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Thermodynamic and Economic Evaluation of Gas Turbine Power Plants

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Abstract. Thermodynamic analysis and economic feasibility of a gas turbine power plant using a theoretical approach are studied here. The operating conditions of Afam Gas Power Plant, Nigeria are utilized. A modern gas turbine power plant is composed of three key components which are the compressor, combustion chamber, and turbine. The plants were analyzed in different control volumes, and plant performance was estimated by component-wise modeling. Mass and energy conservation laws were applied to each component, and a complete energy balance conducted for each component. The lost energy was calculated for each control volume, and cumulative performance indices such as thermal efficiency and power output were also calculated. The profitability of the proposed project was analyzed using the Return on Investment (ROI), Net Present Worth (NPW), Payback Period (PBP), and Internal Rate of Return (IRR). First law analysis reveals that 0.9 % of the energy supplied to the compressor was lost while 99.1 % was adequately utilized. 7.0 % energy was generated within the Combustion Chamber as a result of the combustion reaction, while 33.2 % of the energy input to the Gas Turbine was lost, and 66.8 % was adequately converted to shaft work which drives both compressor and electric generator. Second law analysis shows that the combustion chamber unit recorded lost work of 248.27 MW (56.1 % of the summation), and 77.33 MW (17.5 % of the summation) for Gas Turbine, while air compressor recorded 11.8 MW (2.7 %). Profitability analysis shows that the investment criteria are sensitive to change in the price of natural gas. Selling electricity at the current price set by the Nigerian Electricity Regulation Commission (NERC) at zero subsidies and an exchange rate of 365 NGN/kWh is not profitable, as the analysis of the investment gave an infinite payback period. The investment becomes profitable only at a 45 % subsidy regime.

Keywords: energy conversion system, gas turbine, economic analysis, second law analysis, power plant.

1 Introduction

Thermodynamic Analysis is a technique that was based on the 1st and 2nd law of thermodynamics. These laws provide ground or basis for evaluating several processes, including the evaluation of irreversibility in the processes (Anozie and Ayoola, 2012). Analysis of this kind represents a 3rd step in the plant system. The thermodynamic analysis aims to identify the magnitude and locations of energy losses to improve existing systems or processes or to develop new processes by applying mass and energy balances (Tekin and Bayramoglu, 1998; Umar et al., 2015). This analysis is helpful to quantify efficiency loss in a process due to the loss of energy. Such an analysis cannot point out how the process can be improved. However, it can signify where the process can be improved and, therefore which areas should be given consideration. Sometime the simple energy balance will not be sufficient to find out the simple flaws. In such circumstance, exergy analysis is well thought out to be significant to locate the system imperfection (Habib et al., 1995; Khodak and Romathova, 2001; Umar et al., 2015).

A power plant is an industrial facility used to generate electric power with the help of one or more generators, which converts different energy sources into electric power (Oyegoke and Akanji, 2017). A plant includes several units such as turbine engines, generator, etc., and the building or buildings necessary for the generation of power, as an electric or nuclear power. Some of the available types of power plants are Wind Power, Thermal Power, Solar Power, Hydro-power, and Gas Power Plant.

The gas turbine is a few of the most satisfactory mechanical power-producing engines in the power generation industry (Tara et al., 2013). The main feature of a gas turbine that distinguishes it from others is its operation logic. Thermodynamic processes such as compression, combustion, and expansion are performed in individual and unique components, mainly: compressor, combustion chamber, and turbine (Tony, 2006; Paul, 2016). Overall performance calculation of gas turbines covers the interrelated thermodynamic analysis of these components and can be executed with the help of the Brayton cycle (Pathirathna, 2013).

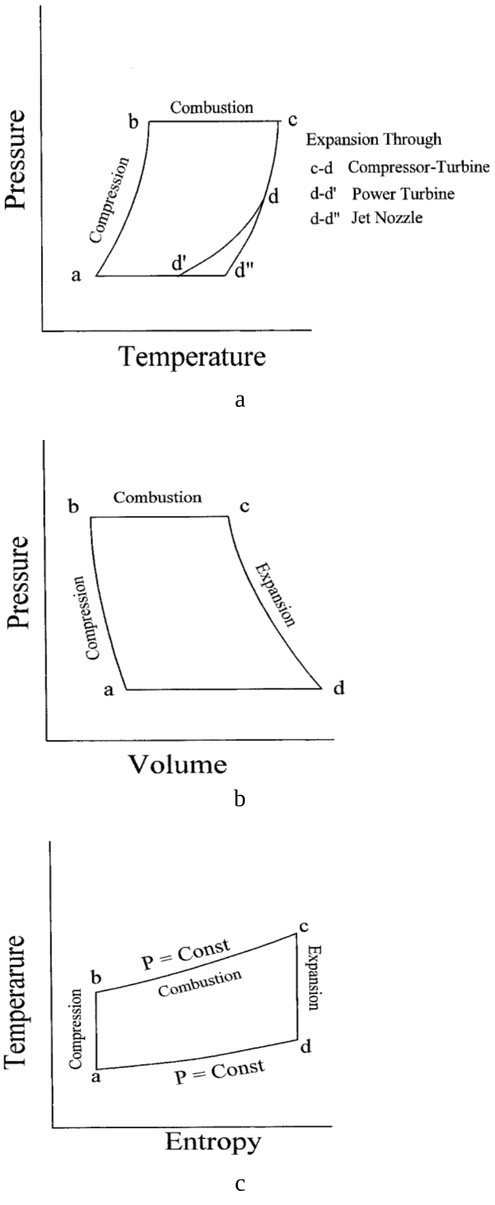

Figure 1 – Brayton cycle P-T (a), P-V (b), and T-S (c) plots (Pathirathna, 2013; Oyegoke and Akanji, 2017)

The Brayton Cycle is commonly used to analyze gas turbine systems (Pathirathna, 2013). The characteristics of the operating cycle are shown on the pressure-temperature (P-T), the pressure-specific volume (P-V), and the temperature-entropy (T-S) plot (Figure 1). These diagrams show the representation of an ideal Brayton cycle.

Some of the available types of gas turbine power plants are Gas-fired steam turbine plant (natural gas-fired steam turbine plant), gas turbine plant with recuperation, gas turbine plant with reheat, gas turbine plant with compressor intercooling, gas turbine plant with steam injection, combined cycle power plant, ISCC cycle power plant, and simple gas turbine plant (Tony, 2006; Paul, 2016).

This study is aimed at evaluating the thermodynamic performance and the economic feasibility of establishing a gas power plant via the use of a theoretical approach. The operating conditions of Afam Gas Power Plant, Nigeria were adopted for the study.

2 Literature Review

Several kinds of research have been carried out in this field of study. Some of the related research works are Rahman et al. (2011) show that the compression ratio, ambient temperature, air to fuel ratio as well as the isentropic efficiencies are strongly influenced on the thermal efficiency. Besides, the thermal efficiency and power output decrease linearly with an increase in the ambient temperature and air to fuel ratio. Tara et al. (2013) deduced that the most sensitive components in the gas turbine plant were the combustion chamber. A considerable fall in power was reported by Barinada and Vining (2015) for the gas turbine. Where it was identified to be as a result of the influence of the site parameters in contrast to designed data. Umar et al. (2015) also show that the significant source of irreversibility, inefficiency in the steam power plant is furnace/boiler. This is because the combustion processes itself account for most of the entropy generation in the steam power plant unit.

In Nigeria, all the gas turbine power plants in the energy utility sector (Grid-connected) are all owned by state governments. The gas turbine plants are all made up of a single shaft simple cycle system. Most of these plants are old. A report indicates that the average age of these plants is above 15 years. In which all the power plants majorly employed the use of natural gas of low heat value (LHV) (Abam et al., 2011).

As Nigeria is considering and implementing the updated national energy strategy with more emphasis on energy efficiency policies in different sectors, it is opined that this study will provide an insight to the general performance of gas turbine plants in the power sector and possible future improvement for energy policy implementation within the power sub-sector (Kotas, 1995; Abam et al., 2011).

Hence, this research seeks to examine the thermodynamic analysis of energy conversion systems (a case study of the gas turbine power plant) using the Afam Gas Power Plant operating condition and also to conduct an economic feasibility study of the said plant in Nigeria using a theoretical approach.

3 Research Methodology

3.1 Working principle of the selected gas plant

Generally, the principle of the gas turbine plant (GTP) or cycle is that air is compressed by the air compressor and transferred to the combustion chamber (CC) to combine with fuel for producing high-temperature flue gas. Afterward, high-temperature flue gas will be sent to the gas turbine, which connected to the shaft of the generator for producing electricity.

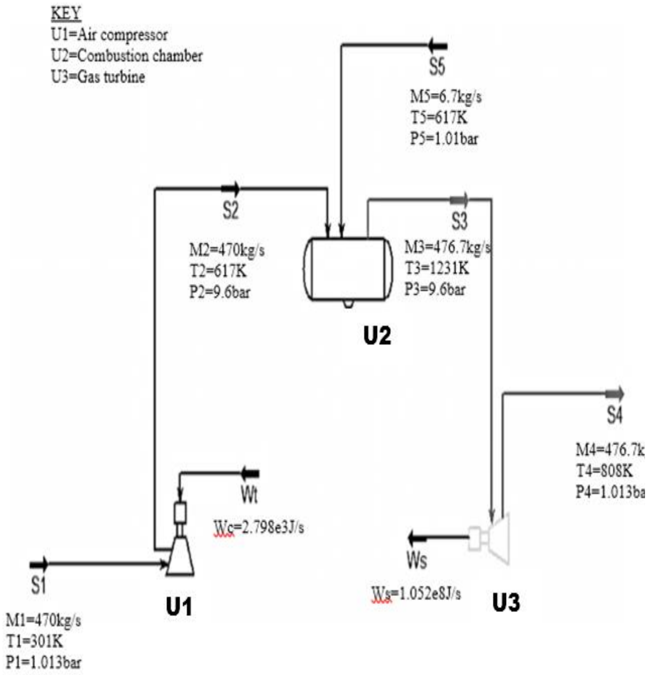

Figure 2 – PFD of a simple gas turbine power plant

A modern gas turbine is composed of three key components which are the compressor, combustion chamber, and turbine. In which air is first drawn via the use of the compressor that compresses it for it to be fed into the combustion chamber where fuel is continuously injected, releasing heat, which raises both the temperature and the pressure of the air due to the combustion reaction taking place in the chamber. This high-temperature gas stream is then fed into the gas turbine for the conversion of mechanical energy into electrical energy to produce electric current or power. In the standard engineering design, the compressor and combustion chamber are often mounted on the same shaft, and that shaft is also coupled to the generator. It is therefore expected that the turbine stage of the plant generates enough shaft power, which would turn the compressor and rotate the generator as well.

3.2 Energy transformation involved in the plant

The air has kinetic energy, which is increased after the Compression, the chemical energy of the fuel is converted into heat energy in the Combustion Chamber, and subsequently, the heat energy helps to increase the Kinetic Energy of the Gas Stream flowing into the Turbine. In the Turbine, this Kinetic Energy then turns the Shaft, which in turn, turns the Compressor and rotates the Generator to generate Electrical Energy.

3.3 Process flow diagram of GTP

The process flow diagram for one unit of the gas turbine plant modeled in this study is based on the operating data, as shown in Figure 2. The components include an air compressor, combustion chamber, and gas turbine.

3.4 Operating conditions of the selected GTP

Operating data for gas turbine units in the energy utility sector of Afam power station was collected from Abam et al. (2011). The data was sourced from the power station daily turbine control log sheet. The power station is one of the three existing main stations supplying over 60 % of electrical energy to the national grid system. The daily average operating thermodynamic variables were calculated using MS-Excel worksheets and MATLAB, and it is reported in Table 1. The conditions and properties for crucial points in the diagram are also given in the same table.

Table 1 – Operating conditions for the streams (Abam et al., 2011)

Stream	*T*, K	*M*, kg/s	*P*, bar	*H*, kJ/kg	*S*, kJ/(kg·K)
1	301	470	1.0	301.3	6.87
2	617	470	9.6	626.3	6.96
3	1231	476.7	9.6	1313.6	8.42
4	808	476.7	1.0	831.4	7.88
5	617	6.7	1.0	625.8	7.07

Taking the surrounding temperature (Ts) to be 298K, based on 1 mole of methane burned with 30 % excess air, the equation of the reaction occurring in the gas chamber can be represented as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O,$$

which was in line with literature for methane combustion reaction process.

3.5 Thermodynamic analysis of the process

The assessment of the plants was divided into several control volumes and the performance of the plants was estimated by component-wise modeling approach. From which, the mass and energy conservation laws were applied to each component and a complete energy balance was determined for each component. The lost energy was then calculated for each control volume and cumulative performance indices such as thermal efficiency and power output were calculated.

Work done on the compressor in J/s was obtained by using equation (1):

$$Wc = Cpa \cdot T1 \left(\frac{Rpa}{nMc}\right), \tag{1}$$

where *Rpa* is 0.90 and Mechanical efficiency (*nMc*) is 99 %. The energy utilized for turbine work in J/s was determined using equation (2):

$$Wt = mg \cdot (Cpgo \cdot T3 - Cpto \cdot T4), \quad (2)$$

where *mg* is gas mass flowrate, *Cpgo* is *Cpg* at the outlet of the gas chamber, and *Cpto* is *Cpg* at the outlet of the gas turbine. The specific heat capacities of both gas and air are expressed in equations (3) and (4), respectively in terms of temperatures (*T*):

$$Cpg = 1.81 - 2.31 \cdot 10^{-3}T + 4.05 \cdot 10^{-6}T^2 - \\ -1.74 \cdot 10^{-9}T^3; \quad (3)$$

$$Cpa = 1.02 \cdot 10^3 - 0.14T + 1.98 \cdot 10^{-4}T^2 + \\ +4.24 \cdot 10^{-7}T^3 - 3.76 \cdot 10^{-10}T^4. \quad (4)$$

The network (*Wnet*) and output power (*P*) of the gas turbine were calculated in J/s using equations (5) and (6) while equation (7) was used to determine the specific fuel consumption in s/kg:

$$Wnet = Wt - Wc; \quad (5)$$

$$P = ma\, x\, Wnet; \quad (6)$$

$$SFC = \frac{3600f}{Wnet}. \quad (7)$$

The power plant efficiency was estimated using equation (8) while the heat consumed in J/s used to generate unit energy of electricity was evaluated as expressed in equation (9):

$$Nth = \frac{Wnet}{Qadd} \cdot 100; \quad (8)$$

$$HR = \frac{3600}{nth/100}. \quad (9)$$

3.6 Entropy generation and lost work analysis

The entropy (*S*) across each unit was used to compute for the overall entropy generation (*S_Gen*) using equation (10) while both entropy (*S*) and enthalpy (*H*) across each unit were used for the estimation of the ideal work (*W_Ideal*) using equation (11):

$$S_{Gen} = \sum m(S_2 - S_1) - \frac{Q}{T_{surr}}; \quad (10)$$

$$W_{Ideal} = \sum \Delta(H) - T_{surr} \sum \Delta(S). \quad (11)$$

The lost work across each unit was evaluated using equations (12) and (13) below:

$$W_{lost} = T_{surr} \Delta(S); \quad (12)$$

$$\% W_{lost} = \frac{W_{lost}}{\sum W_{lost}} \cdot 100. \quad (13)$$

3.7 Second law analysis

The shaft work was evaluated using equation (14) while the second law efficiency, also known as thermodynamic efficiency, was evaluated using equation (15) as an energy-requiring process:

$$W_{Shaft} = W_{Ideal} + \sum W_{Lost}; \quad (14)$$

$$Thermo.\ Efficiency = \frac{W_{Ideal}}{W_{Shaft}} \cdot 100. \quad (15)$$

3.8 Process economic analysis

The total plant equipment cost was used to estimate the total capital investment with the aid of MATLAB using the factorial method, as stated in Max & Klaus (1991). The cost of manufacturing was also estimated with the aid of MATLAB using different reference materials while taking Nigeria as the case study (The MATLAB algorithm for analysis can be found in the Appendix).

3.9 Project Parameters and Assumptions

Project parameters and assumptions, as stated in Table 2, were employed for the assessment of the proposed project's viability.

Table 2 – Project Parameters and Assumptions

Parameter	Value
Working time	24 hours per day, for 335 days per year
Raw material (1)	Methane 6.7 kg/s ($2.4 \cdot 10^4$ kg/h) for 180 NGN/kg
Discount rate	10.00 %
Working capital rate (2)	5.00 % per year
Electricity unit (selling) price (3)	0.0795 USD/kWh (29 NGN/kWh)
Exchange rate	365 NGN/USD
Tax rate / Interest rate	20.00 / 10.00 % per year
The economic life of the project	25 years
Depreciation method (4)	Straight Line
Depreciation period	10 years
Profit	6 %

[1] Alibaba, 2017; [2] Sinnott, 2005; [3] Kedco, 2017; [4] Richard, et al., 2012.

3.10 Project profitability analysis

The profitability of the proposed project was analyzed using the Return on Investment (ROI), Net Present Worth (NPW), Payback Period (PBP), and Internal Rate of Return (IRR).

3.11 Sensitivity analysis

The sensitivity of the cost of methane and subsidy approved on the Return on Investment (ROI), Net Present Worth (NPW), Payback Period (PBP), and Internal Rate of Return (IRR) of the proposed project was examined.

4 Results and Discussion

4.1 Thermodynamic analysis of the process

From the results obtained for the isentropic efficiency of the compressor (Table 3), it was confirmed that the compressor is close to the range of values reported by Rahman et al. (2011). From the correlation chart reported by Thamir and Rahman (2012) for the overall thermal efficiency-compression ratio with the effect of isentropic compressor efficiency, the overall thermal efficiency at $Rp = 9.5$ and $nC = 85.9$ was found to be 0.53 (or 53 %). It was also deduced that $1.44\cdot10^{6}$ kJ of energy is lost per second in a compressor.

Table 3 – Compressor analysis

Analysis	Value
Compression ratio (Rp)	9.5
Isentropic efficiency (nC), %	85.9
Work on compressor, J/s	$2.8\cdot10^{3}$
Mechanical efficiency, %	99.1

The mechanical efficiency of the compressor was found to be 99.1 %, which was satisfactory. This was simply because the energy losses accounted for the compressor was recorded to be less than 1 %. The work done in compressing the air was found to be 2,79 J per second. The fuel rate was found to be 0.014.

From the combustion chamber analysis (Table 4), the enthalpy of the unmixed air entering was found to be $dHa = 0$ kJ which confirms that before the combustion reaction holds, the heat content of the air is zero, while the entropy for unmixed air entering was found to be $dSa = -52.9$ J/K.

Table 4 – Combustion chamber analysis

Analysis	Value
Fuel ratio (f)	0.014
Enthalpy (dH) of reaction, J	–802625
Entropy (dS) of reaction, J/K	–5.305
Free energy (dG) of the reaction, J	–801043

The enthalpy of the reaction was found to be $dHb = -802$ kJ, which confirms the reaction as exothermic. Moreover, it further confirms that the reaction will generate energy or will involve energy release or production. The entropy was found to be $dSb = -5.31$ J/K.

After the mixing and formation of flue gases, the enthalpy was found to be $dHc = 0$ kJ, while the entropy was found to be $dSc = 94.13$ J/K. The combustion chamber outlet streams were found to be 476.7 kg/s while $2.07\cdot10^{7}$ kJ of energy is generated per second within the chamber as a result of the combustion. This made energy loss in the chamber to be zero.

The energy utilized in turning the turbine shaft was found to be $1.05\cdot10^{8}$ J/s. The work or energy loss within the turbine system was found to be $1.05\cdot10^{8}$ J/s. The mechanical efficiency of the gas turbine was found to be 33.2 %, which was a result of the high amount of lost work found within the turbine.

Table 5 – Gas turbine analysis

Analysis	Value
Shaft work (Wt), J/s	$1.1\cdot10^{8}$
Mechanical efficiency (nMt), %	33.2
Net work (Wnet), J/s	$1.1\cdot10^{8}$
Output power (P), W	$4.9\cdot10^{10}$
Power plant efficiency, %	33.2
Specific fuel consumption (SFC), s/kg	$4.9\cdot10^{-7}$
Heating rate (HR), J/s	$1.1\cdot10^{4}$

These losses could be as results of friction, thermal resistances, and poor lagging of the equipment. The result of the gas turbine analysis is presented in Table 5.

The net wok that was used to generate $4.95\cdot10^{10}$ W of electricity was found to be $1.05\cdot10^{8}$ J/s. With specific fuel consumption of 4.855e-7 s/kg and a heat supply of $3.17\cdot10^{8}$ J/s, the efficiency of the power plant turbine was found to be 33.2 % while the heating rate of $1.09\cdot10^{4}$ J/s is required to generate unit energy of electricity.

From the energy loss analysis (Table 6), it was observed that gas turbine unit recorded the highest energy loss (with 98.6 % of plant energy loss), followed by the compressor (with 1.4 % of plant energy loss) while combustion chamber recorded 0 % energy loss and as such, was the only unit that recorded energy generation.

Table 6 – Energy/work losses results

Unit	Loss, J/s	Loss (%) w.r.t. total loss	Loss (%) w.r.t.* loss per unit	Gain, J/s
Compressor	$1.44\cdot10^{6}$	1.35	0.94	0
Combustion chamber	0.00	0.00	0.00	$2.07\cdot10^{7}$
Gas turbine	$1.05\cdot10^{8}$	98.61	33.16	98.65

*'w.r.t' means 'with respect to.'

In the compressor, it was observed that 0.9 % of the energy supplied to the compressor was lost while 99.1 % was adequately utilized. In the combustion chamber, 7.0 % of energy was generated within the chamber as a result of the combustion reaction that took place in the unit. While at the gas turbine, 33.2 % of the energy input was lost while 66.8 % was converted adequately to shaft work, which drives both compressor and electric generator.

From the entropy generation analysis (Table 7), it was confirmed that combustion chamber unit recorded the highest entropy generation with 833.1 kJ/(kg·K) (73.6 % of the summation), followed by a gas turbine with 259.5 kJ/(kg·K) (22.9 % of the summation), while air compressor recorded 39.5 kJ/(kg·K) (3.5 %).

Table 7 – Entropy generation analysis

Unit	Entropy Generation, kJ/(kg·K)	% (Sum)
Compressor	39.5	3.5
Combustion Chamber	833.1	73.6
Turbine	259.5	22.9
Overall	1132.1	100.0

From the second law analysis (Table 8), it was observed that the combustion chamber unit recorded lost work of 248.3 MW (56.1 % of the summation), followed by a gas turbine with 77.3 MW (17.5 % of the summation), while air compressor recorded as 11.8 MW (2.66 %). This is similar to the report of Abam and Moses (2011), which stated that the most substantial amount of exergy destruction occurs in the combustion chamber.

Table 8 – 2nd law of thermodynamic analysis

Unit	Lost Work, MW	% (Sum)
Compressor	11.77	2.66
Combustion Chamber	248.27	56.10
Turbine	77.33	17.47
Ws (from 1st law analysis)	105.20	23.77 (plant efficiency)
Ideal Work (W_{Ideal})	442.57	100.00

The shaft work percentage fraction to the ideal work (442.47 MW) was determined to be 23.8 %, which represents the efficiency of the plant.

4.2 Process economic analysis

Table 9 depicts the purchased cost of equipment of various units of the plant.

Table 9 – Plant equipment costing (PEC), USD

Description	Initial Cost	Escalated Cost
Reactor	382,310	525,610
Air Compressor	12,335	20,600
Gas Turbine	85,973	143,580
Total Cost (PEC)	480,618	689,790

From the table, it was observed that the reactor has the highest purchasing cost while the air compressor has the least purchased cost.

The study of the result collected in Table 10 shows that the total capital investment of the plant is 3.90 million USD, with a capital per kWh of 0.0046 USD.

Table 10 – Total capital investment (TCI)

Description	Unit	Amount
Direct Plant Cost (DPC)	USD	2,021,100
Indirect Plant Cost (IPC)		1,212,700
Total Plant Cost (DPC+IPC)		3,233,800
Fixed Capital Investment (FCI)		3,718,800
Working Capital (WC)		185,940
Total Capital Investment (FCI+WC)		3,904,740
Electricity production	kWh	845,808,000
Capital per kW	USD/kWh	0.0046

The estimation of manufacturing cost reported in Table 11 indicates that the plant uses 119.07 million USD in producing 845,8 MWh of electricity per annum using natural gas as raw material.

Table 11 – Cost of manufacturing (COM)

Description	Unit	Amount
Raw Materials (RM)	M$	95.94
Operating Labour	M$	0.0069
No. of WorkForce	–	6
Utilities	M$	0
Direct Production Cost (DPc)	M$	2.02
Depreciation (DP)	M$	0.37
Fixed Charges (FC)	M$	0.46
General Expenses (GE)	M$	17.90
Cost of Manufacturing (DPc+DP+FC+GE+RM)	M$	119.07
Production	kWh	845,808,000
Cost price	USD/kWh	0.14

Further study of the table manufacturing cost shows that the raw material constitutes about 81 % of the cost of manufacturing, and the cost of producing a kWh of electricity is 0.14 USD.

Table 12 shows that the project is not feasible because the cost of a kWh of electricity (0.14 USD/kWh) is higher than the selling price (0.08 USD/kWh). This was found to be much more expensive when compared to Oyegoke and Jibril (2016) that report 0.07 USD/kWh for the power generated via the use of the sugarcane bagasse as the fuel in the power plant.

Table 12 – Project profitability analysis

Description	Code	Unit	Amount
Subsidy	Sub	%	0
Unit Cost Price	CoPv	USD/kWh	0.14
Unit Sale Price	SPv	USD/kWh	0.08
Exchange Rate	X	NGN/USD	365
Revenue	R	M$	67.20
Gross Income	GI	M$	–51.87
Tax Rate	TR	-	0.20
Net Profit	NP	M$	–41.50
Return on Investment	ROI	%	–1062.70
Net Present Worth @0%	NNPW	M$	–1,033.40
Net Present Worth @10%	NPW	M$	–312.16
Internal Rate of Return	IRR	%	14.33
B/C Ratio of @0%	NBC	–	0
B/C Ratio of @10%	DBC	–	0
Payback Period @0%	PBP	Yr	∞
Payback Period @10%	DPBP	Yr	∞

It also implies that selling electricity produced from Natural gas at the current price set by the Nigerian Electricity Regulation Commission (NERC) at Zero subsidies and an exchange rate of 365 NGN/kWh is not profitable, as the analysis of the investment gave an infinite payback period.

The result in Table 13 shows that a decrease in the price of the natural gas, at a constant selling price of electricity, results in a significant increase in ROI, NPW, IRR, B/C, and a decrease in PBP and cost of manufacturing (cost price).

Further study of the table shows that at a purchased price of 140 and 180 NGN/kg of natural gas, the project is not viable due to the high cost of manufacturing, which leads to the cost of production more significant than the selling price of electricity. More so, at a purchased price of 100 NGN/kg and below natural gas, the project is profitable due to the reduced cost of manufacturing, which makes the cost of production lesser than the selling price.

Table 13 – Effects of change in the price of natural gas

Code	Unit	Selling Price		
	NGN/kg	100	140	180
ROI	%	8.44	–527.11	–1062.70
NPW	M$	1.59	–155.29	–312.16
IRR	%	11.50	14.37	14.33
DBC	–	1.46	0.00	0.00
DPBP	Yrs	9.68	∞	∞

Hence, it can be said that the investment criteria for this study are highly sensitive to change in the price of natural gas.

The profitability analysis shows that selling electricity at NGN 29 per kWh (0.08 USD per kWh) at 0 % subsidy is not feasible, hence the selling price of electricity was increased to NGN 53 per kWh, this is the price at which the project is feasible but not affordable by the masses and not competitive with other sources of electricity.

Table 14 – Effect of Government subsidy on the investment criteria (values) of the proposed plant at a selling price of NGN 53 per kWh

Code	Unit	Change in Subsidy			
		0	15	30	45
CoPv	USD/L	0.14	0.14	0.14	0.14
SPv	USD/L	0.15	0.12	0.10	0.08
R	M$	122.82	122.82	122.82	122.82
GI	M$	3.75	3.75	3.75	3.75
NP	M$	3.00	3.00	3.00	3.00
ROI	%	76.76	76.76	76.76	76.76
NPW	M$	21.60	21.60	21.60	21.60
IRR	%	13.77	13.77	13.77	13.77
DBC	–	7.26	7.26	7.26	7.26
DPBP	Yrs	1.41	1.41	1.41	1.41

The analysis shows that the increase in the rate of subsidy by the Government, from 0 % to 45 %, would not have a significant effect on the investment criteria (values). Nevertheless, Table 6 shows that at a selling price of NGN 53 per kWh (0.15 USD/kWh) and 0 % subsidy, the project is profitable but not affordable

The subsidy rate(s) of 0 %, 15 % 30 % and 45 % infer electricity selling price of 0.15, 0.12, 0.10 and 0.08 USD per kWh, respectively. Thus, an increase in the subsidy rate from 0 % to 45 % would decrease the selling price of electricity from 0.15 to 0.08 USD per liter, even though the cost price is unchanged at 0.14 USD per kWh.

Therefore, a subsidy of about 45 % needs to be approved by the government to be affordable to the masses, unlike the report of Oyegoke and Jibril (2016), which present that it would be feasible to generate power from the use of sugarcane bagasse without seeking for government subsidy.

5 Conclusions

The findings of this research confirm that the efficiency of the power plant is poor (as 33 % and 23.8 % from 1st and 2nd law analysis respectively) based on the operating parameters employed for this analysis. From the results of the analysis, the poor performance of the plant is attributable to the lost work or energy loss in the gas turbine unit. Hence, it is recommended that proper energy management strategies such as proper lagging of the gas chamber, reduction of friction using lubricant and so on, should be employed to reduce the amount of energy loss around the gas turbine.

Based on the economic feasibility study carried out, it is deduced that at a purchase price of between 140 and 180 NGN/kg of natural gas, the project is not economically viable as the cost of producing a unit of electricity, 0.14 USD/kWh, is greater than its selling price 0.08 USD/kWh However, the investment becomes economical feasible at 45 % subsidy for natural gas.

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