Economic Analysis of Natural Gas Pipeline Construction and Electricity Transmission Loss Consideration

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Abstract: **The site of electrical power plants has been a subject of interest due to the advent of electricity and the distance between energy sources (mines, oil and gas fields, and water bodies for renewable energy) and distance load (cities and industrial hubs) centers. The quest for sufficient energy infrastructure to propel Nigeria's huge and growing population of about 190 million and also to power the much-anticipated industrialization and economic growth and development made government embark on unprecedented investment in natural gas and electricity generation, transmission and distribution infrastructure. The Geregu gas turbine project, located in Geregu, Kogi State consist of a FGN 414 MW open cycle gas turbine commissioned in 2007 and a NIPP 444 MW open cycle gas turbine commissioned in 2013. These turbines are fed with atural gas from Oben gas fields in Edo state through 36 inches, 196 ~~km~~ pipeline whose construction cost is $228,317,572.65 and with revenue form current transportation charges of $0.80/MSCF, has a payback period of sixteen years. However, if the power plants were to be sited in Edo State and a ~~330 KV~~ transmission line constructed from the power plant to Kogi state, the construction cost would have been $123,426,000.00 and with revenue from current tariff charges of $8.76/MWH, the payback period is 12 years. Hence it is cheaper to construct the power plant in Edo state and evacuate the generated energy via 330 kV transmission lines to Kogi state than to construct the plant in Kogi state and supply natural gas to it via pipeline. Nevertheless, the Oben-Geregu pipeline has throughput capacity of about 1.2 billion scf/d of gas and since the maximum gas requirement by the power plants is 210 MMSCF, the pipeline can serve additional installation requiring natural gas feed along its route thereby raking in additional revenue and thus reduction in its payback period.**

***Keywords*: Natural Gas, Pipeline, Electricity, Transmission line, Transmission loss, Cash Flow Analysis,**

I. INTRODUCTION

The aim of the research work is to determine the best approach in deciding whether to site a gas fired thermal generating station close to a source of natural gas (a gas field) and evacuating the generated power to a distant load center via a transmission link or to site the thermal generating station close to the load centre and then construct a gas pipeline and its ancillary facilities to connect a distant gas field to the location of the thermal generating plant.

The objectives of this study include;

- Evaluation of the requirements, cost and benefits of pipeline construction from a gas field to a gas fired thermal plant sited at distance (from Oben gas fields in Edo state to Geregu in Kogi state)
- Evaluation of the requirements, cost and benefits of construction of a transmission link (330 kV and 132 kV) from a thermal power plant assumed to be sited close to Oben gas field in Edo state to a distant load centre Federal Capital Territory (FCT), Abuja.
- To carry out an economic and investment analysis of the two approaches and compare their cost and benefits toward the determination of the best electrical power and gas infrastructural developmental approaches.

Nigeria being a gas province and having an acute shortage of electrical energy supply need to rapidly develop it gas and electrical infrastructure to enable it provide enough clean and reliable energy to power the much-anticipated economic growth and development so as ~~to~~ lift its growing population of about 200 million out of poverty and also to meet the millennium development goals.

The main significance of this study is to provide empirical economic, investment, cost and financial information to government, policy makers, government agencies and parastatals, global development and donor agencies, local and international investors. This will help in decision making in the siting of future gas fired electric power stations.

Table 1: Grid Connected Gas Fired Generation Plants.

S/N		POWER STATION NAME	INSTALLED CAPACITY (MW)	NO OF UNITS	GAS REQUIREMENT (MMSCF)
1	PRIVATIZED PHCN COMPANIES	EGBIN	1320	6	352
2		SAPELE	720	10	192
3		DELTA	765	18	204
4		AFAM IV-V	300	8	80
5		GEREGU	435	3	116
6		OMOTOSHO	337	8	90
7		OLORUNSOGO	336	8	90

8	NIPP	GEREGU NIPP	435	3	116
9		SAPELE NIPP	500	4	133
10		ALAOJI NIPP	504	5	134
11		OLORUNSOGO NIPP	750	6	200
12		OMOTOSHO NIPP	500	4	133
13		ODUKPANI NIPP	625	5	167
14		IHOVBOR NIPP	450	4	120
15	IPP	OKPAI	480	3	128
16		AFAM VI	695	4	185
17		IBOM	195	3	53
18		AES	224	9	60
19		ASCO	110	2	29
20		OMOKU	150	150	40
21		TRANSAMADI	136	4	36
22		RIVERS IPP	150	6	40
23		AZURA IPP	450	3	120
	3.75 MW IS EQUIVALENT TO 1MMSCF				
	TOTAL		**10, 570**	**132**	**2818**

Source: TCN Transmission Expansion Plan by Fictner 2017.

Note that a plants generation capacity is always about 20% to 30% lower than the installed capacity because of maintenance and repair requirements. Also, generation capacity of renewable power sources usually has a low utilization factor.

A. Technical Description of the Oben – Geregu 36 Inches Natural Gas Pipeline

The 196 km, 36 inches Oben-Geregu natural gas pipeline receives gas at about 70 bar to 80 bar from Seplat's gas processing station for onward transmission to the Terminal gas station at Geregu. Since the requirement of the Service level agreement (SLA) in the Gas Transportation Agreement (GTA) of the Geregu power plants and NGPTC is for the supply of gas at 30 bar to 32 bar, there is no need for a compression station as the loss of pressure over the distance is less than 10 bar. The presence of propane and butane may however induce a higher gas pressure drop. Instead, a Pressure Regulating and Metering Station (PRMS) makes up one of the component unit of the Terminal Gas Station (TGS). This helps to reduce the pressure of natural gas to about 30 bar in accordance with the SLA with the management of the power plants. Delivering gas pressure higher than 30 bars will attract sanctions from the customers. The actual gas pressure required by the power plants is about 18 bars to 20 bars hence a further gas pressure reduction is carried out by the operator of the power plants. The current capacity of the PRMS stands at 250 MMSCFD of natural gas and this covers the current maximum demand of 210 MMSCFD for the two open cycle gas turbines at Geregu. Each individual plant however has a dedicated PRMS of 105 MMSCFD capacity each because of the difference in pressure requirements.

There are two pigging stations on the 196 km 36 inches Oben – Geregu line. The first pigging station is located at 85 km and serves 0 km –85 km of the line. The second pigging station located at 196 km serves 85 km – 196 km of the gas transmission line. 196 – 200 consist of the line connecting the PRMS to the gas turbine. This line is also referred to as the sales line. The line from 0 – 196 is made of 36" mild steel pipe while the sales line is made of a 24" pipe.

Valve station are located along the line. They are used to segment the line. The number of valves on a particular line length depends on the population density of the pipeline Right of Way (ROW). ASME B 31.8 provides spacing for valve stations.

- 36 km spacing is used for virgin land without human habitation
- 24 km spacing is for low population density ROW
- 12 km spacing is for high density ROW.

There are thirteen main line (36 inches valves) along the 196 km, 36' Oben – Geregu natural gas pipeline.

II. MATERIALS AND METHODS

The method applied consists of the following:

- Evaluate cost of gas plant sited to meet Abuja area demand
- Evaluate cost of gas pipeline from Oben gas field (Edo State) to Geregu (Kogi State)
- Evaluate the cost of construction of different transmission links from Geregu to Abuja
- Evaluate the construction cost of transmission links (330 kV, 132 kV) from Edo state to FCT
- Analyse the electrical transmission losses of the transmission links from Edo to Abuja
- Compare all the evaluations and analysis carried out. Would it have been better to site the plant in Edo state (near the source of gas and design a transmission link from Edo to Abuja.

A. Design Specification

The research design is deterministic and descriptive. The topic shows that:

- Natural gas pipeline transport facilities requirement and associated cost need to be determined.
- We also need to determine the electricity transmission loss consideration for the transmission link for the different voltage levels
- Model to be employed is based on the discounted cash flow model and to be designed according to the World Bank/International Monetary Fund (IMF) regulations for infrastructural investment.

B. Data Collection.

Data was collected from relevant government agencies Nigerian National Petroleum Corporation (NNPC), Transmission Company of Nigeria (TCN), Niger Delta Power Holding Company (NDPHC), pipeline contractor, electrical transmission network contractor.

The discounted cash flow method was used to determine the value per time of the pipeline and transmission infrastructure

The research effort is comparative economic analysis of natural gas pipeline transport and electricity transmission line of bulk energy. The first step of the study was to determine the construction processes, project sequence and cost for the construction of the natural gas pipeline and the counterpart high voltage transmission line. The efficiency of the Geregu gas fired electricity generation plants in the conversion of natural gas to electrical energy was also examined to determine the quantity of natural gas that would be required for the operation of the power plants. The losses that will be incurred in the transmission of electrical energy over the distance covered in the process of evacuation of the generated energy is also evaluated, capitalized and treated as additional cost in the transmission line cost analysis. The cost of construction of transmission line for the different high voltage level are also evaluated.

C. Gas Turbine-Based Generation

Open cycle gas turbine (GTOC) power plants use fuel for heating of compressed air, which is utilized in a turbine for power generation. The hot exhaust gases are emitted to the environment without the use of the containing energy in the form of heat and thrust.

The purpose of combined cycle power plants (GTCC) is to utilize this wasted energy from the hot gas turbine exhaust for steam generation in a downstream Heat Recovery Steam Generator (HRSG). This steam can be further used for power generation in a steam turbine process by expanding the steam.

By that, the total electrical generation capacity of a GTCC power plant is made up from

- The power output of gas turbines and of
- The steam turbine without the need for further fuel

Under ideal operating conditions; without overhaul or other planned/unplanned outages, a utilization factor (load factor) of up to 0.95 is possible for modern open/ combined gas turbine plants. An annual load factor of about 0.85 is assumed to be achievable over the whole life time under consideration of frequent and regular maintenance stops according to manufacturer's recommendation and under consideration of unrestricted fuel availability (no vandalism or other reasons for shortages of gas supply). Under ideal operating conditions i.e. International Standard Organization (ISO) conditions, modern GTCC have an electrical efficiency of up to 35 – 39 %. As this is highly dependent on the local ambient air temperature, about 33 – 36 % should be considered for given climatic conditions in Nigeria.

Table 2: Energy Balance of Gas Fired Power Plants in 2015

S/N	PLANT	QTY OF GAS		ENERGY SENT OUT	NET ENERGY EFF	NET HEAT RATE	AVE OPERATION HR/YEAR
		MMSCF	GJ	MWhe	KWhe/KWhth	MJ/KWhe	h/year
1	EGBIN	53,965.16	59,612,264	5,192,951	0.31	11.479	3934
2	DELTA	35,372.93	39,074,477	2,761,016	0.25	14.152	3140
3	SAPELE	7,632.76	8,431,483	550,937	0.24	15.304	1043
4	SAPELE II	8,449.00	9,333,131	919,606	0.35	10.149	2026
5	AFAM VI	23,935.45	26,440,138	2,991,284	0.41	8.839	4109
6	Omotos gas	16,588.77	18,324,676	1,448,663	0.28	12.649	4325
7	Omotos nip	15,160.50	16,746,949	1,089,840	0.23	15.366	2156
8	Geregu fgn	11,748.63	12,978,047	1,165,646	0.32	11.134	2816
9	Geregu nip	12,461.66	13,546,557	1.165,646	0.31	11.622	2625
10	IBOM	6,223.32	6,874,549	510,565	0.27	13.465	2606
11	OKPAI	19,868.52	21,947,636	2,604,661	0.43	8.426	5788
12	IHOVBOR	12,461.91	13,765,972	1,106,267	0.29	12.444	2447
13	Olorun gas	31,984.79	35,331,788	1,522,245	0.16	23.210	4544
14	Olorunnipp	13,414.04	14,817,736	1,113,488	0.27	13.307	1469

Source: TCN Transmission Expansion Plan by Fictner 2017.

Modern GTCC can achieve energy efficiencies of up to 60% (ISO conditions), which results in efficiencies of 50 – 55% under climatic conditions in Nigeria (Gruwald, 2017).

Several studies have investigated the economics of different means of bulk energy transport, i.e., transport of coal or gas and transmission of electricity via high voltage transmission lines over distances. Oudalov et al., 2009) investigated a method of comparison of bulk energy transport systems.

Economic analysis maximum insight into the basis for a decision to invest in a particular infrastructure or not (Lazson and Ikiensikimama, 2013).

Oudalov *et al*. (2009) stated that:

The method of transport of primary energy sources to power plants and then electricity to the load centres depends on the nature of the resource, quantity of energy to be moved, distance, capital and operating cost of transport and power generating systems, existing facilities etc. Additional contributing factors are environmental and social cost (externality cost). A comprehensive analysis of bulk energy transport system considers all local environmental and social regulations and the situation where a new full-length transmission line or natural gas pipeline must be built.

Environmental and social cost (externality cost), are cost that are not borne by the owner of the power plant. If the ministry of environment removes all externalities, these costs would be zero. However, the most socially beneficial standard is set at the level where the declining marginal benefit of abatement is just equal to the increasing marginal cost of abatement. A tougher standard would impose cost greater than benefits. Even when environmental regulations are properly set, the remaining externalities influence which option has least social cost e.g. 330 kV lines for transmission rather than 132 kV lines. Externalities building blocks include; air pollution emissions, safety hazards, audible noise, visual and electromotive force (EMF) impacts of energy transport infrastructure, power generation.

Having the analysis satisfy standards helps eliminate the controversy associated with estimating dollar costs for constrained visibility, noise and 50/60 Hertz (Hz) electromagnetic field. (Oudalov *et al*., 2009)

Most primary energy sources are usually distant from the main load and population centre, therefore their exploitation usually requires the bulk transmission of electricity >500 MW or the equivalent bulk transportation of primary energy resources over a long distance >100 kM (Oudalov and Reza, 2008), thereby reducing the impact on the environment and time for project execution.

Transporting natural gas and transmission of electricity requires additional capacity to make up for the gas pipeline losses and the transmission losses respectively.

D. Empirical Review

Average transmission line losses are in the range of 7-11% on most utility grids (Glover *et al*., 2017). They however increase exponentially as transmission lines become heavily loaded. A small amount of increase in demand during peak hours can increase transmission line losses by as much as 20% (Glover *et al*., 2017). During such periods, disproportionately more generation resources need to be deployed to deliver the same quantity of electricity to customers' end users.

The optimum line design meets all the technical design criteria at lowest overall cost, which includes the total installed cost of the line as well as the cost of the line losses over the operating life of the line (Glover *et al*., 2017).

Electricity transmission system consist of two or more transformational stages and one or more set of transmission line. The transmission line losses usually range between 3 – 5 % depending on voltage level and distance.

A provision for 0.8% for the annual throughput has been assumed towards unaccounted gas losses.

Wong (2011) stated that:

Transmission losses occur due to the electricity systems physical characteristics. Underestimating the loss factor could lead to under procurement of energy while overestimating the loss factor could lead to over procurement of resources.

Transmission losses are caused by

- The electrical resistance of the power line
- Converting the power between high voltages used for long distance transmission and safe low voltages used in most industry and residential homes

The transmission loss is put at 7% for 330 kV lines, 9% for 132 kV line and 12% for 33 kV line.

The two existing power plant in Geregu are the Geregu FGN 1 which commenced operation in 2007 and Geregu NIPP 1 which started operation in 2013. They are both GTOC with installed capacities of 414MW and 444MW respectively.

From Table 2, Geregu FGN 1 requires 116MMSCF of gas for full operation for an hour while Geregu NIPP requires 116MMSCF of gas for power generation per hour.

Therefore, total gas required by both plants per hour equal 232MMSCF of gas.

Using an annual load factor of 0.85 for the life of the plant to allow for maintenance and planned/unplanned outages.

The diameter of natural gas pipeline for power plants can be calculated using Pan-Handle A and Pan-Handle B equations, assuming a heat rate of 8000Btu/Kwh (to estimate gas through put. i.e. (8MMBtu = 1MWH).

E. Determination of volume of gas requirement by Geregu power plants.

The two existing power plants in Geregu are the Geregu FGN 1 which commenced operation in 2007 and Geregu NIPP which started operation in 2016. They are both GTOC with installed generation capacities of 414 MW and 444 MW respectively. According to the energy balance of gas-powered plants of Table 3 Geregu FGN has energy efficiency of 32% while Geregu NIPP has energy efficiency of 31%.

F. Calculations

Combined capacity of Geregu FGN 1 and Geregu NIPP are

414 MW + 444 MW = 858 MW

Heat value of Nigeria natural gas is 1.06 Joules per 1Btu

Therefore,

1.06 Joules = 1.06 watt-sec = 1Btu

The volume of gas required per second for the Geregu gas fired plant is

858MW. Sec = 858 * 10^6 watt-sec = 809.43 * 10^6Btu = 809.43MMBtu

Therefore, at 31% efficiency, total volume of daily gas requirement is

(809.43*24*3600)/0.31=225,595MMBtu= 226MMScf / day.

However, the agreement between the Nigerian Gas Pipeline and Transport Company (NGPTC) and Geregu Power Companies is for the supply of 210MMSCFD of gas. This will be used as the daily volume of gas required for our analysis.

G. Determination of the size of pipe for transporting natural gas

The optimum pipe size required for the transport of the daily natural gas volume can be determined using the Modified Panhandle Equation below.

$$Q = 0.00123(di)^{2.53}[P_1^2 - \frac{P_2^2}{L}]^{0.51} \quad (1)$$

$Q = Pipeline\ capacity\ in\ MMSCFD$
$\boldsymbol{di = line\ pipe\ internal\ diameter\ in\ inch}es$
$P_1 = Max\ \ pres\ at\ delivery\ pt\ from\ gas\ field\ in\ psia$
$P_2 = Min\ prese\ at\ receipt\ pt\ of\ distribution\ sys\ in\ psia$
$L = Length\ of\ pipeline\ in\ miles.$

The Geregu power plants are fed by two separate pipelines. These are the old 24 inches Oben- Ajaokuta pipeline from the Ajaokuta metering station and the new 196 km, 36 inches Oben Geregu pipeline which is terminated by a 250 MMSCFD Terminal Gas Station (Pressure Regulating and Metering Station). The 36 inches' pipeline is capable of delivering 1.2 billion standard cubic feet per day and is to actually serve as one of the feed trunk for the future AKK pipeline.

Only the 196 km 36 inches' pipeline will be considered in our study. The pipeline was commissioned in June 2008.

TABLE 3: Breakdown of Construction Cost of 196KM, 36 inches Oben – Geregu Natural Gas Pipeline

S/N	DESCRIPTION	COST ($MILLION)
1	LAND	635,362.66
2	ROW	1,588,406.66
3	PIPE COST INCLUDING LAYING	166,782,698.82
4	SCADA AND APPS SYSTEM	635,362.66
5	COMPRESSION STATION	15,884,066.55
6	OTHERS	3,176,813.31
7	**SUB-TOTAL**	**188,702,710.66**
8	PROJECT MGT EXP INCL PMC(4%)	7,548,108.43
9	OWNERS MGT EXP (2%)	3,774,054.21
10	CONTIGENCY (15%)	28,305,406.60
11	**TOTAL**	**228, 317, 572.65**

Source: NGPTC (A Subsidiary of NNPC). Abridge Status Report: Gas supply to PHCN power plant at Geregu by the Project Team.

H. Electricity Transmission Loss Consideration

Main contributory parameter to excessive transmission line losses are

- Small cross-sectional area of conductor
- Length of the line
- Unbalanced load condition
- Power factor problems
- Low operating voltages

Highest value of demand losses (kW) can be generally obtained from load flow analysis. We inspect this from time to time to make sure that reasonable (less than 10%) power losses are achieved at the thermal current ratings for the line at normal power factors (0.95 lagging – to – unity).

Energy losses sometimes vary from year to year mainly because of changes in the utilization pattern of the network, network configuration, the shape of the load profile, the level of the reactive power compensation (power factor correction) and generator patterns. Average transmission line losses are between 6-10% for most utility grids, but they increase exponentially as power lines become heavily loaded. Therefore, by eschewing a fraction of electricity demand in the highest peak period, one can achieve transmission line losses reduction by as much as 20%~~twenty percent~~. At such levels, disproportionately more generation resources need to be deployed.

Transmission line losses usually involve two (or more) additional transformation stages and one (or more) additional set of lines. Depending on voltage and distance, losses on the line ranges from 2-5%.

Core losses (no load losses incurred to energize transformers in substation) are typically 25 – 30% of the total losses and do not increase (or decrease) with changes in the load.

Resistive losses (losses due to wires including those in the transformers) increases exponentially with the current in the line.

I. Determination of transmission line losses

For the 330 kV Transmission line, the following information is required. The conductor type is Aluminum Conductor Steel Reinforced (ACSR). The conductor type is 4 – bundle ACSR per phase with a spacing of 400 mm. The conductor characteristics are

Cross section:

$$Aluminium\ (mm^2) = 381.6$$
$$Steel\ (mm^2) = 49.4$$
$$Total\ (mm^2) = 431$$
$$Stranding\ and\ wire\ diameter$$
$$Aluminium\ (mm) = 54/3.0$$
$$Steel\ (mm) = 7/3.0$$

$$Overall\ diameter\ (mm)\ =\ 27$$

$$On\ the\ basis\ of\ above\ with\ d\ =\ 400\ mm\ (1.32ft)$$

$D_{12}\ = 10.5m\ = 34.44ft$

$D_{23}\ = 10.5m = 34.44ft$

$D_{13}\ = 21.0m\ = 68.88ft$

Inductance for a three phase completely transposed line is

$$L_a\ = 2 \times 10^{-7} \ln\frac{D_{eq}}{D_S}\qquad H/m \qquad (2)$$

Where the equivalent spacing between phases is

$$D_{eq}\ =\ \sqrt[3]{D_{12}D_{23}D_{31}} \qquad (3)$$

Cube root of the product of the three-phase spacing. This is the same as the geometric mean distance (GMD) between the phases.

D_S = Geometric mean radius (GMR) for stranded conductors or $r^/$ for solid cylindrical conductor where

$$r^/ = e^1/_{4r} = 0.7788r \qquad (4)$$

For the 330KV Bison conductors, the GMR (D_S) for one conductor as taken form tables, is GMR = $D_S = 0.0363ft$

D_{12} is the distance between phase 1 and phase 2 conductor?

D_{23} is the distance between phase 2 and phase 3 conductor?

D_{31} is the distance between phase 3 and phase 1 conductor?

For conductor bundling used in extra high voltage (EHV) lines, D_S is replaced by the GMR of the bundle denoted D_{SL}

For 2-Conductor Bundle

$$D_{SL} =\ \sqrt{D_S d} \qquad (5)$$

For 3-Conductor Bundle

$$D_{SL} =\ \sqrt{D_S d^2} \qquad (6)$$

For 4-Conductor Bundle

$$D_{SL}\ = 1.094\ \sqrt[4]{D_S d^2} \qquad (7)$$

Therefore, for four conductor bundle,

$$D_{SL}\ = 1.094\sqrt[4]{0.0363 \times 1.32^3}\ = 0.586ft\ =\ 0.1776m$$

Hence, the equivalent spacing between phases is

$D_{eq}\ = \sqrt[3]{D_{12}D_{23}D_{31}} = \sqrt[3]{34.44 \times 34.44 \times 68.88} = 43.4ft\ = 13.15m$

and then the inductance given as

$$L_a\ = 2\ \times\ 10^{-7}\ \ln\frac{D_{eq}}{D_S} \qquad H/m\ \ (8)$$

$$X_L = 2\pi f L_a \qquad (9)$$

$$X_L = 2\ \times\ \pi\ \times 50\ \times 2\ \times 10^{-7} \ln\frac{13.15}{0.1776}\ = 0.27\ ohms/km$$

D_{eq} is approximated to the distances between bundle centres if the phase spacing is large compared to the bundle spacing.

Capacitance for a 3 phase completely transposed line

$$C_{an}\ =\ \frac{2\pi\varepsilon}{\ln D_{eq}/r}\ \ F/m \qquad (10)$$

$$D_{eq}\ =\ \sqrt[3]{D_{12}D_{23}D_{31}}$$

For bundled conductors, assuming phase spacing is >> than the bundle spacing.

$$C_{an} = \frac{2\pi\varepsilon}{\ln D_{eq}/D_{SC}}\ \ F/m \qquad (11)$$

Where $D_{SC}\ =\ \sqrt{rd}$ for a 2-conductor bundle (12)

$D_{SC}\ =\ \sqrt[3]{rd^2}$ For a 3-conductor bundle (13)

$D_{SC} =\ 1.091\ \times\ \sqrt[4]{rd^3}$ For a 4-conductor bundle (14)

For the 330KV Bison conductors: $r = \frac{D_{out}}{2\times12}\ =\ \frac{1.062}{2\times12}\ = 0.04425ft$

$$D_{SC}\ = 1.09\sqrt[4]{r.d^3} = 1.09\sqrt[4]{0.4425 \times 1.32^3}\ = 0.6156ft$$

$$C_n\ = \frac{0.0388}{\ln\frac{D_{eq}}{D_{SC}}} = \frac{0.0388}{\ln\frac{43.4}{0.6156}} = 0.021\ \mu F/mile$$
$$=\ 0.013\mu F/km$$

Susceptance:$B\ = \omega C\ = 314\ \times 0.013\ = 4.08\ \mu mho/km\ = 4.08\mu S/km$

Resistance:
$R = 0.0762\ ohms/km\ \ =$
$\left(R = 0.019\frac{ohms}{km} for\ 4\ bundle\ conductors\right)$

Summary of the electrical parameters of the 330KV, 202km transmission line is as follows

	$L(km)$	$R(\frac{\Omega}{km})$	$L(\frac{mH}{km})$	$X(\frac{\Omega}{km})$	C ($\frac{\mu F}{km}$)	$R(ohms)$	$X(ohms)$	C(μF)
	202	0.019	0.7962	0.25	0.014	3.838	50.5	2.828

J. Practical line load-ability

Surge Impedance Loading (SIL) is the power delivered by a lossless line to a load resistance equal to the surge impedance$Z_C\ =\ \sqrt{L/C}$. At SIL, the magnitude of the voltage at any point along the lossless line is constant.

Z_C = Characteristic impedance also known as surge impedance

$$Z_C = \sqrt{\frac{L}{C}} \qquad (15)$$

$$SIL = \frac{V_R^2}{Z_C} \qquad (16)$$

V_R = Receiving end voltage

In practice, power lines are not operated to deliver their theoretical maximum power, which is based on rated terminal voltages and an angular displacement δ = 90° across the line. However, in practice, a voltage drops limit of $V_R/V_S \geq 0.95$ and a maximum angular displacement of 30 to 35° across the line (or about 45° across the line and equivalent system reactance) in order to maintain stability during transient disturbances. For short transmission line less than 80km long, load-ability is limited by the thermal rating of the conductor or by terminal equipment rating and not by voltage drop or stability considerations.

The theoretical maximum power delivered is:

$$P_{max} = \frac{V_{S\,p.u.}.V_{S\,p.u}\,(SIL).}{\sin\frac{2\pi L}{6000}} \qquad (17)$$

The practical line load-ability is for a 50 Hz system

$$P_{max} = \frac{V_{S\,p.u}.V_{S\,p.u.}(SIL)\sin\delta}{\sin\frac{2\pi L}{6000}} \qquad (18)$$

Where

$$V_{S\,p.u.} = Sending\ end\ voltage$$
$$V_{R\,p.u.} = Receiving\ end\ voltage$$
$$L = Line\ length$$

$$Z_S = \sqrt{\frac{0.7962 \times 1000}{0.014}}\,238.5\ ohms$$

$$SIL = \frac{330^2}{238.5} = 456\ MW$$

K. Recommended value of transformer losses

From the maximum allowable recommended value of transformer losses by NERC in NESIS 2015 document,

Table 4: Recommended Allowable Transformer Losses

S/N	DESCRIPTION	No Load Losses (KW)	Load Losses(KW)	Auxiliary Losses (KW)	Total Losses (KW)
1	330/132KV, 300MVA	86	482	16	584
2	330/132KV, 150MVA	43	241	10	586
3	330/132KV, 100MVA	28	233	11	272
4	330/132KV, 90MVA	28	233	11	272

SOURCE: Nigerian Electricity Supply and Installation Standard 2015 by NERC.

From Table 4, the recommended transformers losses for 150 MVA and 60 MVA transformers used in our analysis are:

150 MVA = 586KW

60 MVA = 272 KW

III. RESULTS & DISCUSSION

A. Method of Cost Analysis.

The methods of cost analysis employed include:

Discounted cash flow analysis

Payback period

B. Determination of the Investment, Operation and Maintenance Cost of Transmission Lines and Substations

Table 5: Operation and Maintenance (O & M) cost (1 percent of investment cost)

S/N	DESCRIPTION OF ACTIVITY	132KV (60 MVA TRF)	330KV (150 MVA TRF)
1	RATED POWER 900MW	(4 CCTS; 15 NO 60MVA TRANSFORMERS)	(1 CCTS; 6 NOS 150 MVA TRANSFORMERS
2	STATION EQUIPMENT INCLUDING REACTIVE COMPEMSATION	$0.7M * 15 = $10.5M	$1.0M * 6 = $6M
3	TRANSFORMERS ($M)	$0.8M * 15 = $12.0M	$1.5M * 6 = $9M
4	TX LINE COST PER KM ($M/KM)	$0.26M	$0.45M
5	DISTANCE IN KM	202KM BY 4 CCTS	202KM BY 1 CCTS
6	TX LINE COST ($M)	$210.08M	$90.90M
	TOTAL ESTIMATED EQUIPMENT COST	**$232.58M**	**$105.9M**
7	ENGINEERING- FOREIGN = 5%	$11.629M	$5.295M
8	OWNERS ENGINEER = 3%	$6.977M	$3.177M
9	OTHER CONSULTING SERVCES (ESIA) = 1%	$2.326M	$1.059M
10	ENVIRONMENTAL SAFEGUARD = 1%	$2.326M	$1.059M
11	LAND ACQUISITION, RESETTLEMENT = 1%	$2.326M	$1.059M
	TOTAL CAPEX	**$258.164M**	**$117.549M**
12	PHYSICAL CONTIGENCIES = 5%	$12.908M	$5.877M
	PROJECT INVESTMENT	**$271.072M**	**$123.426M**
	LOSSES AT FULL LOAD	80.1 MW	68.4 MW
	LOSSES AT FULL LOAD IN %	8.9 %	7.6 %
	COST OF LOSSES @ FULL LOAD		

Also note that

a) Total project cost includes cost of new transmission lines and substation
b) Physical and price contingencies

c) Estimates of engineering, consulting and environmental cost
d) Taxes and duty
e) 2018 prices are used

Here, we will use a simplified cost model

Cost will be based per km of transmission line for each voltage level. The cost of construction of the requisite substation will also be evaluated.

For Substations, we look at the cost of

- HV Feeders comprising of HV equipment and other substation components such as civil works, steel protection, control equipment and auxiliary power supply.

Main Power Transformers, Reactors and Capacitors where necessary. For new 132/33KV substations, we also look at the cost of new 33KV switchgear and additional 33KV switch gear in case of increase of transformer capacity.

Table 6. Analysis of Construction Cost for 196km, 36 Inches Natural Gas Pipeline

S/N	DESCRIPTION	COST IN $ (USD)
1	LAND	635,362.66
2	RIGHT OF WAY	1,588,406.66
3	PIPELINE CONSTRUCTION INCLUDING LAYING	166,782,698.80
4	SCADA & APPS SYSTEM	635,362.66
5	COMPRESSION STATION	15,884,066.55
6	OTHERS	3,176,813.31
7	**SUB-TOTAL**	**188,702,710.6**
8	PROJECT MGT EXPENSE INCLUDING PMC (4%)	7,548,108.43
9	OWNERS MGT EXP (2%)	3,774,054.21
10	CONTIGENCY (15%)	28,305,406.60
11	**TOTAL**	**228,330,279.8**

Table 7. Analysis of Construction Cost for 132KV and 330 KV Super Grid Transmission Lines

S/N	DESCRIPTION OF ACTIVITY	132KV (60 MVA TRF)	330KV (150 MVA TRF)
1	RATED POWER 900MW	(4 CCTS; 15 NO 60MVA TRANSFORMERS)	(1 CCTS; 6 NOS 150 MVA TRANSFORMERS)
2	STATION EQUIPMENT INCLUDING REACTIVE COMPEMSATION	$0.7M * 15 = $10.5M	$1.0M * 6 = $6M
3	TRANSFORMERS ($M)	$0.8M * 15 = $12.0M	$1.5M * 6 = $9M
4	TX LINE COST PER KM ($M/KM)	$0.26M	$0.45M
5	DISTANCE IN KM	202KM BY 4 CCTS	202KM BY 1 CCTS
6	TX LINE COST ($M)	$210.08M	$90.90M
	TOTAL ESTIMATED EQUIPMENT COST	**$232.58M**	**$105.9M**
7	ENGINEERING-FOREIGN = 5%	$11.629M	$5.295M
8	OWNERS ENGINEER = 3%	$6.977M	$3.177M
9	OTHER CONSULTING SERVCES (ESIA) = 1%	$2.326M	$1.059M
10	ENVIRONMENTAL SAFEGUARD = 1%	$2.326M	$1.059M
11	LAND ACQUISITION, RESETTLEMENT = 1%	$2.326M	$1.059M
	TOTAL CAPEX	**$258.164M**	**$117.549M**
12	PHYSICAL CONTIGENCIES = 5%	$12.908M	$5.877M
	PROJECT INVESTMENT	**$271.072M**	**$123.426M**
	LOSSES AT FULL LOAD	80.1 MW	68.4 MW
	LOSSES AT FULL LOAD IN %	8.9 %	7.6 %
	COST OF LOSSES @ FULL LOAD		

Table 8. Cash Flow Analysis for NaturalGas Pipeline

CASH FLOW	YEAR 0	YEAR 1	YEAR 2	-	YEAR 30
REV(TARIFF@$0.80/MSCF)		16,288,125.00	16,288,125.00		16,288,125.00
LAND USE AND RENTS		1,230,000.00	1,230,000.00		1,230,000.00
NET REVENUE		15,058,125.00	15,058,125.00		15,058,125.00
OPERATION& MAINTAIN (1%)		2,228,317.27	2,228,317.27		2,228,317.27
DEPRECIATION (3.33%)		7,353,447.98	7,353,447.98		7,353,447.98
PRETAX PROFIT		5,476,359.45	5,476,359.45		5,476,359.45
TAX (10%)		547,635.95	547,635.95		547,635.95
NET PROFIT		4,928,723.50	4,928,723.50		4,928,723.50
OPERATING CASH FLOW		4,005,953.52	4,005,953.52		4,005,953.52
INVESTMENT	228,317,572.65	-	-	-	-
NET CASH FLOW	-228,317,572.65	4,005,953.52	4,005,953.52		4,005,953.52
CUMULATIVE CASH FLOW	-228,317,572.65	-224,311,619.05	-220,305,665.53		-108,138,966.55

Table 9. Cash Flow Analysis for 330 KV Super Grid Transmission Line

CASH FLOW	YEAR 0	YEAR 1	YEAR 12	-	YEAR 50
REV. (WHEELING CHARGE @ $8.76/MWH) @ N305/ $1		51,503,207.62	51,503,207.62		51,503,207.62
COST OF TX LOSS@ N24/KWH ($78.69/MWH) @ N305 = $1.00		20,038,660.31	20,038,660.31		20,038,660.31
NET REVENUE		31,464,547.31	31,464,547.31		31,464,547.31
OPERATION & MAINTAIN (1%)		6,594,400.00	6,594,400.00		6,594,400.00
DEPRECIATION (2%)		13,188,800.00	13,188,800.00		13,188,800.00
PRETAX PROFIT		11,681,347.31	11,681,347.31		11,681,347.31
TAX (10%)		1,168,134.73	1,168,134.73		1,168,134.73
NET PROFIT		10,531,212.58	10,531,212.58		10,531,212.58
OPERATING CASH FLOW		27,801,195.04	27,801,195.04		27,801,195.04
INVESTMENT	123,426,000.00	-	-	-	-
NET CASH FLOW	-123,426,000.00	27,801,195.04	27,801,195.04		27,801,195.04
CUMMULATIVE CASH FLOW	-123,426,000.00	-112,912,787.42	2,732,550.93		402,234,628.86

IV. CONCLUSION

Electricity and gas infrastructure projects have been at the front burner of the Nigerian government and international development partners in recent times. The desired result in the form of electricity availability and increase local commercialization and utilization of electrical energy however is yet to be realized. The realization of this objective will depend on a careful planning and execution of the gas and electricity projects towards investment in the most appropriate infrastructure that meet the require social and economic demand and yield the best financial returns on investment. Toward achieving the said objective, an economic analysis of gas pipeline transportation and electricity transmission loss consideration using the Geregu Gas Turbine Project as a case study investigates the economics of gas pipeline and transmission line as two different means of bulk energy transport and the merits of the one over the other.

At the current tariff of eighty cents ($0.80) per thousand scf of natural gas and a current capacity utilization of 210MMSCFD, the payback period for the natural gas line is sixteen years excluding the years of construction.

At the current wheeling charge of $8.76 per MWH of electricity for the transmission of 858MW (Total capacity of the Geregu Power Plants) using a single circuit 330KV transmission line with 6 number 150KVA transformers, the payback period is 12 years. Doubling the transmission line for sake of redundancy will increase the construction cost of the transmission line thereby reducing the payback period.

An increase of the wheeling charge to $12.79 per MWH as stipulated in the Multi Year Tariff Order 2015 for the TCN for the period of Jan 2016 – Dec 2024 will however drastically reduce the payback period for the transmission line to four years.

The through put capacity of the Oben- Geregu natural gas pipeline is about 1.2 billion scfd of natural gas hence an increase in the gas requirement along the line and commensurate investment in additional compression or gas pressure reduction facility will increase the revenue generated for the pipeline and hence reduce its payback period.

Increase in the usage of the pipeline to a throughput of 500MMSCFD will reduce the payback period to 10 years but that will require additional investment in compression station or pressure reduction station at the sales point where the additional gas is required.

The total construction cost of 196KM, 36-inch Oben Geregu pipeline is $228,330,279.80.

The total construction cost of suggested single circuit, 330KV super grid to evacuate the generated 838MW is $123,426,000.00.

Extra high voltage (EHV) transmission line is proven here as in other studies as the cheapest source of bulk energy transport. The higher the voltage level, the cheaper the cost of construction of transmission line for a give quantity of bulk electrical energy.

However, natural gas pipeline as a means of bulk energy transport provides economic benefits such as the establishment of heavy industries (steel mills, cements, ceramics mills, fertilizer plants, LPG plants, gas to liquids (GTLs), and other heavy industries that require natural gas either as feedstock or source of energy can be set up anywhere along the path of the natural gas pipeline and a spur constructed to supply gas to them.

How good the return on investment on the pipeline depends on its effective capacity utilization. A low capacity utilization as presently experienced will not yield the potential economic and financial benefits.

The 196KM, 36 inches Oben – Geregu pipeline as is currently being utilized for 210MMSCFD of gas and $0.80 per one thousand SCF will give a payback period of sixteen years. This is however not feasible as the recurrent shut down and capacity underutilization of the Geregu power plants implies that the gas requirement is lesser and so is the revenue that comes from the transportation charge.

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