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Assessment of Economic Viability of Conversion of Open Cycle to Combined Cycle Gas Power Plant

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Abstract

The chapter identified the types of gas turbines available in the electric power generating system in Nigeria and assessed the economic viability of converting open cycle to combined cycle gas power plants in order to maximize the electricity generation output without further gaseous fuel consumption in the existing thermal plants in the country. Data were obtained through primary and secondary sources on all the operational power plants in Nigeria. These data were analyzed using engineering economy methods. The result showed that by using the average generation of each plant for a period of 3 years as a baseline for conversion, an additional 1142.1 MW would be obtained after conversion to combined cycle without increase in gas consumption. In addition, the result showed the NPV values and benefit-cost ratio were greater than zero and one respectively, indicating that the project is economically viable for each conversion process. The sensitivity analysis over a range of values from ±10 to ±30% of the investment cost did not affect the economic viability of the project. Furthermore, the result showed that the cost of generating electricity borne by the society is much lower for a combined cycle than for an open cycle. The study concluded that conversion of the gas turbine from open cycle to combined cycle is economically viable and an additional generation of 1142.1 MW can be obtained without increasing the gas consumption.

Keywords: *Economic viability; Engineering economics; Conversion; Open cycle; Combined Cycle; Gas Turbine; Power Plants*

1.0. Introduction

Energy is the backbone of growth and development in Nigeria because it serves as a tradable commodity for generating the national income to put up with government development programs (Sambo, 2005). Due to rapid population growth, industrial development, agricultural production and improving living standards, the demand for energy in Nigeria is increasing. The Country has abundant primary energy resources which are enough to meet its present and future development requirements (Akuru and Okoro, 2009). Yet, when talking about energy infrastructure in Nigeria, what actually comes to the mind is the electric power system. Electricity is a form of energy that relishes substantial and innumerable applications because of its flexibility and ease of transmission and distribution (Akuru *et al*., 2017).

Electricity supply in the country has been erratic and epileptic, thus resulting in frequent power outages that have decreased economic growth and development (Nwachukwu *et al.*, 2014). Meanwhile, there have been enormous investments by the government into the power sector in the recent past, running into billions of dollars but without any meaningful impact (Akuru and Animalu, 2009; Akuru *et al*., 2017). This situation is worsened by the remarkable growth in population and economic activities, lack of maintenance of the existing power stations as well as failure of the government to improve on the Naation's generating capacity in order to meet the growing demand in the various sectors of the economy (Akuru and Animalu, 2009; Akuru *et al*., 2017).

All the efforts aimed at addressing the power problem have also been marred by corruption. Considerable expansion in quantity, quality and access to infrastructural services, especially electricity, is fundamental to rapid and sustained economic growth, and poverty reduction (Becker *et al*., 2008; Oseni, 2012; Oyedepo *et al.*, 2014). The performance of a power plant, in view of its reliability, efficiency and some operational factors has certain socio-economic importance both on the company operating the plant as well as on the Nation at large. On the contrary, the socio-economic transformation of the country would remain an illusion in the absence of adequate and reliable electricity supply. Appropriate measures can be taken by monitoring the operation status daily in order to reasonably maintain facility performance in thermal power plants (Gujba *et al.*, 2010; Fadare *et al.*, 2018).

Nigeria as a developing country with urgent need for increase in electricity generation has initiated many policies in form of power sector development for the past decades. Despite the efforts of Federal Government of Nigeria to generate power capacity that will sustain the economy having recognized its importance to drive the economy to top level, electricity supply in Nigeria is yet to be consistent. This has constituted a great an impediment to the electricity production which is required to drive the Nation's economy. Electricity as a key infrastructure, plays a crucial role in advancing economic development by interacting with other sectors. It is essential to note that low generation of electricity affects the level of productivity, profitability, income and employment opportunities and this is linked with national security, public safety, social order and health of the people who live in Nigeria (Uduma, 2009).

In describing electricity generation deficiency in Nigeria, it is estimated that about 70% of rural communities do not have access to electricity in Nigeria. This has contributed to low rate of economic development and increase in rural - urban migration in Nigeria (Onyeisi *et al.*, 2016). Data from National Electricity Regulatory Commission (NERC) website depicted that an estimated 90 million Nigerians were without access to the national grid (Onyeisi *et al.*, 2016). In essence, electricity generation deficiency somewhat hampers industrial development, the growth of small and micro entrepreneurs, energy penetration to rural communities and economic growth. It is also retarding manufacturing capacity and the growth rate of gross domestic product (GDP), resulting in increase in unemployment. The importance of developing thermal systems that effectively use energy resources such as natural gas is apparent. Based on this fact, assessment of energy system performance becomes paramount (Oyedepo *et al.*, 2015).

1.1. Combined Cycle Power Plant

Combined cycle is an assembly of gas and steam turbines that work in tandem from the same source of heat, converting it into mechanical energy which in turn drives electrical generators to produce electricity (GE, 2017). The principle is that after completing its cycle (in the first engine), the working fluid of the first heat engine is still low enough in its entropy that a second subsequent heat engine may extract energy from the waste heat (energy) of the working fluid of the first engine. By combining these multiple streams of work upon a single mechanical shaft turning an electric generator, the overall net efficiency of the system may be increased by 50 – 60 per cent. That is, from an overall efficiency of say 34% (in a single cycle) to possibly an overall efficiency of 51% (in a mechanical combination of two cycles) in net Carnot thermodynamic efficiency. This can be done because heat engines are only able to use a portion of the energy their fuel generates (usually less than 50%). In an open cycle gas turbine (non-combined cycle) engine, the remaining heat (hot exhaust fumes) from combustion is generally wasted.

Combining two or more thermodynamic cycles result in improved overall efficiency, thus, reducing fuel costs (GE, 2017). The exhaust gas from an open cycle gas turbine usually exits the turbine with a temperature higher than 500^{o}C and can be used as heat input in a bottoming steam power cycle. In this situation, a combined cycle is formed, where the gas turbine cycle is acting as a topping cycle and its exhaust heat feeds the heat recovery steam generator fully or partially substituting the required fossil fuel of the bottoming steam Rankine cycle (Kosmadakis *et al*., 2013). This combined cycle efficiency depends on many parameters of the cycles, such as the combustion chamber temperature, the exhaust gas temperature from the gas turbine, the gas turbine efficiency, the live steam parameters, the condensation temperature, and the heat recovery steam generator efficiency. The ambient temperature also plays a significant role, since higher ambient temperatures lead to lower gas turbine power output and efficiency, thus lowering combined cycle power output. Therefore, and especially in hot climates, the combined cycles have air chillers which cool the inlet air temperature down to 10^{o}C (Kakaras *et al*., 2006).

1.2. Heat Recovery Steam Generator

The Heat Recovery Steam Generator (HRSG) is an energy recovery heat exchanger or series of heat exchangers that recovers heat from a hot gas stream. It produces steam that can be used in a process (cogeneration) or used to drive a steam turbine (combined cycle) (Ganapathy, 1996). HRSG provides the thermodynamic link between the gas and steam turbines in a combined-cycle power plant. It is widely used in process and power plants, refineries and in several cogeneration or combined cycle systems (Ganapathy, 1996). HRSG is also called a boiler, as it creates steam for the steam turbine by passing the hot exhaust gas flow from a gas turbine or combustion engine through banks of heat exchanger tubes. It can rely on natural circulation or utilize forced circulation using pumps. As the hot exhaust gases flow past the heat exchanger tubes in which hot water circulates, heat is absorbed turning the water into steam in the tubes. The tubes are arranged in sections, or modules, each serving a different function in the production of dry superheated steam (IMIA, 2015). It is usually designed for a set of gas and steam conditions but often operate under different parameters due to plant constraints, steam demand, different ambient conditions (which affect the gas flow and exhaust gas temperature in a gas turbine plant), etc. Heat recovery steam generator consists of four major components namely; the economizer, evaporator, super-heater and water pre-heater. These different components are put together to meet the operating requirements of the unit (Ganapathy, 1996).

2.0. Engineering Economic Studies

Engineering economics is the application of economic techniques to the evaluation of design and engineering alternatives (ASTM, 2010). The role of engineering economics is to assess the appropriateness of a given project, estimate its value, and justify it from an engineering standpoint. Engineers and managers use engineering economics to assist with decision making. Engineering economics contains a set of tools which engineers use to evaluate the economic viability of an engineering project. In carrying out engineering economic studies, according to DeGarmo *et al.* (1997), five basic methods are commonly used to assess economic worth namely; Present Worth (PW), Annual Worth (AW), Future Worth (FW), Internal Rate of Return (IRR), External Rate of Return (ERR).

According to the Nigerian electricity system operator's daily broadcast of the 30th of April, 2016, there was a total available capacity of 8,232 MW out of which an average of 3,746.91 MW was generated, while 3,662.20 MW was transmitted representing 45.52% and 44.49% of the available capacity respectively. A close look at the daily broadcast reveals that 15.46% of the daily available generation was hydro turbine, 16.28% was steam turbine, 54.90% was gas turbine while 13.36% was from combined cycle plants respectively. Similarly, by considering the relationship between the available capacities to the energy generated, it reveals that 48.17% of total hydro plants availability was generated, 51.80% of total steam turbine availability was generated, 35.14% of total gas turbine availability was generated while 77.41% of total combined cycle plant availability was generated. It is clear that though gas turbine plants have the highest available capacity of 4,519.5 MW representing 54.90% of the total availability, its ratio of energy generated remains the lowest at 35.14%. It is therefore necessary to evaluate ways of improving the utilization and increase the power generation without increasing gas consumption. This can be done by converting the open cycle gas turbine units to combined cycle plants. The technological feasibility of the conversion has been established in previous studies. Hence, there is need for the engineering economy assessment of the conversion to establish the economic viability of the project.

3.0. METHODOLOGY

3.1. Research Design

The study utilised descriptive method of survey to identify the types of gas turbines available in electric power generating system in Nigeria and assess the economic viability of conversion of open cycle to combined cycle gas power plants.

3.2. Coverage of the Study and Sampling

The study covered the current operating open cycle and combined cycle power plants in Nigeria. Specifically, Transcorp Power (Delta), Forte Oil (Kogi), Pacific Energy (Ogun and Ondo), Afam VI (Rivers), Okpai (Delta) and all NIPP gas turbine plants that are operational were considered.

3.3. Engineering Economy Models

The engineering economy assessment established the fact that a technically feasible project is economically viable. The following variables were used to measure the economic viability of conversion of open cycle to combined cycle gas power plant;

First Cost: Cost of conversion of selected open cycle turbines was provided by General Electric, Siemens and Mechano.

Operating cost: The projected fixed and variable operating and maintenance cost for the converted combined cycle plants were given by General Electric, Siemens and Mechano.

Salvage cost: A cost of 30% of first cost was assumed at the end of the life cycle of the plant (30 years).

Cost of electricity generated: This was provided by market operators (MO). The multi-year tariff order (MYTO) which was provided by MO ended in 2028, and a constant tariff was assumed from 2029 to 2046.

The following Engineering economic models were used:

a) Net present value (NPV)

The NPV of a series of cash flows refers to the equivalence of a single sum of money to be received or disbursed at t = 0 if all future receipts and disbursement over time are properly discounted to the present time and then summed algebraically. The net present value (NPV) model was employed to determine the profitability of the project before tax (DeGarmo *et al.*, 1997). If the NPV is positive (i.e. NPV ≥ 0), then the project can be accepted.

The formula is

$$NPV_{(i)} = \sum_{t=0}^{n} (C_b - C_c)_t (1+i)^{-t} \qquad (1)$$

where;

C_b is the cash benefit of investment

C_c is the cash cost of investment

$(C_b - C_c)_t$ is the net cash flow in the year (t)

i is the real interest rate or cut-off discount rate or the minimum attractive rate of return (MARR)

n is the calculation period also known as project life-cycle.

The MARR is usually chosen to maximize the economic well-being of an organization subject to the following considerations (De Garmo *et al.*, 1997).

i. The amount of money available for investment, the source and cost of these funds;
ii. The number of good projects available for investment, and their purpose;
iii. The amount of perceived risk that is associated with investment opportunities available to the firm, and the projected cost of administering the project over a short planning horizon versus a long planning horizon;
iv. The type of organization involved (public or competitive industry). Private competitive industries frequently employ the opportunity cost viewpoint towards choosing MARR.

In this study, the opportunity cost viewpoint was employed to choose the MARR of 15% which is the present bank savings rate. The NPV method has been used in the economic analysis of various engineering projects (Ilori *et al.*, 1999). It has also been used to study the economic viability of production of ethanol from breadfruit and cassava via plant enzyme and acid hydrolysis (Ilori *et al.*, 1999).

b) The benefit cost ratio

It is defined as the ratio of the equivalent worth of benefits to the equivalent worth of costs or dividing the net cash inflow by the net cash outflow. The formula as expressed in terms of equivalent present worth is;

$$B/C = \frac{\sum_{t=0}^{n} C_b(1+i)^{-t}}{\sum_{t=0}^{n} C_c(1+i)^{-t}} \qquad (2)$$

The project is accepted if $B/C \geq 1$, otherwise it is not accepted. The benefit-cost ratio must be considered before a final decision is reached.

c) Sensitivity analysis

This is a process of varying input parameters of a model within allowed area and observing the resulting changes in the model solution. The purpose of sensitivity analysis is to indicate the sensitivity of simulation to uncertainties in the values of input data in the model (Martina, 2002). The investment cost for General Electric, Siemens and Mechano was varied by a range of ±10% to ±30% to determine if this change would affect the project viability. The investment cost for each conversion capacity was calculated for each power plant for the study.

4.0. Results and Discussion

The economic viability of the conversion process from open cycle to combined cycle gas turbines for General Electric, Siemens and Mechano are presented in this section. Net Present Value, Sensitivity analysis, Sensitivity plots and Benefit Cost ratio were used to capture the economic acceptability of the conversion process.

4.1. Economic Viability of Conversion of Open Cycle to Combined Cycle Gas Power Plants for General Electric

Table 1 reveals the economic viability of converting open cycle gas turbine to combined cycle using net present value method. A project is understood to be viable if the net present value is greater than zero. Table 1 shows the project viability for the power plants based on the data collected from General Electric on first cost, operations and maintenance cost, major and minor maintenance cost of equipment, and revenue projections from the plants. The results indicate that the net present value for conversion of open cycle gas turbine to combined cycle is profitable for each power plant. Also, the additional conversion capacity for the power plants such as Omotosho NIPP reveals increase in net present value projection from ₦39,063,561,000 to ₦85,365,931,000,20. Similarly, it shows a cash inflow of ₦357,961,946.00 and ₦715,923.890.00 for 125 MW and 250 MW which is about 5 times higher than the cash outflow, hence a profitable net present value for each additional conversion capacity. In the same vein, the additional conversion capacity for Transcorp (26.9 MW, 53.8 MW, 80.7 MW, 107.6 MW, 134.5 MW and 161.4 MW) shows increase in net present value viability for each conversion capacity from ₦9,400,948,000.91 to ₦84,483,978,000.09. This increase is as result of the high value of the cash inflow for each conversion capacity as compared to the cash outflow.

For instance, the additional conversion capacity of 161.4 MW has a cash inflow of ₦592,942,408.00 which is five times more than the cash outflow of ₦99,442,200.00. The results in Table 1 clearly shows that converting to combined cycle power plant has greater cost value in the present. This could mean that deploying combined cycle gas turbine because its advantage of additional conversion capacity yields more in terms of present cost value when compared to the deployment of open cycle gas turbine. Calabar NIPP net present value also affirms that deploying combined cycle gas turbine by the power plants for electricity generation is profitable and can give more additional conversion capacity.

As shown in Table 1, the power plant will experience increase in net present value from ₦34,405,987,000.92 to ₦76,050,783,000.45 for 112.6 MW and 225.2 MW, respectively. Ihovbor NIPP presented a slight difference in the net present value. For 112.5 MW capacity with a cash inflow of ₦322,165,748.00 and outflow of ₦77,775,000.00, the net present value is ₦34,321,378,00.35, while the NPV for 225 MW conversion capacity with a net cash flow of ₦194,151,518.00 reduces to ₦3,780,299,000.48. The change might be as a result of high cost of operating and maintenance in the region. The reduction in NPV does not invalidate the profitability of the choice of combined cycle gas turbines for the power plant. From the Table1, combined cycle gave additional capacity depending on the number of gas turbines each power plant operates and the additional conversion capacity yielded more in the present value. Also, Table 1 shows the benefit cost ratio of converting open cycle to combined cycle gas turbine for the power plants under consideration using General Electric data. For Ihovbor power plant, the Table reveals that the benefit

Table 1: Net Present Value and Benefit Cost Ratio on the Economic Viability of Converting Open Cycle Power Plants to Combined Cycle using General Electric Data

Power Plant	**Capacity** (MW)	**First Cost** (₦,000,000)	**Cash Inflow** (₦,000,000)	**Cash Outflow** (₦,000,000)	**Net Cash Flow** (₦,000,000)	**NPV** (₦,000,000)	**Net Cash Inflow** (₦,000)	**Net Cash Outflow** (₦,000)	**Benefit Cost Ratio**
Ihovbor	112.5	(37,743.75)	322,165.748	77,775	244,390.748	34,321.378	80,423,401.73	46,593,286.88	1.73
	225	(75,487.50)	644,331.518	450,180	194,151.518	3,780.299	160,846,805.23	157,066,505.75	1.02
Omotosho NIPP	125	(41,937.50)	357,961.946	81,968.75	275,993.196	39,063.561	89,359,334.78	50,295,773.38	1.78
	250	(83,875)	715,923.89	129,167.50	586,756.39	85,365.931	178,718,668.95	93,352,737.75	1.91
Geregu NIPP	145	(61,915)	419,216.108	101,946.25	317,269.858	33,443.656	102,522,105.34	70,273,273.38	1.46
Omotosho 1	38	(12,749)	129,166.203	42,715.25	86,450.953	12,884.024	31,845,530.42	18,961,506.88	1.68
	76	(25,498)	258,332.385	60,496.75	197,835.635	30,907.670	63,691,059.83	32,783,390.13	1.94
	114	(38,247)	387,498.569	78,278.25	309,220.319	48,931.316	95,536,589.54	46,605,273.38	2.05
	152	(50,996)	518,164.77	96,288.50	421,876.27	66,931.032	127,404,769.55	60,473,737.75	2.11
Transcorp	26.9	(9,024.95)	95,722.425	38,991.20	56,731.225	9,400.949	24,638,405.78	15,237,456.88	1.62
	53.8	(18,049.90)	197,647.47	53,048.65	144,598.82	24,035.182	49,370,472.58	25,335,290.13	1.95
	80.7	(27,074.85)	296,471.194	62,073.60	234,397.594	39,695.467	74,055,707.50	34,360,240.13	2.16
	107.6	(36,099.80)	395,294.939	76,131.05	319,163.889	54,282.871	98,740,944.33	44,458,073.38	2.22
	134.5	(45,124.75)	494,118.662	85,156	408,962.662	69,943.155	123,426,178.30	53,483,023.38	2.31
	161.4	(54,149.70)	592,942.408	99,442.20	493,500.208	84,483.978	148,111,415.84	63,627,437.75	2.33
Calabar NIPP	112.6	(37,777.30)	325,543	77,808.55	247,734.45	34,405.988	80,541,561.30	46,135,573.38	1.75
	225.2	(75,554.60)	651,085.98	120,847.10	530,238.88	76,050.783	161,083,121.20	85,032,337.75	1.89
Geregu Forte Oil	145	(61,915)	528,805.093	101,946.25	426,858.843	61,783.173	130,533,026.86	70,273,273.38	1.86

cost ratio is 1.73 for 112.5 MW and 1.02 for 225 MW, while it shows a benefit cost ratio of 1.75 (112.6 MW) and 1.89 (225.2 MW) for Calabar NIPP.
Furthermore, Geregu Forte Oil shows a higher B/C of 1.86 than Geregu NIPP with a B/C ratio of 1.46. This might be because Geregu Forte Oil has a higher net cash inflow due to their forecasted revenue stream for conversion. Similarly, Omotosho Phase 1 reveals an increased B/C ratio as the con version capacity increases from 1.68 (38 MW), 1.94 (76 MW), 2.05 (114 MW) to 2.11 (152 MW). Also, Transcorp NIPP indicates increases in B/C ratio from 1.62 (26.9 MW), 1.95 (53.8 MW), 2.16 (80.7 MW), 2.22 (107.6 MW), 2.31 (134.5 MW), to 2.33 (161.4 MW). The Table explains that the higher the conversion capacity the higher the B/C ratio. This could be due to the higher revenue streams that will be accrued from converting open cycle to combined cycle gas turbines. From the Table, it was also discovered that as the conversion capacity increases it will become more profitable to convert from open cycle gas turbine to combined cycle gas turbine for electricity generation.

3.2. Economic Viability of Conversion of Open Cycle Gas Turbine to Combined Cycle for Mechano

Table 2 reveals the project viability of converting open cycle gas to combined cycle gas turbine for the power plants under consideration based on Mechano data. The result reveals the cash inflows and outflows for each power plants additional conversional capacity. The cash inflows as shown has a higher value which surpasses the cash outflows indicating that the project will become viable if deployed. Furthermore, the Table shows that Ihovbor NIPP and Calabar NIPP will be able to successfully convert from open cycle to combined cycle for additional capacity of 112.5 MW and 225 MW, as shown by the net present value of ₦27,920,387,000.42 and ₦58,548,063,000.60 for Ihovbor, ₦27,949,216,000.30 and ₦58,605,718,000.40 for Calabar NIPP respectively.

The similarity in net cash flow is because both plants have the same capacity of 112.5 MW and 225 MW for electricity generation. The net cash flows of ₦94,901,203, ₦206,320,385, ₦317,415,569 and ₦418,293,770 for Omotosho Phase 1 and ₦69,298,435, ₦155,114,870, ₦242,452,294, ₦327,944,939, ₦415,282,162 and ₦494,057,608 for Transcorp plants shows that there is increase in project viability for each additional conversion capacity from ₦11,823,489,000.92 to ₦51,183,766,000.55 and ₦9,402,895,000.07 to ₦72,876,612,000.84 for each capacity respectively. The result shows that conversion of open cycle to combined cycle gas turbine is profitable and will give good returns on investment under existing fiscal and regulatory framework in Nigeria. Similarly, Table 2 reveals the benefit cost ratio of converting open cycle to combined cycle gas turbine using Mechano data. The Table depicts the net cash inflow and outflow for the data provided for each plants and their capacity. From the results of Table 2, it is viable to covert from open cycle to combined cycle because the B/C ratios for the power plants is greater than 1. Ihovbor and Calabar NIPP show a B/C ratio of 1.53 for 112.5 MW and 1.57 for 225 MW capacity respectively. The same B/C ratio might be due to similar capacity for both gas power plants. Omotosho NIPP shows a B/C ratio of 1.54 (125 MW) and 1.58 (250 MW). Geregu NIPP and Geregu Forte Oil with capacity of 145 MW have a B/C ratio of 1.36 and 1.73. This is probably due to the difference in value of the net cash inflow.

3.3. Economic Viability of Conversion of Open Cycle Gas Turbine to Combined Cycle for Siemens

Table 3 shows the economic viability of converting open cycle gas turbine to combined cycle based on Siemens data. The results reveal that for the power plants, it is economically viable to convert to combined cycle gas turbine. This is simply because for additional conversion capacity, there is noticeably positive increase in the net present value which could indicate that it is vital to convert from open cycle to combined cycle gas turbine. The cash inflow and outflow for Transcorp power plant as revealed by Table 3 increased from ₦97,679,197.10 to ₦586,075,241.50 and ₦14,920,153.00 to ₦89,520,905.00 respectively for each additional conversion capacity of the plant. The higher the additional conversion capacity the more viable it will become as indicated by the increased net cash flow from ₦9,400,948,000.91 to ₦84,483,978,000.09.

Table 2: Net Present Value and Benefit Cost Ratio on the Economic Viability of Converting Open Cycle Power Plants to Combined Cycle using Mechano Data

Power Plant	**Capacity** (MW)	**First Cost** (₦,000,000)	**Cash Inflow** (₦,000,000)	**Cash Outflow** (₦,000,000)	**Net Cash Flow** (₦,000,000)	**NPV** (₦,000,000)	**Net Cash Inflow** (₦,000)	**Net Cash Outflow** (₦,000)	**Benefit Cost Ratio**
Ihovbor	112.5	(37,743.75)	325,253.873	69,442.50	255,811.373	27,920.387	80,470,032.42	52,549,645.00	1.53
	225	(96,075)	650,507.768	126,042	524,465.768	58,548.064	160,940,066.60	102,392,003.00	1.57
Omotosho NIPP	125	(53,375)	361,393.196	74,780	286,613.196	31,524.002	89,411,146.66	57,887,145.00	1.54
	250	(106,750)	722,786.39	136,717	586,069.39	65,755.290	178,822,292.70	113,067,003.00	1.58
Geregu NIPP	145	(70,760)	421,869.608	92,165	329,704.608	28,484.852	102,562,173.19	75,272,145.00	1.36
Omotosho 1	38	(16,226)	129,166.203	34,265	94,901.203	11,823.490	31,845,530.42	20,022,040.50	1.59
	76	(32,452)	258,332.385	52,012	206,320.385	27,111.279	63,691,059.83	36,579,781.25	1.74
	114	(48,678)	387,498.569	70,083	317,415.569	42,346.445	95,536,589.54	53,190,145.00	1.80
	152	(69,904)	518,164.77	99,871	418,293.77	51,183.767	127,404,769.55	76,221,003.00	1.67
Transcorp	26.9	(11,486.30)	98,823.735	29,525.30	69,298.435	9,402.895	24,638,405.78	15,282,340.50	1.61
	53.8	(22,972.60)	197,647.47	42,532.60	155,114.87	22,270.091	49,370,472.58	27,100,381.25	1.82
	80.7	(34,458.90)	296,471.194	54,018.90	242,452.294	35,469.026	74,055,707.50	38,586,681.25	1.92
	107.6	(45,945)	395,294.939	67,350	327,944.939	48,283.799	98,740,944.33	50,457,145.00	1.96
	134.5	(57,431.50)	494,118.662	78,836.50	415,282.162	61,482.533	123,426,178.30	61,943,645.00	1.99
	161.4	(68,917.80)	592,942.408	98,884.80	494,057.608	72,876.613	148,111,415.84	75,234,803.00	1.97

	112.6	(48,080.20)	325,543	69,485.20	256,057.80	27,949.216	80,541,561.30	52,592,345.00	1.53
Calabar NIPP	225.2	(96,160.40)	651,085.98	126,127.40	524,958.58	58,605.718	161,083,121.20	102,477,403.00	1.57
Geregu Forte Oil	145	(70,760)	531,458.593	92,165	439,293.593	56,824.369	130,573,094.71	75,272,145.00	1.73

Ihovbor power plants show increase in net present value from ₦43,199,476,000.91 to ₦86,398,957,000.10 for converting 2 units (112.5 MW) and 4 units (225 MW) gas turbine. The results show that Ihovbor power plant will become viable in deploying combined cycle gas turbine as also seen by the high value of the cash inflows ₦320,467,279.40 and ₦640,934,580.50 as compared to the cash outflows for each conversion capacity. Similarly, Omotosho NIPP power plants with a cash inflow of ₦356,074,758.50 and ₦712,149,515.00 increase in net present value from ₦47,999,418,000.86 to ₦95,998,836,000.51. The positivity and increase in net present value for each conversion capacity might be because of the viability of the project of converting open cycle to combined cycle gas turbine. Geregu NIPP and Geregu Forte Oil plants with capacity of 145MW each, have net present value of ₦55,679,325,000.06 and ₦84,018,842,000.44 respectively.

The project profitability of Geregu NIPP and Forte oil is also as a result of the cash inflows that supersedes the outflows. Falode and Ladeinde (2016) on the economic evaluation of gas power plant project for the first gas industrial park in Nigeria stated that in investment theory, projects that have positive NPV values are implementable. It is assumed that the discount factor will handle inflation and some uncertainty in the time value of money. The result of their finding showed that for the project, net cash flow is forecasted to be positive for most years. There was a negative cash flow before 2019 because those years are the construction period of the power plant and where capital is mostly invested, but after that period, net cash flow was positive throughout the power generation period.

Similarly, Table 3 shows the Benefit Cost ratio for converting open cycle gas turbines to combine cycle using Siemens manufacturer data for each gas power plants considered. As stated in the previous B/C ratio discussion, final decision on project acceptability is taken if the economic evaluation is greater than 1 for each capacity of the gas power plants. From the Table, it can be revealed that the B/C ratio of the gas power plants have values of 2 and above. The Table depicts that Ihovbor power plant has a B/C ratio of 2.16 for 112.5 MW and 225 MW. Similar result was observed in Omotosho NIPP for 125 MW and 250 MW.

3.4. Sensitivity Analysis for the Conversion Viability of Open Cycle to Combined Cycle General Electric Plants

The sensitivity analysis of the project viability of converting open cycle to combined cycle gas turbine captured variations in investment cost from ±10% to ±30% in order to determine if a change over the variations can alter the decision taken on the net present value. The results of the analysis are represented by the spider plots as shown in Figure 1 to 7 for each individual power plant. Figure 1 shows that for Ihovbor NIPP plant, the additional conversion capacity of 112.5 MW is not sensitive to change in investment cost over a range of ±10% to ±30%. However, 225 MW additional conversion capacity indicated that net present value would be affected by a change in investment cost over the range of values for +10% (-₦3,768,450,000.52), +20% (-₦11,317,200,000.52) and +30% (-₦18,865,950,000.52) thereby making the project not viable at these new investment costs. Similarly, Figures 2 to 7 show the additional conversion capacity for Omotosho NIPP (125 MW and 250 MW), Geregu NIPP (145MW), Omotosho Pacific Energy (38 MW, 76 MW, 114 MW and 152 MW), Transcorp (26.9 MW, 53.8 MW,80.7 MW, 107.6 MW, 134.5 MW and 161.4 MW), Calabar NIPP (112.6 MW and 225.2 MW) and Geregu Forte oil (145 MW). These Figures show that the net present value remains positive for the variations of ±10% to ±30% in the investment cost and as such not sensitive to the change. This means that uncertainties like increased cost of acquisition of equipment and installation cost would probably not affect the decision taken on the net cash flow.

Table 3: Net Present Value and Benefit Cost Ratio on the Economic Viability of Converting Open Cycle Power Plants to Combined Cycle using Siemens Data

Power Plant	**Capacity** (MW)	**First Cost** (₦,000,000)	**Cash Inflow** (₦,000,000)	**Cash Outflow** (₦,000,000)	**Net Cash Flow** (₦,000,000)	**NPV** (₦,000,000)	**Net Cash Inflow** (₦,000)	**Net Cash Outflow** (₦,000)	**Benefit Cost Ratio**
Ihovbor	112.5	(37,743.75)	320,467.279	62,398.401	258,068.878	43,199.477	80,397,754.85	37,186,451.19	2.16
	225	(75,487.50)	640,934.581	124,796.796	516,137.785	86,398.957	160,795,511.47	74,396,554.37	2.16
Omotosho NIPP	125	(41,937.50)	356,074.759	69,331.557	286,743.202	47,999.419	89,330,838.25	41,331,419.40	2.16
	250	(83,875)	712,149.515	138,663.110	573,486.405	95,998.837	178,661,675.89	82,662,839.37	2.16
Geregu NIPP	145	(61,915)	413,046.721	80,424.605	332,622.116	55,679.325	102,428,947.59	47,944,446.36	2.14
Omotosho 1	38	(12,749)	127,549.398	21,076.792	106,472.606	19,256.366	31,821,116.66	12,564,750.85	2.53
	76	(25,498)	255,098.775	42,153.586	212,945.189	38,512.729	63,642,232.32	25,129,503.68	2.53
	114	(38,247)	382,648.154	63,230.379	319,417.775	57,769.094	95,463,348.27	37,694,254.22	2.53
	152	(50,996)	510,197.55	84,307.170	425,890.380	77,025.459	127,284,464.53	50,259,005.70	2.53
Transcorp	26.9	(9,024.95)	97,679.197	14,920.153	82,759.044	15,773.432	24,667,953.04	8,894,521.26	2.77
	53.8	(18,049.90)	195,358.415	29,840.301	165,518.114	31,546.865	53,869,131.20	17,789,042.79	3.03
	80.7	(27,074.85)	293,037.611	44,760.453	248,277.158	47,320.296	74,003,860.39	26,683,564.70	2.77
	107.6	(36,099.80)	390,716.828	59,680.605	331,036.223	63,093.728	98,671,814.85	35,578,086.61	2.77
	134.5	(45,124.75)	488,396.023	74,600.754	413,795.269	78,867.159	123,339,766.46	44,472,607.52	2.77
	161.4	(54,149.70)	586,075.242	89,520.905	496,554.337	94,640.592	148,007,721.63	53,367,129.84	2.77
Calabar NIPP	112.6	(37,777.30)	320,752.152	62,453.864	258,298.288	43,237.877	80,469,219.49	37,231,342.03	2.16
	225.2	(75,554.60)	641,504.283	124,907.725	516,596.558	86,475.754	160,938,437.58	74,462,684.08	2.16
	145	(61,915)	522,635.706	80,424.605	442,211.101	84,018.842	130,439,869.11	47,944,446.36	2.72

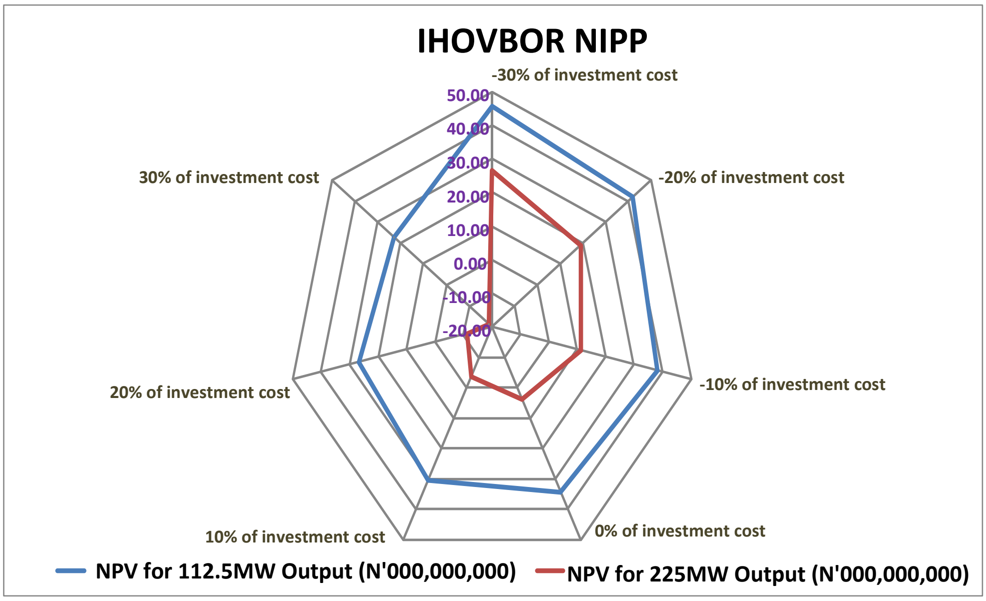

Figure 1: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Ihovbor NIPP using GE data

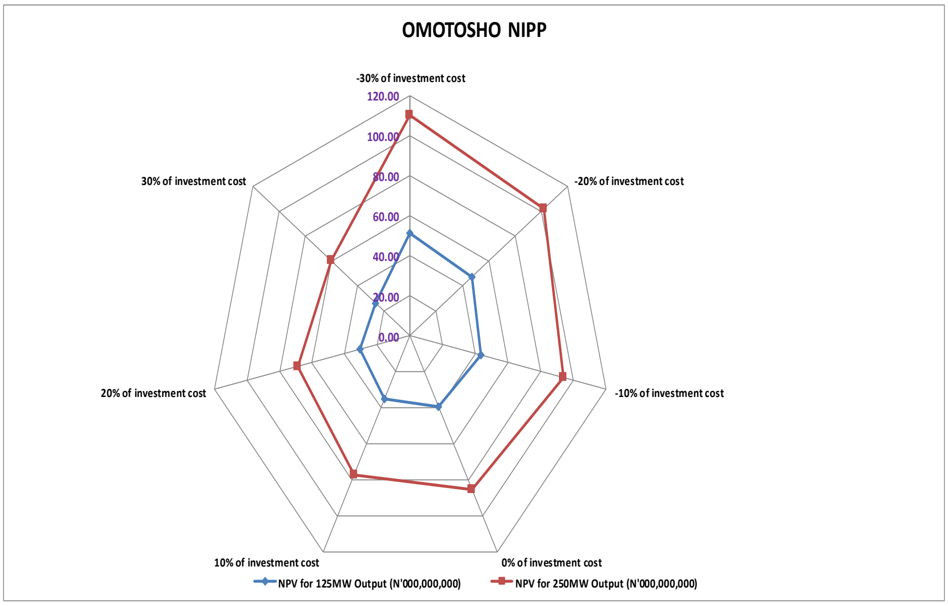

Figure 2: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Omotosho NIPP using GE data

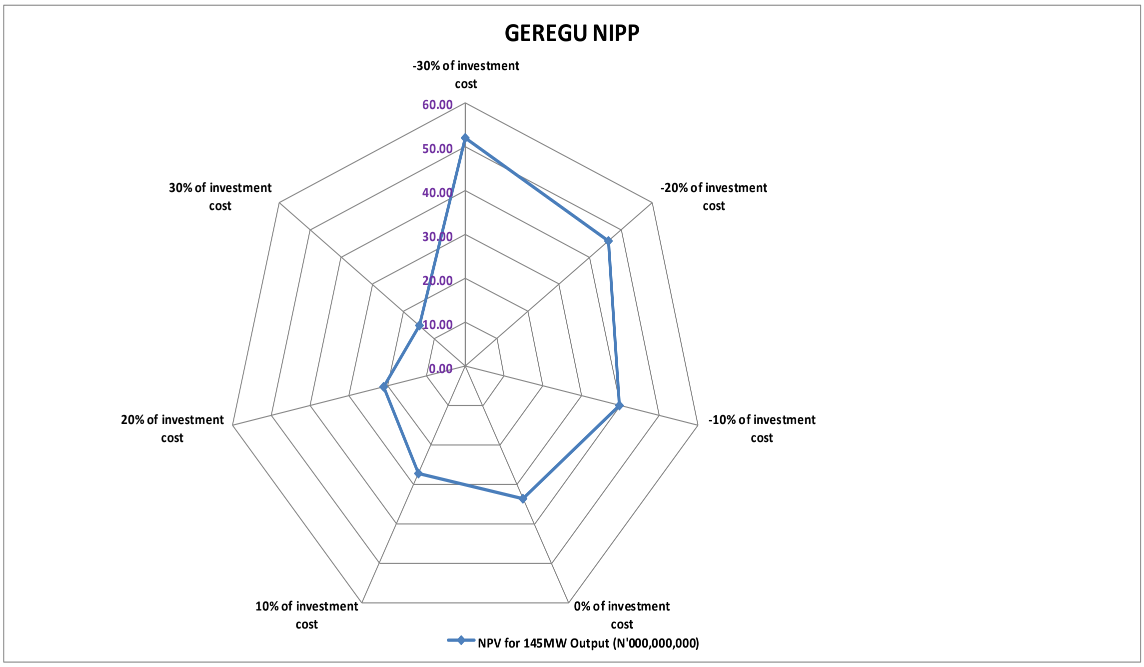

Figure 3: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Geregu NIPP using GE data

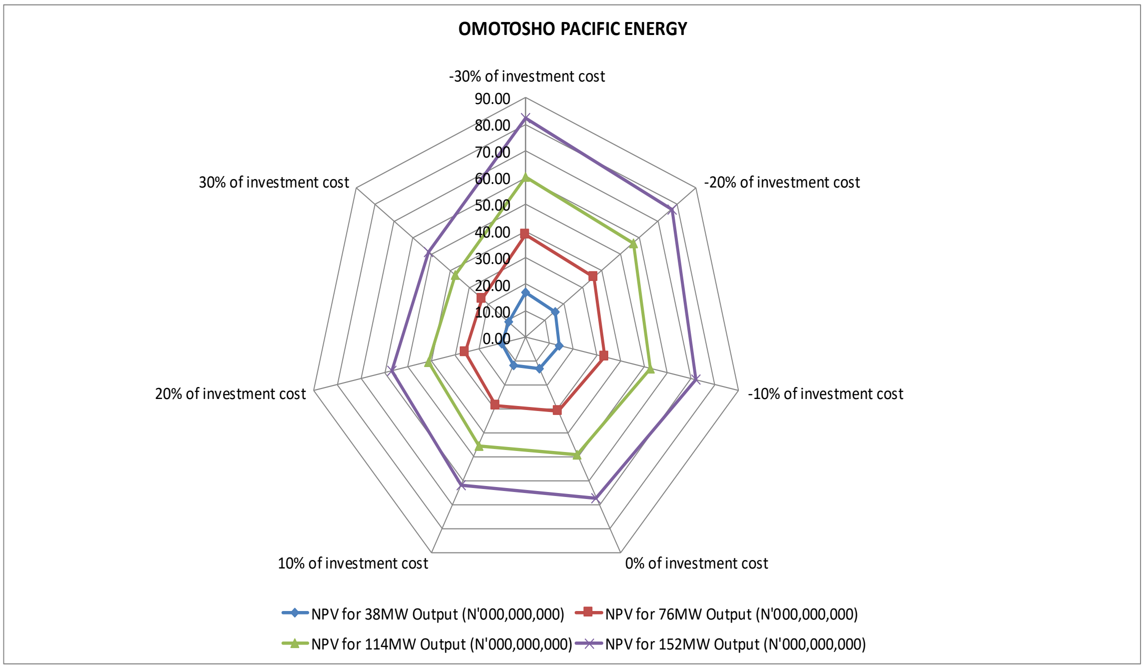

Figure 4: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Omotosho Pacific Energy using GE data

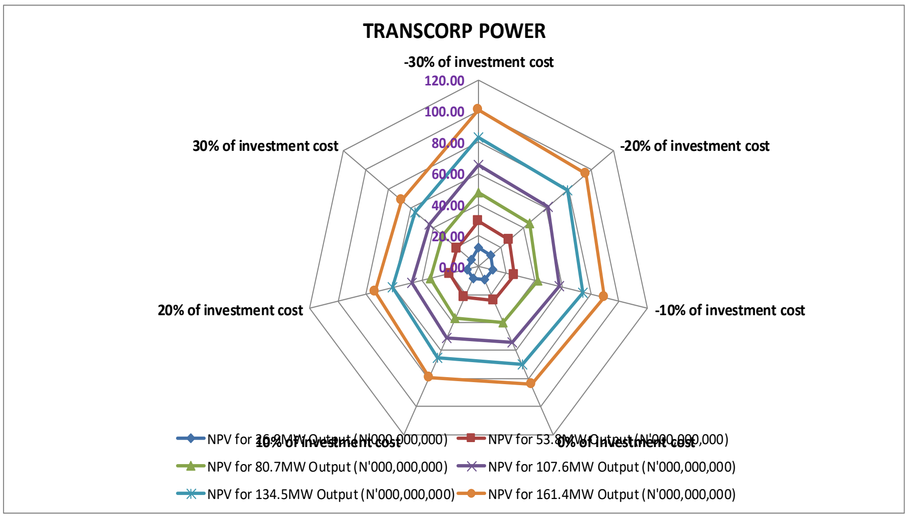

Figure 5: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Transcorp Power using GE data

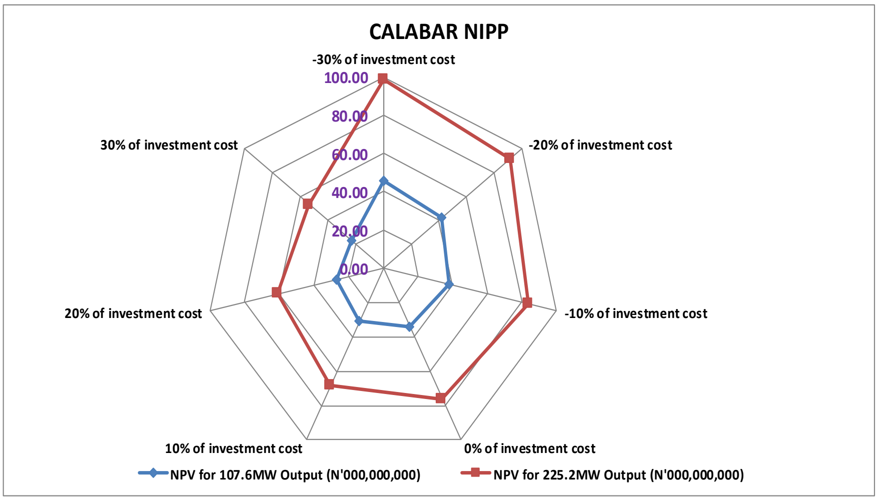

Figure 6: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Calabar NIPP using GE data

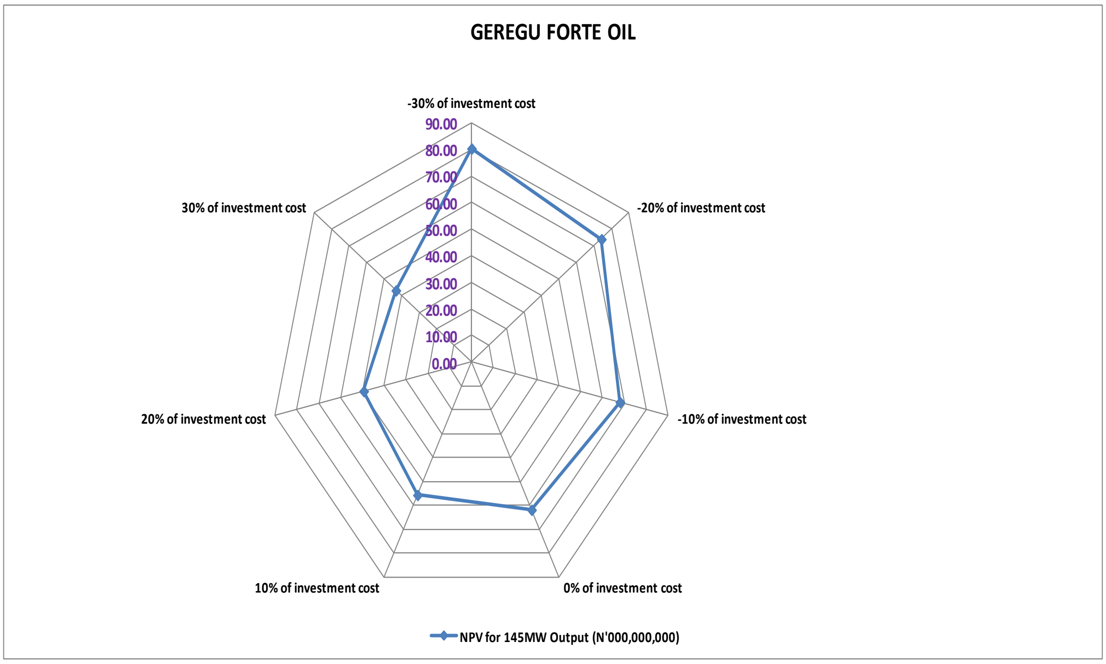

Figure 7: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Gregu Forte Oil using GE data

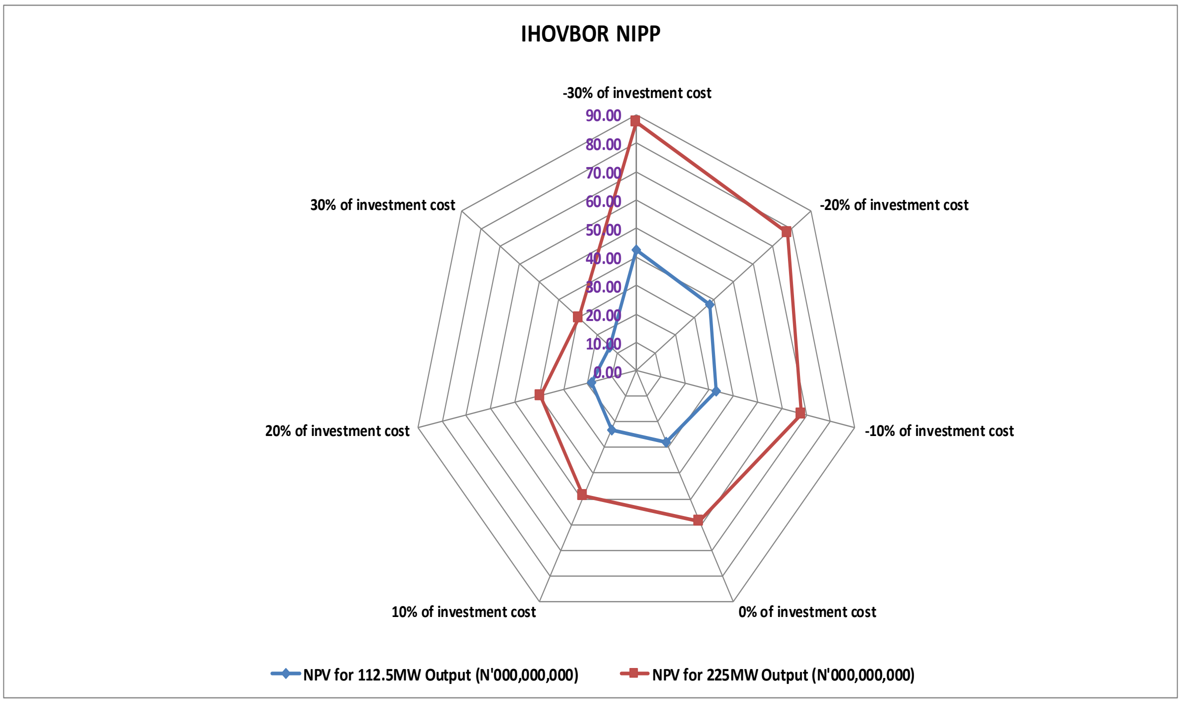

Figure 8: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Ihovbor NIPP using Mechano data

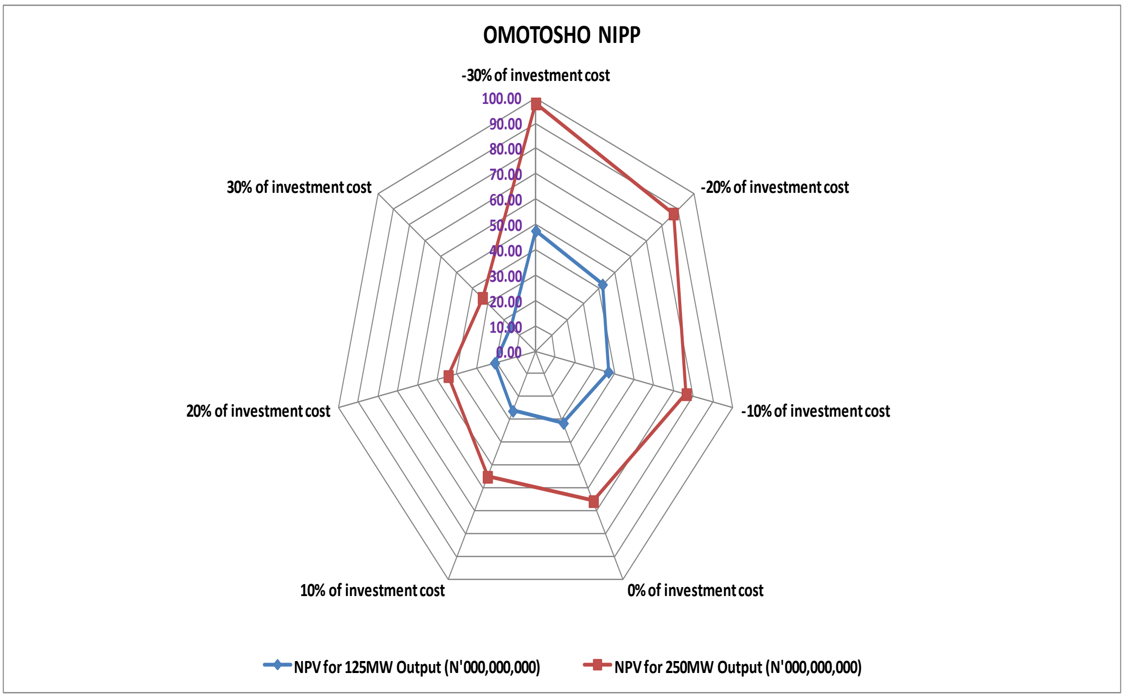

Figure 9: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Omotosho NIPP using Mechano data

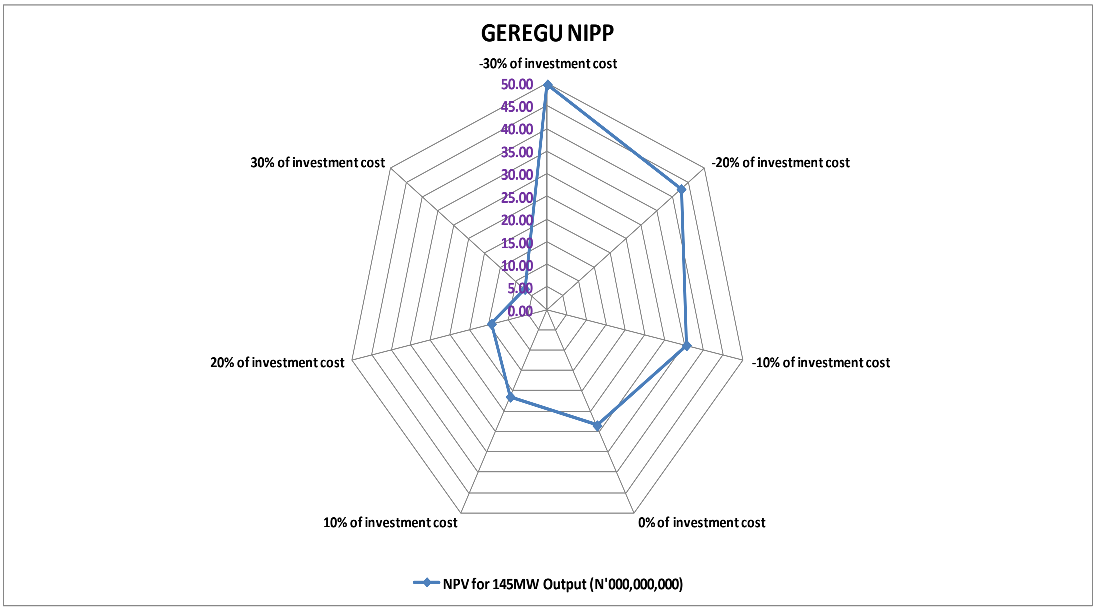

Figure 10: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Geregu NIPP using Mechano data

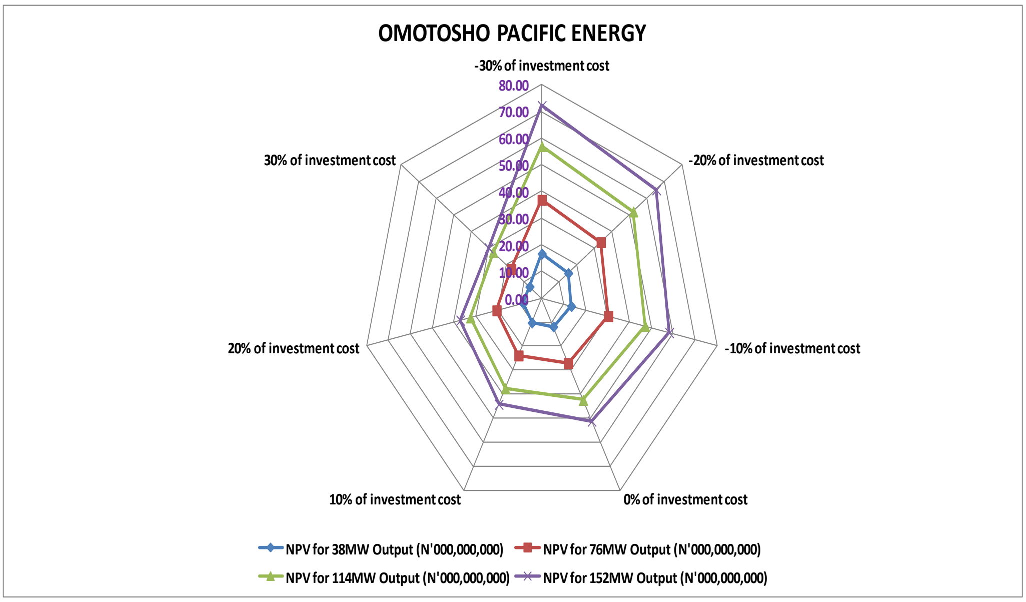

Figure 11: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Omotosho Pacific Energy using Mechano data

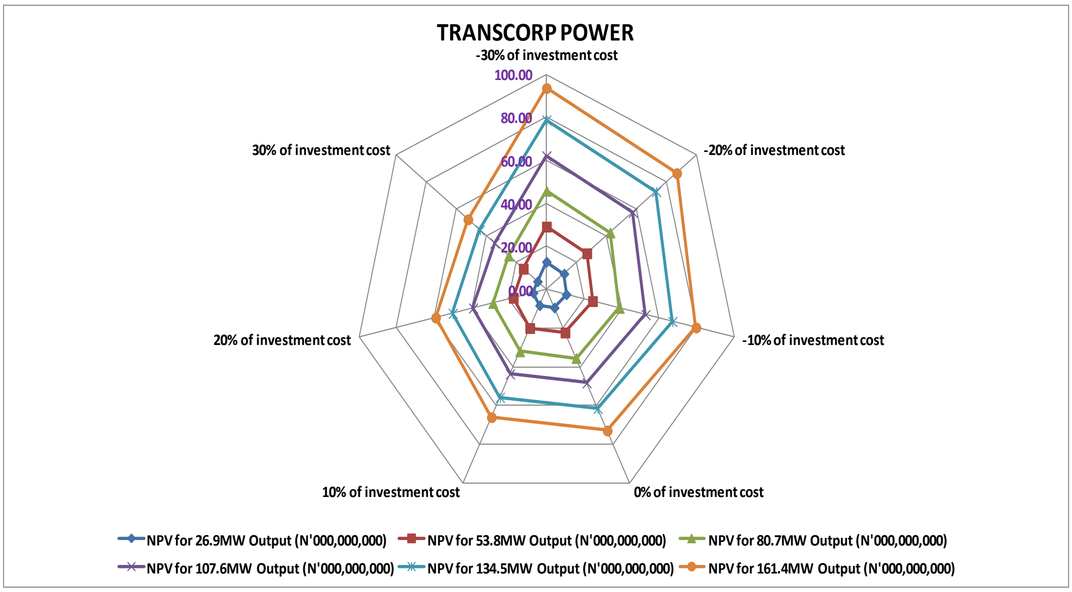

Figure 12: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Transcorp Power using Mechano data

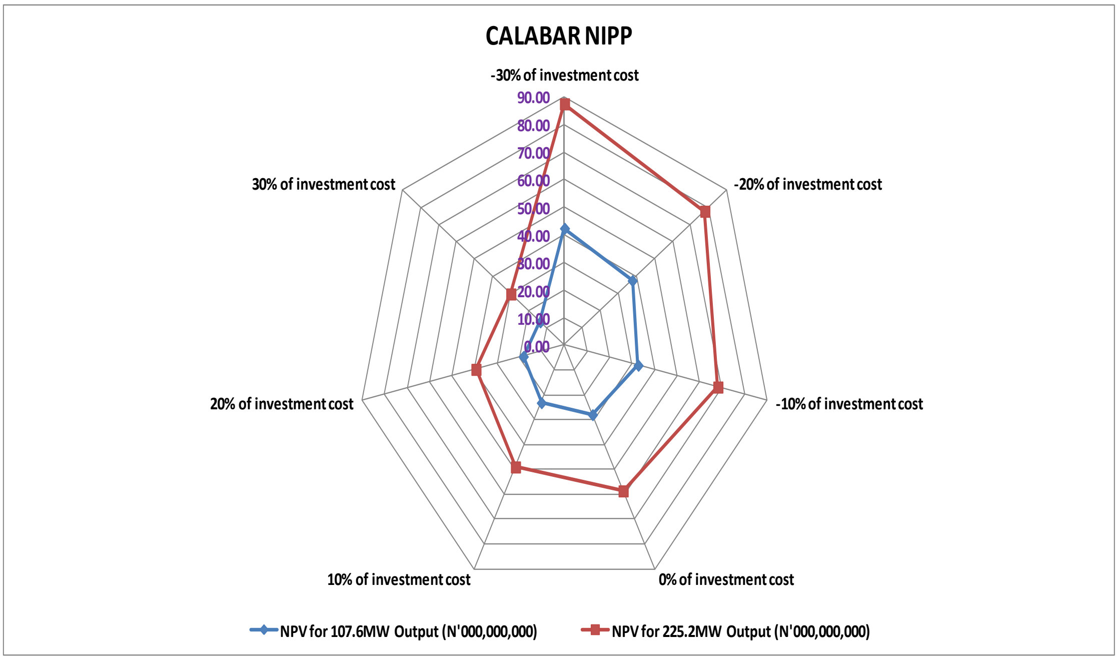

Figure 13: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Calabar NIPP using Mechano data

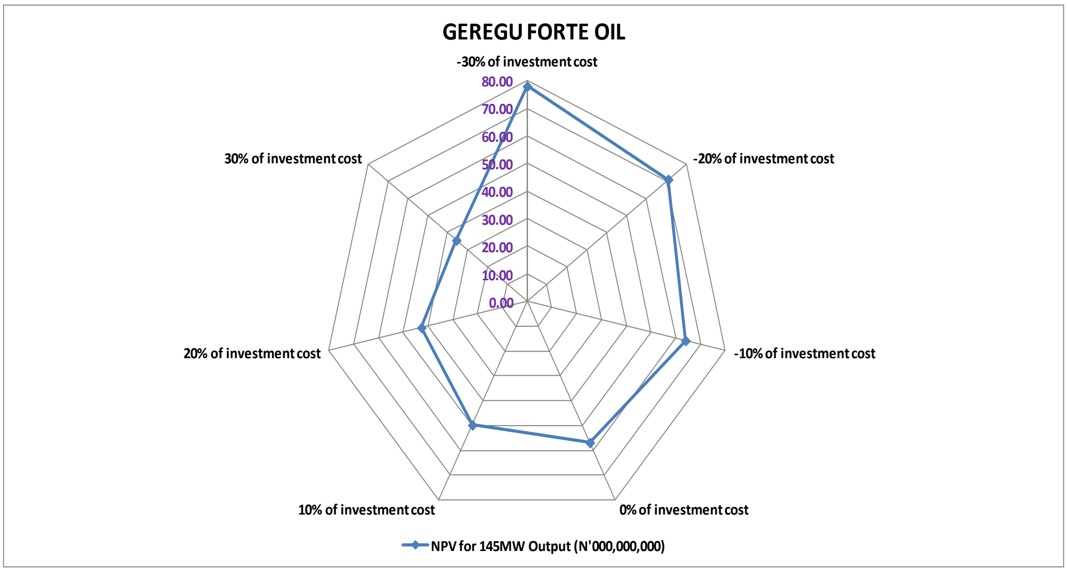

Figure 14: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Geregu Forte Oil using Mechano data

3.5. Sensitivity Analysis for the Conversion Viability of Open Cycle to Combined Cycle Mechano Plants

Similarly, the sensitivity analysis of the project viability of converting open cycle to combined cycle gas turbine using Mechano data captured variations in investment cost from ±10% to ±30%. Figures 8 to 14 show the spider plot of the sensitivity analysis. The result obtained is much similar to sensitivity analysis result for Siemens. This indicates that a change in investment cost over a range of values from ±10% to ±30% gives a positive NPV. This indicates that change in the investment cost would not affect the decision of the economic viability of the conversion of open cycle gas turbine to combined cycle for each additional conversion capacity.

3.6. Sensitivity Analysis for the Conversion Viability of Open Cycle to Combined Cycles Siemens Plants

The sensitivity analysis of the project viability of converting open cycle to combined cycle gas turbine for Siemens manufacturer data captured variations in investment cost from ±10% to ±30% in order to determine if a change over the variations can alter the decision taken on the net present value. The results of the analysis are represented by the spider plots as shown in Figures15 to 21 for the individual power plants. Figure 15 reveals that for Ihovbor NIPP Plant, a change in investment cost over a range of values from ±10% to ±30% would not affect the decision on the economic viability of the conversion of open cycle gas turbine to combined cycle. This means that for both available conversion options (112.5 MW and 250 MW) at Ihovbor power plant, a variation of the investment cost by +10% (₦39,991,258,000.11, ₦79,982,519.60), -10% (₦46,407,695,000.71, ₦92,815,394.60), +20% (₦36,783,039,000.31, ₦73,566,082.10), -20% (₦49,615,914,000.51, ₦99,231,832.10), +30% (₦33,574,820,000.51, ₦67,149,644.60) and -30% (₦52,824,133,000.31, ₦105,648,269.60), respectively. This implies that the variations are not sensitive to uncertainties or changes. Similarly, Figures 16 to 21 show the additional conversion capacity for Omotosho NIPP (125 MW and 250 MW), Geregu NIPP (145 MW), Omotosho Pacific Energy (38 MW, 76 MW, 114 MW and 152 MW), Transcorp (26.9 MW, 53.8 MW, 80.7 MW, 107.6 MW, 134.5 MW and 161.4 MW), Calabar NIPP (112.6 MW and 225.2 MW) and Geregu Forte oil (145 MW).

These Figures show that the net present values remain positive for the variations of ±10% to ±30% in the investment cost. This implies that the NPV is not sensitive to uncertainties regarding the investment cost.

4.0. Conclusion

The study concluded that most of the open cycle plants considered in this work are adequate to undergo the conversion process. The results of the net present value, benefit cost ratio and sensitivity analysis helped to determine the project viability of the conversion process. The sensitivity analysis of the project viability shows that a change in investment cost over a range of values from ±10% to ±30% would not affect the decision on the economic viability of the conversion of open cycle gas turbine to combined cycle. There is a positive net present value for increased additional conversion capacity for the power plants under consideration, thereby making the conversion viable for all the power plants and scenarios considered. The conversion process for the power plants for each additional conversion units shows that it is profitable to convert to combined cycle gas turbine for generation of electricity. Therefore, additional power can be generated from converting the open cycle plants to combined cycle. This additional generation will not need an increment in the capacity of gas consumption of these plants.

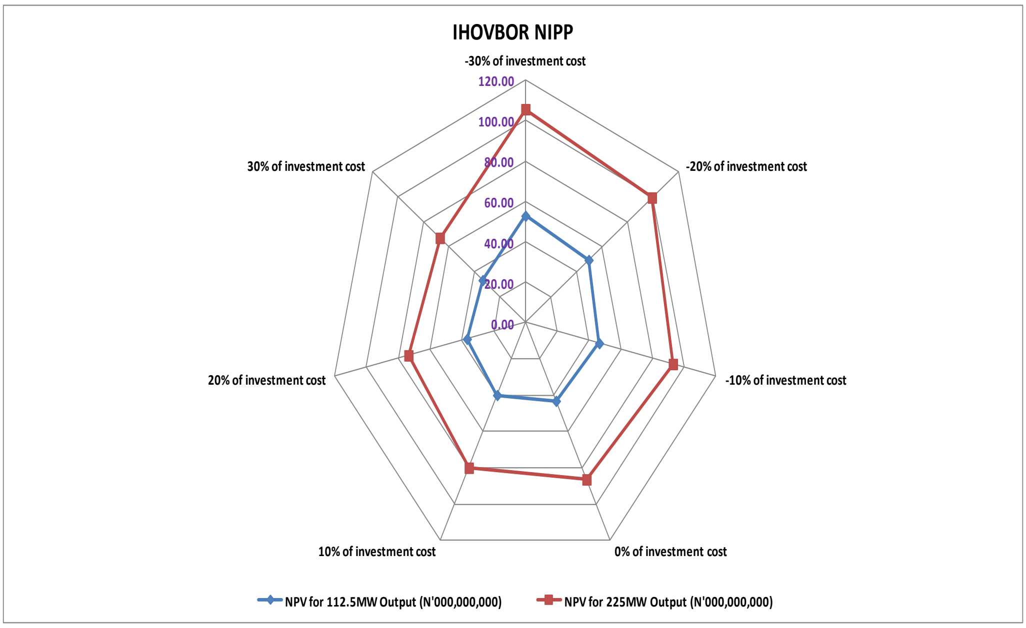

Figure 15: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Ihovbor NIPP using Siemens data

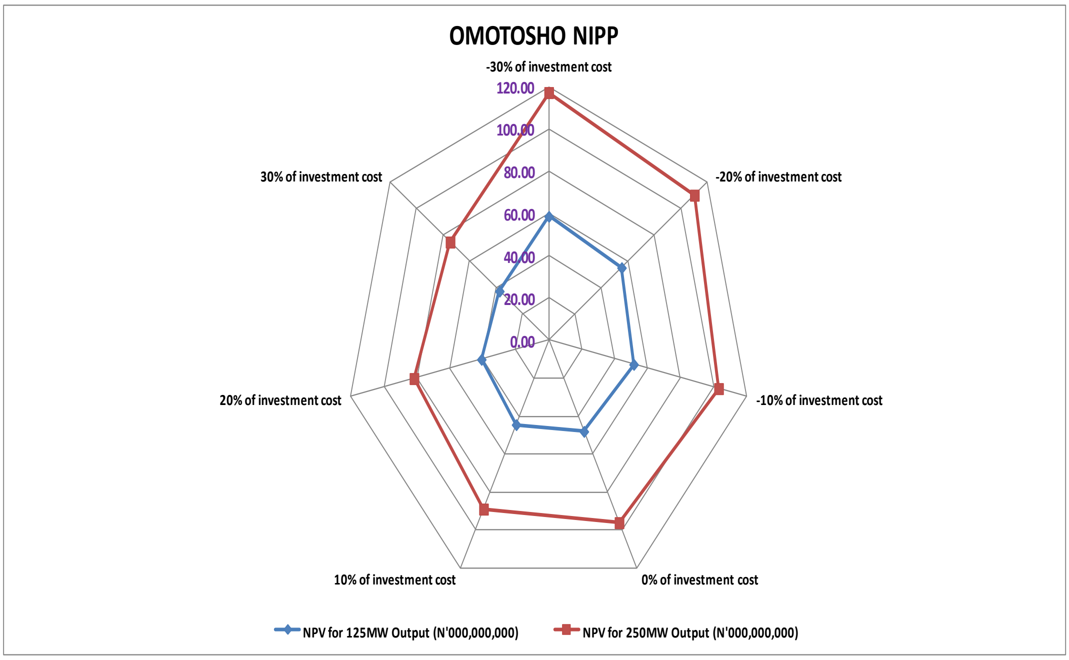

Figure 16: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Omotosho NIPP using Siemens data

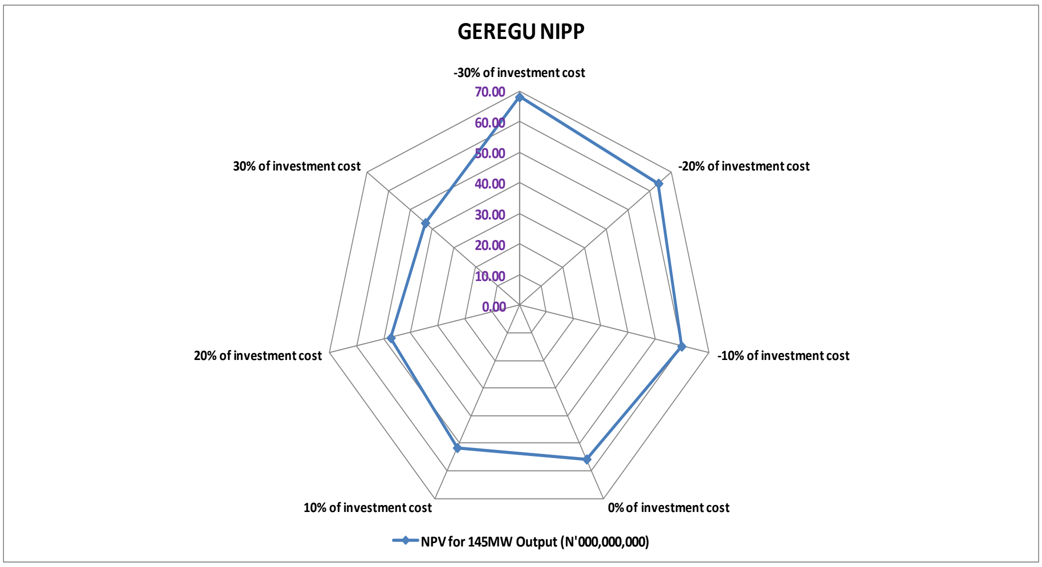

Figure 17: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Geregu NIPP using Siemens data

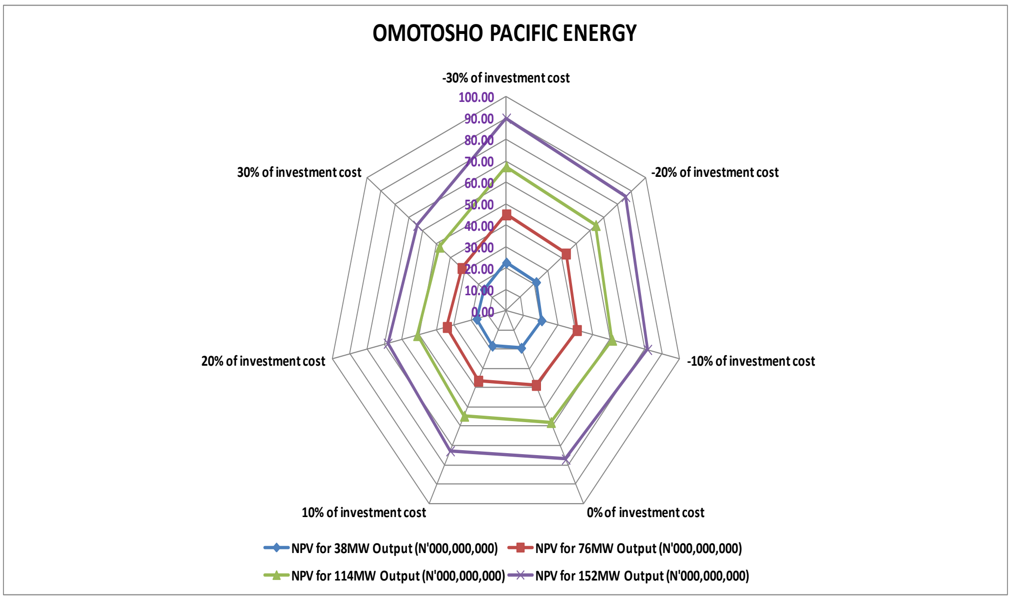

Figure 18: NPV chart for sensitivity analysis (±10% to ±30% variation of Investment cost) for Omotosho Pacific Energy using Siemens data

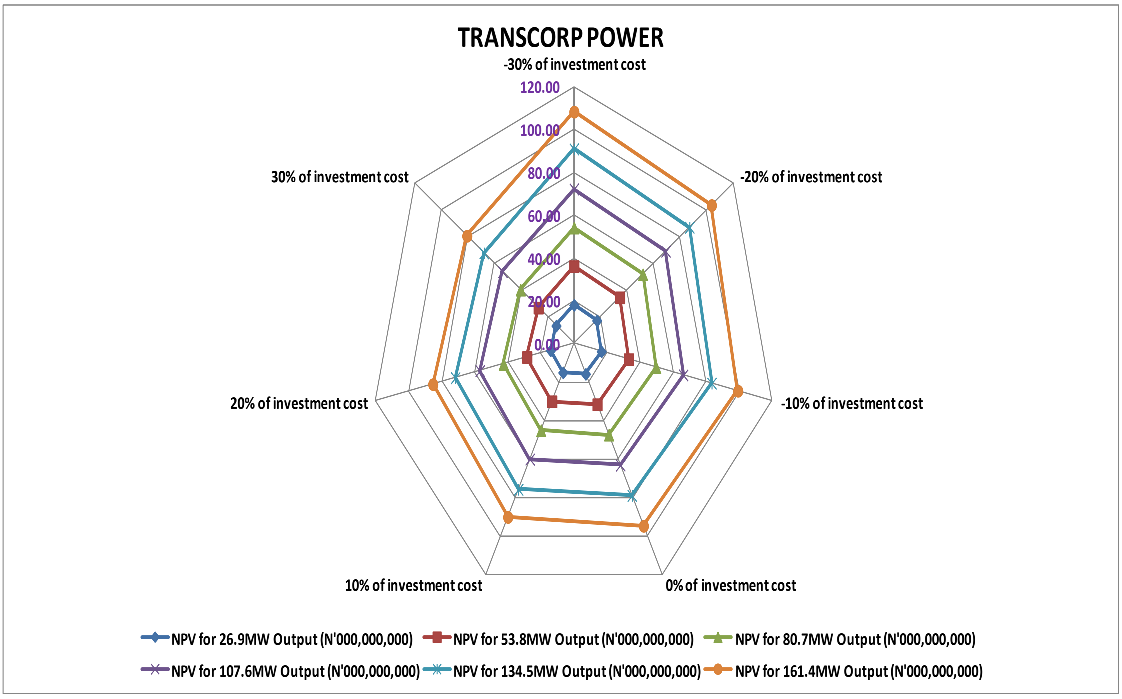

Figure 19: NPV chart for sensitivity analysis (±10 % to ±30 % variation of investment cost) for Transcorp Power using Siemens data

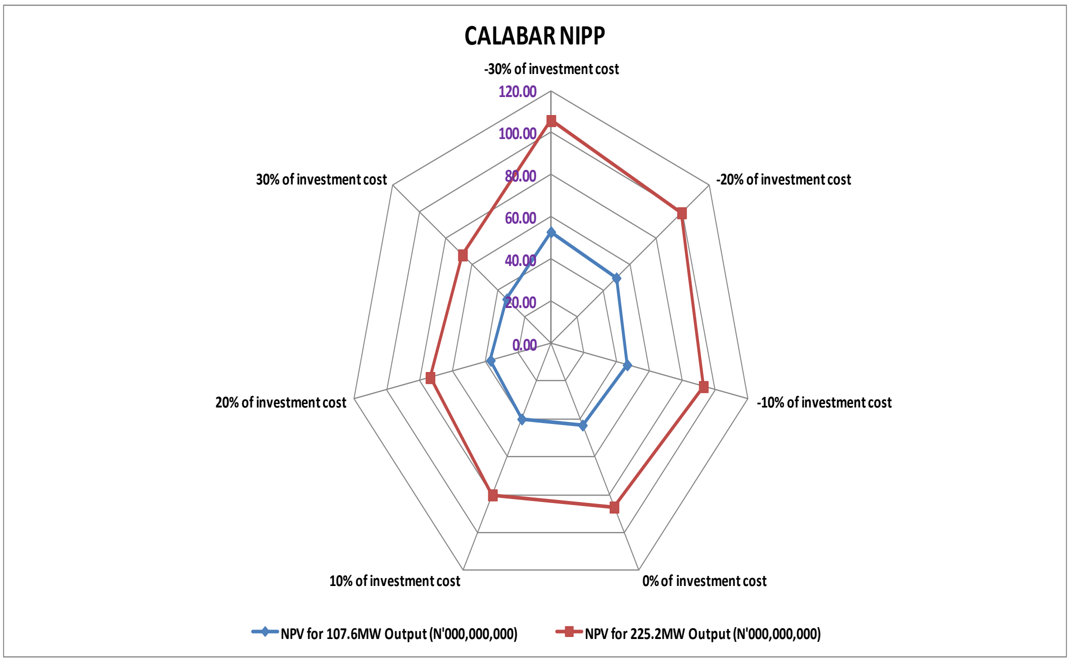

Figure 20: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Calabar NIPP using Siemens data

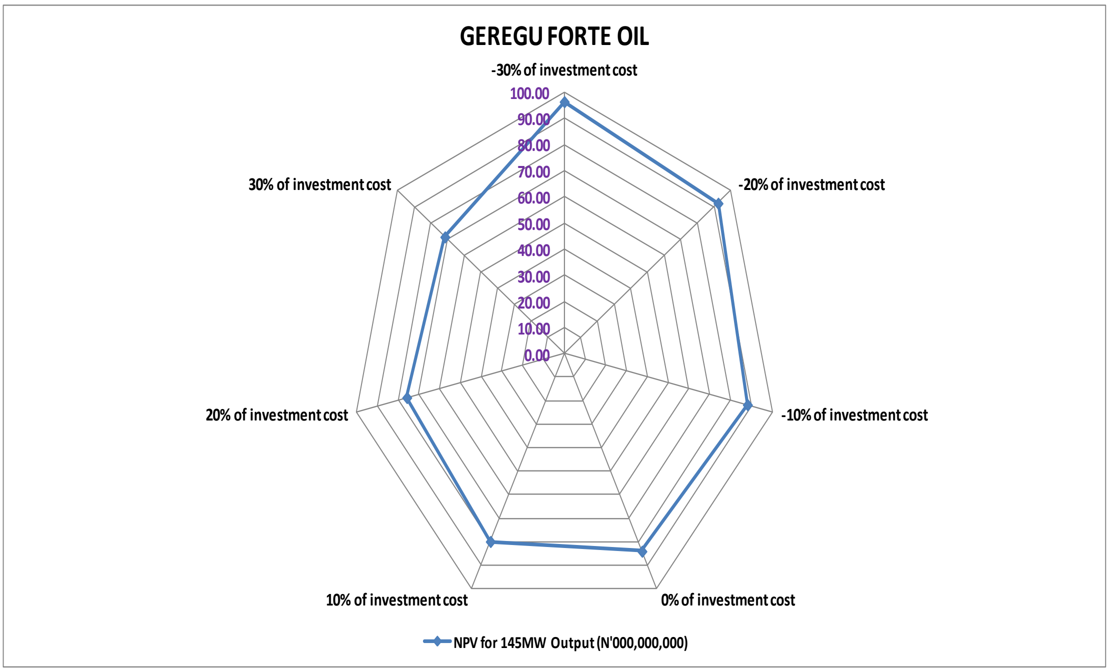

Figure 21: NPV chart for sensitivity analysis (±10% to ±30% variation of investment cost) for Geregu Forte Oil using Siemens data

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