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Mechanical drive gas turbine selection for service in two natural gas pipelines in Nigeria

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ABSTRACT

The performance characteristics of land-based gas turbines are known to be greatly affected by ambient and operating conditions including inevitable machine deterioration. This study makes a selection of gas turbines for use as compressor station drivers on two natural gas pipelines in Nigeria taking into account the local site conditions of ambient temperature and altitude as well as some level of turbine deterioration. The analysis involved modelling and simulating the on-site performance of five gas turbine engines within the power requirement range of the compressor stations as dictated by pipeline gas flow studies. The overall effect of all considered factors was an engine thermal efficiency loss of 5.3% and a 26.3% decrement in power output. Selected turbines for driving the compressor stations must therefore have a minimum of 26.3% more power output than the value established by pipeline flow analyses. More generally, the results suggest that gas pipelines of 24-in. diameter with a throughput of 450 MMSCFD require a compression power of about 0.04 MW/km if flow pressure is to be maintained at a minimum of 50 bar. Also, a gas turbine driver should be capable of 0.05 MW/km of pipeline given the local site conditions and engine deterioration.

1. Introduction

Natural gas, an increasingly popular source of energy [1], is transported from source to sink by several means including pipelines [2]. Gas pipelines span hundreds to a few thousand kilometres and could have a range of capacities (indicated by the gas flow rate) and limited by, among other things, pipeline diameter. However, to achieve desired gas flow in pipelines, the kinetic energy gas molecules initially possess at the well-head must be replenished as it is reduced in transit primarily due to frictional losses. Pipeline gas pressure reloading points are known as compressor stations (CS) and house appropriately sized compressors. For two gas pipelines in Nigeria, the Oben-Ajaokuta (billed for upgrade) and the proposed Ajaokuta-Abuja-Kaduna pipeline, [3] carried out a CS location and compression power requirement analysis. Given the results obtained by [3], this work makes a selection of gas turbines for use as CS drivers at the various sites taking into consideration the peculiarities of the CS locations.

Because gas turbines (GTs) are rated at ISO conditions of 15 °C and 101.3 kPa [4], their performance in the context of power output and efficiency is greatly affected by operating ambient conditions of temperature and pressure. Ambient temperature is the most influencing factor of the lot as shown in several literature involving studies on the effect of ambient conditions on GT performance. For instance, [5–7] opine that for every °C rise in temperature above the ISO standard, GT power output decreases by 0.5–0.9% depending on its size and other characteristics. Also, thermal efficiency of a GT engine is negatively impacted when the machine operates in climes with temperatures above the design conditions. An empirical study of the SGT 94.3 by [8] reached the

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Nomenclature

c_p	specific heat capacity ($kJkg^{-1}K^{-1}$)
CS	compressor station
GT	gas turbine
H	enthalpy ($kJkg^{-1}$)
ISO	International Standards Organisation
K	kelvin
m	mass flow rate (kgs^{-1})
MMSCFD	million standard cubic meter per day
NDMF	non-dimensional mass flow
OEM	original equipment manufacturer
P	pressure (kPa)
Q	heat (kW)
T	temperature
TET	turbine entry temperature
W	work (kW)

Greek symbols

Δ	change
η	efficiency (%)
γ	specific heat ratio

Subscripts

air	pertaining to air
c	compressor
ff	fuel flow
gas	pertaining to burnt gasses
in	input
pt	power turbine
t	turbine
th	thermal

conclusion that thermal efficiency drops by about 0.1% for every K rise in ambient temperature. Power losses as ambient temperature rises are not peculiar to medium/large scale gas turbines. Microturbines (with power output ranging from 25 to 500 kW) also experience performance deterioration at increased ambient temperatures. [9] developed a simulation code, based on experimental data, and studied the behaviour of a 100 kW machine and reported a 1.22% reduction of electrical power output per degree rise in ambient temperature above ISO conditions. These seemingly small decrements in GT performance can amount to a lot in hot regions like Nigeria where temperatures of in excess of 30 °C are not uncommon. The effect of ambient air pressure (occasioned by altitude) are not quite as much as that of temperature variations especially for land-based GTs [10]. However, ambient pressure does affect the performance of GTs and for an all-inclusive approach to GT selection, the effect of pressure must be accounted for as well. To improve machine performance, several turbine inlet air cooling methods have been developed and applied. A more novel method by [11] replaces throttle valves at natural gas pressure relief stations with turbo expanders that exploit the potential cooling and power capacity of such stations that is otherwise wasted. The economics and choice among various inlet air cooling systems including inlet chilling and inlet fogging has also been extensively investigated by works such as [12–14] and found to be largely location-dependent.

Notwithstanding the employment and effect of inlet air cooling, GT performance depreciates as turbine component deteriorate over time. The efficiency of the GT individual components, particularly the compressor, combustor and turbine determines the overall performance of the machine [15]. Degradation in any one of these components will, invariably, impact engine performance [16]. Since deterioration is ultimately inevitable, and presents itself as added losses and reduced flow capacity [17], it has been accounted for in this work by perturbing the turbine compressor with a simultaneous 3% reduction in flow capacity and 1% reduction in efficiency – one of the extreme allowable cases of GT engine degradation.

In this work therefore, the parameters affecting GTs in the particular locations of the gas pipeline compressor stations are investigated. Five GTs within the desired compression power requirement range are modelled similar to existing machines and their performance along the Oben-Ajaokuta and the Ajaokuta-Abuja-Kaduna pipeline route simulated. The specific aim is to develop working data that will assist in the selection of GTs as CS drivers along the pipeline route.

The choice of gas turbines as CS drivers in the first instance, is predicated upon the fact that, generally in Nigeria, and in the particular case of the remote locations of the CSs, there is lack of reliable electric supply to warrant the use of electric motors as CS drivers [18,19]. Therefore, whereas gas turbines utilise 3–5% of pipeline gas flow for their operation [20,21], they still enjoy wide usage in places like Nigeria.

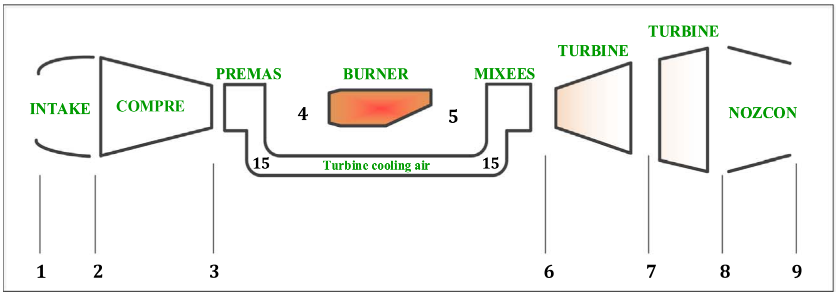

Fig. 1. Engine model schematic for selected gas turbines.