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Gas turbine combined cycle start-up and stress evaluation: A simplified dynamic approach

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HIGHLIGHTS

- A simplified dynamic model of a GTCC bottoming cycle for plant start-up is presented.
- Particular emphasis is placed on determining thermal stress on Steam Turbine rotor.
- To enhance accessibility, the model is developed within Microsoft Excel environment.
- The target system is the 390 MW Tirreno Power GTCC of Napoli Levante (Italy).
- Model validation is pursued against field measurement data (mean error of 5%).

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ABSTRACT

The main topic of this work is the development and validation of a simplified approach for the dynamic analysis of a Gas Turbine Combined Cycle (GTCC), with a particular focus on start-up procedure and associated mechanical stresses on the steam turbine (ST). The currently deregulated energy market led GTCC to undergo frequent startups, a condition often not considered during plant design. Moreover, the time required for the start-up is crucial under an economical viewpoint, though it is constrained by mechanical stresses imposed to thick components by thermal gradients. The framework proposed in this work aims to improve the accessibility to simulation software by applying commonly used office suite – Microsoft Excel/Visual Basic – with acceptable reduction in accuracy. Simplicity of model allow fast computation and its exploitation can be pursued by non-qualified plant operators. The obtained tool can be than adopted to support decision process during plant operations. The developed tool has been validated for a hot start-up against field measurements supplied by Tirreno Power S.p.A. Italy. Data are recorded through control and monitoring sensors of a 390 MW multi-shaft combined cycle based on the GT AEN94.3 A4 frame, but the results can be easily generalized to other layouts. Simulation result and stress evaluations around the steam turbine (ST) rotor show good agreement with experimental data.

1. Introduction

One of the main consequences of energy deregulations is the operational flexibility required to conventional power plants, which suddenly has become a key parameter. This has driven many changes to the whole energy field in recent years [1–3]. Energy plants started to undergo weekly and daily startups and shutdowns. As a consequence, plant components experience severe mechanical stress. In addition, the increasing share of renewable energy systems, together with restriction on pollutant emissions associated to energy production, have been deeply influencing the energy market [4–8]. Nowadays, the challenge deals with driving power plants from stand-still conditions to energy production as fast as possible. Hence, turbine manufacturers have focused their attention on engine quickness and their emissions, but the problem of efficient management of the whole plant persists.

In this regards, new ways to fasten the energy systems during startups [9] as well as in case of rapid transient load conditions [10], have been studied and tested [11–15]. Moreover, advanced monitoring technique were introduced to control the productive parameters of energy systems and life of their components [16–20]. Analysis on reliability and maintenance turned from a periodical approach to equivalent life-impact due to new high stressing working conditions. Modern technology and performance of

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Nomenclature

Acronyms

BSE	boiler stress evaluator
DTMS	distributed thermal mass system
ECO	economizer
EVA	evaporator
FL	full load
FSNL	full speed no load
GT	gas turbine
GTCC	gas turbine combined cycle
HP	high pressure
HT	high temperature
HRSG	heat recovery steam generator
HX	heat eXchanger
IGV	inlet guide vane
IP	intermediate pressure
LCM	lumped capacitance method
LP	low pressure
LT	low temperature
MEL	minimum environmental load
R.H.	relative humidity
RH	reheater
RSE	rotor stress evaluation
SH	super heater
ST	steam turbine

Symbols

a	exponent of off-design relations
c_p	specific heat at constant pressure
E	Young module
f	model value
h	enthalpy
$\dot{m}$	mass flow rate
Nu	Nusselt number
$\dot{Q}$	heat power
T	temperature
T'	rate of change in temperature
Pr	Prandtl number
p	pressure
RE	Reynolds number
t	time
y	plant measurements
α	thermal coefficient
η	heat exchanger efficiency
ν	Poisson coefficient
ρ	density
σ	mechanical stress
τ	time constant

Subscripts

0	initial state
app	approach
att	attemperator
b	design condition (base load)
cool	cooled by the steam
exh	exhaust gas
gas	GT gas flow
inf	free stream condition
ss	design steady-state
stm	steam
unc	uncooled by the steam

present GTCC plant [21] is also derived from studies based on energy system models, different in terms of software environment, purpose and structure [22–27].

In this scenario, the simulation software has gained significant importance in last decades and several approaches to model energy plants and their components have been studied and explored. Validation of software models consisted of testing the target systems under different situations and over several scenarios [28,29]. Despite of recent improvement in accessibility to the simulation tools, application of specific high-profile software [30,31] still require highly qualified users. From such considerations, Gulen and Kim [32] proposed a different approach to model GTCC power plant in a simple way, in order to implement this kind of analysis through common Microsoft Office suite. Their idea was focused on creating a flexible and reliable tool to perform dynamic simulation with a particular emphasis on the Heat Recover Steam Generator (HRSG) and Steam Turbine (ST), the most stressed components [32]. The main goal of the approach unveils its novelty: in the field of dynamic analysis of energy system, to extend simulation software to a wider number of users. This is pursued by proposing a framework that can be implemented through software usually available on normal desktop computer. The framework proposed here consists of a hybrid numerical and physical approach. This was critically analyzed in [33] by the Authors, and validation against experimental data has been presented for normal operating condition of the plant. Nevertheless, crucial operations of GTCC plant belong to start-up procedure. Integration of simplified method with rotor stress model proposed in [34] led to obtain a tool able to perform start-up analysis of a GTCC and predict stresses on ST.

2. Reference system

This work is based on the Tirreno Power 390 MW GTCC of Napoli Levante (Italy). It is a three pressure levels HRSG, which produces steam for a steam turbine in a 1 + 1 multi-shaft layout. The gas turbine is a 270 MW Ansaldo AEN94.3A4. Global performance of the turbine is presented in Fig. 1, where it is possible to see how the exhaust temperature increases during startups from full speed no load (FSNL) to the Minimum Environmental Load (MEL), which corresponds to 30 ppm CO emissions. MEL, for this GT frame, is reached around the 40% of GT base load, when the IGV are fully closed.

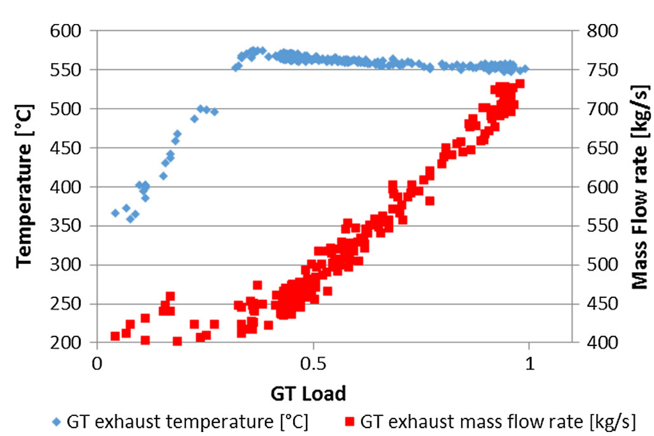

Fig. 1. GT exhaust temperature and mass flow rate.