The Economics of Gas Flaring in Oil and Gas Processing Environments: A Case Study of Electric Power Station in a Developing Country

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ABSTRACT

Gas flaring continues to pose significant threat to the environment and economy of oil and gas producing countries in particular and the globe in general. This process impacts adversely to the health and safety of the inhabitant of these countries. About 100 Billion Cubic Meters (BCM) of gas is being flared globally on annual basis with Russia and Nigeria flaring more than other countries to the tune of 35.5 and 15.2 BCM, respectively. During oil and gas processing, excess gas that is generated could be managed and beneficially harnessed by systematic channelling of the gas to the power sector where turbines utilize it to generate power. The aim of this study therefore is to investigate the production, distribution, consumption and wastage/misuse of associated gas in a typical gas-processing environment to find out the cost and effect of gas flaring. The methodology adopted to gather data involves case studies, interviews, questionnaires, artefacts and observations. The investigation site has seven gas production wells with an output of 7.2 million cubic meters per day (mmcmd). While 91.7% of this output is supplied to customers for consumption, the remaining 8.3% is controllably flared. The flared quantity increases with reduction in customers' demand and during production down time. It was found in the investigation that an average power station comprising three gas turbines and one steam turbine utilises about 3.0 mmcmd of gas to generate approximately 600-650MW of electricity. Consequently, this research proposes that with the employment of an additional gas turbine, substantial quantity of the flared gas could be sustainably used to generate power if the flaring process is properly managed.

1. INTRODUCTION

Crude oil exploration comes with associated gas that needs to be separated before the crude oil is refined [1]. One of the ways that the separation is achieved is through a controlled system that involves the burning of associated gas, which is referred to as gas flaring [2]. Gas flaring, aimed at managing excess gas generated in an oil and gas-processing environment, continues to pose serious threat to the environment, economy, health and safety of the oil and gas producing countries in particular, and the globe in general. Figure 1 below shows a typical flare site with visible burning flame and smoke which go into the atmosphere.

Fig. 1. Typical gas flaring site [3].

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In estimate, over 100billion Cubic Metres of natural gas is flared annually worldwide [4]. This huge figure demonstrates a global increase in gas flaring, which could be attributed to increased flaring from countries like Russia, Nigeria and other major crude oil producing countries [5]. Figure 2 below significantly identifies the 5 major gas-flaring countries and shows their respective flare volumes. However, it is estimated that the global production of gas will increase from about 2.6 Trillion Cubic Meters (TCM) to about 4.3 TCM [6] between 2001 and 2025 respectively. At this rate, if no effective consumption measures are put in place, this could potentially lead to increased gas flaring with severe consequences to the environment and loss of revenue.

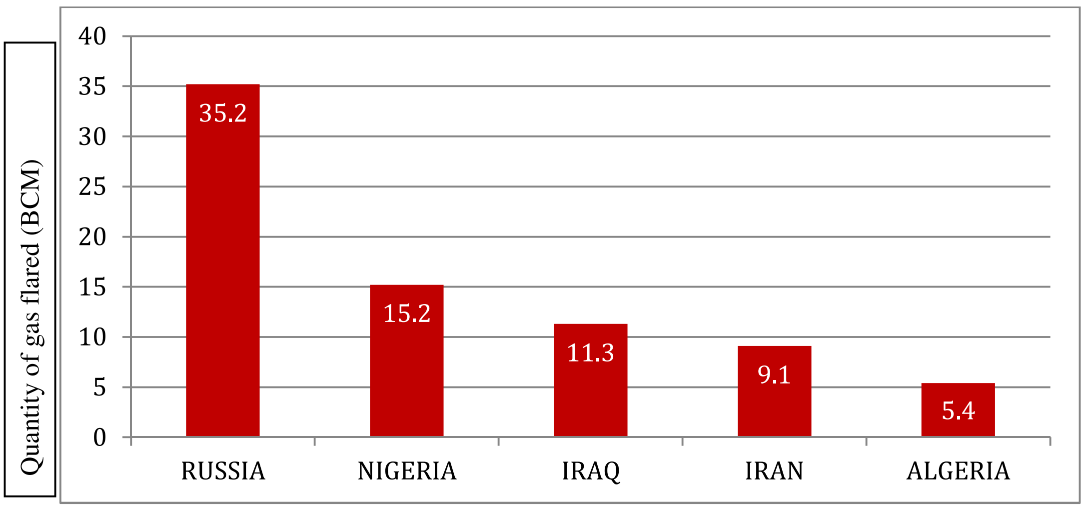


Fig. 2. Representation of quantity of gas flared by top five flaring countries [4].

The volume of gas that is lost through flaring bears a financial cost and negatively affects the economies of the associated countries, both directly and indirectly. For instance, Nigeria has a proven natural gas reserve of about 4.84 TCM, while it annually flares more than 15 BCM, which potentially leads to a financial loss of about $2.5 billion annually [8]. Therefore there is need to investigate the production, distribution, consumption and wastage/misuse of associated gas in a typical oil and gas processing environment to find out the cost and effect of gas flaring.

2. LITERATURE REVIEW

2.1. A BRIEF VIEW ON GAS FLARING

Crude oil exploration comes with associated gas that needs to be separated before the oil is refined; and there are three major options for separating the associated gas [1]: the first is reinjection of the gas to the ground for future reuse, the second option is to use it for domestic and commercial purposes, which will involve acquiring equipment for liquidification and transportation. The third option, which seems to be the easiest and possibly cheaper (financially) is to flare the gas [9]. Gas flaring is prohibited by law in most countries due to its harmful effect on the environment, except in unavoidable circumstances such as accidental breakdown of machinery or pipelines.

There are various reasons and sources that bring about the flaring of gas. OGB [2], states that some of them include and not limited to unburned process gas that results from the processing process, excessive gas that could not be supplied to commercial customers, vapours that are collected from the top of tanks during the filling process, production shutdown: this involves all the available gas in the facility to be temporarily flared, so that high pressure will be released, during process upsets, maintenance and equipment changeover. However, in a typical developing country like Nigeria, gas flaring could also take place due to crude oil theft by illegal bunkers.

The United States of America (USA) is not exempted from gas flaring. About 30 percent of the natural gas that is produced in North Dakota is flared [10]. This is arguably the highest volume of flaring in any major domestic oil field. Regulations on flaring are loose in North Dakota, as they are in most states in the USA, and there are no current federal regulations on flaring at oil and gas wells. That is largely because flaring has not been a significant concern since the 1970s, when the federal government insisted that oil companies re-inject gas into Alaska's North Slope rather than flare it. With few government regulations that limit the flaring, more flaring also takes place in the Eagle Ford shale field in Texas. This has led some environmentalists and industry executives to forecast that it could happen in Oklahoma, Arkansas and Ohio.

The estimate by EIA [6] predicts that annual flaring will increase by 60% from 1999 to 2020. It further reveals that the greatest increase in gas production will emanate from the Middle East (46%), seconded by Africa (18%), with the least in line coming from North America (3%). Therefore this shows that the developing countries are highly affected by gas flaring. But with the availability of some stringent measures or efforts, there will be reduction in gas flaring.

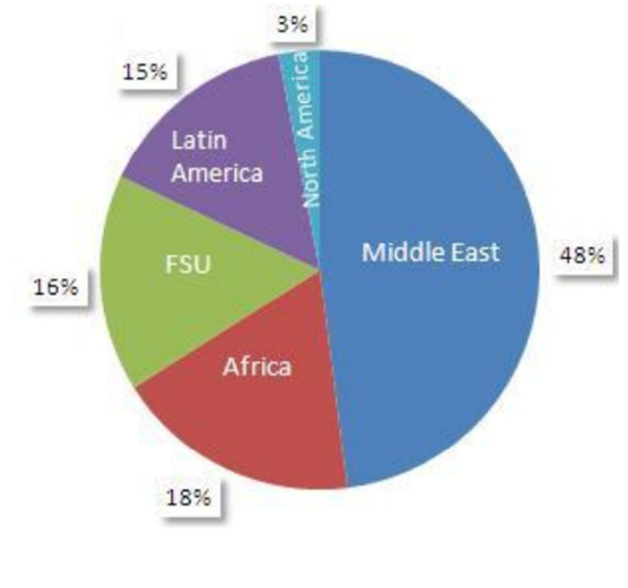


Fig. 3. Estimated future increase in gas Production and Flaring Trends [6].

2.2. FLARE REDUCTION PROCESS

To reduce gas flaring, it became imperative to device means of harnessing and utilising gas for economic reasons. [7] and [8] show that the use of pipelines, liquefied natural gas (LNG), gas to Liquid (GTL), compressed natural gas (CNG), Gas-to-wire (GtW), reinjection, among others are currently in use, though each still has their downsides. Table 1 highlights some shortfalls that are associated with some specified gas flaring management technologies.

Table 1. Disadvantages of specific Gas Management Technology (7 and 8).

Gas Management Technology	Disadvantages
Pipeline	• Vulnerable to sabotage • Faces difficulty due to political boundaries • Gas is not readily stored
Gas-to-Wire (GtW)	• Installing high power lines to reach the shoreline could be very expensive • Loss of energy from cables along distant transmission lines
Liquefied Natural Gas (LNG)	• Requires complex machinery with moving parts • Capital intensive project
Gas To Liquid (GTL)	• Still at primordial stage • Very capital intensive • Raw materials for conversion to commodity (silica sand, limestone) might prove difficult to import to site

The GtW is a gas flaring reduction technology that involves the use of gas to power/fuel a turbine, thereby to generate energy. Two major ways that this technology could be achieved are combined heat and power (CHP) and combined cycle gas turbine (CCGT). CHP is a process where the heat produced during electricity production is captured and re-used. According to [11], CHP system deals with the simultaneous cogeneration of electrical and heat energy in the form of low-pressure steam or hot water. Pilavachi [12] in his research, stated that the CHP technology is characterized by the prime movers, which are devices that are capable of converting heat energy into mechanical energy; engines, that could be operated with gas, bio, diesel or bio-diesel; turbines, that could be operated with gas, fuel, steam, combined gas and steam system; or fuel cells, that could be operated with fuels obtained from natural gas.

A schematic process that shows the processes from gas production to gas being used as fuel to power a turbine and finally the production of energy is shown in figure 4.

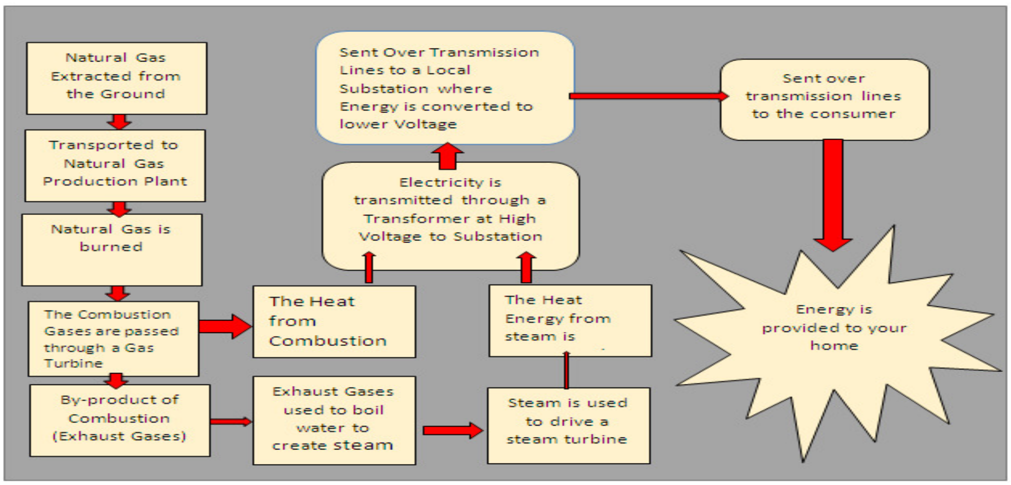
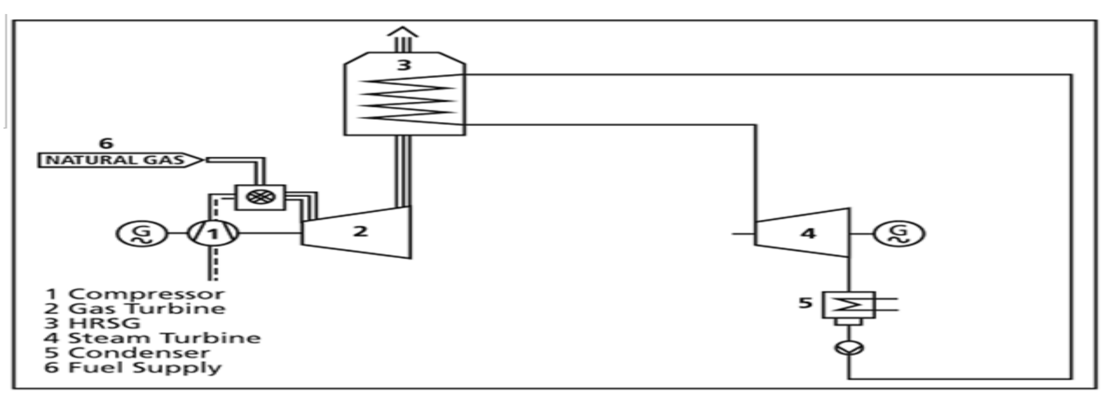


Fig. 4. Simple Flow Chart for Conversion of Gas-to-Energy [13].

The CCGT is a very highly efficient energy generation technology, which combines gas-fired turbine units of 100 or more Mega Watts (MW), and a steam turbine [14]. It is a process whereby a gas turbine creates electricity and then captures the resulting waste heat to create steam, which is used to drive a steam turbine and then increase the system's power output, without using any extra fuel [15]. The gas turbine is termed the 'topping cycle' because it operates at a higher temperature; while the steam turbine is termed 'bottoming cycle' because it operates at a lower temperature [16]. It is good to note that due to the laws of thermodynamics, heat is produced as a necessary by-product of power production [17], and the same heat is converted to steam and used to produce extra energy.

As exhibited in the schematic diagram below (Fig. 5), the gas turbine generates shaft power at the upper range of the energy stream. The exhaust that comes from the gas turbine is passed to the Heat Recovery Steam Generator (HRSG) where it is converted to steam in the HRSG, and then passed through a steam turbine to generate additional power. The steam cycle here converts about 30% of the rejected heat energy into additional electric power, hence a combined-cycle thermal efficiency of up to 60%.

Fig. 5. Simplified Flow Diagram Of Combined Cycle [16].



This paper aims investigates the production, distribution, consumption and wastage/misuse of associated gas in a typical gas-processing and utilization environment to find out the cost and effect of gas flaring.

3. METHODOLOGY

A case study approach was used in this study for two different organisations that operate in an African country in order to appreciate their planning, production and use of gas as well as electricity production and transmission. For ethical and security reasons, the organisations are identified as Gas Company and Electric Company respectively. Existing data were collected from the organisations' files and were carefully studied to obtain the outcome of this paper.

3.1. THE GAS COMPANY

This is a gas production and distribution organisation made up of about 50 staff, which include superintendents, team leaders (operations and maintenance), supervisors/support engineers, field operators, control room operators and maintenance team. The Gas Company is a product of a project known as Associated Gas Gathering (AGG). Gas from various wells are gathered and channelled to the plant through pipelines. During processing, the gas enters the train at 100 bars; but later reduced to about 60 bars. Gas that is produced from this company is forwarded to two various destinations – Electric Company and Gas Utility Company at 60 bars and 35 bars respectively. The gas supplied to the former is finally used to power gas turbines and electricity is generated; while the gas supplied to the latter is supplied to customers as liquefied petroleum gas for commercial and domestic use.

The site is composed of 7 gas wells that are responsible for the production of gas, which is distributed to two major power stations for electricity generation. However, gas is still flared in this site. From the company's official data files, the quantities of gas produced, distributed to users as well as controllably flared daily were systematically collected. Furthermore, interviews and questionnaires were carried out on field Engineers in the company to determine the mode of operations of gas production and reasons for routine gas flaring in the site.

Interviews also revealed the current situation of infrastructure in the company. Direct observation was also applied, in the form of monitoring and identifying routine processes like gas flaring frequency and severity, gas production and site maintenance. Also the possibility of diverting the excessive gas being flared towards additional generation of electricity was also carefully evaluated.

3.2. ELECTRIC COMPANY

This Company is responsible for generation and distribution of energy. It is a branch of the country's official sole electricity provider and employs about 400 staff that work on different work-shifts over the clock. There are about 200 employees in the administrative department, 70 staff in operations department, 50 staff in maintenance department, and 20 staff each in store keeping, technical services and civil departments. There are also some casual employees to make up with the number.

This site was selected because it uses gas as the sole source of fuel for electricity generation and receives its gas from the Gas Company. Based on input data, including the amounts of gas produced, demand for gas, financial cost of gas and cost for electricity, the economics of gas flaring was evaluated.

4. DISCUSSION

4.1. QUANTITY OF GAS PRODUCED AND USED

This depends on the needs of their customers (Electric Company and Gas Utility Company) demand-capacity. However, the gas plant produces 7.2 million cubic meter per day (mmcmd): 3.0 mmcmd is supplied to Electric Company; while Gas Utility Company is supplied with 3.6 mmcmd; while the remainder is flared. However, in a situation whereby the demand from the customers becomes less, there is a regulatory system, which sends signals, and the production is minimized to reduce waste (flaring). Table 2 shows a typical production, utilisation and gas flare situation at the Gas Company.

Table 2. Typical Production, Use and Flaring condition.

Total amount of gas produced (mmcmd)		7.2
Quantity used (mmcmd)	Electric Company	3.0
	Gas Utility Company	3.6
Quantity flared by Gas Company (mmcmd)		0.6

4.2. GAS FLARING IN THE GAS COMPANY

Flaring of gas takes place in this plant, but at a minimal volume and period of time. Results from the data collected shows that about 20 mmscfd is flared and could be higher due to the following reasons:

- Reduction in demand by customers: Whenever there is a sudden trip (reduction in consumption) from customers, it brings about excessive pressure to the inlet valve. To avoid disaster or rather for safety reasons, the excess gas is channelled to the flare stack.
- Plant Shutdown: This could either be in the form of Planned shutdown and the Un-planned shutdown. Unplanned shutdown is also known as emergency shutdown. It happens due to loss of control or emergency situations like fire outbreak in the facility. In such a situation, there are measures to keep the gas plant safe, which involve instant shutting down of the plant and then the subsequent result is gas flare. This means that all the gas in the plant will be flared. There could also be a case of process upset – high level of vessels will shut down thereby leading to chain shut down. Planned Shutdown is a type of shut-down that is pre-planned and arranged. It could last for about 1 – 2 weeks. In this situation, the gas is channelled to the stack and lost through flaring.
- Separation of condensate: During separation of condensate from gas, there is need to stabilize the liquid. This leads to the gas being flashed off. So in the absence of a flash-gas compressor, more gas is flared. In this scenario, much gas is flared.
- Loss of electricity power: This is an indirect reason for gas flaring in the plant. This is as a result of power failure or lack of use of gas to generate electricity by their customers. During routine maintenance or unplanned maintenance in the power plants, there could be lack or less generation of electricity, and this signifies that all or some of the turbines might not be operational. Therefore, lesser gas will be utilized. In this situation, the excessive gas in the plant is channelled to the gas stack for flaring.
- Plant overhaul: During maintenance of the site/gas plant, gas is flared.

4.3. GAS USE AND COST

The Electric Company, at the time of research constitutes of 20 units of gas turbines, of which only 1 turbine is actively in service or in good condition; 6 units are unavailable due to one minor or major mechanical problem; 13 units have been technically decommissioned. The records from the Corporation state that it utilises 60 mmscfd. Table 3 below shows the cost and volume of gas utilised from January to December in 2011. It shows that the Electric Company utilises about 8million to 16million cubic meters (M^3) monthly, depending on availability of turbines. This process generates about £1.1 million to the Gas Company (at 27 cubic feet costing £0.16). The gas consumption as specified in the table is unstable and varies monthly. This variation is obviously due to the number of active gas turbine during each month. In November, December and August, the Electric Company experienced the highest volume of gas consumption and that is connected to the availability of about 5 to 3 active gas turbines, as compared to September, June and January, which had varying number of active gas turbines from 3 to 1. Also as expected, the amount of gas consumed by this company significantly affect the money realised by the Gas Company because, the Electric Company is one of the two major clients.

Table 3. Monthly gas consumption and cost report for 2011 (Source: Author's Field Survey, September 2013).

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MONTH/YEAR (2011)	QTY. OF GAS CONSUMED (M^3)	COST (£) @ 0.16 PER 27 M^3	VAT 5% (£)	TOTAL (£)
JANUARY	7,088,598.79	29,885.00	1,494.25	31,379.30
FEBRUARY	8,889,621.20	37,478.00	1,873.90	39,351.90
MARCH	8,744,574.85	36,866.50	1,843.32	38,709.70
APRIL	10,040,429.12	42,329.7	2,116.49	44,446.20
MAY	8,158,776.01	34,396.80	1,719.84	36,116.60
JUNE	6,366,692.99	26,841.50	1,342.08	28,183.60
JULY	10,832,749.20	45,670.10	2,283.50	47,953.60
AUGUST	14,268,919.21	59,402.00	3,007.84	63,164.60
SEPTEMBER	6,236,672.27	26,293.40	1,314.67	27,608.00
OCTOBER	10,963,581.99	46,221.70	2,311.08	48,532.70
NOVEMBER	16,587,097.37	69,930.00	3,496.50	73,426.50
DECEMBER	14,414,904.25	60,772.20	805,211.95	63,810.80
TOTAL	122,592,616.77	516,841.00	25,612.40	1,108,730.00

4.4. ENERGY GENERATION AND GAS CONSUMPTION

The energy generated by the Electric Company over 12 years varies greatly. This depends to a large extent, on the availability and working conditions of the gas turbines, than on the availability of gas. Table 4 below demonstrates the yearly consumption of gas from 2001 to 2012 as well as the capacity of energy generated within the same period. The years 2003, 2004, 2005, 2006, 2007 witnessed greatest period of generation in the site because during these periods, 4 gas turbines with an average capacity rating of 105 MW were in good working condition. While 2010 witnessed the least in energy generation just because this same period was plagued with decommissioned and defective turbines. However, it is good to note that due to technical issues, maintenance or breakdown, the turbines may not produce to full capacity and that leads to reduction in amount of energy produced. This is hugely demonstrated in table 4, where 2002 and 2009 had two available turbines, yet provided lesser energy than in 2001, 2011 and 2012 that also had same number of turbines.

Sonibare and Akeredolu [18] states that a lot of developing countries in Africa currently experience crisis in power generation. For example in Nigeria, the national grid is providing just about 30% of the daily demand of over 10,000MW. This scenario keeps getting worse because of lack of planning and maintenance on the existing power stations. However, out of the 8 power stations in the country, 5 are thermal, while 3 are hydro. Therefore, the acquisition of new gas turbines and routine maintenance of the old and new turbines will boost electricity generation and minimize gas flaring. Finally, table 3 also supports this paper to establish that more gas turbines will guarantee possible use of more gas and this represents more energy being generated as well as improved financial economy.

Table 4. The Electric Company's energy generation and gas consumed from 2001 – 2012 (Source: Author's Field Survey).

YEAR	AVAILABLE TURBINES	TOTAL CAPACITY (MW)	ENERGY GENERATED (MWH)	QUANTITY OF GAS CONSUMED (M^3)
2001	2	180	340,194.90	150,654,602.87
2002	2	105	184,672.10	967,598.27
2003	4	420	2,090,548.30	713,770,984.70
2004	4	420	1,247,813.10	449,833,371.00
2005	4	420	1,838,866.90	635,663,342.81
2006	4	420	1,864,110.30	664,138,805.91
2007	4	420	1,393,932.40	476,226,077.87
2008	2	180	305,340.00	127,526,576.25
2009	2	180	151,859.00	61,096,500.11
2010	1	105	95,947.40	25,957,142.27
2011	2	180	391,577.00	122,592,616.77
2012	2	180	497,885.20	204,378,866.54

However, between February and September 2013, the Electric Company generated between 600,000 – 650,000MWh, depending on the production capacity of the turbines. This is basically because of the introduction of three new turbines into the system. This has created massive improvement to the national grid and has also improved gas use and financial economy of the country.

5. CONCLUSIONS

Gas flaring is a serious problem facing the oil and gas industry, particularly in the developing world. Its management requires committed planning and good sustainable approach: therefore, the gas-to-wire technology is a very vital means to minimize gas flaring and at the same time provide the much needed improvement in energy sector and also improve the economy of the nations, through the money that will accrue from electricity distribution.

This study has also shown that the introduction and use of more gas turbines in the power sector in the developing countries, particularly the oil and gas producing countries, will reduce gas flaring and improve electricity generation. Obsolete gas turbines that still exist in some of the power stations should be replaced with more modern ones for more use of gas and electricity generation.

5.1. RECOMMENDATIONS

For better planning and improved energy generation and reduced gas flaring, the study recommends the following:

i. More units of GT could be installed in the Electric Company to allow for more gas usage. This will also lead to enhanced energy production and cash generation.
ii. With increased GTs comes increased demand for gas. So there is need for the production of gas at Gas Company to be increased and if possible, more Associated Gas Gathering sites should be built closer to other power stations.
iii. The Gas Company can utilise the gas flared in the site for electricity generation, which could be used solely for site operations. This will further reduce flaring of gas.

5.2. FUTURE OF THIS STUDY

The next stage of this research will look into the following areas before drawing final conclusions:

i. Simulation and modeling of real-life gas-flared and opportunities for its potential utilization.
ii. The impact of re-use of more flared gas to the environment and revenue generation.

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