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Analysis of Transmission Line Performance Characteristics For Effective Investment In A Deregulated Nigerian Power Market

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Abstract

This paper studies the Nigerian electricity industry and the prospects of the latest proposed liberalization/ privatization of the incumbent Power Holding Company. The challenges of investment in a deregulated power market are examined. In view of the crucial role the transmission lines play, various transmission pricing schemes have been reviewed. Since none is yet to be implemented in Nigeria, the use of performance metrics for choosing transmission lines for effective investment in a deregulated power market is recommended. The solution approach utilizes mathematical formulation of transmission line model and MATLAB functions in a program, *Lineperf* for calculation of line parameters and performance. The results of the analysis revealed that investment decision could be taken based on the ranking of identified attributes. The transmission line with the highest aggregate will guarantee best optimal performance. The use of the recommended framework will help investors quickly recover their invested resources at the earliest time possible and then maximizing profit.

Keywords: Deregulation, market entity, market forces, market structure, power market, attributes.

1.0 Introduction

The electricity industry in Nigeria has not been meeting the demands of the populace. For many years it has been a government monopoly. While the telecom industry has been liberalized and privatized, the electricity industry has been a thorn in the neck of government. One of the reasons stalling the privatization of the power sector is the nature of the existing technology for payment of electricity bills. The sector requires huge investment while there is no sure technology for recovering money from consumers. Although, a few developing countries have successfully liberalized, the tasks are daunting. Market forces are expected to drive the price of electricity and reduce the cost of investment through increased competition (Shahidehpour *et al.* 2002).

The Nigerian government has recently unbundled electric power industry into generation, transmission and distribution. The new structure recognizes generation entities as GENCOs and Independent Power Producers (IPPs), transmission entity (Transmission Company of Nigeria – TRANSYSCO), distribution entities as DISCOs and then a Regulator - Nigerian Electricity Regulatory Commission (NERC) (see Nigeria Electricity Regulatory Commission 2005).

The Nigerian Electricity Regulatory Commission (NERC) is independent of individual market participants, such as transmission owners, generators, distribution companies, and consumers. In order to operate the competitive market efficiently while ensuring the reliability of a power system, the NERC, as the market regulator, is establishing rules on energy and ancillary services markets, hopes to manage the transmission system in a fair and non-discriminatory manner, facilitate hedging tools against market risks, and monitor the market to ensure that it is free from unfair competition. Ideally, the GENCOs, DISCOs and TRANSYSCO should be private companies but this is yet to happen because of the huge investment required, non existence of clear standards and controls for operation. A lot of work needs to be done for the various entities that will attract and retain investors. For instance for the DISCOs, a framework to ensure that consumers pay bills promptly or before is yet to be established, also there is need for a control to ensure that consumers get the power they pay for. The fundamental challenge is that electricity cannot be

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stored, a Generating company needs some assurance that he will have market for the power he is generating, while the distributing company needs to have access to transmission line that will deliver optimally at destination sites, etc. Thus investment in a deregulated environment could be very demanding and a lot of research needs to be carried out for the Nigerian market.

1.1 Problem Definition

All parts of the Power system need to function efficiently, if we generate adequate power but the transmission line characteristics are poor, most of the power will be dissipated before it gets to its destination. Hence it is important to determine in advance the transmission line with the best optimal performance to enable the investor to recoup the huge costs of investment within a reasonable time frame. This research work addresses the provision of a decision-based framework for investment in the transmission lines component of the power sector.

2.0 Transmission Pricing Scheme

Since electricity cannot be stored, the industry looks for extra generating capacity and efficient delivery system to absorb the variations in supply and demand. Generation investments are capital intensive, so developers face the challenge of recovering high fixed costs through high utilization. High utilization may not be possible without efficient performance of transmission lines. The choice of a transmission line where there are options depends on an agreed pricing scheme. Because of the uncertainty in the electricity industry it is difficult to achieve an efficient transmission pricing scheme that could fit all market structures in different locations. The ongoing research on transmission pricing indicates that there is no generalized agreement on pricing methodology [Jun 2005; Momoh *et al.* 2005; Gebremicael and Tomsovic 2005; Yao *et al.* 2005; Ejebe 2005). Measuring whether or not a certain transmission pricing scheme is technically and economically adequate requires additional standards. Different transmission pricing schemes have been proposed and implemented in various markets during the last few years (Shirmohammadi *et al.* 1996; Lima 1994). They include the following methods: postage stamp rates, contract path, MW-Mile, Unused Transmission Capacity, among others. Nigeria is yet to decide on the pricing scheme to adopt as the market rules are being drawn by the NERC. Also there is no framework within which electricity utilities can coordinate their investment plans and develop reliable trading relationships as has been successfully done in southern Africa (Sparrow and Masters 1998).

2.1 Transmission Planning

It should be specified that transmission systems planning standards cover the types of contingencies that must be examined for conditions for all facilities in-service and facilities out-of-service for maintenance while delivering generator output to projected customer demands and providing contracted firm transmission services, at all demand levels. These contingencies can result in the lost of single or multiple components. For each of the contingencies, the system must be stable and applicable thermal and voltage limits must be observed. For the loss of multiple components, the controlled interruption of customer demand, the planned removal of generators, or the curtailment of firm power transfers may be necessary.

2.2 Generation Expansion Pattern and Transmission Planning

As a generation expansion pattern develops, transmission planners would address the transmission needed to accommodate the generation and the forecast load growth. There are three situations that confront the transmission planner:

(1) Connect a new generator or generating station to the grid.
(2) Connect a new substation to the grid.
(3) Reinforce the existing grid.

For connecting a new generator or a new distribution substation is to build one or more lines to the nearest bulk power substation. However, this may not be sufficient or adequate. An examination is needed to see if the capability of the existing grid is sufficient to accommodate either. For example, if generation is presently being sited outside a generation deficient load area, an initial reaction might be to build a large-scale transmission development into that area. If, however subsequent generation additions are within the generation deficient area, the result could be that the transmission additions could be lightly loaded and do not carry enough power to pay for their costs.

An important consideration is that the transmission additions may not always be near the new generation. The restriction on the capacity of a section of the grid can be far removed from the new generator addition. Other instances have been where new lines are added to increase the stability margins although they carry little if any power themselves.

After examining the need over a sufficiently long time span, decisions are needed on the voltage level of the new line(s), their thermal capacity, their terminal locations, etc.

The design objective for the transmission system is being expanded to include provision for sufficient transmission capability to facilitate a geographically wide scale wholesale power market.

2.3 Procedure for Power System Development Planning

Figure 1 gives the procedure for long range system development planning (Saadat 2002). This includes transmission planning. The steps to take include:

(1) Conduct an accurate demand forecast

(2) Develop several plans for generation, transmission and distribution systems and the system operation facilities. These plans must meet the reliability requirements, conform to the utility policy and guidelines, and must take into account the existing system elements and characteristics

(3) Make a comparative study on these plans by emphasizing reliability and economic efficiency. The most appropriate plan is selected based on management policy and available sources of fund.

2.4 Investor Behaviour In A Deregulated Power Market

Simulations reveal that construction could appear in a steady, even fashion, causing for instance, power facilities like power plant to come on line exactly in time to meet the profitability goals of investors. But this is not the dominant pattern as revealed by simulations rather the more likely pattern shows construction lagging behind the growth in demand, allowing prices to climb to surprisingly high values during peak periods in summer (see NEPA Generator Controller Study and Upgrade Project 2004). When new power plants are completed, they come on line in great number causing a bust in wholesale prices.

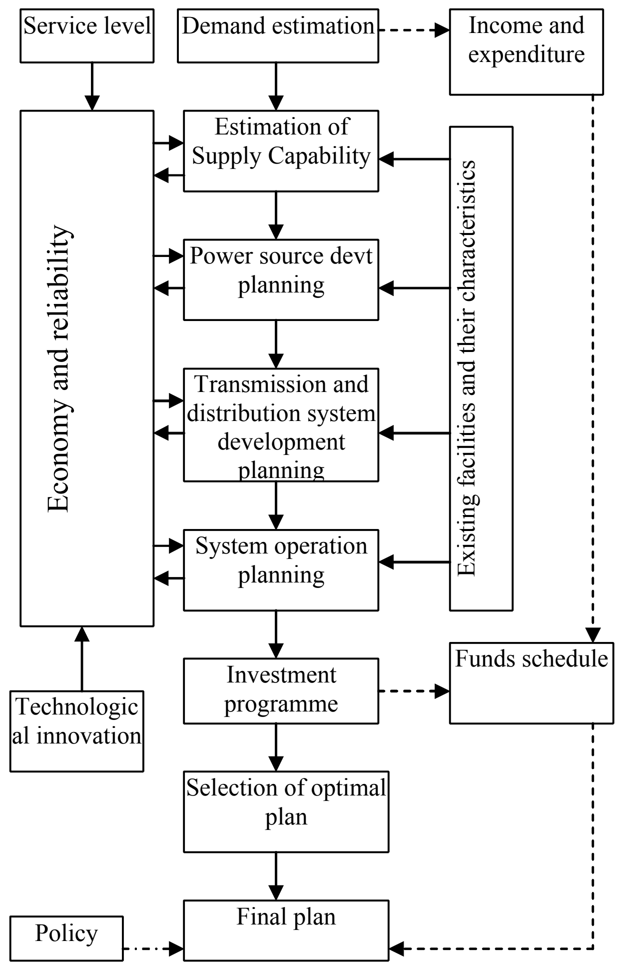

Figure 1: Procedures for Long-Range Development Planning

2.4.1 Theory of Investor Behaviour

The key decision is whether to start construction. Figure 2 shows the theory of construction. Natural gas was priced at 2.50\$/mmBTU, and a developer was looking at a levelized cost of 31.5\$/MWh for a new CC (Combined Cycle). But the investors expect the market to clear at 26\$/MWh, which is simply too low for a significant fraction of the developers to begin construction. The investors were inclined to wait for expected conditions to improve. With time, demand will grow, expected reserve margins will fall and expected prices will rise. When expected

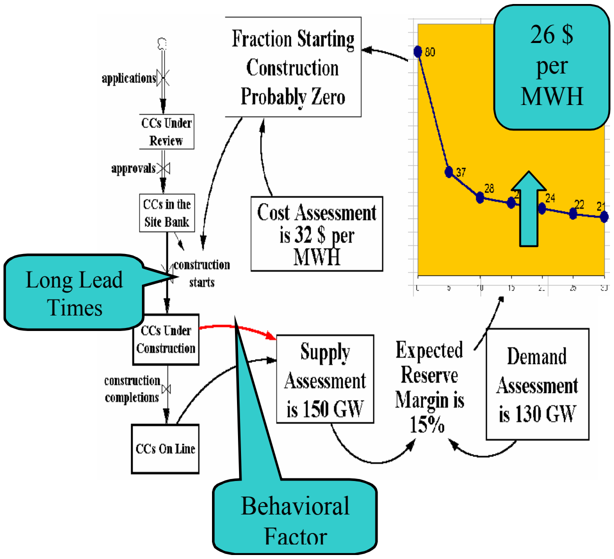

Figure 2: The Theory of Investor Behaviour Implemented in the Western Market Model

market prices are closer to the investor's target for a new CC, they will turn their permits into actual construction profits.

3.0 Evaluation of Transmision Line Parameters for Effective Investment

In view of the crucial role transmission lines play, this work proposes the use of a computer program for transmission line performance analysis. The MATLAB program called lineperf [13] will help an investor determine the choice of a transmission line where there are alternatives. The Nigerian power system, PHCN is used as a case study.

The PHCN power system transmission network comprising of the 330kV and 132kV was studied. Only the 330kV transmission network will be considered in this work. The nominal system is 50Hz, while the base MVA is 100 MVA. Considering the typical environmental conditions in Nigeria, the maximum continuous current capacity of each 350mm^2 conductor is 680A. The 30kV circuits use twin "Bison" (350mm^2 ACSR) conductors in either single- or double-circuit configuration. The transmission circuit parameters, system loads, and other power system data obtained from the Power Holding Company of Nigeria (PHCN) are in Table 1 and Table 2. Table 1 is abbreviated. The breakdown of the real and reactive system loads for each substation under maximum and minimum demand conditions is shown in Table 2. The information from these tables serves as data for the performance analysis. For SC 2 X Bison, R1(ohm/km) is 0.0390, X1(ohm/km) is 0.3310 and B1(μS/km) is 3.490. For DC 2 X Bison, R1(ohm/km) is 0.0394, X1(ohm/km) is 0.3030 and B1(μS/km) is 3.812.

A load power factor of 0.9 lagging has been used. For the purpose of this work, the five regions in Nigeria recognized by PHCN were used namely: Lagos, Benin, Enugu, Kaduna and Bauchi. A transmission line was chosen from each of the regions namely Gombe – Jos (TX 1), Benin – Ajaokuta (TX 2), Ikeja – Benin (TX 3), Shiroro – Jebba (TX 4), and Onitsha – Alaoji (TX 5), for Bauchi, Benin, Lagos, Kaduna, and Enugu regions respectively.

Table 1: Existing 330kV transmission circuits

From	To	No. of Circuits	Construction	Length (Km)
Birnin Kebbi	Kainji	1	SC 2 X Bison	310
Kainji	Jebba	2	SC 2 X Bison	81
Jebba	Jebba P S	2	DC 2 X Bison	8
Jebba	Oshogbo	3	SC 2 X Bison	157
Jebba	Shiroro	2	SC 2 X Bison	244
Shiroro	Kaduna	2	SC 2 X Bison	96
Kaduna	Kano	1	SC 2 X Bison	230
Kaduna	Jos	1	SC 2 X Bison	196
Jos	Gombe	1	SC 2 X Bison	264
Oshogbo	Aiyede (Ib)	1	SC 2 X Bison	115
Aiyede (Ib)	Ikeja West	1	SC 2 X Bison	137
Oshogbo	Benin	1	SC 2 X Bison	251
Oshogbo	Ikeja west	1	SC 2 X Bison	252
Ikeja west	Akangba	2	SC 2 X Bison	17
Ikeja west	Benin	2	DC 2 X Bison	280

4.0 Results

The results generated for the Transmission Line Performance using MATLAB software are as represented in Figures 3 to 10. The figures show the result of the line performance for specified sending end quantities. A critical look at the performance

Table 2. The breakdown of the real and reactive system loads for each substation under maximum and minimum demand conditions

Region	Substation	Transformer Loading (MW)	Max Demand (MW)	Max Demand (MVar)	Min Demand (MW)	Min Demand (MVar)
Lagos	Aja	120	130	63	82	40
Lagos	Akangba	413	447	217	282	136
Lagos	Ayede	194	210	102	132	64
Lagos	Egbin	185	200	97	126	61
Lagos	Ikeja west	440	476	231	300	145
Lagos	Oshogbo	143	155	75	98	47
Benin	Ajaokuta	11	12	6	8	4
Benin	Aladja	40	43	21	27	13
Benin	steel	220	238	115	150	73
Benin	Benin-Main Delta	41	44	21	28	13
Enugu	Afam	41	44	21	28	13
Enugu	Alaoji	255	276	134	174	84
Enugu	Enugu/NH	132	132	64	83	40
Enugu	Onitsha	140	152	73	95	46
Kaduna	Birnin-	81	88	42	55	27
Kaduna	kebbi	9	10	5	6	3
Kaduna	Jebba	198	214	104	135	65
Kaduna	Kaduna	138	149	72	94	46
Kaduna	main Kano kumbotso Shiroro	214	231	112	146	71
Bauchi	Gombe	139	150	73	95	46
Bauchi	Jos	90	97	47	61	30

characteristics revealed some variations in certain parameters that can be employed as technical inputs into decision making in transmission line investment. Some of the identified parameters, further referred to as attributes, include power supplied (Ps, Qs), power received, power factor at the sending and receiving ends, Power loss (Pl, Ql), voltage regulation (VR), Transmission Line Efficiency, Currents (Is, Ir). Figure 3 is a plot of the voltages at the receiving end of the selected five transmission lines.

The aggregation of these attributes was achieved by the simplex ranking method. The attributes were weighted based on known performance principles. The total aggregate indicates the transmission line with the best optimal performance, and by extension, offers the best investment opportunity.

Figures 3 to 10 are outputs of the test system while Figure 10 represents the aggregation of different parameters.

From the foregoing, it is evident that Transmission line number 5 has the best investment opportunity followed by 2 & 3, 4, and 1 respectively. The effect of Transmission Line Efficiency (TLE) was not well pronounced since almost all the transmission line efficiencies are reasonably high. Transmission line number 5 (with total aggregate of 46) will most likely give the investor the best opportunity to recoup his investment and make profit.

5.0 Discussion of Results

From Figure 3, power factor at the receiving – end of transmission line 1 (TX 1) was 0.74 which is unacceptably low while transmission line 3 (TX 3) has a very high receiving – end power factor of 0.98. This low power factor could be as a result of dielectric loss of materials that absorb some power from the circuit. A low power factor, obviously, means a relatively higher current on this transmission line and it affects in the following ways:

Line losses are proportional to I^2 which means pro-

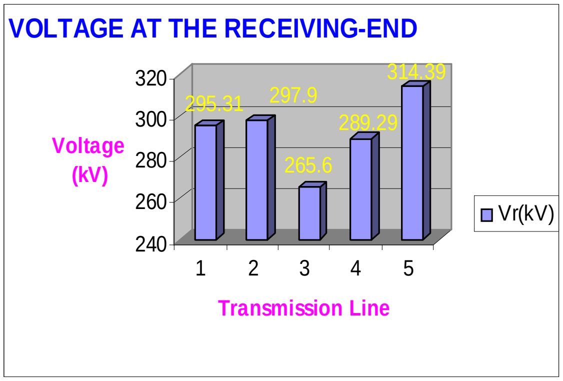

Figure 3. Voltage at the receiving-end

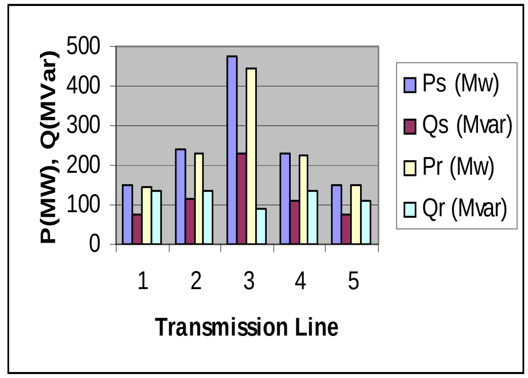

Figure 4. Sending- and Receiving-end power

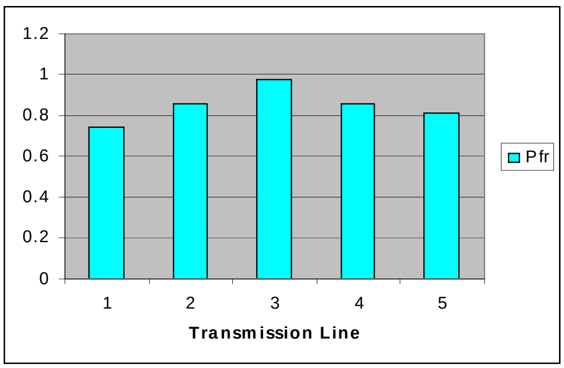

Figure 5. Power factor.

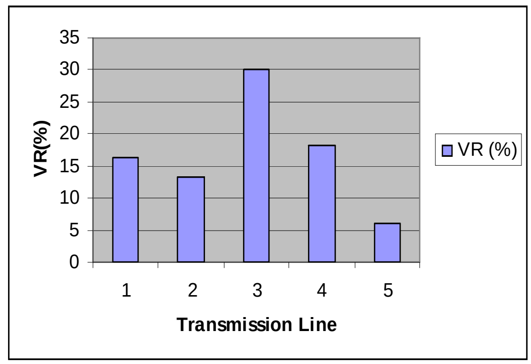

Figure 6. Voltage Regulation

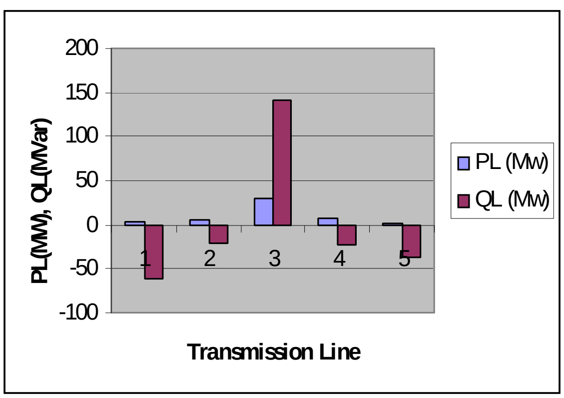

Figure 7. Line Losses

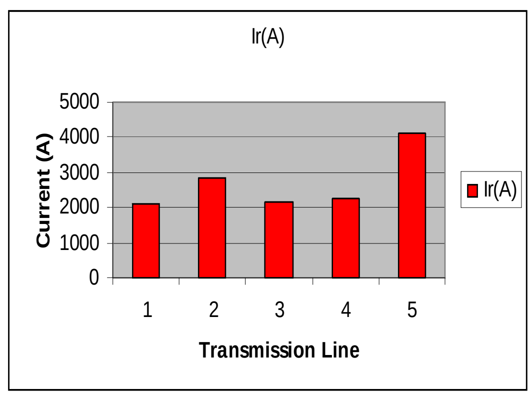

Figure 8. Short-circuited line Currents at Receiving end

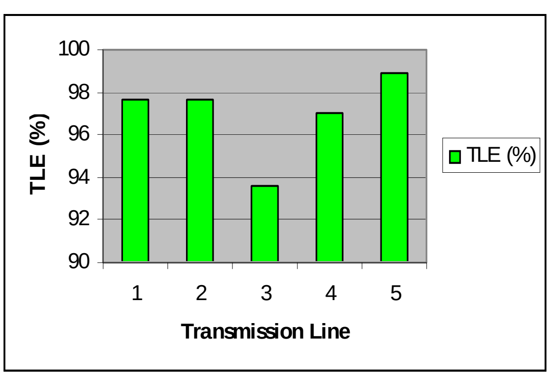

Figure 9. Transmission Line Efficiency

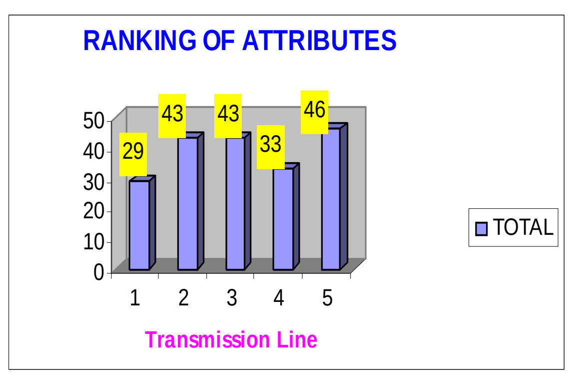

Figure 10. Ranking of Attributes

portional to $1/(pf)^2$. Thus losses at pf of 0.74 give $1/0.74^2 = 1.83$ for transmission line 3 with pf of 0.98, $1/0.98^2$ gives 1.04. That is TX 1 gives 1.76 times that of TX 3. Transformers, cables, etc are limited in their current- carrying capacity by the permissible temperature rise which is proportional to I^2. Hence, TX 1 may be fully-loaded with respect to its rating without delivering their full power. Ratings of transformers and other machinery are proportional to 1/pf, hence, 1/cos Ø, therefore, large transformers are required. No investor would like to identify with a system that incurs extra expenses. Low lagging power factor will cause a large voltage drop, hence extra regulation equipment will be required to keep voltage drop within prescribed limits. This may necessitate expensive voltage stabilizing equipment to keep voltage fluctuations within the statutory limit. A critical look at transmission line 3 *(TX 3)* shows that a whooping 30.59MW of power was lost while transmission line 5 (TX 5) gives the least power loss of 1.63MW. This gives an investor a clear indication that much energy will be lost in TX 3 per hour than, say, TX 5. If converted to money and summed over time the loss will be quite enormous.

The line loading in TX 3 resulted in a voltage regulation of 30.09 per cent, which is unacceptably high. TX 5 gave the least voltage regulation of 6.13 per cent. To improve the voltage regulation of the performance, the line will need appropriate compensation. The high voltage regulation and losses of TX 3 also reflected in the efficiency of the line. The Transmission Line Efficiency of TX 3 shows the least at 93.57 per cent while TX 5 had the best efficiency of 98.93 per cent.

An investor would be very willing to invest on TX 5 by submitting the highest bid. If the same investor wins the bid for the five lines, he is likely to start investing on TX 5 first in order to recoup his investment before embarking on others. This is akin to the scenario during the liberalization of the telecommunications industry where investors first invested on those towns like Lagos, Abuja, Port Harcourt with the greatest prospects for profit.

Figure 8 indicates the current flow over the transmission lines under short-circuit contingency at the receiving-end. TX 5 would draw a large current of about 4096.84A if short-circuited while TX 1 had the least of 2106.94 A. This high short-circuit current may lead to insulation failure resulting from overvoltages. The short-circuit currents may attain such high values, that if allowed to persist, they may result in thermal damage to the cables and other equipment. The faulty section should be isolated as quickly as possible. Most of the short-circuits do not cause permanent damage. As soon as the fault is cleared, the insulation is restored. Reclosing breakers are, therefore, used in practice which automatically closes periodically to find out if the line has recovered. This demands extra expenditure from the investor.

6.0 Conclusion

This paper has set the framework for selection of best transmission line option in a deregulated power market where there are alternatives. The study of power markets worldwide revealed the challenges investors and developers face. A detailed critical analysis of the performance of transmission lines using the Nigerian 330kV network as the test system has been presented. The Transmission Line Performance results of the analysis revealed that the following parameters: sending- and receiving-end power, power factor, power loss and current, voltage ratio, transmission line efficiency can be useful inputs in the modeling of transmission component. Transmission Line Efficiency (TLE) effect was not well pronounced as all the transmission lines gave reasonable values above ninety percent.

The ranking of the parameters gave the needed basis to bring the variations in the different attributes to the same platform. The transmission line with the highest aggregate was discovered to be the choice with the best optimal performance and by extension best investment option. This information will serve both to make the case to provide data to system planners, and private investors as to how to improve efficiency of investments in the electricity sector.

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