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Improving distribution system stability by predictive control of gas turbines

F. Jurado [a,*], J. Carpio [b]

[a] Department of Electrical Engineering, University of Jaén, Alfonso X, No. 28, 23700 EPS Linares, Jaén, Spain
[b] Department of Electrical and Computer Engineering, UNED, 28040 Madrid, Spain

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Abstract

Lately, the use of gas turbines following the deregulation of the electricity supply industry has quickly become greater. The motivation for modeling gas turbines and their controllers is the need to interpret their impacts on distribution systems. Model predictive control (MPC) is used to damp the oscillation when the power distribution system is subjected to a disturbance. MPC is selected because it can explicitly handle the nonlinearities and constraints of many variables in a single control formulation. The IEEE 13 node power distribution system is employed to demonstrate the effectiveness of MPC to damp the oscillations of gas turbines.

Keywords: Gas turbines; Modeling; Nonlinear systems; Power distribution; Predictive control

1. Introduction

Gas turbines can offer solutions to today's energy situation as a supplement or support function to the conventional central generation and power system [1]. Complimentary answers are needed to meet the projected growth in new load and peak demand while providing power system stability, security and end user power quality solutions. Distributed generation (DG) integration into the existing power grid can enhance asset utilization without demanding major capital investment in new large generation or energy delivery facilities.

Synchronous machine stability surveys have been a discipline of interest for many years. Much of the work produced has been based on steam or hydro turbine generating units. Power system stability is normally associated only with large utility systems. However, with DG operating in parallel with the utility, stability has become an issue that is crucial to preserve critical functions [2]. Compared to the transmission system, the distribution system has several important characteristics. The power of DG is relatively small compared to the capacity of the substation. The substation is stiff enough to keep the frequency constant and, thus, can be conceived as an infinite bus.

* Corresponding author. Tel.: +34 953 648518; fax: +34 953 648508.
E-mail address: fjurado@ujaen.es (F. Jurado).

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Nomenclature

A_o	compressor exit flow area (m^2)
a, b, c	valve parameters
c_{pa}	specific heat of air at constant pressure (J/(kg K))
c_{pg}	specific heat of combustion gases (J/(kg K))
c_{ps}	specific heat of steam (J/(kg K))
e_1	valve position
F_d	fuel demand signal
K_I	PID parameter
K_P	PID parameter
k_f	fuel system gain constant
k_{LHV}	factor that depends on LHV
LHV	lower heating value (MJ/kg)
m_a	polytropic index
N	rotation speed of the turbine (rad/s)
P_c	compressor power consumption (W)
p_{cin}	air pressure at compressor inlet (Pa)
p_{cout}	air pressure at compressor outlet (Pa)
P_m	mechanical power delivered by turbine (W)
P_T	total mechanical power delivered by turbine (W)
p_{Tin}	pressure of combustion gases at turbine inlet (Pa)
p_{Tout}	pressure of combustion gases at turbine outlet (Pa)
r_c	pressure ratio (outlet/inlet)
t	time (s)
T	mechanical torque delivered by turbine (N m)
T_{cout}	outlet air temperature (K)
T_{is}	temperature of injected steam (K)
T_{Tin}	turbine inlet gas temperature (K)
$U(t)$	control signal
Y_T, U_T	finite time Fourier transforms
w_a	air mass flow into the compressor (kg/s)
w_f	fuel mass flow (kg/s)
w_g	turbine gas mass flow (kg/s)
w_{is}	injection steam mass flow (kg/s)
Δh_{25}	specific enthalpy of reaction at reference temperature of 25 °C (J/kg)
Δh_{IC}	isentropic enthalpy change for a compression from p_{cin} to p_{cout} (J/kg)
Δh_{IT}	isentropic enthalpy change for a gas expansion from p_{Tin} to p_{Tout} (J/kg)
ΔN	rotation speed deviation of the turbine (rad/s)
η_c	overall compressor efficiency
η_T	overall turbine efficiency
η_{trans}	transmission efficiency from turbine to compressor
$\eta_{\infty c}$	compressor polytropic efficiency
ρ_i	inlet air density (J g/m^3)
τ_f	fuel system time constant (s)

Model predictive control (MPC) is a control strategy that uses a model of the system to predict the response over a future interval, called the costing or prediction horizon [3–5]. The application of MPC to control the gas turbine was introduced by van Essen [6] and Vroemen [7]. Model based control schemes are highly related