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Evaluation of Network Reliability Investments Costs

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ABSTRACT: *This thesis evaluates network reliability investment costs and resultant electricity pricing in Nigeria. It explores the interrelationship between optimal reliability, cost of investment and resultant electricity pricing using a cost-benefit approach. Five feeders in Port Harcourt distribution company which are Trans Amadi, Abuloma, Imiringi II, Itu, and Amika 33kv feeders were selected for this study. These selected feeders were mapped and load flow studies were carried out using Electrical Transient and Analysis Program (ETAP). Consequently, network reinforcement projects were proposed using reliability and deterministic approach for areas of identified weakness as revealed by the study. The reliability indices were calculated before and after the reinforcement projects. The reliability indices showed an improvement of 80 percent across the five selected feeders with varying the associated cost of investment. In line with the cost of investment using reliability approach energy pricing for Trans Amadi 33Kv feeder was estimated as ₦62.12, Abuloma as ₦75.51, Imiringi II as ₦75.44, Amika as ₦71.75 and Itu as ₦69.51. Using a deterministic approach, the energy pricing for Trans Amadi 33Kv feeder was estimated as ₦64.14, Abuloma as ₦75.67, Imiringi II as ₦75.69, Amika as ₦71.81 and Itu as ₦69.81. This result showed a close margin in the determined pricing for reliability approach and pricing for reliability and deterministic approach combined. However, the combined reliability and deterministic approach present higher reliability. Hence, it was concluded that the reliability and deterministic approach combined should be considered as the best option. In view of the foregoing, it is recommended that regulatory bodies should allow distribution companies to charge a cost-reflective tariff according to the reliability and quality of power delivered.*

KEYWORDS*:Electrical Transient and Analysis program,Cost reflective tariff,Bill of engineering measurement, System Average Interruption Duration Index, System Average Interruption Frequency Index, Customer Average Interruption Duration Index, Expected energy not supplied.*

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I. INTRODUCTION

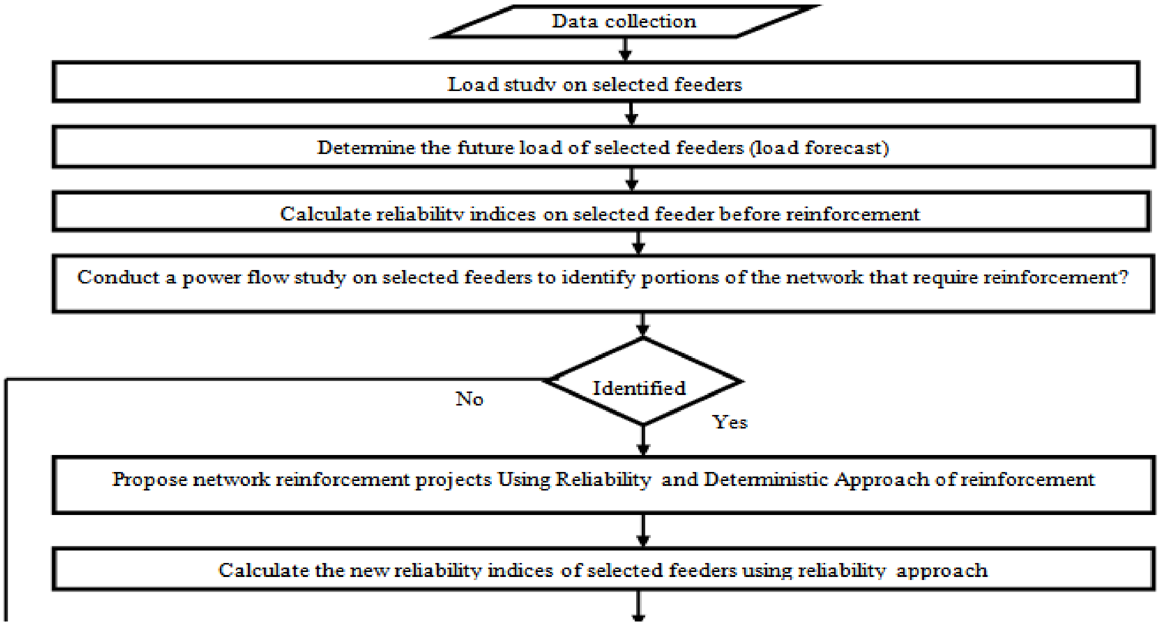
In power systems operation and planning, reliability generally refers to maintaining the continuity of energy supply to the customer [1]. For the fact that their primary responsibility lies on continuity of power supply, power systems are made to overcome possible outages and failures in a way that customers can carry out their daily activities even during contingency events. Since investing in generation units and transmission grids is capital intensive, long term planning becomes inevitable and unavailability signifies energy supply interruption for a large number of customers, they were the actual interests behind reliability analyses in the time past [2]. Nowadays, due to the rapid increase in energy demand and primary energy prices and also when efficient system operation is imperative. The main idea behind reliability analyses is relocating to distribution networks, as they became the most vulnerable part of the power system. In actual sense, a considerable amount of investments is yet to be done in the system. More than 90% of all customer reliability issues and costs take prevalence and therefore, it is imperative to design a reliable distribution system. The investment needs for the power sector imply that even small improvements in efficiency will lead to significant savings and this also have an impact on tariff.

Today emphasis on economic efficiency in the power sector, particularly in the aspects of marginal cost pricing and improved tariff policy, is welcome and long overdue. But the topic of electric power system reliability, or dependable quality of electricity service, has previously received detailed treatment only from the supply side, using engineering models and analysis. The economic effect of the reliability of electricity supply on consumers has been examined in a more general and descriptive way. Thus, the traditional design and planning of power systems have been based on the principle of minimizing the supply costs needed for a given load at a specified level of reliability. Increasingly, economists are realizing that even the most sophisticated planning models for the least-cost expansion of power systems are usually developed with respect to arbitrary standards of supply reliability. These standards are derived from past practice and vague notions surrounding the quality of service that the electricity consuming public would accept. Investigators have generally jettisoned the effects on the part of the demand that relate to the economic worth of reliability. The problems involved in measuring the economic benefits of improved quality of service were the main reasons which gave rise to the neglect.

According to [4], the reliability of supply is an outcome of the standards and processes by which the power system is operated, planned and developed. This implies that efficient long term and short term plans that balancecost, capacity, performance, and reliability is required for the success of a power distribution company. The devastating consequences of major power out age are proof of how heavily dependent society is on a continuous supply of electricity. Generation, transmission and distribution networks as a system, is one of the most complex technical systems created by humans. There liability demands on this technical infrastructure are high and, irrespective of its complex nature, it is in several cases a nextremely reliable system. However, a completely reliable system is impossible to obtain, andacertain levelof interruption of power has to be accepted. While underinv estments in reliability account for anun acceptable number of power interruptions, over investments give rise to too high costs for society. The challenge is to find an economically adequate level of reliability. This approach to reliability will address the above weakness by considering reliability as a variable to be optimized rather than arbitrary imposed standard. To achieve this goal, a cost-benefit approach will be adopted to evaluate the inherent tradeoff between the increase in power system supply costs required to obtain higher-level reliability and the corresponding decline in outage cost which implies economics cost incurred by customers due to power shortages [5]. In order words, optimum reliability level, which maximizes the net benefits of constant electricity supply should be determined at the point where the marginal increase in system supply costs due to reliability increase is offset by the marginal decrease in outage costs.

II. RESEARCH FLOW PROCESS

This is the most primary representation of the research methodology which depicts the entire process flow of this research work. It is a multiple-step process with steps interlinking with the other in a continuous flow to achieve the end result of this work. The vivid research flow process is as shown below.



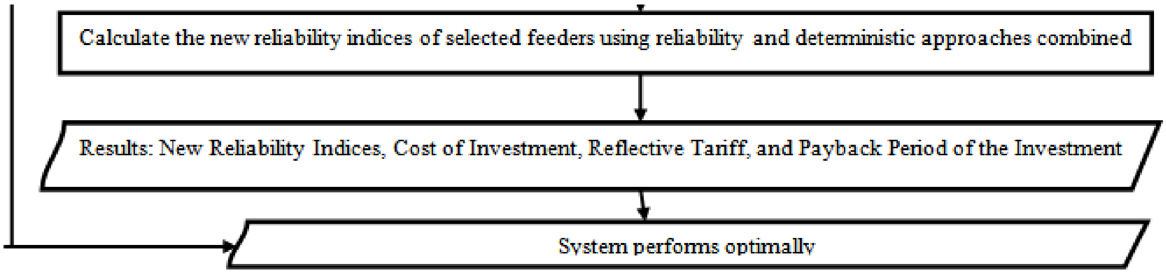


Figure 2.1 Process flow diagrams

2.1 Data Collection

In this work, eight-year data of feeder interruption frequency and duration (such as fault reports, interruptions and hourly load reading) was collected from the existing Port Harcourt electricity distribution (PHED) dispatch center and Network Status Information System (NSIS), for both the commercial and residential feeders. This data was collected for the selected areas of study within the Port Harcourt, Bayelsa, Akwa-Ibom and Cross River metropolis. The data was collected in terms of monthly load consumption data from January to December for each year which was processed and screened to obtain the annual maximum load consumption for the years on each feeder under study. See appendix A for the details of the data collected.

2.2 Power System Study on Selected Feeders

Power System Study which is the first paramount study was conducted on the feeders to determine their performance under various loading conditions. It involves determining the performance under the present load and also the forecasted load. This study was carried out on the five feeders understudy as shown below.

2.2.1 Feeder load demand study

The historical data collected was analyzed, the average and maximum load were determined. The installed capacity of each feeder, the route length, population size, conductor size, and availability was fed into an excel software tool for statistical analysis.

2.2.2 Feeder load determination (forecast)

The load forecast which is a technique used by power companies to predict the power needed is used to forecast the future demand of electricity for the area under study using the regression analysis method of forecasting. The raw data from appendix A was analyzed and summary to table 3.1 below. This Forecast was based on historical data from 2010 to 2017. After careful examination of the data, a quadratic regression model was applied to it. The quadratic regression model is a hybrid model that applies a time series and time trend modeling approach blended with regression analysis. These values are substituted into the equation to determine the base load of the individual feeders and then their forecasted load. The forecasted load that is gotten is an important criterion that will be considered during network reinforcement.

Table: 2.1: Historical maximum load on the selected feeders

FEEDERS	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**2015**	**2017**
Trans Amadi	21.5	19.8	23.0	19.5	20.6	24.1	24.6	19.9
Abuloma	9.5	6.2	15.0	10.0	12.0	15.4	10.8	12.0
Imiringi II	19.3	21.0	16.6	19.3	20.4	20.0	20.3	19.8
Itu/Oku Iboku	4.6	6.2	8.5	7.0	7.9	8.0	8.1	8.2
Amika	14.0	20.0	30.0	47.0	29.8	29.8	34.2	29.3

According to Saravanan and others (2012), one major advantage of forecasting load through the use of regression analysis is that it is easy to understand the input and output variables in terms of their relationship. Using the regression analysis method of load forecast [3].

$$p(j) \quad = a_1 + a_2 w_j + a_3 w_j^2 \qquad 2.1$$

Where p(j) is the maximum annual load consumption forecast for any year in the future measured in Megawatts (MW). w_j is any particular year required whose load consumption is to be forecasted having integral values of j = 1, 2, 3, - - - k, (k+1), (k+2), (k+3)… (k+n)

$$a_1 k + a_2 \sum_{j=1}^{k} w_j + a_3 \sum_{j=1}^{k} w_j^2 = \sum_{j=1}^{k} p_j \qquad 2.2$$

$$a_1 \sum_{j=1}^{k} w_j + a_2 \sum_{j=1}^{k} w_j^2 + a_3 \sum_{j=1}^{k} w_j^3 = \sum_{j=1}^{k} w_j \, p_j 2.3$$

$$a_1 \sum_{j=1}^{k} w_j^2 + a_2 \sum_{j=1}^{k} w_j^3 + a_3 \sum_{j=1}^{k} w_j^4 = \sum_{j=1}^{k} w_j^2 \, p_j \qquad 2.4$$

2.2 Calculation of feeder reliability indices before reinforcement

Assessment and analysis along with the computation of the system performance were done in two segments; measuring the past performance of Trans Amadi, Abuloma, Amika, Imiringi II and Itu 33kv feeders respectively and also predicting the future reliability of all the five Feeders when reinforcement project is done. Feeder reliability indices for the selected feeders were calculated before network reinforcement using the standard reliability indices formula below.

a. System Average Interruption Duration Index:

$$\text{SAIDI} = \frac{\text{SUM OF ALL CUSTOMER INTERRUPTION DURATIONS}}{\text{TOTAL NUMBER OF CUSTOMERS SERVED}}$$

$$\text{SAIDI} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} \tag{2.5}$$

b. System Average Interruption Frequency Index:

$$\text{SAIFI} = \frac{\text{TOTALNUMBEROFCUSTOMERINTERRUPTION}}{\text{TOTALNUMBEROFCUSTOMERSSERVED}}$$

$$\text{SAIFI} = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \tag{2.6}$$

c. Customer Average Interruption Duration Index

$$\text{CAIDI} = \frac{\text{SUM OF ALL CUSTOMER INTERRUPTION DURATIONS}}{\text{TOTAL NUMBER OF CUSTOMER INTERRUPTIONS}}$$

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}} = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} / \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \tag{2.7}$$

d. ENS- Energy Not Supplied

$$\text{ENS} = \sum_{i=1}^{n} U_i \ \lambda_i \ \times 1000 \tag{2.8}$$

Where λ_i = Total number of customer's interruption duration

N_i is the number of customers per load

U_i = Total number of customer's interruption

2.3 Power Flow Study on Selected Feeders

The five sample 33kv feeder study was mapped for the purpose of developing the feeder network schematic. Feeder mapping which entails proper geo-referencing and inventory of all network components (Generators, lines, cables, transformers, breakers, fuse, ring main unit, etc.) was carried out on the selected feeder using GPS receiver. A power flow study was carried out on the feeders using the developed network schematic to identify areas on the network that requires reinforcement using Electrical Transient and Analysis Program (ETAP).A power flow study was carried out on the distribution networks using the produced network schematic to identify the area that required reinforcement for reliability improvement. The network asset inventory and power system studies conducted on the selected feeders revealed some defects which have a direct impact on the general system availability. Some of the observed network flows are excessive voltage drop, overloading, phase imbalance, etc. which all violate performance criteria which are the thermal limit, voltage limit, and power factor limit.

2.3.1 Overloading

Consequent upon the studies conducted, it was discovered that Trans Amadi, Imiringi II, Itu, and Amika 33kv feeders are overloaded (thermal limit of performance criteria is violated) and most of the distribution transformers on these feeders are also overloaded which explain the reason for incessant wire cut in these networks. On the other hand, Abuloma 33kv line is not overloaded but a larger percentage of the connected distribution transformers feeding on this feeder are overloaded, explaining the reason for periodic fuse cut on the affected distribution substation.

2.3.2 Voltage Drop

On the other hand, it was observed that Imiringi II, Amika and Itu 33kv feeders are experiencing more voltage drop due to the lengthy nature of the feeders (both thermal and voltage limit of performance criteria are violated).The feeders are well over 100km and customers with transformers connected towards the end of theses feeders experience low voltages below the stipulated voltage drop by regulation. Irregular sizes of conductors were used on these feeders (150mm, 100mm, and 70mm). On this premise, it was assertively deduced that Imiringi II, Itu, and Amika are experiencing more voltage drop due to the lengthy nature of the feeders and wrong conductor sizing. These are quite lengthy and customers who have their distribution transformer towards the end of the feeders are experiencing low voltage and it was observed that irregular sizes of conductor were used in the construction of all the feeders. Some of the conductor sizes used include (AAC, ACSR) 150mm, 100mm, and 70mm.This introduces high resistance at the point where the undersized conductors were used, thus leading to heat dissipations and subsequent voltage drop. This also explains the reason for the periodic wire cut on these feeders. Generally, all the feeders understudy show that some bus voltages are critical which needs to be corrected.

2.3.3 Phase Imbalance

This is a measure of inequality of the phase voltages which degrade the performance and shortens the life of the equipment. Phase imbalance was observed on Imiringi II, Itu, and Amika 33kv feeder. In the case, the load was not evenly balanced across the three phases of the feeder. There was an increase in the reactive power flow on the line which therefore increases the losses on the line. As a result of this, the power factor limit is violated.

2.3.4. Physical Inspection

During network asset inventory and mapping, physical inspection shows the aging of distribution equipment, undersized cross arm, undersized jumpers, wrong conductor binding and cable jointing, the intrusion of vegetation along the line. These generally impact the line characteristic which includes an increase in the line inductance and introduction of imbalance defect which leads to high technical losses (line losses) and as well leads to reduced reliability as a result of incessant faults.

2.4 Network Reinforcement Project

Network reinforcement projects are the projects proposed to correct all flows and the anomalies discovered during the power flow studies. These projects will improve the reliability of the electrical network and increase access to electricity services at the consumer’s end. There are generally two approaches to network improvement, first is to restore the failed components in a shorter time and the second one is to ensure sufficient redundancies in systems. The deterministic approach here reinforces the network when it can no longer securely supply its demand under network contingencies as required by security standards. Both reliability and deterministic approaches were considered in the planning of network reinforcement projects in this research work.

2.4.1 Reinforcement project on Imiringi ii 33kv feeder

Considering the route length of Imiringi 11 33kv, Auto-reclosers was proposed at some points on the mainline and Operatable D-fuse (line fuse) on all t-offs on the line. This will ensure segregation and sectionalisation of faults on the line thus limiting the number of customer's interruption due to certain faults on the line. Gang isolators were proposed on the t-off's to be positioned after the D-fuses. This enables proper physical isolation of the line to allow for safe working space and guarantee during maintenance without interrupting the entire feeder. Reconductoring was proposed for the weak and undersized conductor on the line to reduce the voltage drop and conductor snapping. An alternative supply source was proposed from the Gbarin Generating station to provide for backup supply in the event of failure of the grid, thus mitigating against N-1 contingency. Vegetation control was also proposed to reduce transient faults due to overgrown vegetation.

2.4.2 Reinforcement project on Itu 33kv feeder

In considering the nature of this feeder as revealed by the study, Auto-reclosers was proposed at some points on the mainline and Operatable D-fuse (line fuse) on all t-offs on the line. This will ensure segregation and sectionalisation of faults on the line thus limiting the number of customer's interruption due to certain faults on the line. Gang isolators were proposed on the t-off's to be positioned after the D-fuses. This enables proper physical isolation of the line to allow for safe working space and guarantee during maintenance without interrupting the entire feeder. Reconductoring was proposed for the weak and undersized conductor on the line to reduce the voltage drop and conductor snapping. An alternative supply source was proposed from the Odukpani Generating station to provide for backup supply in the event of failure of the grid, thus mitigating against N-1 contingency. Vegetation control was also proposed to reduce transient faults due to vegetation contact with the line.

2.4.3Reinforcement project on Amika 33kv feeder

Considering the result gotten from the load flow, Amika 33kv feeder is overloaded and from the data gathered, overhead load shedding is been carried on a daily basis to enable the feeder to withstand the electrical power flowing through. Hence, load on Idun-dun t-off on this feeder will be transferred to another feeder called water board feeder of which presently is utilizing only 6% of its capacity and in close proximity spatially to Amika feeder. This network reconfiguration will deload the overloaded Amika feeder.Due to the lengthy nature of the feeder, Auto-reclosers was proposed at some points on the mainline and Operatable D-fuse (line fuse) on all t-offs on the line. This will ensure segregation and sectionalisation of faults on the line thus limiting the number of customer's interruption due to certain faults on the line. Gang isolators were proposed on the t-offs to be positioned after the D-fuses. This enables proper physical isolation of the line to allow for safe working space and guarantee during maintenance without interrupting the entire feeder. Reconductoring was proposed for the weak and undersized conductor on the line to reduce the voltage drop and conductor snapping. An alternative supply source was proposed from the Odukpani Generating station to provide for backup supply in the event of failure of the grid, thus mitigating against N-1 contingency. Vegetation control was also proposed to reduce transient faults due to vegetation contact with the lines and all bad feeder pillar unit was changed to allow all customers to use supply and to prevent local load shedding.

2.4.4 Reinforcement project on Trans Amadi 33kv feeder

Considering the fact that Trans Amadi has a short route length and at the same time looking at the result from the load flow study, gang isolators were proposed on the t-off's to be positioned after the D-fuses. This enables proper physical isolation of the line to allow for safe working space and guarantee during maintenance without interrupting the entire feeder. Reconductoring was proposed for the weak and undersized conductor on the line to reduce the voltage drop and conductor snapping. An alternative supply source was proposed from the Trans Amadi gas turbine to provide for backup supply in the event of failure of the grid, thus mitigating against N-1 contingency. Vegetation control was also proposed to reduce transient faults due to vegetation contact with the lines and all dilapidated feeder pillar unit was changed to allow all customers to use supply and to prevent local load shedding. See Appendix D1 for this network reconfiguration.

2.4.5 Reinforcement project on Abuloma 33kv feeder

Taking into account that the Abuloma feeder is not a long line and also looking at the results from the load flow study, Gang isolators were proposed on the t-off's to be positioned after the D-fuses. This enables required physical isolation of the line to allow for safe working space and guarantee during maintenance without interrupting the entire feeder. Reconductoring was proposed for the weak and undersized conductor on the line to reduce the voltage drop and conductor snapping. An alternative supply source was proposed from the Trans Amadi gas turbine to provide for backup supply in the event of failure of the grid, thereby mitigating against N-1 contingency. Vegetation control was also proposed to reduce transient faults due to vegetation contact with the lines and all dilapidated feeder pillar unit was proposed to be changed to allow all customers use supply and to prevent local load shedding. From the load flow, it was observed that some substations are overloaded and installation of relief transformer will reduce frequent fuse cut for the distribution transformers. See Appendix D2 for this network reconfiguration.

2.5 Calculation of New Feeder Reliability Indices After Reliability Improvement Project

The new reliability indices were calculated for both network reinforcement approaches used which are reliability approach, reliability, and deterministic approaches combined. The first reliability was calculated for reliability approach and reliability and deterministic approaches combined was also considered thereafter using equation 2.5, 2.6 and 2.6.

2.6 Determination Of Cost Reflective Tariff For The Feeders Understudy With Improved Reliability.

A tariff is cost-reflective if all the "allowable frugal costs" of the sector can be covered through the tariff over the regulatory period. It is very important for a tariff to be cost-reflective so that investors can still be in business. From the cost that has been determined from the BEME (see appendix E), the cost-reflective tariff of the feeders was determined using the formula below. The overall cost of the improved reliability which was calculated and used to estimate the new electricity tariff that is cost-reflective

$$\text{Tariff} = \frac{\text{AllowableRevenue}}{\text{CollectableSales}} \quad \ldots\ldots\ldots\ldots\ldots \quad 2.9$$

Where Allowable Revenue is

Genco cost + Transco cost + SO cost + MO cost + Auxiliary services + Disco cost…………………………………...... 2.10

a. Genco cost can be calculated thus

Genco cost = Capacity + Opex …….….... 2.11

Where Opex is operating expenses

b. Transco Cost can be calculated thus

Transco cost = Opex + ROI + Depreciation … 2.12

Where ROI is Return on Investment

c. System Operator (SO) cost

SO cost = Opex + ROI …………………….… 2.13

d. Market Operator (MO) cost

MO cost = Opex + ROI + MO ………………. 2.14

Ancillary Services are assumed by NERC, where 6.5% belong to Port Harcourt. Regulatory shares the Ancillary services among all discos. Each disco has its percentage allocation according to NERC rules. The feeders under study fall within the Port Harcourt Disco and Port Harcourt priority of 6.5%.

a. Disco Cost

Disco cost = OpEx + ROI + Depreciation + Debt repayment ……2.15

Where depreciation is 20.74% of capital expenditure (CapEx) and WAIC is assumed to be 11% of the deficit.

b. Collectible Sales

Where Collectable Sales, CS is a function of the energy delivered to disco's less certain percentages of technical loss (Tc), Commercial Loss (Cm), and less Collection Loss (Co).

Where Tc, is Energy delivered less 12% technical losses, Cm is Tc less 13% of Commercial loss, CS is Cm less 20% of Collection loss, Tc = 12% < technical losses, and Cm = 13% < Commercial loss, CS = 20% < Collection loss

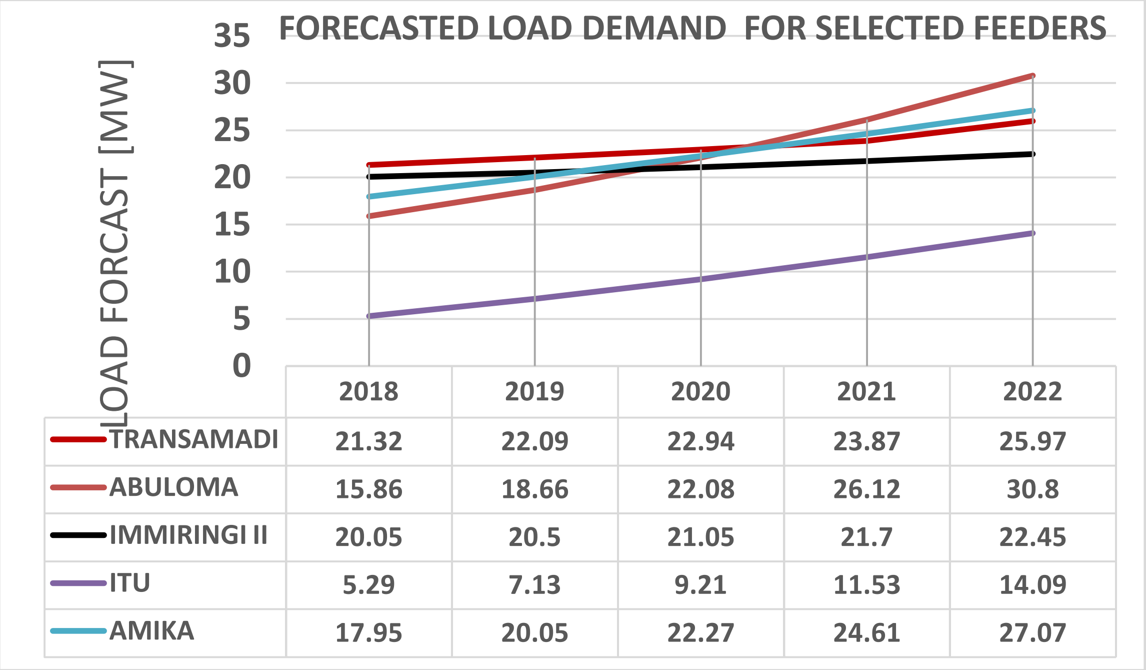
III. RESULT AND DISCUSSION

3.1 Reliability issues.

To tackle reliability issues in the power sector and as part of system restructuring, incentives should be introduced to encourage distribution company. This action is intended to address reliability issues and improve customer satisfaction. It will lead to a major behavioral change in the consumers concerning attitude to payment, which in turn leads to high collection efficiency on the side of the distribution company.The customer outages (both frequency and duration), historical peak loads, present important data which was used here to evaluate the impact of outages on the general system performance. The plot of reliability for the period prior to when reinforcement project was carried out and after reinforcement projects show that the reinforcement will lead to increased revenue, decrease outage costs and increase the longevity of distribution equipment.

3.1.1 Determination of Feeder Load Demand

Forecasted load demand was calculated for the selected feeders using regression analysis as specified in equation 2.1. In the load forecast table below, a five-year data sample from the control room logbook was used to determine the expected load demand of the area under study. A closer look at these values presented below shows there will be an increase in the load demand over time resulting from the impact of development in the area where these feeders are supplying power to. The essence of determining the load demand is to take into account the growth rate where reinforcement projects are being proposed. This will help in making important decisions like energy purchasing, adding new generation, load switching, contract evaluation, and infrastructure development.



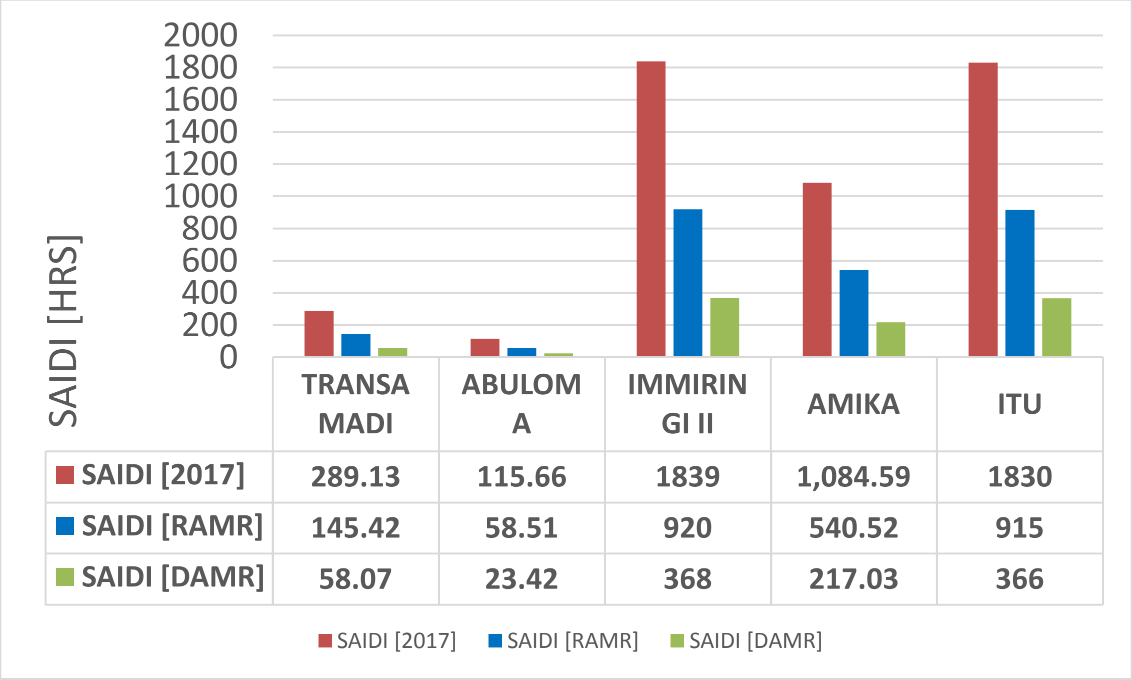
	2018	2019	2020	2021	2022
TRANSAMADI	21.32	22.09	22.94	23.87	25.97
ABULOMA	15.86	18.66	22.08	26.12	30.8
IMMIRINGI II	20.05	20.5	21.05	21.7	22.45
ITU	5.29	7.13	9.21	11.53	14.09
AMIKA	17.95	20.05	22.27	24.61	27.07

Figure 3.1: Chart showing forecasted load demand of the feeders under study.

3.2 Impact of Reinforcement Projects on Network Reliability.

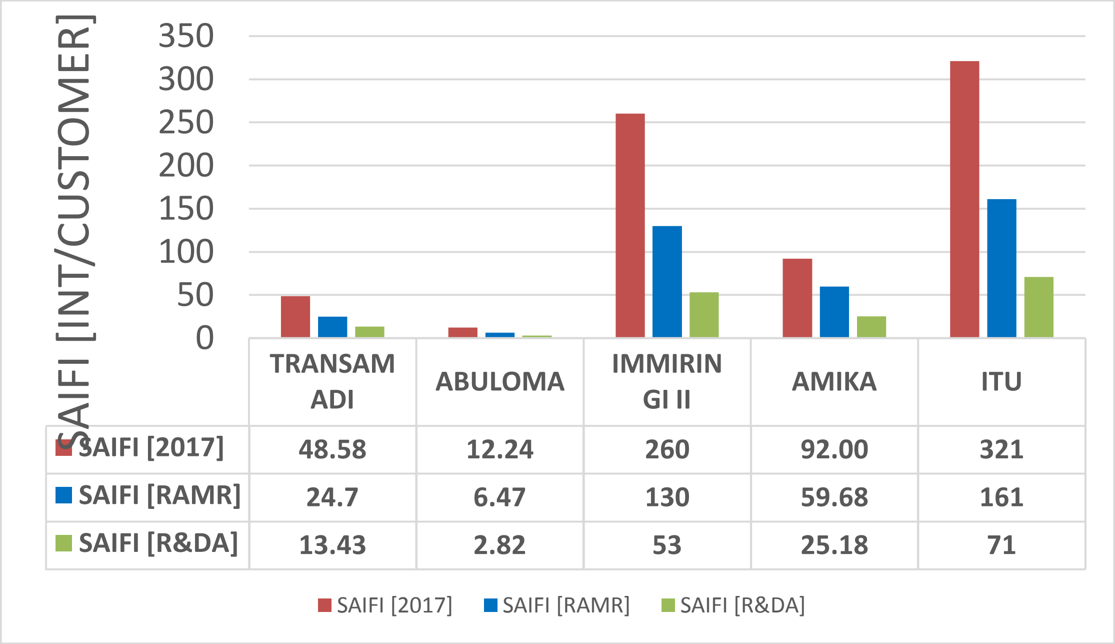
The extent of the impact of improved network reliability occasioned by the increased availability of feeders and reduction in outages as a result of network reinforcement projects was measured by the reliability indices calculation as in table 3.2 below. The result shows a systematic decrease in the value of reliability indices which translate to improved reliability of the networks. Two approaches of reinforcement project which are reliability approach, deterministic and reliability approach combined were considered and it was determined that the deterministic and reliability approach combined produces better reliability results which are not yet the acceptable figures but they have been improved from the state they were previously. From the analysis made, there was 80 percent improvement in the reliability of the network using this approach and frequency of feeder tripping and duration (hrs.) lost as a result of fault reduced further with this approach and presented in the graph below. These values can be decreased further by faster fault detection, quicker crew response but this cannot be conducted by technical improvement. From both approaches, the result indicates more availability as most distribution equipment and fuses burn out less frequently, faulty section of feeders is sectionalized when a fault occurs and makes the network more reliable. This implies that reinforcing the network can effectively and quickly restore the power system from localized problems and potential system-wide imbalance. The distribution system reliability gives us a measure of how the system has performed and will perform if all proposed projects are carried out. It can be seen that maintenance plays a significant role in distribution system reliability.

From figure 3.2 below it can be seen that SAIDI was improved when the reliability approach was used. The impact of reinforcement was noticed in the duration in which feeders remain out on faults and when both approaches are combined, a better result was gotten which shows that providing another source of supply when the grid fails provides an additional level of reliability in the network and this impact is seen above in fig 3.



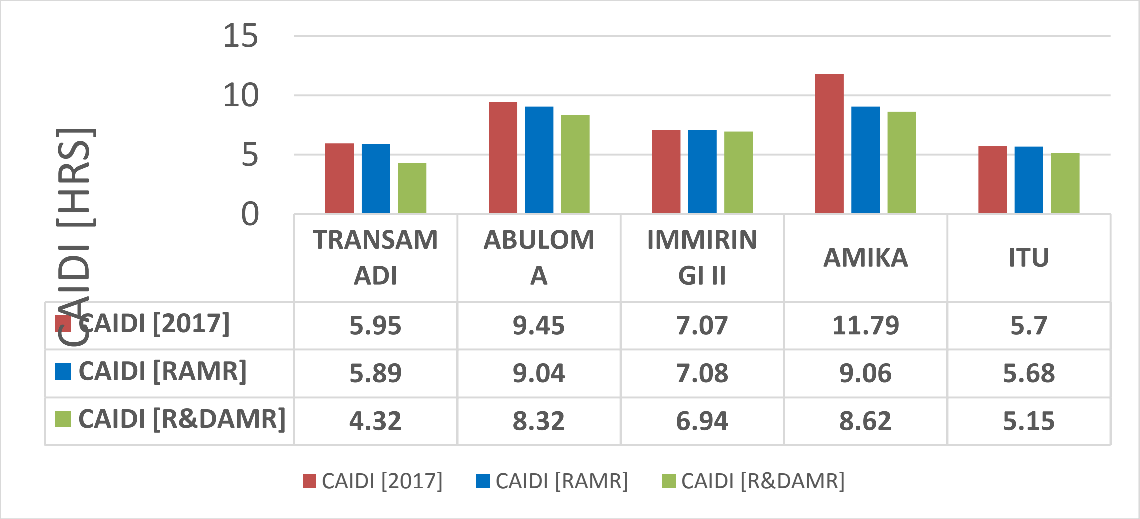
	TRANSA MADI	ABULOM A	IMMIRIN GI II	AMIKA	ITU
🟥 SAIDI [2017]	289.13	115.66	1839	1,084.59	1830
🟦 SAIDI [RAMR]	145.42	58.51	920	540.52	915
🟩 SAIDI [DAMR]	58.07	23.42	368	217.03	366

Figure 3.2: Chart showing Present SAIDI of the feeder and Calculated SAIDI of the improved network when reliability approach and combined approach were used.



	TRANSAMADI	ABULOMA	IMMIRINGI II	AMIKA	ITU
🟥 SAIFI [2017]	48.58	12.24	260	92.00	321
🟦 SAIFI [RAMR]	24.7	6.47	130	59.68	161
🟩 SAIFI [R&DA]	13.43	2.82	53	25.18	71

Figure 3.3: Chart showing Present SAIFI of the feeder and Calculated SAIFI of the improved network when the reliability approach and combined approach were used.



	TRANSAMADI	ABULOMA	IMMIRINGI II	AMIKA	ITU
🟥 CAIDI [2017]	5.95	9.45	7.07	11.79	5.7
🟦 CAIDI [RAMR]	5.89	9.04	7.08	9.06	5.68
🟩 CAIDI [R&DAMR]	4.32	8.32	6.94	8.62	5.15

Figure 3.4: Chart showing Present CAIDI of the feeder and Calculated CAIDI of the improved network reliability approach and combined approach were used.

From figure 3.2, 3.3 and 3.4 above it can be seen that SAIDI, SAIFI, and CAIDI were improved when the reliability approach was used. The impact of reinforcement was also noticed in the frequency in which feeders tripped on faults. Vegetation control and trace clearing impact were felt as feeders no longer trip on fault compared to the previous condition of the network. When both approaches are combined, a better result was gotten which shows that providing another source of supply when the grid fails provides an additional level of reliability in the network and customers see less outage. This impact is seen above in fig 3.2, 3.3and 3.4.

3.3 Determination of the cost of investment : Considering the level of reliability desired on the feeders under study, it is highly imperative to determine the cost of such investment that will yield the desired result of availability. The cost was calculated by preparing the bill of engineering measurement and evaluation for each feeder according to identified weaknesses in the network as shown by the power system study.The cost was determined for both deterministic and combined approach as shown in the table below and from the table, the cost of using reliability and deterministic approach combined is higher due to provision for redundancy than using the reliability approach only.

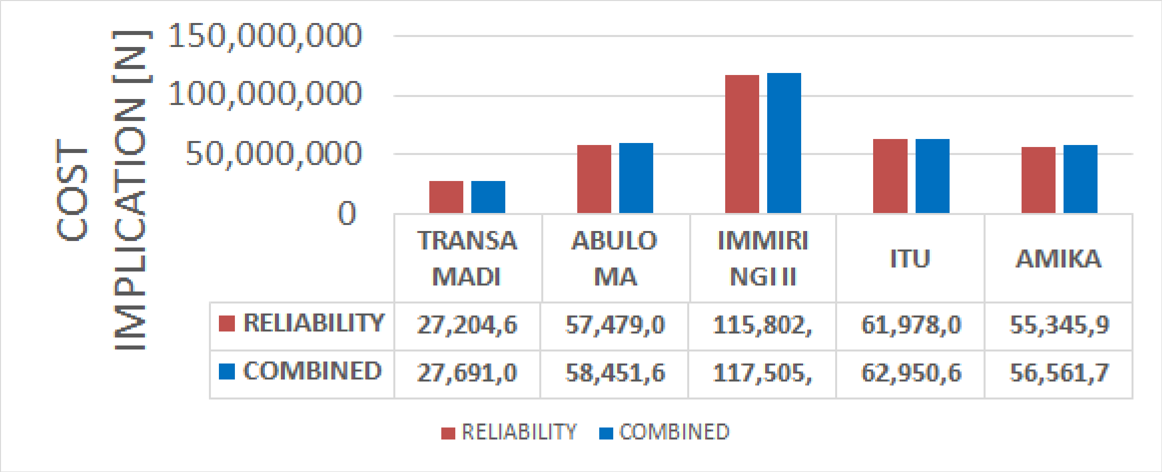


Figure 3.5 Chart showing the cost of investment using both the reliability approach and combined approach.

3.4 Determination of cost-reflective tariff for the feeders understudy with improved reliability

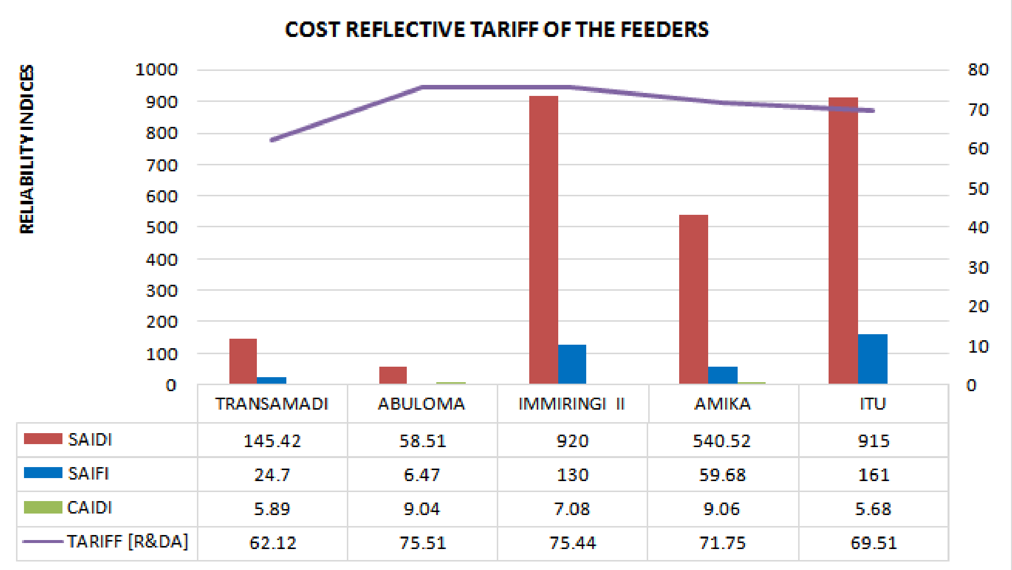
A tariff is cost-reflective and therefore, it is highly imperative to calculate the tariff which must have two objectives which are to collect the money required to cover all the cost of supplying electric power and also to send the right economic signal to each customer. These two objectives are taken care of in the tariff calculated below. The cost-reflective tariff is calculated using equation 3.8.1, 3.8.2, 3.8.3, 3.8.4, 3.8.5, 3.8.6 and 3.8.7. In tariff determination, NERC only allows distribution companies to recover 20.74% of its cost of investment and the Weighted Average Cost of Capital allowed is also 11%. With all this condition put into consideration, the tariff was calculated for the two reliability value gotten using the cost of an investment calculated and other parameters as shown in the table below. The electricity pricing gotten using the cost of investment from the deterministic and reliability approach combined is higher than electricity pricing from the deterministic approach as shown in table 4.5c and 4.6c below. From the result gotten, it was discovered that the higher the reliability desired, the higher the cost of electricity and invariably customers will be satisfied because of the improved reliability.

Table 3.1: Comparative impacts of Network reinforcement approach to reliability and energy pricing

Feeders	Reliability approach (₦)	Deterministic & reliability approach combined (₦)
TRANS AMADI	**62.12**	**64.14**
ABULOMA	**75.51**	**75.67**
IMMIRINGI II	**75.44**	**75.69**
AMIKA	**71.75**	**71.81**
ITU	**69.51**	**69.81**

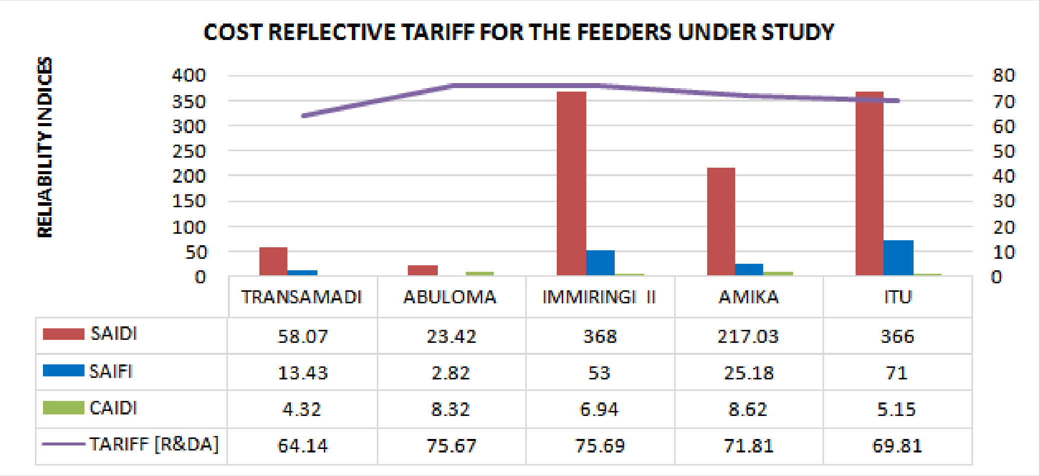
3.5 Comparative impacts of network reinforcement approach to reliability and energy pricing

Cost reflective tariff is highly imperative to the electricity sector and from table 3.1 above, it shows that the cost of electricity on each feeder is different because the different cost of investment was involved. Imiringi II, Amika and Itu which are rural feeders almost fall in the same category of tariff if given the best line of fit. From figure 3.6 and 3.7, it confirmed that reliability is a function of cost. The higher the reliability required in a network, the higher the cost of achieving such reliability. Figure 3.6 depicts a cost-reflective tariff involving the reliability approach and figure 3.7 shows cost-reflective tariff using deterministic and reliability approach combined. From the analysis above, the cost of using a combined approach is higher than when only the reliability approach was used and this led to improved reliability. Here, the cost of electricity when reliability is further improved is higher which implies that the higher the reliability attained, the higher the cost of electricity and there will be an inherent tradeoff between the increased costs of supply and reduction in the inconvenience and costs imposed on consumers due to power shortage. It can be seen that change in the reliability of the network is directly proportional to the cost of electricity and customer satisfaction. Hence, this reliability is considered as a variable to be optimized rather than an arbitrary imposed standard.



	TRANSAMADI	ABULOMA	IMMIRINGI II	AMIKA	ITU
🟥 SAIDI	145.42	58.51	920	540.52	915
🟦 SAIFI	24.7	6.47	130	59.68	161
🟩 CAIDI	5.89	9.04	7.08	9.06	5.68
— TARIFF [R&DA]	62.12	75.51	75.44	71.75	69.51

Figure 3.6 Chart showing the impact of the cost-reflective tariff on network reliability using a reliability approach.



	TRANSAMADI	ABULOMA	IMMIRINGI II	AMIKA	ITU
🟥 SAIDI	58.07	23.42	368	217.03	366
🟦 SAIFI	13.43	2.82	53	25.18	71
🟩 CAIDI	4.32	8.32	6.94	8.62	5.15
— TARIFF [R&DA]	64.14	75.67	75.69	71.81	69.81

Figure 3.7 Chart showing the impact of the cost-reflective tariff on network reliability using deterministic and reliability approach combined.

IV. CONCLUSION

The power sector is the biggest sector that can establish the course of infrastructure reforms and revival of our economy (Jha I.S and others 2002). Nigeria's power sector is at crossroads and time has come for taking drastic measures. The reliability of distribution networks is a significant part of power distribution system planning and improved reliability can lead to the more economic operation of the system. Hence, systemized and reasonable investment in new network components and gradual automation improves networks' ability to supply more customers even in an emergency. Along with such improvements, constant monitoring and diagnostics of grid elements and replacement of aged and not reliable equipment can further improve system reliability while proper asset management together with reliability analyses is required to maintain satisfactory reliability standards. It can be shown from this work that some acceptable levels of reliability can be achieved with a resultant cost-reflective tariff which will not put pressure on the customer and as well ensure return on investment on the side of the investor. Analyses like those provided in this thesis will become of great significance as customers are becoming more sensitive to supply interruptions.

REFERENCES

[1]. Richard, E.Brown, (2006): Electric Power Distribution Reliability, Brown ABB Inc. Second Edition, pp.355.
[2]. Hossein S. and Mohammad S.S (2011): Electric power system planning", Springer Heidelberg, New York, pp.3
[3]. Saravanan S., Subramanian K. and Thangaraj C. (2012): "Electricity demand forecast using regression analysis" a journal on soft computing, India, vol.2 pp. 365-368
[4]. Utilities Commission (2005): "Annual power system review" a report submitted to the electricity commission, Darwin, Australia, pp.5.
[5]. Maris T.L, Sideris K.M, Pappas S.S (2006): "Reliability increase using cost-benefit decision-making process" WSEAS transaction power systems, Greece, vol.1, pp.1851
[6]. Kumar, N.M, Sangmeswara R. and Porika V. (2013): Reliability indices evaluation of a real-time rural radial, distribution feeder, IEEE journal, vol.5, pp. 5-6
[7]. Achinaya A.A (2019): "Network planning and financial analysis", PHEDC presentation on energy management, Port Harcourt, Nigeria, pp.3-5
[8]. Chenghong Gu, Jianzhong W.U and Furong Li (2013): "Reliability-based network pricing", A Doctorate thesis of University of Bath, UK, pp. 3-4
[9]. Jha I.S, Subir S. and Kashish B. (2002): "Improvement of power distribution system", national power system conference, New Delhi, India, pp.236-237.

A.A Dahunsi. "Evaluation of Network Reliability Investments Costs". *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp 56-67.