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Performance modeling of industrial gas turbines with inlet air filtration system

Samuel O. Effiom [a,*], Fidelis I. Abam [b], Olayinka S. Ohunakin [c]

[a] Department of Mechanical Engineering, Cross River University of Technology, P.M.B 1123 Calabar, Nigeria
[b] Department of Mechanical Engineering, Michael Okpara University of Agriculture, Umudike, P.M.B 7276 Umuhia, Nigeria
[c] Department of Mechanical Engineering, Covenant University Ota, Ogun State, Nigeria

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ABSTRACT

The effect of inlet air filtration on the performance of two industrial gas turbines (GT) is presented. Two GTs were modeled similar to GE LM2500+ and Alstom GT13 E2-2012, using TURBOMATCH and chosen to operate at environmental conditions of Usan offshore oilfield and Maiduguri dessert in Nigeria. The inlet pressure recovered (P_{recov}) from the selected filters used in Usan offshore, and Maiduguri ranged between $98.36 \le P_{recov} \le 99.51$ % and $98.67 \le P_{recov} \le 99.56$ % respectively. At reduced inlet P_{recov} by 98.36% (1.66 kPa) and, at a temperature above 15 °C (ISA), a reduction of 16.9%, and 7.3% of power output and efficiency was obtained using GT13 E2-2012, while a decrease of 14.8% and 4.7% exist for power output and efficiency with GE LM2500+. In addition, a reduction in mass flow rate of air and fuel under the same condition was between $4.3 \le m_{air} \le 10.6$% and $10.4 \le m_{fuel} \le 11.5$% for GT13 E2-2012 and GE LM2500+, correspondingly. However, the GE LM2500+ was more predisposed to intake pressure drops since it functioned at a higher overall pressure ratio. The results obtained were found worthwhile and could be the basis for filter selection and efficient compressor housing design in the locations concerned.

1. Introduction

Gas turbines consume a large volume of ambient air during in-service condition. For this reason the quality of ambient air incoming the system is essential to the overall performance and the longevity of the gas turbine. A filtration mechanism is usually employed to regulate the quality of ambient air by removing foreign bodies or contaminants present in the moving air. Additionally, the choice of filtration system can be tasking, due to several factors considered during the selection of filtration system [1]. Nonetheless, the latter is predicated on the operational environment of the turbine, which includes contaminants from ambient air, surroundings emission, and seasonal changes. Inadequate filtration system leads to inlet pressure drop, reduction in power output and the overall engine efficiency [2–4]. The parameters for defining filters are average arrestance, dust holding capacity, the average efficiency and initial pressure drops [5]. The main high-efficiency filters comprise EPA, HEPA, and ULPA. HEPA and EPA filters have minimum efficiencies defined at 99.95 and 85%, respectively for particle size larger than or equivalent to 0.3 μm. In addition, the ULPA filters are described equally to have 99.995% minimum efficiency for particle sizes of 0.12 μm [6].

* Corresponding author.
E-mail address: oliver.lytleton@yahoo.com (S.O. Effiom).

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Nomenclature

COP	compressor outlet pressure (kPa)
c_p	specific heat capacity (kJ kg^{-1} K^{-1})
COT	compressor outlet temperature (°C)
DP	design point
EGT	exhaust gas temperature (°C)
EPA	efficient particulate air filter
FAR	fuel air ratio
FCV	fuel calorific value (kJ kg^{-1})
FF	fuel flow rate (kg s^{-1})
g	acceleration due to gravity (m s^{-2})
GE	general electric
GT	gas turbine
h	enthalpy (kJ kg^{-1})
HEPA	higher efficiency particulate air filter
ISA	international standard atmosphere
m	mass flow rate (kg s^{-1})
OPR	overall pressure ratio
P	pressure (kPa)
PR_C	compressor pressure ratio
Q	heat input (kW)
T	temperature (°C)
TIT	turbine inlet temperature (°C)
ULPA	ultra low particulate air filter
W	work input (kW)
z	elevation (m)

Greek symbols

ι_{oval}	overall efficiency (%)
γ	specific heat ratio
Δ	change
$\cap$	isentropic efficiency (%)

Subscripts

air	pertaining to air
amb	ambient
c	compressor
comb	combustion chamber
cool	cooling
cout	compressor outlet
fout	filter outlet
gas	pertaining to burnt gases
in	input
mix	mixture of air and burnt gasses
recov	recovery
t	turbine

Studies have shown that for large power generating plants, a slight enhancement in the system efficiency can result in high system performance. For example, improvement in the global efficiency of the installed 2500 GW capacity gas turbines by 1%, would lead to a reduction of approximately 300 million tons of CO_2 per year. Moreover, about 100 t of fossil fuel can be saved from entering the atmosphere [5].

In Nigeria, the total installed capacity of gas turbine plants was estimated at 5976 MW in 2012 with actual average generating capacity of 3200 MW [7]. The plants are characterized by low performances, caused by varied technical problems leading to significant losses. However, issues related to system design, economic costing, efficient energy utilization and energy conversion process were viewed important in this period of limited conventional energy resources [8]. Adequate understanding of environmental conditions in which gas turbine operates will help reduce maintenance cost and unnecessary downtime, as appropriate design and operating parameters are upheld.

In this study, the initial and final pressure drops associated with the filtration system applied to two industrial gas turbines (heavy duty and small aero-derivative gas turbines) are investigated. The two gas turbines (GTs) are modeled similar to GE LM2500+ and Alstom GT13 E2-2012, chosen to operate at environmental conditions of Usan offshore oilfield and Maiduguri dessert in Nigeria. The specific aim is to develop working data that will assist in the selection of filtration system and further enhance the design of compressor housing in these locations.

2. Methodology and analysis

Two industrial gas turbines selected, comprise a heavy duty gas turbine (Alstom GT13 E2-2012) and an aero-derivative gas turbine (GE LM2500+). Performance data at ISA condition acquired from public domain is presented in Table 1. The data were used to create engine models similar to the selected engines using the in-house software developed by Cranfield University (TURBOMATCH) [9] as depicted in Figs. 1 and 2. Comparison between the simulated performances at ISA condition with that obtained from the literature for the two models is shown in Table 2. The Alstom GT13 E2-2012 is a single shaft system that produces 202.7 MW with efficiency of 38%. While GE LM2500+ is a single-shaft aero-derivative GT incorporated with free power turbine that produces 30.2 MW with efficiency of 39%. In addition, this study adopted the multistage filtration layout for both locations. A total of 520 filters, for the heavy duty industrial gas turbine are assumed with an air mass flow rate of 624 kg/s. In the same vein, 70 filters were considered for the aero-derivative gas turbine, having air mass flow rate of 85 kg/s. The initial and final pressure drops in the filtration system layout as specified by the manufacturers was adopted (Table 1) [10].