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Reliability Assessment of 33KV Power Distribution System -A Case Study of Calabar 33kV Distribution Network

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ABSTRACT: Electric power distribution companies are faced with the challenge of providing a reliable, safe and cost-effective electricity to customers. Regular interruptions and outages are experienced in the distribution network leading to increase in the loss of revenue, increase in the cost of electricity supply, maintenance and customer's dissatisfaction. As the frequency and duration of interruptions and outages are rising even when electricity is available to the distribution network, there is need to regularly carry out reliability assessment of the distribution system. This paper presents the Reliability Assessment of 33kV power distribution System of Calabar. The assessment was carried out using outage and interruption data from the year 2017 to 2021 of the eleven 33kV distribution feeders obtained from Transmission Company of Nigeria, Calabar Control Area and Port Harcourt Electricity Distribution Company (PHEDC), Calabar Zone. These data were used as input to the ETAP simulation software to evaluate the reliability indices such as SAIFI, SAIDI, CAIDI, Expected Energy not supplied and Expected Interruption Cost. The results of the assessment shows that the Calabar distribution system SAIFI, SAIDI, CAIDIare higher and is less reliable compared to international standards. The results also shows that Amika and EPZ1 feeder contribute more to the reliability problem of the distribution system. Recommendations to improve the reliability of the distribution system are introduction of distributed generation, static VAR compensators, and replacement of isolators with higher current capacity and construction of parallel feeders.

KEYWORDS: Distribution System, Reliability, ETAP, Reliability Assessment, Feeder, Reliability Indices, Expected Interruption Cost, Expected Energy Not Supplied and Distribution System.

I.INTRODUCTION

Electrical power system main function is to provide adequate power supply at all times to all the points of utilization at an economically acceptable rate with high level of safety, quality and reasonable level of reliability. Anelectric power system is said to be reliable when it performs its functions adequately without any failure within a stipulated period of time when subjected to all operating conditions. Meanwhile electric power system is usually subjected to all kinds of faults, disturbances, malfunction and environmental conditions in addition to inadequacy of power supply against power demand resulting to interruptions and outages [1]. Interruptions and outages occur when any parts of the power system network fails. Therefore, the reliability of power system has to be continuously monitored and maintained all times for the benefit of the supplier and consumers [2]. Reliability studyrelates to all the parts of power system namely, the generation system, transmission system, distribution system, customers and all the functional parts of the power system such as protection system.Among all the parts of power system, electric distribution system is closer and responsible for the distribution of electricity to the final customers. It continuous operation is important to the performance of power system but it contributes more to the reliability problems faced by electric power suppliers and customers. As a fact most electric power distribution companies are faced with the challenge of providing reliable, safe and cost effective energy to customers. Regular interruptions and outages are experienced in distribution network leading to increase in cost of maintenance and electricity supply, and customer's dissatisfaction in the services provided and loss of revenue to the power supplier [3]. A reliable electricity supply is critical for the growth and operation of businesses and national economy. Hence, reliability study is necessary to assess the power system performance based on system configuration and data, therefore identifying faulty and weak components as well as recommending preventive/predictive maintenance of such to improve network reliability.

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This paper presents the reliability assessment of Calabar 33kVpower distribution network using Monte Carlo method implemented in ETAP simulation software. Calabar City has been experiencing increase in population, increase in small and medium scale enterprises, and rapid residential and commercial building development in the satellite towns. This has led to greater power demand than supply putting pressure on the existing distribution systeminfrastructures with regular occurrence of faults and disturbances leading to regular power failures, outages and interruptions.In some areas of the city, outages and interruption lasted for hours, days and even months. This has adversely affected the economy of the state. Industries and businesses such as hotels, salons, water processing factories, etc. operate below their installed and targeted capacities with high cost of running standby generators leading to high cost of production and reduced productivity.

Hence, the research intends to know the reliability level of the distribution system, identify parts of the distribution system that contributes the most to power failures, outages and interruption and suggest ways of improving reliability of Calabar 33kVdistribution network. It also analyze the costs implication due to the regular interruptions on the 33kV power distribution network in Calabar.

II.RELIABIITY ASSESSMENT OF DISTRIBUTION SYSTEM NETWORK

Reliability assessment of a distribution system is a genuine technique in planning, operation and expansion of power distribution system towards utility and customer's safety and satisfaction. It helps to determine the quantitative and qualitative assessment of the performance of distribution system. In assessing the reliability of a distribution system network, there are two things that needs to be considered, namely the methods of assessment and reliability indices. There are two main methods that can be used to evaluate distribution system namely the Monte Carlo method otherwise known as simulation methods and analytical methods. The Monte Carlo method is based on drawings from statistical distributions of failure rates and outage times while analytical methods based on mathematical models of failure rates and repair times. These methods are widely used by researchers to assess the reliability of distribution system [4] – [8]. The difference between the two methods is that the simulation method is time consuming compared to the analytical methods. Apart from these two methods, several advanced reliability methods such as Genetic Algorithm, Artificial Neural Network, Particle Swamp Optimization (PSO) are now widely used to analyses reliability of power distribution system [9][10] . These methods calculate reliability of power system based on the loss of load probably (LoLP) method and the frequency and duration method. While Loss of load indices such as Loss of Load Expectation (LOLE), Loss of Load Frequency (LOLF), and Loss of Load Duration (LOLD) are used to determine power system generation adequacy, frequency and duration of outages are used for the distribution system. Therefore, basic indices used to assess reliability of distribution system based on frequency and duration of interruption and outages are system point indices and customer point indices such as SAIFI, SAIDI, CAIDI, etc. Khaidir Ali etal. [11] carried out analysis power distribution system based on SAIDI and SAIFI and compared the results with both national and international standards for reliability such as IEEE std. 1366-2003 which has a standard value of SAIFI to be 1.45 times/customer/year. They were able to discover repeaters that were reliable or not.

III. POWER INTERRUPTIONS

Power interruption also referred to as power outage is the partial or complete loss of electric power supply by electrical power network to the end-users or customers. It is caused by natural, environmental and weather conditions, human errors, failure or faults such as overload, malfunction of some components, control and protection systems of the power system or distribution system. Power interruptions can be divided into two, namely Momentary and Sustained interruption. Both interruptions are differentiated by the duration of time it takes to restore power supply. Momentary interruption of power supply is the loss of power supply for a short time usually few seconds up to one minute. It is caused by temporary faults resulting to the voltage supply level of less than 10% of nominal for up to one minute duration. Sustained interruption is caused by permanent faults resulting to a decrease in the voltage supply to zero for more than one minute duration.It is a complete or long duration loss of electric power supply which would results to complete shutdown of customer facility [12] [13]. Consequently, it requires physical corrective maintenance to restore power supply.

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IV. DISTRIBUTION SYSTEM

In most power system network, the generating plants are located far away from the load centers or customers, so transmission network and distribution network are used to convey electric power to the consumers or load centers. The transmission network conveys bulk electric power from the generating plant to the transmission substation while the distribution network distributes electric power to consumers.

4.1 DISTRIBUTION SYSTEM

The distribution system network is divided into two based on the voltage level as primary and secondary distribution system. The primary distribution system network is a three-phase (three-wire) system and operates at a voltages of 33kV and 11kV which is stepped down from the sub-transmission voltage of 132kV or 66kV. The 33k or 11kV are connected to a particular area and are called feeders. The feeders are given names based on the name of the area it is serving. The secondary distribution system network is directly connected to the consumers, it is a three-phase, four-wire system and operates at a reduced voltage of 415V/230V stepped down from the primary distribution network voltage of 33kV or 11kV.

4.2 DESCRIPTION OF THE DISTRIBUTION SYSTEM UNDER STUDY

Calabar distribution 33kV network consists of eleven (11) 33kV distribution feeders, located at Transmission Company Nigeria (TCN). These eleven (11) feeders gets their supply from four (4) 60MVA, 132/33KV power transformers located at the 132/33kV Calabar transmission station. The length of the transmission line from Adiabo to 132/33kV Calabar transmission station is approximately 12km in length. The details of the loading of the eleven 33kV feeders are analyzed. Akamkpa is a 33KV line with peak load of 3.1MW supplied from Feeder 1. UNICEM, Niger Mills, Iron and Steel, OLAMS and Water Board are 33KV dedicated line with peak load of 0.1MW, 3.7MW, 16MW and 4.6MW supplied from feeder 2, feeder 3, EPZ I feeder 10 and feeder 7 respectively. AMIKA 33KV feeder has a peak load of 16.7MW its supplies two injection substations it been fed from feeder 9. These substations includes Amika 2 x 15MVA 33/11KV Injection Substation with four outgoings 11kV feeders namely Cameroun, UNICAL, Target and Goldie feeders and CRUTECH 2 x 7.5MVA 33/11KV Injection Substation which comprises of two outgoings 11kV feeders namely Anatigha and CRUTECH(faulty).Flour Mills and State Housing feeders feeds an Injection substation called flourmill injection substation which is a 2 x 15MVA 33/11KV capacity with a peak load of 8.3MW and 6MW respectively. The injection substation has three (3) outgoing 11kV feeders, the State Housing 33kV feeder feds MCC 11kV feeder while flour mill 33kV feeder feds Industrial and Essien II feeders. EPZ II having peak load of 9.8MW feeds Genesis Power Company, Monty Suites 33/0.415KV, and EsukUtan 2 x 7.5MVA 33/11KV Injection substation which has three (3) outgoing 11kV feeders namely Federal Housing, 8 Miles, and EsukUtan 11kV feeders. Diamond 33kV feeder has a peak load of 3.9MW which feeds Navy Jetty, Naval Eastern Command and a 2 x 7.5MVA 33/11KV Injection substation. This injection substation supplies Essien 1(faulty) and Leopard 11kV outgoing feeders. The single line network of the 123/33kV network is shown in Fig. 1.

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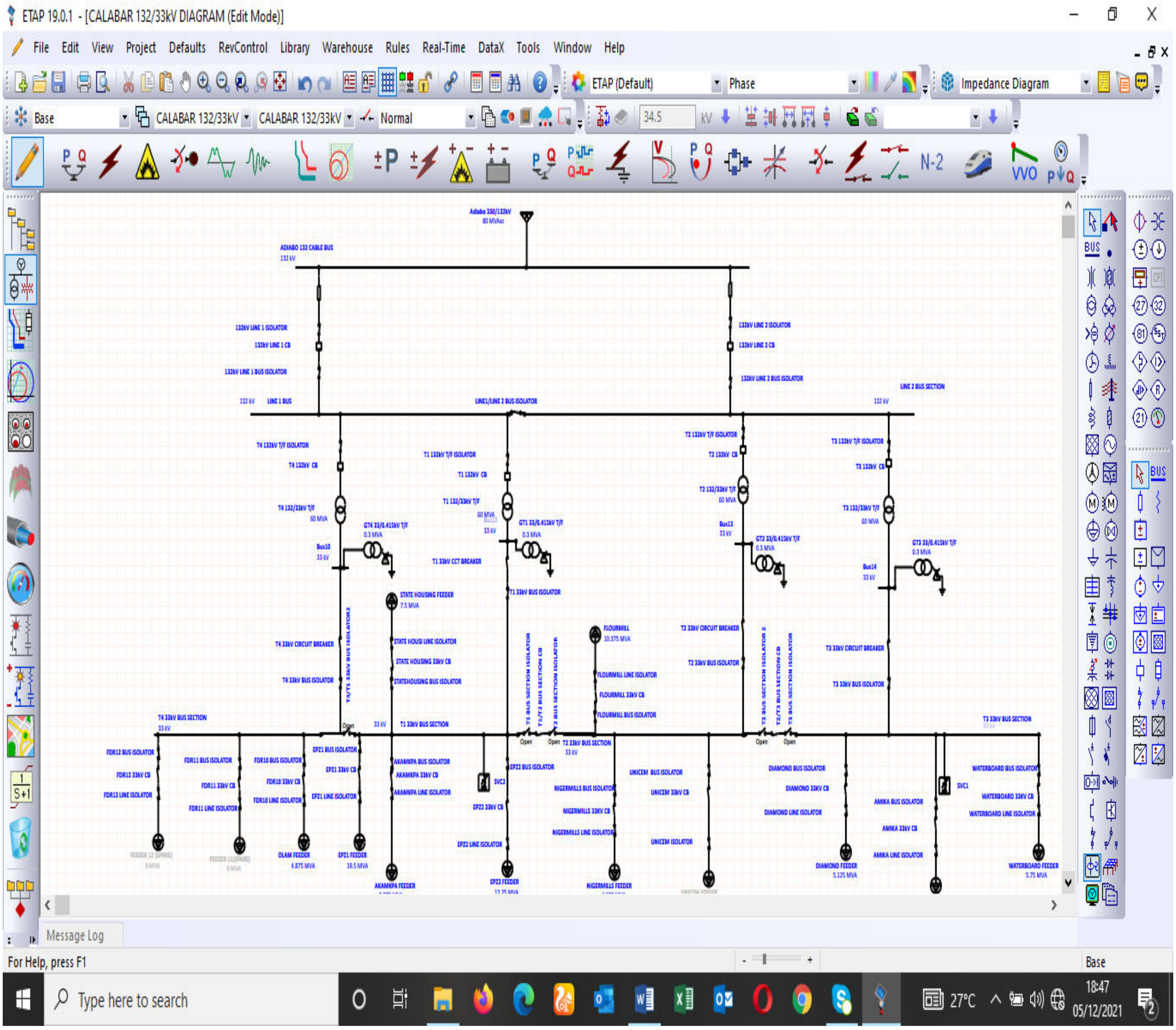

Fig.1.Single Line Diagram of Calabar 132/33kV Network on ETAP Environment

V.MATERIALS AND METHODOLOGY

5.1 MATERIALS

This study utilizes historical data about the distribution system such as the number and ratings of the power transformers, the type of conductors, length and properties as well as records of the number of customers, daily outages, daily tripping, daily interruptions and daily blackout of the eleven (11) 33kV distribution feeders that make up the Calabar distribution system network. These data were collected and grouped per month for a period of five (5) years (2017 – 2021), their duration and frequency recordedfrom the daily returns for transformer station reports, daily dispatch and operational logbooks of the eleven 33kV feeders as well as the summary of monthly hours of availability and grid meter reading logbooks under review which are owned by the Transmission Company of Nigeria and Port Harcourt Electricity Distribution Company.

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5.2 METHODOLOGY

The method involves a detailed description and a single line model of the Calabar 33kV distribution system in ETAP software. Then, data of failures, outages, interruptions and their duration and frequency collected were keyed into the ETAP software and simulated. The Monte Carlomethod was used with the ETAP simulation software to determine reliability indices that can be used to assess the reliabilitylevel of the distribution system.The computed reliability indices is then compared with the standard national and international reliability indices such as IEEE std.1366 – 2003 to know the level of reliability of the system.

VI. DISRIBUTION RELIABILITY INDICES

The distribution system reliability performance evaluation is normally concerned with the electric supply adequacy and availability at the customer load point. The basic distribution system reliability indices are the three load point indices of Average Failure Rate, (λ), the Average Outage Duration, (r) and the Annual Outage Duration, (μ), Mean Time To Repair (MTTR), Mean Time Between Failure (MTBF), Mean Time To Failure (MTTF) [14].These reliability indices are used to evaluate the severity and implications of system outages and interruptions. For sustained interruptions, reliability indices are calculated based on the interruption duration and frequency as given in equations 1-7.

6.1 Distribution Network Reliability Indices Equations

Reliability indices such as customer based, load-based and energy-based indices are used to assess the past, present and future performance of power system network. Their definition starts from the understanding of failure rate (λ) and repair time (μ).

6.1.1 Failure Rate ($\boldsymbol{\lambda}$)shows how often fault occurs in a component, node or system. It is the ratio of the number of outages in a component in a given period to the total time the component is in operation. It is also the reciprocal of the mean time to failure. It is given mathematically as;

$$\lambda = \frac{Number\ of\ outages\ on\ component\ in\ a\ given\ period}{Total\ component\ is\ in\ operation} = \frac{1}{MTTF} \quad (1)$$

Where MTTF is the Mean Time to Failure

6.1.2 Repair Rate ($\boldsymbol{\mu}$) is a value which defined how often repair is carried out on a component, part or the whole system. It is related to the mean time to repair as follows;

$$\mu = \frac{1}{MTTR} \quad (2)$$

Where MTTR is the Mean Time to Repair

6.1.3 Average Failure Rate at Load Point *i*, $\boldsymbol{\lambda_i}$ (failure/yr.)

$$\lambda_i = \sum_{j \epsilon Ne} \lambda_{e,j} \quad (3)$$

Where $\lambda_{e,j}$ the average failure is rate of element$j$; N_e is the total number of the elements whose faults will interrupt the load point i

6.1.4 Annual Outage Duration at Load Point *i*, Ui(hr/yr)

$$U_i = \sum_{j \epsilon Ne} \lambda_{e,j} r_{ij} (4)$$

Where r_{ij} is the failure duration at the load point *i* due to a failed element,j.

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6.1.5 Average Outage Duration at Load Point *i*, r_i(hr)

$$r_i = \frac{Annual\ outage\ duration\ at\ load\ point\ i,\ U_i}{Average\ Failure\ rate\ at\ load\ point\ i,\ \lambda_i} = \frac{U_i}{\lambda_i} \quad (5)$$

From (1) and (5), the customer-based reliability indices can be determined as follows.

6.1.6 System Average Interruption Duration Index, SAIDI (min or hr/customer.yr)

SAIDI is the total duration of interruption for the average customer during a predefined period of time. It is measured in customer minutes or customer hour and expressed as follows;

$$SAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ number\ of\ Customers\ Served} = \frac{\sum r_i Ni}{\sum N_i} \quad (6)$$

Where, r_i is interruption duration andN_i is the total number of customers served in the load point i.

6.1.7 System Average Interruption Frequency Index, SAIFI (f/customer.yr)

This shows how often the average customer experienced a sustained interruption over a predefined period of time. It's given by;

$$SAIFI = \frac{Total\ number\ of\ Customers\ Interrupted}{Total\ number\ of\ Customers\ Served} = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (7)$$

Where λ_i is the failure rate at point load i.

6.1.8 Customer Average Interruption Duration Index, CAIDI (min or hr/customer interruption)

This index refers to the average time it takes to restore power supply to the average customer for each sustained interruption. It is given by;

$$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ number\ of\ Customer\ Interrupted} = \frac{\sum r_i Ni}{\sum N_i} = \frac{SAIDI}{SAIFI} \quad (8)$$

Where, r_i is interruption duration (restoration time for each interruption event), N_i is the number of interrupted customers for the period.

6.1.9 Customer Average Interruption Frequency Index, CAIFI.

This shows the average frequency of sustained interruptions for customerswho experienced a sustained interruption over a predefined period of time. It's given by;

$$CAIFI = \frac{Total\ number\ of\ Customers\ Interrupted}{Total\ number\ of\ Customers\ experineced\ interruptions} = \frac{\sum r_i Ni}{N} \quad (9)$$

Where, N is the total number of customers who have experienced sustained interruption during the reporting period.

On the other hand, CAIFI measures the average number of interruptions per customers interrupted per year. It is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions. CAIFI is

$$\frac{\sum(N_0)}{\sum(N_i)} \quad (10)$$

Where, N_0 is the number of interruptions, N_i is the total number of customers interrupted.

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6.1.10 Average Service Availability Index (ASAI)

ASAI is the ratio of the total number of customer hours that service was available during a given time period to the total customer hour demanded. It can be calculated for any time period, however it is usually calculated for a month or for a year. It gives part of the time that a customer has received power during the defined reporting period. It can be expressed in fraction or percentage.Mathematically, it's given by;

$$ASAI = \frac{Customer\ Hours\ Service\ Availability}{Customer\ Hours\ Service\ Demand} = \frac{^{N}T\ X\left(Number\ of \frac{hours}{yr}\right) - \sum r_i Ni}{^{N}T\ X\left(Number\ of \frac{hours}{yr}\right)} = \frac{\sum Ni\left(Number\ of \frac{hours}{yr}\right) - \sum r_i Ni}{\sum Ni\left(Number\ of \frac{hours}{yr}\right)} \quad (11)$$

Where there are 8760 hours in a non-leap year and 8784 hours in a leap year, Ni is the number of customers served at point load i

6.1.11 Average Service Unavailability Index (ASUI)

Given the Average Service Availability Index (ASAI), the Average Service Unavailability Index (ASUI) can be computed using;

$$\text{ASUI} = 1 - ASAI \quad (12)$$

6.1.12 Expected Energy Not Supplied Index at load point$i$,(EENS$_i$) (MWhr/yr)

This represent the total energy not supplied by the system to customers. It can be calculated using

$$EENS_i = P_i U_i \quad (13)$$

Where, P_i is the average load connected to load point i and U_i is the annual outage time at load point i.

6.1.13 Average Energy Not Supplied Index (AENS) (MWhr/yr)

This also referred to as the Average System Curtailment Index (ASCI). It is the ratio of the total energy not supplied to the total number of customers served. Mathematically,

$$AENS = \frac{Total\ Energy\ not\ supplied}{Total\ number\ of\ customers\ served} = \frac{\sum P_i U_i}{\sum N_i} (14)$$

6.1.14 Expected Interruption Cost Index at Load Point i, ECOST$_i$(Naira/yr)

$ECOST_i = P_i \sum_{j \epsilon Ne} f(r_{ij}).\lambda_{e,j}$ (15)

Where $f\,(r_{ij})$ is the composite customer damage function.

VII.RESULTS AND DISCUSSION

The reliability analysis of Calabar 33kV distribution system network was carried out in ETAP simulation software as shown in Fig. 2.The results of the simulation was used to compute the reliability indices which were further used to assess the level of reliability of the distribution system under study.

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i. Reliability Indices

The reliability indices such as SAIFI (f/customer.yr), CAIDI (hr/customer interruption), SAIDI (hr/customer.yr), AENS (MWhr/customer.yr), EENS (MWhr/yr) and ASUI (pu) for Calabar 33kV distribution system network were calculated in the software and the results illustrated in Fig. 3.

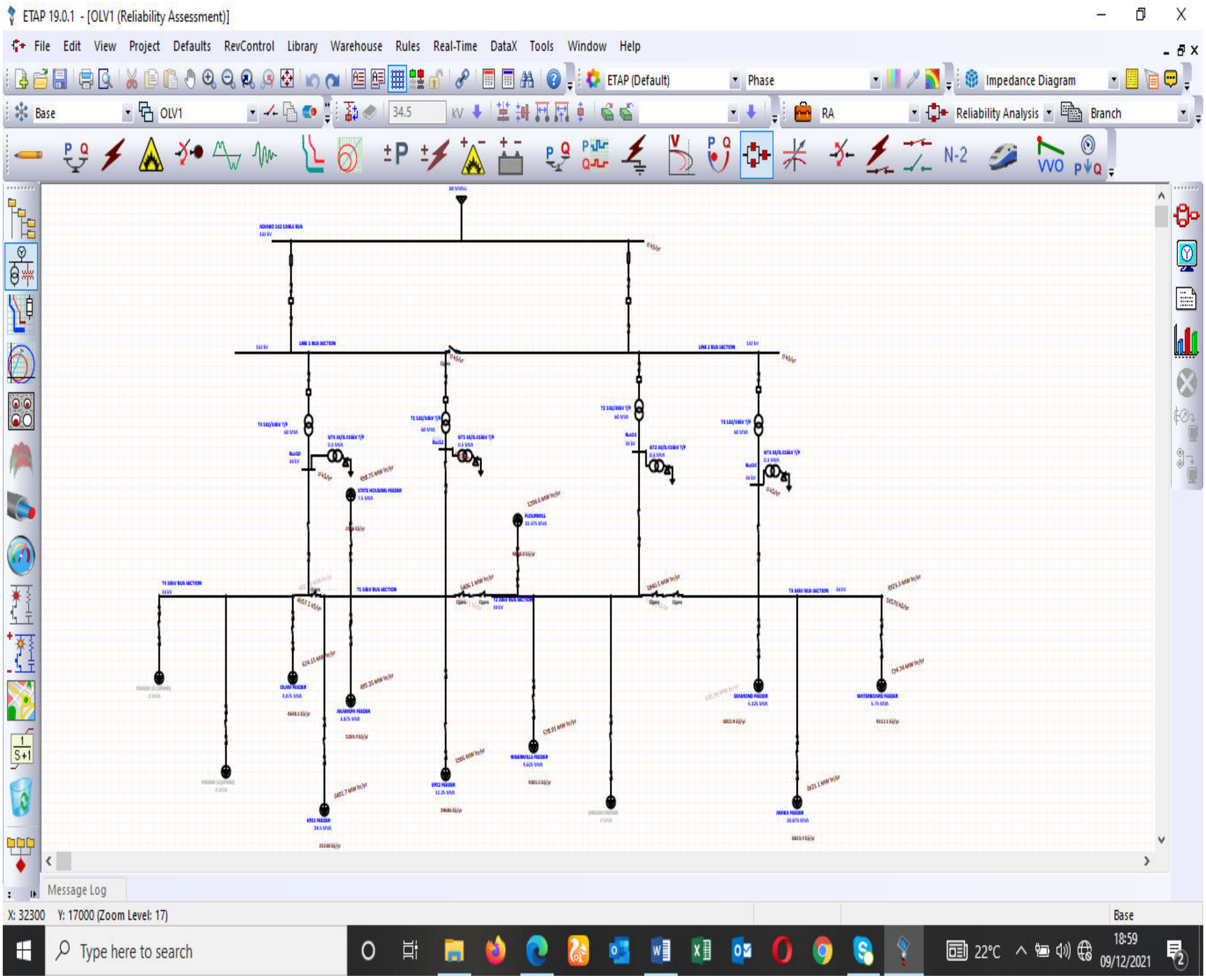

Fig. 2 (a): Model and Reliability Analysis of the distribution system on ETAP Environment

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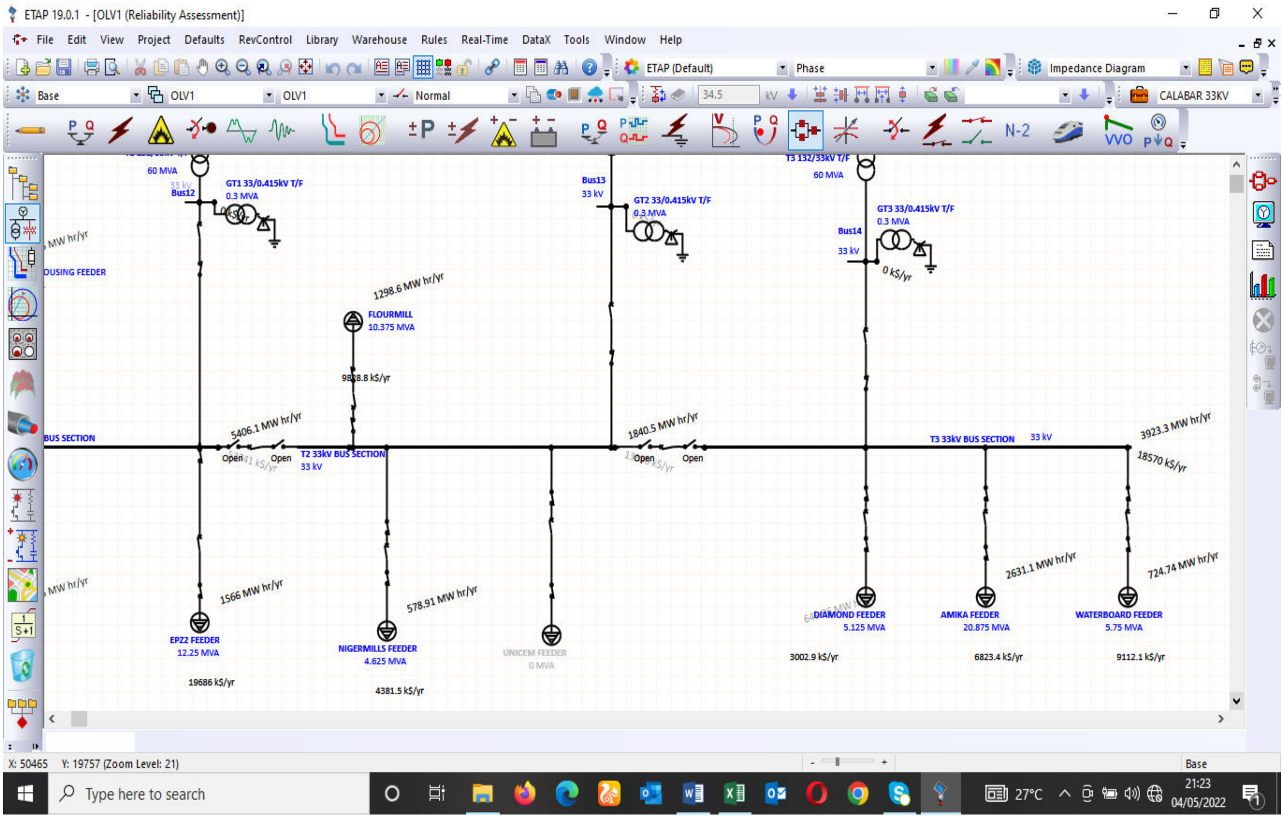
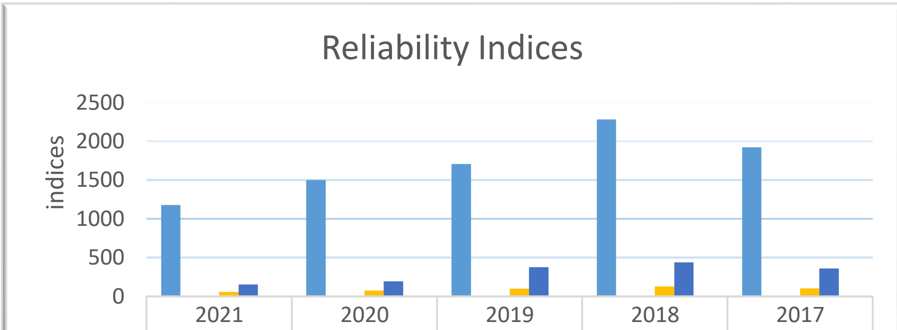


Fig. 2 (b): Zoomed section of the Model of the Distribution System for Reliability Analysis on ETAP Environment



	2021	2020	2019	2018	2017
AENS	1177.198	1498.4383	1705.4133	2282.4391	1919.8711
ASAI	0.9823	0.9413	0.8621	0.7845	0.8688
ASUI	0.01771	0.01732	0.03757	0.05831	0.03969
CAIDI	58.402	74.813	98.842	129.612	103.152
SAIDI	155.13	196.44	375.87	439.12	361.17
SAIFI	2.6562	2.9812	3.9815	4.5151	3.7171

load point

Fig. 3: Reliability Indices of Calabar Network 2017 – 2021

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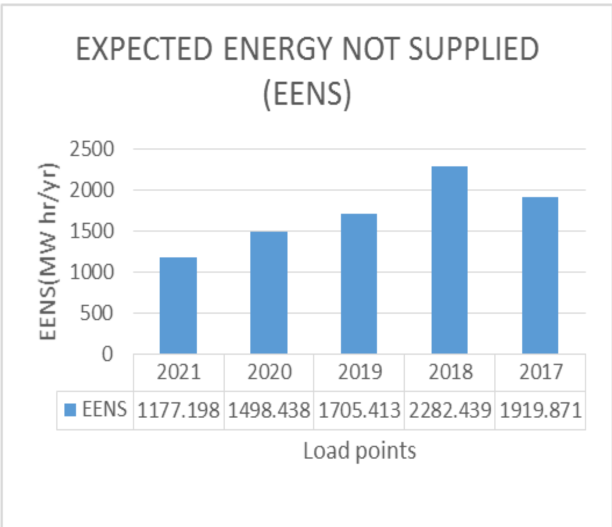
From the ETAP simulation results, SAIFI value for the period of five (5) years varies between 2.6 times/customer/year to 4.5 times/customer/year with improvement in 2020 and 2021. Generally the SAIFI is considered to be less reliable when its compared with the international IEEE std. 1366-2003which has a standard value of SAIFI to be 1.45 times/customer/year.

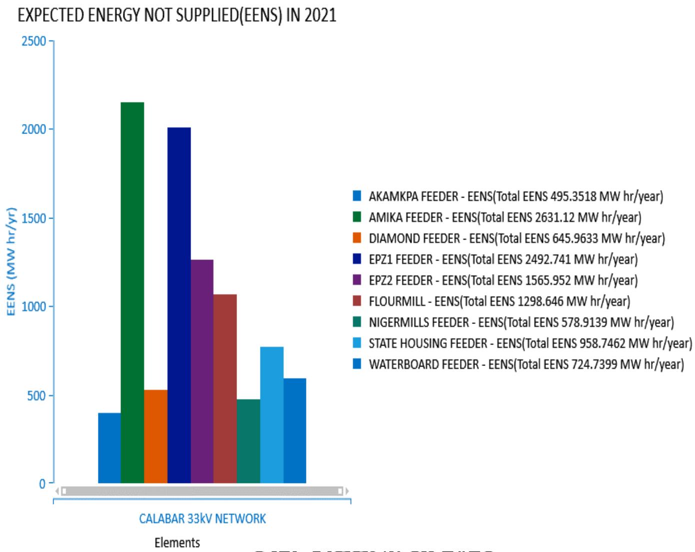
The performance of the distribution network was also assessed based on SAIDI. The SAIDI rangesfrom 155 hours/customer/year to 439 hours/customer/year. Again looking at the results, there is an improvement in the value of SAIDI in 2020 and 2021 with respective value of 196 hours/customer/year and 155 hour/customer/year. These values when compared with the IEEE std. 1366-2003, even when there is considerable progressive improvement is more than the value of IEEE std. of 23 hours/customers/year and is considered to be less reliable.

The Average Service Availability Index (ASAI) of the distribution network improved greatly in 2020 and 2021 having values of 94% and 98% respectively but the value is still below the ‘four nines’ or 99.99% reliability standard.

ii. Annual Expected Energy Not Supplied (EENS) Analysis for the Network

The reliability assessment was also based on energy not supplied to customers per year. The Expected Energy not supplied per year for period of study is shown in Fig. 4. It shows that there is great improvement in the expected energy not supplied except for 2018 which recorded the highest energy not supplied. A comparison of the expected energy not supplied by the different feeders of the distribution networksin 2021 as shown in Fig. 5, shows that Amika and EPZ 1 contributed the most to the energy not supplied of which Amika contributed the highest value of EENS of 2631.12 MW hr/yr. The high record of energy not supplied by Amika and EPZ1 feeder is due to high consumption of electricity on the feeder resulting to overload and frequent sustained interruptions and outages. The slight improvement recently isas a results of the recent expansion at the transmission network feeding the distribution system network as well as recent upgrade in the system.





iii. Annual Expected Interruption Cost (ECOST) for Calabar 33kV Distribution Network

The annualized Expected Interruption Cost, ECOST have also shown that there was a significant improvement as shown in Fig. 6, while, Fig. 7 shows the recent ECOST across the various 33kV feeders in Calabar distribution network with EPZ 1 having the highest ECOST.

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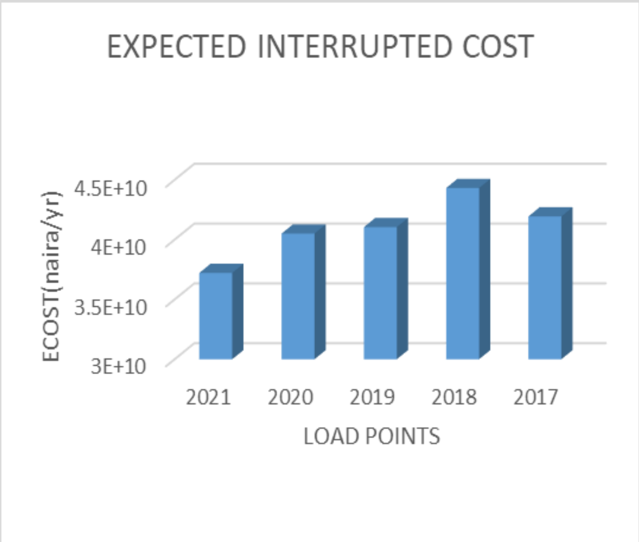

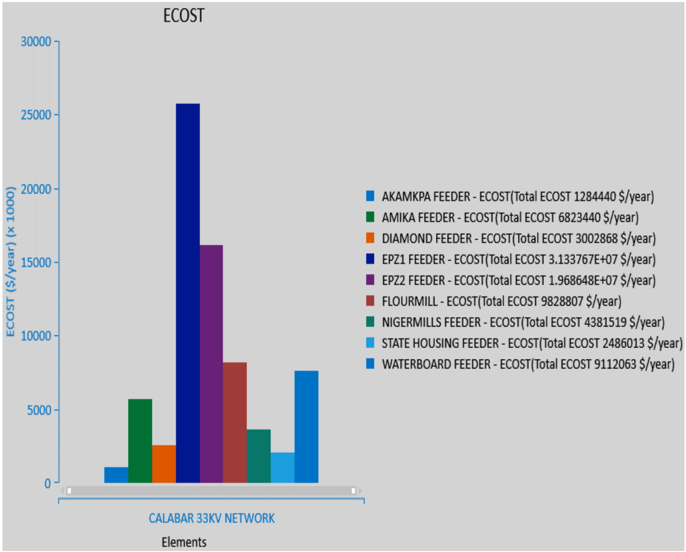

Fig. 6: ECOST from 2017- 2021 **Fig. 7: ECOST for feeders in 2021**

VII.CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The value of SAIFI, SAIDI and CAIDI of the Calabar 33kV distribution system shows remarkable improvement over the past five years. For examples SAIFI which was 3.72 in 2017 reduces to 2.66 as at 2021, while SAIDI 155 hour/customer/year. However, there is improvement, it can be referred to as less reliable when compared with the SAIFI and SAIDI standard value according to IEEE std. 1366-2003 which have standard values of SAIFI to be 1.4 times/customer/year and SAIDI of 23 hours/customer/year. On average, the ASAI shows remarkable improvement in the availability of electricity in 2020 and 2021 but still below the international standard of ‘four nines’ that is 99.99% reliability. Customers on Amika and EPZ 1 suffers more of energy not supplied due to large consumption resulting to overloading and interruptions. Consequently,the Calabar distribution network is considered less reliable and requires improvement.

7.2 Recommendations:

1. The operating capacity of transformers T1 and T3 bus isolators is 400A. In the course of this study, it was discovered that T1 and T3 isolators were operating on load current of 792.6A and 576A respectively against the 400A and are overloaded. This study therefore recommends that the transformer T1 and T3 bus isolators requires urgent replacement to a higher amperage of 1200A and 1000A respectively to accommodate the present capacity, future expansion and the ever increasing load demand.

2. Distributed Generation (DGs)utilizing available renewable energy resources e.g. Solar, Wind, Biogas, small hydro should be developed and incorporated at different location of the Calabar distribution network to further improve its reliability.

3. There is need to introduce static VAR Compensators at T1 and T3 bus section to cushion the effect of the high reactive power and hence improve the voltage profile.

4. Equipment which are cost beneficial to the network like auto reclosing devices, line isolators as well as overvoltage protection should be introduced into the distribution network to reduce the long outages periods. Replacement of faulty or aged system components with new and quality ones so as to reduce failure frequency.

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5. There is need to run parallel lines on some feeders especially Amika 33kV, EPZ 1 and EPZ2 33kV feeders instead of single line hence line reactance can be reduce. This will lower accelerating power and hence the risk of the network unreliability.

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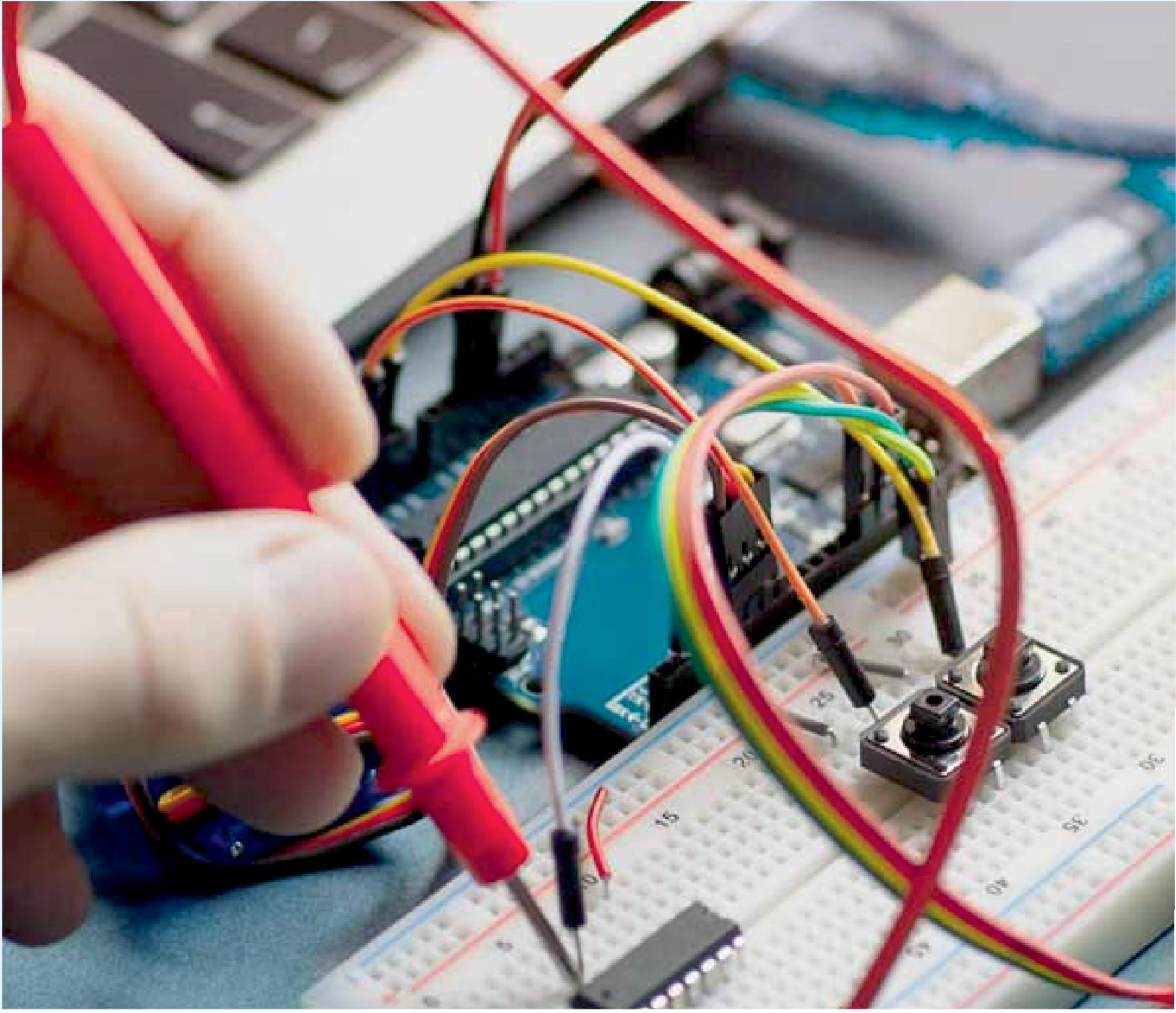

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