this equipment should be matched at system's

* Corresponding author.
E-mail addresses: mehrpanahi@srttu.edu (A. Mehrpanahi), g.payganeh@srttu.edu (G. Payganeh), arbabtafti@srttu.edu (M. Arbabtafti).

http://dx.doi.org/10.1016/j.energy.2016.12.012
0360-5442/

Nomenclature

BE	Bias error
C_P	Constant pressure specific heat [kJ/kgK]
C_v	Constant volume specific heat [kJ/kgK]
CC	Combustion chamber
Dist	Disturbance
HP	High pressure
HPC	High pressure compressor
HPT	High pressure turbine
K	Extraction function
LHV	Low heat value [kJ/kg]
LVHC	Low heat value change [kJ/kg]
LPC	Low pressure compressor
LP	Low pressure
LPT	Low pressure turbine
LVS	Low valve selector
M,m	Mass flow rate [kg/s]
N,n	Shaft speed [rew/min, rad/s]
P	Pressure [bar]
PI	Performance input
PO	Performance output
PR	Pressure ratio
PT	Power turbine
$\dot{Q}$	Heat rate [kJ/kg]
R	Gas constant [J/kg K]
RMS	Root mean square error
SI	Standard input
SISO	Single input single output
SO	Standard output
T	Temperature [K]
TF	Tuning function

Greek symbols

η	Efficiency
γ	Specific heat ratio
Γ	Flow parameter

Subscripts

1,amb	Ambient condition
2	High pressure compressor input
3	Combustion chamber input
4	High pressure turbine input
5	Low pressure input
6	Power turbine input
a, air	Air flow
cor	Corrected
f	Fuel
g	Gas
is	Isentropic
N	Nominal
Niso	Non Iso condition

operation points in addition to the convergence of solutions for each compressor. Such a procedure can significantly increase time and operation procedures to find the answer. Thus, this process is not preferred for a dynamic system designing a control system that requires the on-line analysis of the conditions, receiving output and setting inputs. Some papers have been conducted in recent years which explore the dynamic modeling of multi-shaft turbines and simplification of these models. The response cycle in these systems requires the simultaneous use of thermodynamic equations and some performance correlation functions [28].

Here, compared with the previous models, HPC and LPC matching, extraction tuning for power and speed production according to high and low pressures and dynamic loop in each path in the three-shaft model are needed. Also, the effects of main inputs (environmental temperature and fuel type) were considered on the system behavior. To perform the modeling, two scenarios were used and compared based on the system's output responses (see Fig. 1).

The first method was set based on the gas turbines' operational data in various environmental conditions and more extensive operational information provided the control outputs in the system more quickly and accurately. In the second scenario, it was possible to adjust the model parameters based on operating information in terms of different conditions. In this method, the output responses had greater interoperability and, out of the range, the estimate errors were lower in this type of modeling.

Despite the complexity of the studied turbine and ambiguities regarding the location and condition of extractions and maps of high pressure and low pressure compressors, the obtained models were capable of generating outputs in different locations. In the proposed model, delays caused by the LPT exhaust temperature sensors and valve operator as a result of slight effect during loading and unloading were considered based on the manufactures' catalogues. Subject to the component performance delay, conventional transfer functions were applied in the presented dynamic model.

This procedure for the mentioned dynamical structures led to the following advantages:

- Performance outputs such as temperature and pressure at different points and mass flow rate through different components in design and off-design conditions with high accuracy are obtained. In this structure, the calculation error due to the removal of approximations and errors of compressor map calculation had low values. On the other hand, compared with the simplified models which use estimated functions to produce measured variables, these models use thermodynamic equations.
- The model is capable of expanding the controlled output behavior of the system without having to refer to compressor map data in various environmental conditions and input

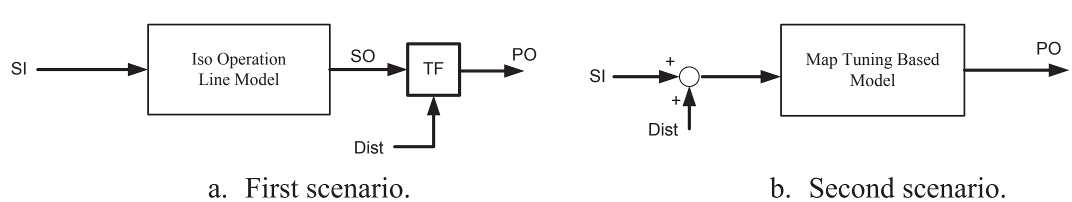

Fig. 1. Proposed scenarios.