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Monitoring and Evaluation of The Reliability of Distribution Network with Distributed Generation

Original Research Article

ABSTRACT

With the growing population of Ezenei 11KV feeder radiating from the Asaba mains Injection Substation and overstretched distribution network, monitoring and evaluation of the reliability and improvement of distribution network feeder is essential. Failure of some of the equipment at supply restoration is frequent due to weakness of some of the line conductors and long usage of the equipment. In this research work, simulation, analysis and evaluation of the reliability and improvement of Ezenei 11kV feeder was investigated. Load data used were collected from Benin Electricity Distribution Company (BEDC) Asaba between February and April 2018 and this was used to model the sixty – seven (67) buses on the network using Electrical Transient and Analysis Program (ETAP). Load flow analysis was carried out on the modelled network using Newton – Raphson (N-R) iteration method to determine the various bus power (active and reactive) and voltage magnitude using the base and distributed generation injected power. Reliability study was carried out on the network and result showed that the load point indices were increasing as distance of load point increased from feeder. The Seventeen load buses which was Okeke bus to Starcom bus forms the location A. and St. Rebecca bus to Chief Ofili bus forms location B. while Odogu bus to Old Deputy Govt. bus forms location, Iyabi bus to MTN III bus forms location D. Okeke and Jimok water which are the closest load buses to the feeder have an Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr) of 8.9264f/yr, 417.1507hr/yr while Victor Odogu and Auditor General has an Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr) of 8.9318f/yr, 417.2857hr/yr and 8.9264 f/yr, 417.1507hr/yr. It was also observed that Chief Osita, Anacho and Estate buses had the highest Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr).

Keywords: Reliability; Improvement; assessment and assessment; monitoring and evaluation; loss sensitivity factor; system indices; ETAP; photovoltaic; newton-raphson.

1. INTRODUCTION

The main function of power system is to supply electricity to its customers at optimal operating costs at all times with a reasonable quality and continuity assurance. Reliability is the probability that a power system will perform its functions adequately without any failure within a stipulated period of time when subjected to normal operating conditions [1]. The reliability study can be utilized to assess the performance of the distribution system based on the availability of suitable input component data and the configuration of the system. The reliability assessment can also be used to identify the malfunctioned components that need urgent replacement in the distribution system as well as recommending the numbers of new components that should be incorporated in order to improve the reliability of the networks. Owing to these technical and economic attributes, the reliability technique has been accepted as a benchmark for power system design and operation at all phases of the power system, that is, conceptual, design, planning and operational phases [2]. In power system, the following reliability indices are considered: the amount of power interrupted, load connected, frequency of interruptions, number of consumers and duration of interruption. From the basic definition of reliability stated above, probability is the most important determinant factor. Distribution systems network carries electricity from the transmission system and delivers it to the consumer. Such network include medium voltage power lines, substations, pole mounted transformers and low voltage (less than 1kV) distribution wiring meters. All modern distribution systems start as the primary circuit leaves the substation and ends as the secondary services enter the consumers meter sockets. Initially energy leaves the substation in a primary circuit usually with all three phases [3].

Injection Substation is a substation where higher voltage is stepped down to a lower voltage, especially for transmission in a densely populated area. The transformer used is in MVA range, so that the output can serve a wide area or large consumers. The common injection substations in Nigeria are 15MVA or 7.5MVA, 33/11kV injection substation.

The injection of DG helps to maintain acceptable voltages at all points along the feeder and reduce technical losses in the network. Distributed generation is therefore the method of using series of smaller size technology installed in strategic points of the electric power system to generate or produce electricity in the range of small kilowatts up to 10MW located at or close to the site of use or near the loads centre [4]. It is either connected to a grid or operating in a stand-alone mode at the distribution or sub transmission level thereby protecting households, businesses and institutions from unexpected power cuts as well as reducing costs and losses associated with transmission while improving energy efficiency and reliability [5]. Renewable technology such as; solar (photovoltaic), fuel cells, wind, etc, and non renewable energy technology such as micro turbines, small gas turbine, hydro etc are adopted in DG and can be used in an integrated way, supplying energy to the remaining of the electric system or in an isolated way, supplying energy to the consumer's local demand. DG can provide benefits for the consumers in a distribution system as well as for the utilities, especially at sites where the central generation is impracticable or where there are deficiencies in the transmission system [6].

The increase in electrical energy demand in Nigeria as a result of the increase in population and social advancement has has caused the loading of the distribution network beyond their design limits; with consequent reduction in power quality and increased power outages [7]. This peculiar problem has hindered many industrial capacity utilization, efficiency, reliability, economic growth etc in Nigeria. One of the major problems faced by Nigeria is incessant power failures especially on the transmission and distribution Systems. This has caused losses and outages along each individual consumer point in the feeder. This problem, having grounded so many activities in the country, has also destroyed many industrial processes. This ceaselessly electric power supply problems faced by various consumers in Nigeria is a pointer to the fact that there is great need for monitoring, fault evaluation and reliability assessment of electric power system in the country and providing possible solutions. In order to ameliorate the performance of the distribution network, investment on distributed generation infrastructure has increased. The reliability analysis of distribution system was considered and analyzed in this research work, the result shows that the reliability of load points in distribution system decreases as distance from feeder increase, while the most reliable location in distribution system is the location closer to the feeder.These analyses were executed on Roy Billiton Test System (RBTS), which was modeled and evaluated in ETAP. The aim of this research work is to monitor some Parameters of the distribution network of study and evaluate the reliability of the network to ascertain the seriousness of the various violations and mitigate the severity of the violations with the injection of distributed generators.

2. POWER SYSTEM RELIABILITY ASSESSMENTS AND INDICES

To assess the reliability of a power system, aspects of multiple disciplines have to be considered and analysis framework needs to be specified [7] which consisting of: identification of which aspect of reliability to be adopted, definition of system boundaries to limit the extent of the analysis, selection of the level of modeling detail and analysis method, in order to be able to study the correct phenomena and selection of proper reliability indices during computation. Reliability can be measured in by the frequency, duration and magnitude of adverse effect on electric supply as defined in IEEE Standards. The three most common tools include [8]: System Average Interruption (SAIDI) which is designed to provide information about the average time for customers and indicates the sum of the restoration time for each interruption event times, Customer Average Interruption Duration Index (CAIDI) which is the average time need to restore service to average interrupted customers, System Average Interruption Frequency Index (SAIFI) which is the total number of interrupted customers divided by the total number of customers utilizing the electricity and Momentary Average Interruption Frequency Index (MAIFI) which is the reliability index that considers momentary interruptions and It is equated to the total number of customers momentarily interrupted divided by the total number of consumers.

Reliability of distribution system evaluation with DG using ETAP was considered [9]. Effort was made in this research work to study on the reliability of the distribution network impact of DG and Ran 11kV feeder distribution network from Bauchi on IEEE 33 Bus distribution network was used for the study. The results showed that as the reliability of the system increases, also the number of DG in the system increases. Using Ikorodu, Lagos state in Nigeria as a case study, the reliability of distribution network was examined [10]. The occurrence, causes of faults and outages in the Distribution Network Area for a period of eight (8) years was evaluated in the research work. The result showed that the effects of power losses were reduced and the performance and reliability of the distribution system improved. Reliability Assessment of Electrical Energy Distribution System – A Case Study of Port Harcourt Distribution Network was investigated [11]. The analysis was carried out using 2014 and 2015 historical data of Secretariat, Silver Bird, Water Works, UST and School of Nursing Injection Substations obtained from the Port Harcourt Electricity Distribution Company [PHEDC]. The results of the analysis revealed that Secretariat Injection Substation is the most reliable in the network when compared to the other four substations as it recorded system indices of ASAI: 99.90, SAIFI: 0.877, SAIDI: 8.11, CAIDI: 9.25. Distribution network enhancement and efficiency improvement using Photovoltaic DG was examined [4]. The result revealed that before DG was placed in the network, only 10.4% of the buses were within statutory voltage limit (394.25V – 435.75V or 0.95p.u – 1.05p.u), 86.6% of the total buses violated the statutory voltage limit and high losses of 1329.08kW and 2031kVar respectively. After DG was located and placed optimally, the losses on the network minimized by 57.5% (active) and 70.7% (reactive) respectively. While the voltage profile enhanced by 94.8%, thereby improving the reliability and efficiency of the distribution network.

3. METHODOLOGY

The power network (2 X 7.5MVA, 33/11kV) of Benin Electricity Distribution Company (BEDC) injection substation in Asaba, Delta State of Nigeria, Comprises of two power transformers ((T_1 and T_2). Transformer (T_1) has 3no 11kV feeders namely; Okwe 11kV feeder, SIO 11kV feeder and Ezenei feeder. The study was carried out using only Ezenei 11kV feeder network with a total of sixty- seven (67) number secondary distribution transformers. The field data used for this study was collected between February and April 2018 from Benin Electric Distribution Company (BEDC) which include: the load on each transformers, network diagram, cable types and diameters, rating and names of secondary distribution transformers, load point and system indices, the line parameters such as impedance and route distances from one transformer to the other etc. A detailed single line diagram of the network as shown in Fig. 1 was used for the modelling, simulation and analysis of the result of network of study. The power flow analysis, injection of photovoltaic (PV) DG and impact of component failure and evaluation of the reliability of Ezenei 11kV injection substation network with close observation on the power factor, active and reactive power flow was done using Newton-Raphson algorithm iteration technique and loss sensitivity factor algorithm to ascertain the average interruption rate of each buses, optimal location and sizing of DG in ETAP 12.6 environments as shown in Fig. 2, 3, 4, 5 and 6 under base loading condition. The network overall performance was noted and taken into consideration with parameters like percentage loading and bus voltages. In the deficient network, optimal sizing and location of DGs placement was done using loss sensitivity factor. The improved network performance (system indices) was then compared before and after DG placement as shown in Table 3.

4. RELIABILITY INDICES

The term reliability means the ability of the system to perform its intended function, where the past analysis helps to estimate future performance of the system. Reliability is the probability of a device or system performing its function adequately, for the period of time intends, under the specified operating conditions. Reliability data for set of components, loads and customers in a distribution network shows reliability characteristics of complete system. Loss of service voltage to customer is called Interruption and they can be momentary or sustained. They are usually considered a reliability issue. Interruptions longer than five (5) minutes are traditionally included in sustained interruptions. In order to reflect the severity or significance of a system outage, reliability indices are evaluated.

The reliability that the equipment will not fail before time is given by:

$$R(t) = P(T>t) \quad (1)$$

The probability of equipment surviving under failure environment is given by:

$$R = e^{-\lambda t} \quad (2)$$

Where: R = Reliability, e = Exponential, λ = Failure rate and t = Time.

Generally, extent governs by probability are generally connected mathematically by an exponential formula and IEEE defined a set of indices to evaluate the reliability of electric power system (Matthew et al., 2015). These indices are divided into two viz: load point indices and system indices Average load point indices are calculated as:

$$\lambda_t = \sum_i \lambda_t \quad (3)$$

$$U_t = \sum_i \lambda_t r_i \quad (4)$$

$$r_i = \frac{\sum_i \lambda_t r_i}{\sum_i \lambda_t} \quad (5)$$

r_i = Outage time (Average).
λ_t = Failure time (Average)
U_t = Annual outage time (Average).

System indices are estimated as:

SAIFI: System average interruption frequency index

The SAIFI index gives information about how often these interruptions occur on the average for each customer.

$$\text{SAIFI} = \frac{\text{Total number of all interruptions}}{\text{Total number of customers connected}} \text{ (f/c/r)} \quad (6)$$

SAIDI: System average interruption duration index

The SAIDI index gives information about the average time the customer is interrupted in minutes (or hours) in one year.

$$\text{SAIDI} = \frac{\text{Total duration of all interruptions}}{\text{Total number of customers connected}} \text{ (hr/cr)} \quad (7)$$

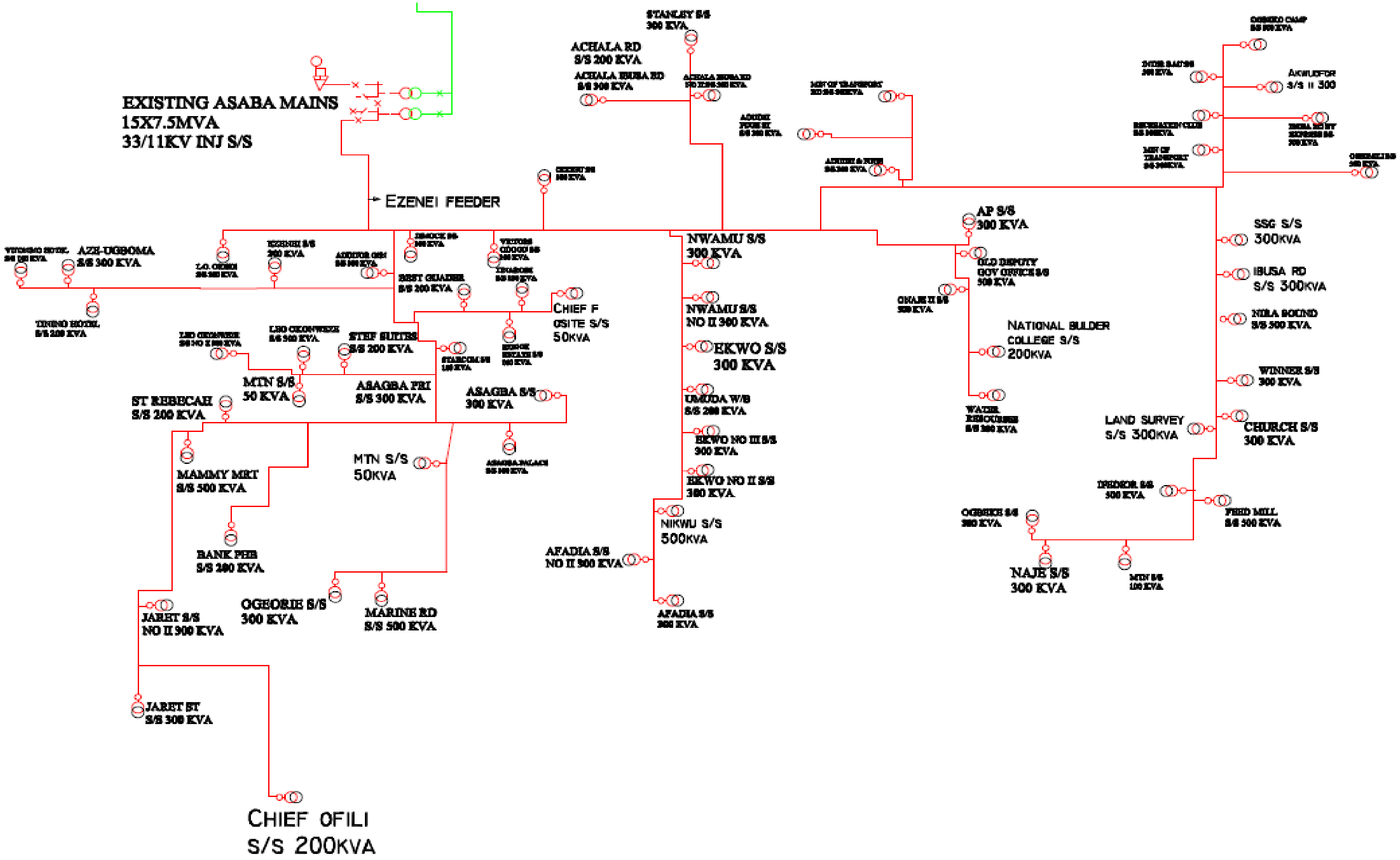


Fig. 1. Ezenei 11Kv single line distribution network feeder

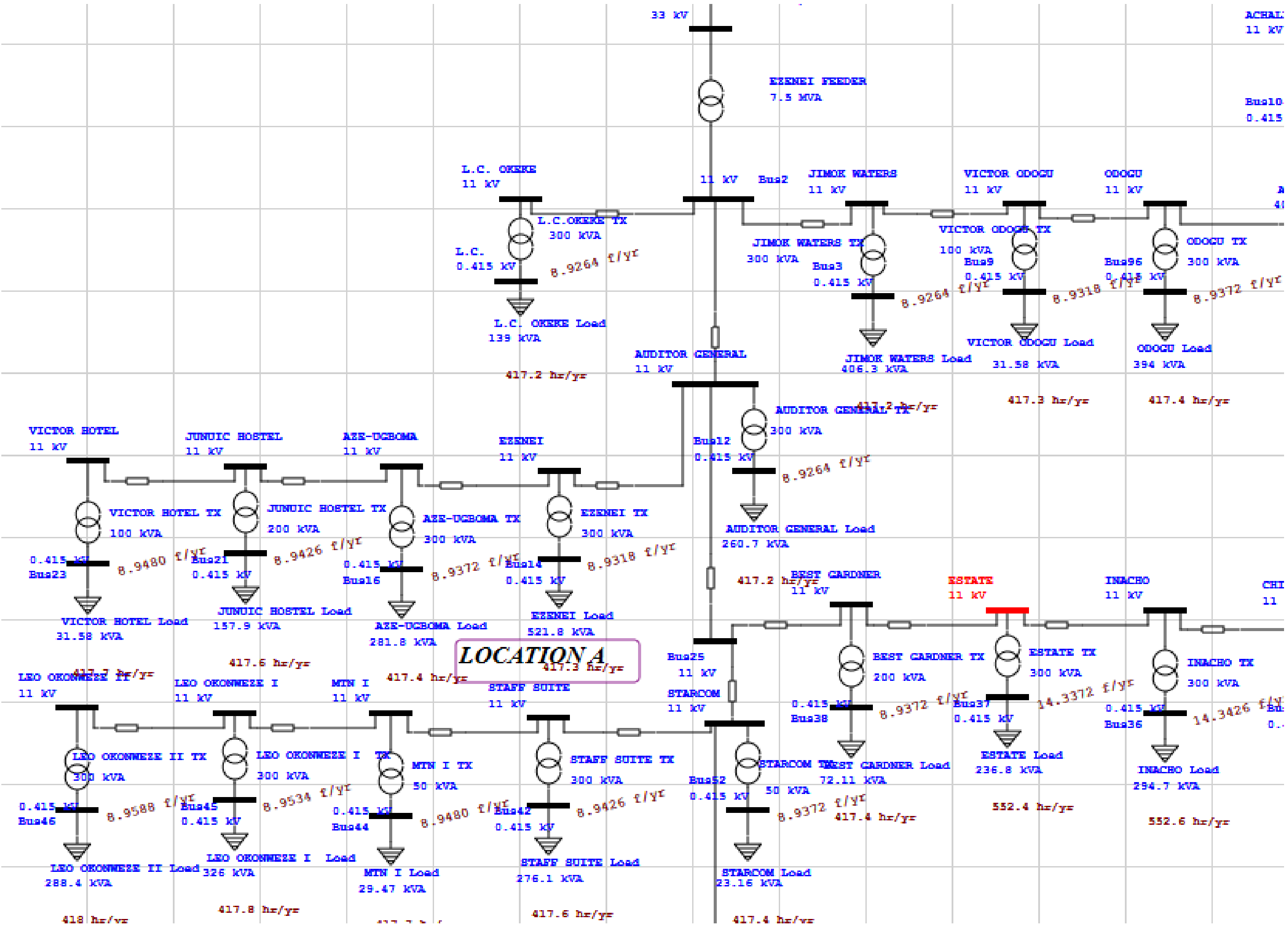


Fig. 2. Location A on ETAP reliability run mode

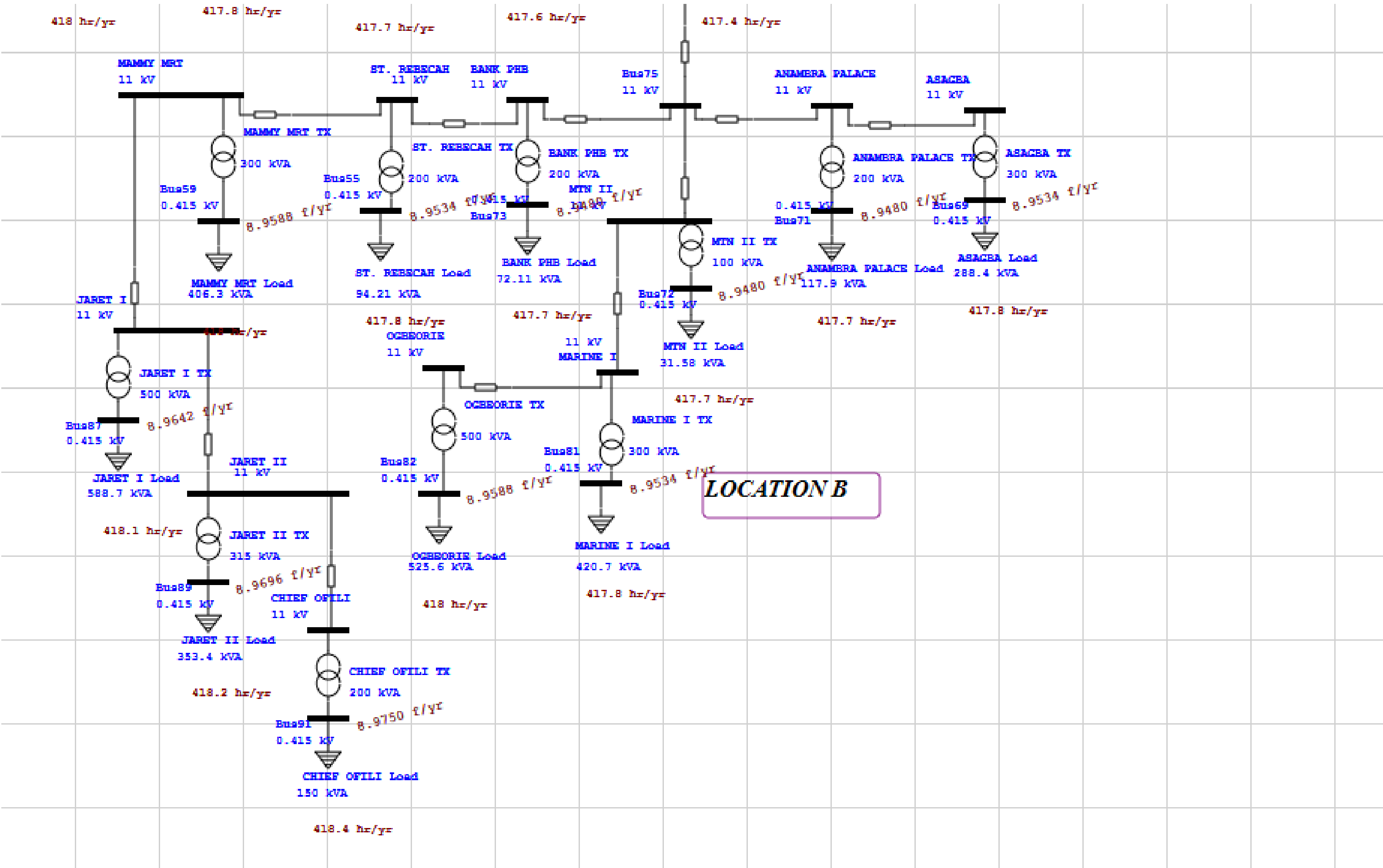


Fig. 3. Location B on ETAP reliability run mode

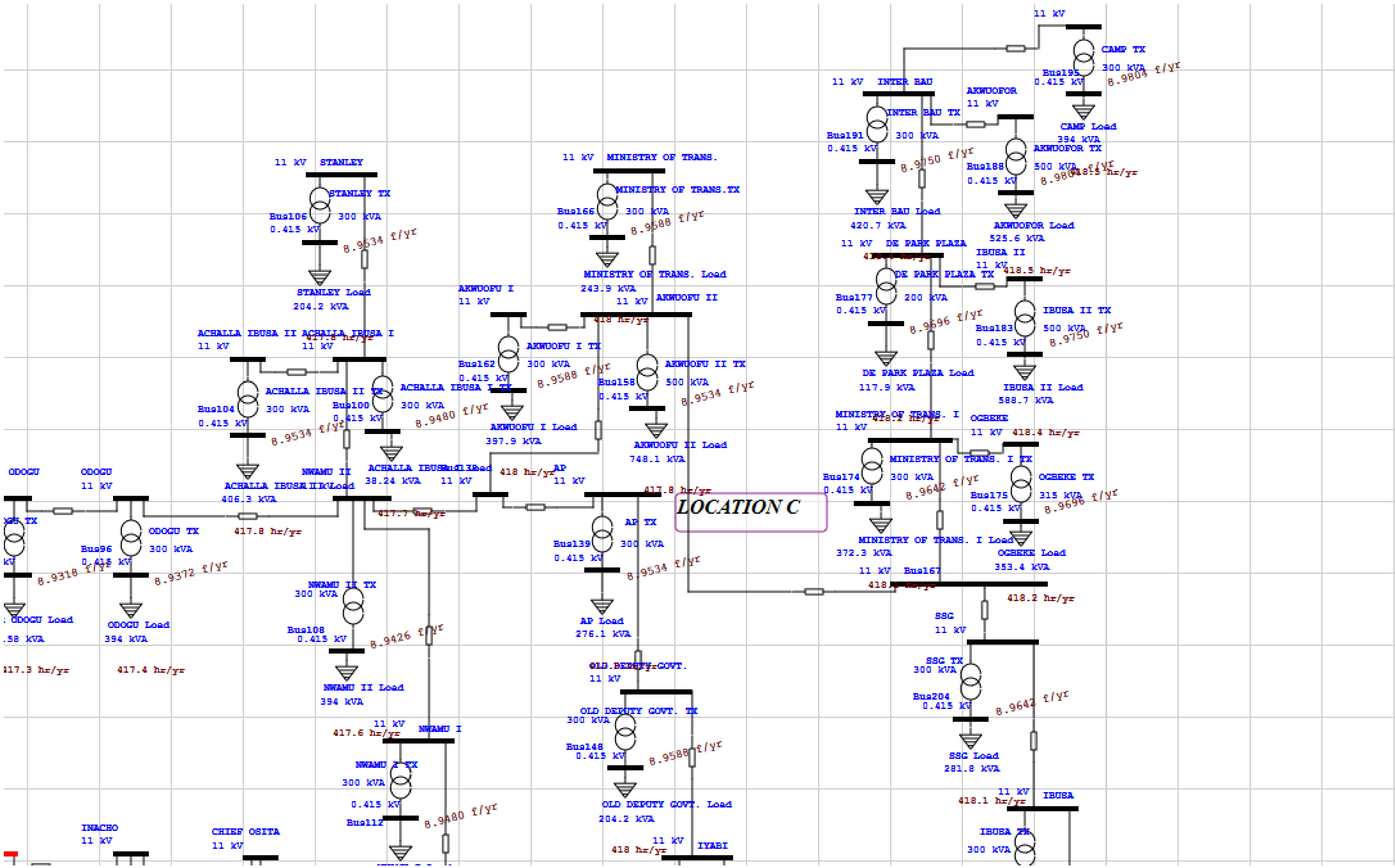
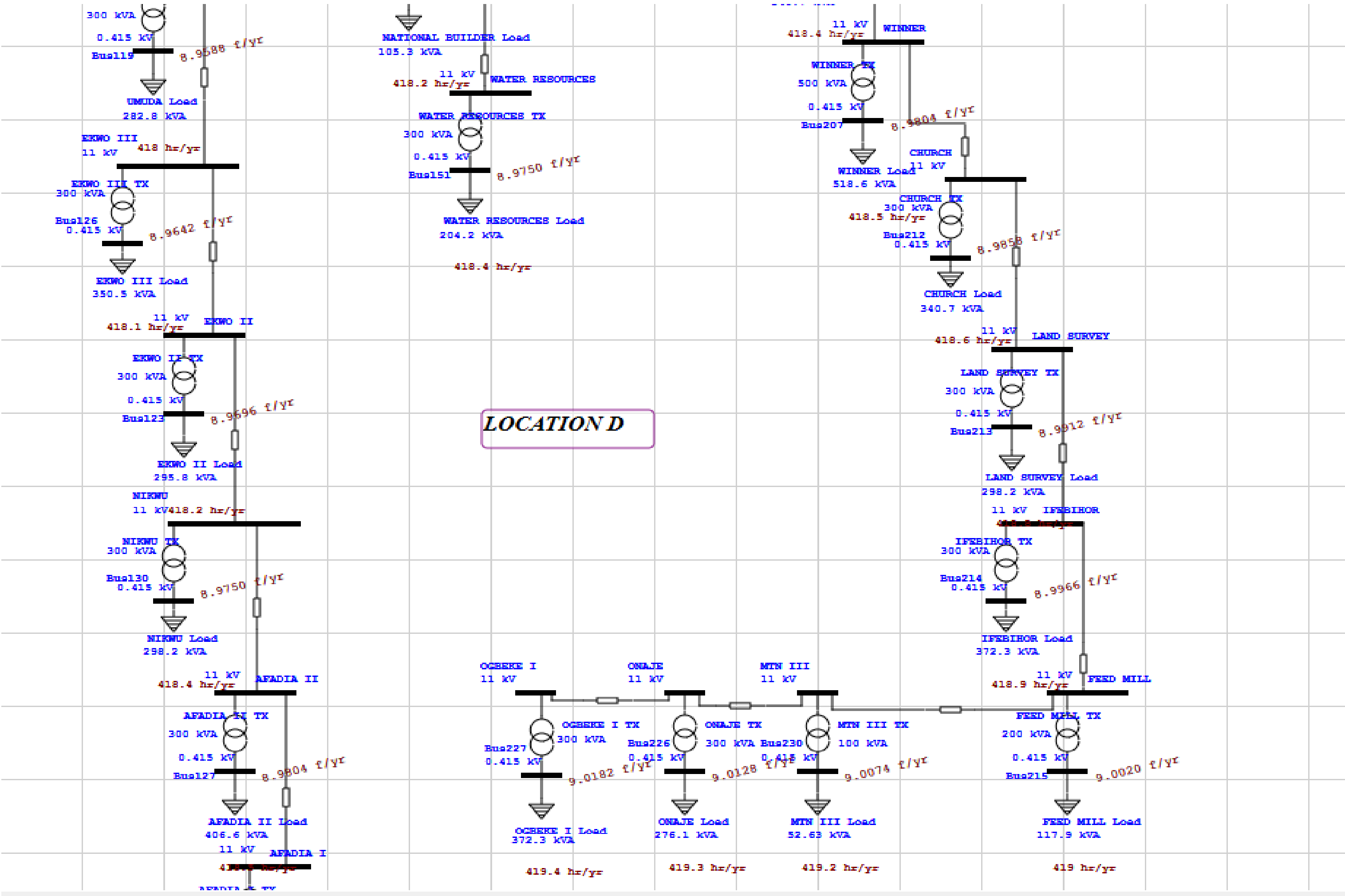


Fig. 4. Location C on ETAP reliability run mode



Fig, 5. Location D on ETAP reliability run mode

Table 1. Load point indices analysis

S/N	Bus ID	Average Interruption Rate (f/yr)	Average Output Interruption Rate (hr)	Annual Output Interruption Rate (hr/yr)	EENS (MWhr/yr)
1	L.C. OKEKE	8.9264	46.73	417.1507	68.8558
2	JIMOK WATERS	8.9264	46.73	417.1507	201.2676
3	VICTOR ODOGU	8.9318	46.72	417.2857	15.6488
4	AUDITOR GENERAL	8.9264	46.73	417.1507	129.1420
5	EZENEI	8.9318	46.72	417.2857	258.5663
6	AZE-UGBOMA	8.9372	46.71	417.4207	139.6846
7	JUNUIC HOSTEL	8.9426	46.69	417.5557	78.2944
8	VICTOR HOTEL	8.9480	46.68	417.6907	15.6640
9	CHIEF OSITA	14.3480	38.52	552.6917	13.8156
10	INACHO	14.3426	38.53	552.5566	193.3701
11	ESTATE	14.3372	38.53	552.4216	155.3407
12	BEST GARDNER	8.9372	46.71	417.4207	35.7440
13	STAFF SUITE	8.9426	46.69	417.5557	136.9037
14	MTN I	8.9480	46.68	417.6907	14.6174
15	LEO OKONWEZE I	8.9534	46.67	417.8257	161.7510
16	LEO OKONWEZE II	8.9588	46.65	417.9607	143.1413
17	STARCOM	8.9372	46.71	417.4207	11.4801
18	ST. REBECAH	8.9534	46.67	417.8257	46.7440
19	MAMMY MRT	8.9588	46.65	417.9607	201.6584
20	ASAGBA	8.9534	46.67	417.8257	143.0950
21	ANAMBRA PALACE	8.9480	46.68	417.6907	58.4792
22	MTN II	8.9480	46.68	417.6907	15.6640
23	BANK PHB	8.9480	46.68	417.6907	35.7671
24	MARINE I	8.9534	46.67	417.8257	208.7383
25	OGBEORIE	8.9588	46.65	417.9607	260.8703
26	JARET I	8.9642	46.64	418.0957	292.2828
27	JARET II	8.9696	46.63	418.2307	175.5160
28	CHIEF OFILI	8.9750	46.61	418.3657	78.4438
29	ODOGU	8.9372	46.71	417.4207	195.3009
30	ACHALLA IBUSA I	8.9480	46.68	417.6907	18.9674
31	ACHALLA IBUSA II	8.9534	46.67	417.8257	201.5932
32	STANLEY	8.9534	46.67	417.8257	101.3175
33	NWAMU II	8.9426	46.69	417.5557	195.3641
34	NWAMU I	8.9480	46.68	417.6907	208.6708
35	EKWO I	8.9534	46.67	417.8257	232.5540
36	UMUDA	8.9588	46.65	417.9607	140.3617
37	EKWO III	8.9642	46.64	418.0957	174.0195
38	EKWO II	8.9696	46.63	418.2307	146.9086
39	NIKWU	8.9750	46.61	418.3657	148.1487
40	AFADIA II	8.9804	46.60	418.5007	202.0683
41	AFADIA I	8.9858	46.59	418.6357	201.9841
42	AP Load	8.9534	46.67	417.8257	136.9923
43	OLD DEPUTY GOVT.	8.9588	46.65	417.9607	101.3502
44	IYABI	8.9642	46.64	418.0957	148.0531
45	NATIONAL BUILDER	8.9696	46.63	418.2307	52.2970
46	WATER RESOURCES	8.9750	46.61	418.3657	101.4484
47	AKWUOFU II	8.9534	46.67	417.8257	371.1835
48	AKWUOFU I	8.9588	46.65	417.9607	197.4896
49	MINISTRY OF TRANS.	8.9588	46.65	417.9607	121.0548
50	MINISTRY OF TRANS. I	8.9642	46.64	418.0957	184.8431
51	OGBEKE	8.9696	46.63	418.2307	175.5160
52	DE PARK PLAZA	8.9696	46.63	418.2307	58.5548

S/N	Bus ID	Average Interruption Rate (f/yr)	Average Output Interruption Rate (hr)	Annual Output Interruption Rate (hr/yr)	EENS (MWhr/yr)
53	IBUSA II	8.9750	46.61	418.3657	292.4716
54	INTER BAU	8.9750	46.61	418.3657	209.0080
55	AKWUOFOR	8.9804	46.60	418.5007	261.2073
56	CAMP	8.9804	46.60	418.5007	195.8062
57	SSG	8.9642	46.64	418.0957	139.9104
58	IBUSA	8.9696	46.63	418.2307	174.0757
59	NIRA SOUND	8.9750	46.61	418.3657	268.6249
60	WINNER	8.9804	46.60	418.5007	257.7293
61	CHURCH Load	8.9858	46.59	418.6357	169.3724
62	LAND SURVEY	8.9912	46.58	418.7706	148.2921
63	IFEBIHOR	8.9966	46.56	418.9056	185.2012
64	FEED MILL	9.0020	46.55	419.0406	58.6682
65	OGBEKE I	9.0182	46.51	419.4456	185.4399
66	ONAJE	9.0128	46.52	419.3106	137.4792
67	MTN III	9.0074	46.54	419.1756	26.1977

Table 2. System indices

S/N	System indices	Failure rate
1	AENS (MWhr/customer yr)	146.5085
2	ASAI (p.u)	0.9516
3	ASUI (p.u)	0.04841
4	CAIDI (hr/customer interruption)	46.079
5	EENS (MWhr/yr)	9816.070
6	SAIDI (hr/customer yr)	424.0598
7	SAIFI (f/customer yr)	9.2028

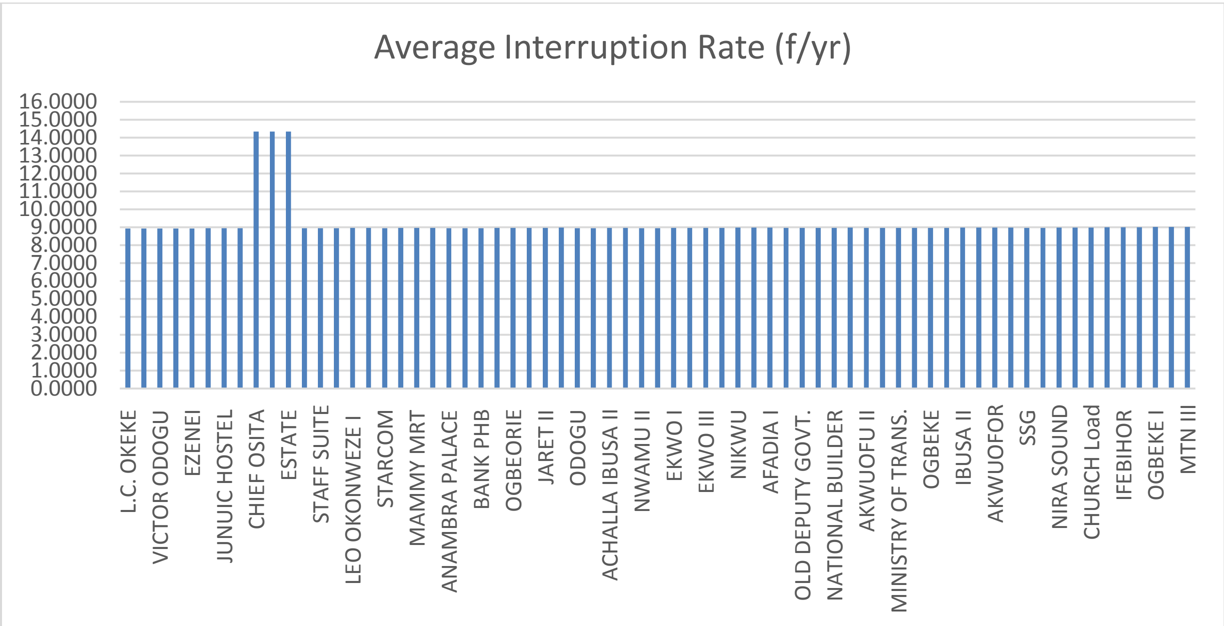


Fig. 6. Average interruption rate of each

Table 3. System indices before and after DG placement

S/N	System indices	Failure rate Before DG placement	Failure rate After DG placement
1	AENS (MWhr/customer yr)	146.5085	118.1931
2	ASAI (p.u)	0.9516	0.9514
3	ASUI (p.u)	0.04841	0.04856
4	CAIDI (hr/customer interruption)	46.079	33.474
5	EENS (MWhr/yr)	9816.070	7918.939
6	SAIDI (hr/customer yr)	424.0598	425.4088
7	SAIFI (f/customer yr)	9.2028	12.7088

CAIDI: Customer average interruption duration index.

CAIDI captures the average time that the utility responds by measuring the average time to restore service.

$$\text{CAIDI}=\frac{Total\ duration\ of\ all\ interruptions}{Total\ number\ of\ all\ interruption}\ \text{(hr/c/Int.)} \quad (8)$$

ASAI: Average service availability index.

$$\text{ASAI}=\frac{Total\ number\ of\ hours\ availability}{Total\ demand\ hours}\ \text{(p.u)} \quad (9)$$

ASUI: Average Service Unavailability Index

ASUI=1−ASAI (p.u).

EENS: Expected energy not supplied.

EENS = Capacity outage x Probability of Capacity outage x Time of Capacity outage (MW/Yr).

These are measuring tool that are used in order to evaluate the performance of the system. Utility supply companies are seeking to be within the standard approved range to motivate customers selecting them among others [12-15].

The exact loss formula for finding the active power loss of the system is derived from the active power injected based loss sensitivity factor [2,7].

$$P_L = \sum_{i=1}^{N}\sum_{i=j}^{N} \alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - PiQj\right. \quad (10)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right);\ \beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \quad (11)$$

Based on the active power injected on the $i\ th$ bus, the loss sensitivity factor of the particular bus can be represented as:

$$\alpha_{ij} = \frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = \frac{2QR}{V^2} \quad (12)$$

The active and reactive power injected at bus *i*, where the DG located, are given by (13) and (14), respectively [2,11,12],

$$P_i = P_{DGi} - P_{Di} \quad (13)$$

$$Q_i = Q_{DGi} - Q_{Di} = P_i = aP_{DGi} - Q_{Di} \quad (14)$$

From (10), (16), and (13), the active power loss can be rewritten as

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left(\alpha_{ij}\left[(P_{DGi} - P_{Di})P_j + aPDGi{-}QDiQj{+}\beta ijaPDGi{-}PDiPj{-}PDGi{-}PDiQj\right.\right. \quad (15)$$

and the optimal size of DG at each bus i for minimizing loss is given as;

$$P_{DGi} = \frac{\alpha_{ii}(P_{Di}+aQ_{Di})+\beta_{ii}(aP_{Di}-Q_{Di})-X_i-aY_i}{a^2\alpha_{ii}+\alpha_{ii}} \quad (16)$$

5. RESULTS AND DISCUSSION

The load point reliability index modeling and analysis of Asaba mains7.5MVA 33/11kV injection substation and its associated feeders was carried out in ETAP 12.6 environment shows that in Tables 1 to 2 and Fig. 6 shows the average interruption rate, average output interruption rate, annual output interruption rate and the Expected Energy Not supplied (EENS) which is the average energy that was not supplied by the injection substation in the predefined time.

The results generated as shown in Tables 1 – 2 and Figs. 2,3,4,5 and 6, evidently indicate that the load point indices are increasing as distance of load point increases from the feeder. From Table 1, the Seventeen (17) load buses which is L.C. Okeke bus to Starcom bus forms the location A. and St. Rebecah bus to Chief Ofili bus forms location B, while Odogwu bus to Old deputy Govt. bus forms location C, and Iyabi bus to MTN III bus forms location D. L.C Okeke and Jimok water which are the closest load buses to the feeder have an Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr)of 8.9264f/yr, 417.1507hr/yr while Victor Odogu and Auditor General have an Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr) of 8.9318 f/yr, 417.2857hr/yr and 8.9264 f/yr, 417.1507hr/yr. It was also observed that Chief Osita, Anacho and Estate buses have the highest Average Interruption Rate (f/yr) and Annual Output Interruption Rate (hr/yr). Thus from these four locations, optimum location is found to be at point B where system is most reliable. While Fig. 6 depicts that location A and D is worst location where system is least reliable. As seen in Table 2, an average customer is subjected to 9.2028 interruption over a predefine time interval, whereas the total duration of interruption of an average customer is subjected for predefined interval is 424.0598.The average time required to restore service is 46.079. The fraction of time that a customer received power during the predefined interval of time is 0.9516 while the average energy the customer has not received in the predefined time is 9816.070. These values give a complete picture of the system. The load point reliability of the network system improved as seen in Table 3 and the distribution line loss was reduced from 1492.8kW and 3599.6kVar to 691.63kW and 748.62kVar (i.e.53.7% and 79.2% decrease in the loss) respectively. This result shows that the reliability of load points in distribution system decreases as distance from feeder increase, while the most reliable location in distribution system is the location closer to the feeder.

6. CONCLUSION

It can be concluded from the load flow analysis carried out on the network. The results show that the injection substation is unable to cater for the installed capacity of the network and hence there is a severe voltage violation and losses on the network. The load point indices increased as distance of the load point increases from the injection substation and Location A and D were found to be the worst location where the system is least reliable. Power losses and voltage violations in the distribution network prior to the placement of DG were more as compared after the optimal placement of DG. The optimal placement of DG in the network played a vital role in enhancing and maintaining good voltage profile and reducing losses and improved the load point reliability. The load shedding in the system will be reduced as more power is made available to customers thereby boosting their commercial activities and improving revenue generation for the Electricity Company.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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