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Performance appraisal of gas based electric power generation system using transfer function modelling

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Abstract Gas flaring for years has been a major environmental problem in many parts of the world. One way of solving the problem of gas flaring is to effectively utilize the abundant supply of gas for power generation. To effectively utilize gas for power generation requires highly efficient gas turbines and power facilities. Traditional methods of assessing the efficiency of power generation turbines do not take into consideration the stochastic nature of gas input and power output. This is because in a power generation system, as in any typical production system, there is generally marked variability in both input (gas) and output (power) of the process. This makes the determination of the relationship between input and output quite complex. This work utilized Box-Jenkins transfer function modelling technique, an integral part of statistical principle of time series analysis to model the efficiency of a gas power plant. This improved way of determining the efficiency of gas power generation facilities involves taking input–output data from a gas power generation process over a 10-year period and developing transfer function models of the process for the ten years, which are used as performance indicators. Based on the performance indicators obtained from the models, the results show that the efficiency of the gas power generation facility was best in the years 2007–2011 with a coefficient of performance of 0.002343345. Similarly, with a coefficient of performance of 0.002073617, plant performance/efficiency was worst in the years 2002–2006. Using the traditional method of calculating efficiency the values of 0.2613 and 0.2516 were obtained for years 2002–2006 and 2007–2011 respectively. The result is remarkable because given the state of the facilities, it correctly predicted the period of expected high system performance i.e. 2002–2006 period, but the traditional efficiency measurement method failed to do so. Ordinarily, using efficiency values obtained through the traditional method as the metric, the system managers would

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assume that the period 2002–2006 was better than in the period 2007–2011 whereas the reverse is the case. The result of this study is expected to open new ways to improving maintenance effectiveness and efficiency of gas power generation facilities.

Nomenclature

k	lag variable	χ	covariance function
β_t	pretreated output series	b	transfer function lag
α_t	prewhitened input series	ω	difference equation variable for input
$v(B)$	transfer function	δ	difference equation variable for output
B	backshift operator	r	order of the output series
Y_t	process output at time t	s	order of the input series
X_t	process input at time t	S	sample standard deviation
y_t	differenced output series	σ	population standard deviation
x_t	differenced input series	ρ	auto correlation function
$\widehat{Y}_t$	output forecast	γ	cross correlation function
$\widehat{X}_t$	input forecast	μ	mean
a_t	error term/white noise	V	voltage
υ_k	impulse response weight at lag k	I	current
h	ACF/PACF lag	T	time
q	order of moving average operator	q_g	gas consumption (m^3)
p	order of autoregressive operator	ρ_g	density of gas
d	number of differencing	C	calorific value of the gas (J/kg)
θ	autoregressive operator	MW h	megawatts hour
φ	autoregressive operator	η	efficiency
Ξ	coefficient of output variable of differential equation	ACF	auto correlation function
		PACF	partial auto correlation function
H	coefficient of input variable of differential equation	b_1	parameter of regression equation

1. Introduction

Gas flaring has been a major environmental problem in the Niger Delta region of Nigeria where most of its crude oil is produced. Effectively utilizing the abundant natural gas resources found in the Niger Delta will help in eliminating the environmental impact of gas flaring. One way of doing this is to utilize the gas in power generation to solve the problem of acute power shortages facing Nigeria. Poor electric power generation has remained a very serious problem in Nigeria ever since the 80s. The problem has hampered industrial development and contributed immensely to the poor economic state of Nigeria. Improving power generation in Nigeria has been a top priority of successive Nigerian government since 1999. Apart from insufficient number of power generation plants, existing ones are facing declining output due to ageing, neglect and ineffective maintenance. The gas powered electric power generation plant at Ughelli in Delta State, Nigeria, which started operation in 1964 is no exception to this, and has been facing declining output due to same reasons mentioned previously.

Transfer function modelling of power generation facilities will help in performance evaluation of the facilities leading to better maintenance planning, repairs, replacements and management based on the fact that transfer functions could be used as the predictor tool, with the variables serving as maintenance status and operation's efficiency indicators [1,2]. Putting the modelling results to good use would result to improved maintenance and management of power stations. Good maintenance and management of power plants in Nigeria will help improve electric power generation in Nigeria. Improved electric generation will lead to increase in gross domestic product of the country and better standard of living for the populace.

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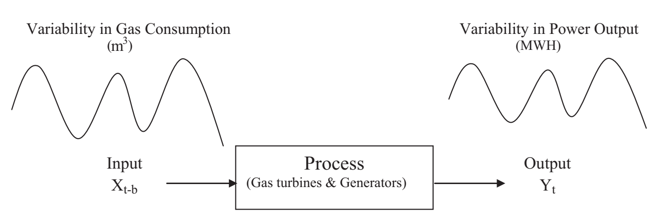

Figure 1 Schematic of the input–output relationship of a gas power generation system.