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Reliability Improvement Study of a Distribution Network with Distributed Generation

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Abstract: The reliability of power supply to customers is an important factor in the design, planning and operation of a distribution network. This study analyzed the effect of Distributed Generation (DG) on the reliability of distribution network in Port Harcourt metropolis. Five injection substations were used as case studies. Electrical Transient Analyser Programme (ETAP 16.0) was used to model the network using the data collected from the utility company. The reliability of the network was investigated with and without DG units. The reliability of the network improved when DG units were integrated into it at different locations. Multiple integration of DG into network near load points further increased the reliability of the system. The results showed that the utility company can better satisfy their customers with DG in the network and hence increase their revenues. The reliability indicators used for analysis in this study are System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI) and Average Service Availability Index (ASAI).

Keywords: Distribution; Distributed generation; Electric Power; Reliability; Simulation.

1. INTRODUCTION

The traditional way of meeting the electricity demand of consumers all over the world consists of three stages: generation, transmission and distribution. As the demand of consumers continues to rise, power utilities are expected to satisfactorily meet this demand. Electric power is generated at a central large generating station far away from the load centers. The power is generated at about 11 kV to 16 kV and through the step-up transformer, the voltage is stepped up to about 132 kV and 330 kV. Electricity is transmitted at this high voltage in order to reduce technical losses on the line. The transmitted power is stepped down to lower voltage such as 33 kV at the distribution substation and distributed feeders carry the power to consumers at a lower voltage of 11 kV and 0.415 kV.

The principal aim of every power utility is to supply electricity in a manner that is cost effective and reliable to customers. The benefit of good planning and maintaining of reliable electricity supply to customers is that there will be reduction in the price of interruptions of power supply to customers. Reliability is an important aspect in the planning and design of a distribution system that will function effectively in terms of cost with minimal interruptions to customer loads [1]. An electrical utility company in a deregulated environment has the main objective of increasing the market value of its services to customers. This can be achieved by supplying reliable electricity at lower operational and maintenance cost and the construction of new electricity infrastructures at lower cost. All these factors will help to bill the customers at a lower rate which will likely lead to customer satisfaction. There are so many ways by which a utility company can achieve this objective. One of the effective ways is to employ the use of Distributed Generation (DG) [2]. In both the developed and developing nations of the world, the power sector is going through transformation in terms of structure, operation and regulation. Other factors are due to some governmental policies concerning the greenhouse effect on the environment, deregulation of power sector and power supply security. Many literatures have reported on studies carried out on the benefit of integrating distributed generators into distribution network. DG is an alternative way to generate electricity by integrating generator units into distribution network in order to provide electricity to customers. These types of generators are not planned centrally and dispatched like the conventional large generating sets [3]. The technology used in distributed power generation can be classified into DG with synchronous generator interface, induction generator interface and inverter interface [4]. Sources of energy are classified into the conventional non-renewable and the non-conventional which is renewable energy resources [5]. Distributed generators have the capacity to provide electricity to customers during emergency and help power utilities to defer distribution network expansion [6].

Many literatures reported that in power system, distribution network is responsible for the highest percentage of outages experienced by the customers. More than 85% of all the interruptions experienced by customers is as a result of faults in the distribution system. The reason is because distribution system is radial in nature. Any interruption on it will cause power outage to customers. A radial distribution system usually has main feeders and lateral distributors that provides power to customers. The concept of reliability in distribution system is different from that of generation and transmission system because it is more of customer load point oriented instead of system oriented. Distribution system is a very important aspect of power system because it provides a vital link to customers [7].

Since the deregulation of power sector, the overall performance of Nigeria power sector has not really experienced the expected result. The electricity demand has not been met satisfactorily. As a result, there has been an increased interest to generate electricity using distributed generators that will make the system a reliable one. The network needs to be improved to provide electricity that is reliable and economical to the customers. The integration of distributed generation units into the power network will lessen the duration of outage and the number of interruptions with its associated cost. This will in turn lead to increase in the revenue that utility companies will generate from the customers.

The generated electricity that is presently available in Nigeria is not adequate to meet customers demand due to electricity infrastructures that are old and not being properly maintained. As a result, power supply to industrial consumers as well as commercial and domestic customers are not stable. No doubt, the economic growth of the country is negatively impacted. The available generated electricity can only serve less than half of the country population. In order to bridge the gap, the independent power producers (IPP) have turned to the option of using distributed generation technologies [8].

The aim of this paper is to employ the use of distributed generator to improve the reliability of a distribution network and the objective is achieved by incorporating 3 MW distributed generator into the distribution network in Port Harcourt, Rivers state Nigeria. The proposal of using distributed generator is to improve the network overall performance to provide reliable electricity that will meet the demand of consumers. The research questions are: 1. What is the impact of DG unit on the reliability of a distribution network? 2. Does the number of DG units in a distribution network directly improve the network reliability? This work will provide answer to these research questions by using five injection substations in the distribution network of Port Harcourt metropolis as a case study. Several cases will be considered such as locating DG unit at different locations in the test network and varying the number of DG units in the system. This network is modelled in Electrical Transient Analyser Programme (ETAP) 16.0 and its reliability module is used to carry out this study. Actual time parameters and data of feeders were obtained from Port Harcourt Distribution Company (PHEDC), Port Harcourt. The three basic reliability indices used in this paper are frequency of failure, average duration of failure and average outage time while the system reliability indices used to determine the performance of the network are System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI) and Average Service Availability Index (ASAI).

2. RELIABILITY OF DISTRIBUTION SYSTEM

The major requirement of a power system is that it should be able to provide customers with good quality electricity continuously and should operate at optimal cost [9]. Reliability is the ability of a system to carry out its functions as per the given normal operating condition without outage during a specified period of time [10]. The configuration of distribution network (radial or mesh), environment, load type, and their locations have roles to play in the reliability of distribution network. Reliability analysis is useful to identify how effective a distribution system can perform its functions and those of its components that are not functioning well which must be replaced. It is also useful for the recommendation of new distribution components that are needed to improve network reliability. Due to its usefulness to identify technical and economical characteristics of a power system, reliability technique can be employed to design a power system that will be able to meet electricity demand of customers from the conception to planning, installation and operation stages [11]. Reliability is given utmost importance in power system because any interruption in the system directly affects customers negatively [12]. A distribution network that is healthy will provide power to every customer connected to it. Any fault in the system will disrupt its normal operation and cause outage to customers. Factors that can cause outage to customers are trees falling on overhead feeders resulting to short-circuit fault, lightning, wind, failure of isolators and protective equipment due to age and planned maintenance. Distribution networks are seriously affected by climatic conditions, lightning that may cause failure or outages. They are radial in nature and many loads are affected by the failure of a single section. In a radial network, its components such as isolators, breakers, busbars, and cables are connected in series. Customers connected to this kind of network can only receive power when all the components are in operation.

The objective of reliability analysis in power system is to provide a qualitative analysis and indices that distribution operators can use for planning and operation of the system [13]. Reliability of power in a distribution network has high importance on the customers that are supplied by the network. Customers consider power quality from utilities as an issue when electricity supplied by the utility makes their electrical devices or equipment to malfunction. Therefore, reliability can be related to voltage quality level. It is necessary for utilities to provide customers with sufficient voltage. Quality of power provided must meet the acceptable level with a sinusoidal wave of constant frequency and amplitude. Low level of power quality will be experienced by customers when a fault of transient nature causes a disturbance to the source of voltage which will lead to distorted value in the frequency and amplitude of load point voltage. The reliability of a power system has two divisions: the adequacy of the system and its security [14]. The three functional systems in power system: generation, transmission and distribution are zoned to have three hierarchical levels: HL-I, HL-II and HL-III. [15]. These levels are used to judge the reliability of the power system. HL-I is used solely for the generation equipment. HL-II involves both generation and transmission equipment while HL-III is used for all the system equipment [16]. HL-III is the most complex to analyse in terms of the reliability of the system since it involves all the three functional zones. Therefore, a method is employed to analyse the distribution functional zone separately as an entity. Reliability of distribution network has always been given a secondary attention compare to generation and transmission, but its capacity planning is of major concern. This distribution system which is majorly planned for capacity with least amount of protection costs about 50% of the normal overhead design. This system is not planned to have isolator sections, no lightning protection. Any amount of money spent above the overall design cost of a power system is completely for reliability improvement [5].

There are many techniques used to calculate reliability of a distribution network as explained in [17] such as voltage stability method, Artificial Intelligence, Genetic Algorithm method, Fuzzy Logic and Artificial Neural Network. The authors in [1] divided the different techniques into two main classes: Analytical and Monte Carlo techniques. In analytical approach, mathematical models are used to evaluate the reliability of a distribution system. System issues such as thermal overloads, low voltage and collapse of voltage can be identified by this method. This technique is not capable to model a system with large range of operating states and as a result many assumptions are made to simplify the problem. In Monte Carlo simulation technique, modelling of the whole range of operating states is possible. This technique is useful for the assessment of distribution system with distributed generators. It can model the erratic characteristics of distributed generators based on renewable resources. According to [9], Monte Carlo simulation technique is an effective method that gives approximate solution to problems in power systems. The drawback of this technique is that it takes a long time to compute result and is difficult to apply in a large power system that has multi-objective functions. Due to the long time it takes to compute result, it can only be used for electrical power system that is small. Another method that can be used to compute a traditional distribution reliability index is the analytical method that can handle many generation units. This method is useful to compute reliability indices of a power system that has no-intermittent power output. When used for small scale power system it gives accurate solution with smaller computation time than Monte Carlo simulation technique. The limitation of this technique is its inability to be used for stochastic characteristics of power system major components at different operating state. In order to realise a correct solution for the reliability of a distribution system, the authors have proposed a multi-state model that can model the erratic behaviour of renewable based distributor generators. The method can provide adequate information on system and load point reliability indices better than Monte Carlos simulation and analytical methods.

In [18], the authors used NEPLAN software to predict the reliability of Port Electricity distribution network using Choba as a case study. The reliability indices from the study showed that the distribution network is not reliable. In another study on the same network [19], the authors used four feeders from 2 x 15 MVA 33/11 kV Marine Base injection substation to investigate the reliability of distribution system in Port Harcourt. The reliability indices as shown in result of the study indicated that the reliability of the entire system is below international standard. The whole system is unreliable and cannot meet the needs of electricity consumers. In view of the result presented on the two case studies on distribution network in Port Harcourt, this study will propose how the reliability of the network would be improved using distributed generators. The studies carried out in [18] and [19] have only determined the level of reliability of the network but in this study, the authors have been able to propose solutions to improve the network reliability by integrating DG units into the network.

3. RELIABILITY INDICES

In order to measure the reliability at each load point in a distribution network, there are three basic indices that are related to customers: Rate or frequency of failure (λ_s), average outage time or average duration of failure (R_s) and average annual outage time (U_s) [15]. The rate of failure is the frequency of interruption of power supply to load point. It is the sum of active failure rate and passive failure rate. In the active failure, the protective devices operate when a component fails such as short circuit, but the protective device does not operate for a component that experiences a passive failure such as an open circuit [20]. The indices can be obtained as:

$$\lambda_s = \sum \lambda_i \tag{1}$$

$$U_s = \sum \lambda_i \, r_i \tag{2}$$

$$R_s = U_s / \lambda_s \tag{3}$$

where λ_i is the rate of failure of load point *i* and r_i is restoration time in minutes of load point *i*. These basic indices permit the reliability measurement from individual customer`s point of view. In order to know the performance of the entire distribution system, additional indices are calculated using the basic indices. The reliability indices used by utilities to determine system performance are:

System Average Interruption Frequency Index (SAIFI): This index provides information on how many numbers of sustained interruptions an average customer will experience in one year. The meaning of predefined area is flexible depending on the area under consideration. The frequency of interruptions and the number of customers affected with the defined area vary. For example, a feeder SAIFI indicates the average frequency of interruptions experienced by a customer serviced by the particular feeder in a year. Similarly, SAIFI reported for a substation or a distribution system encloses the total customers in the service area [1]. For a utility that has a fixed number of customers, SAIFI can be improved by reducing the number of interruptions that customers experience. SAIFI can be obtained by using:

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customer\ Served} = \frac{\sum N_i}{N_T} \tag{4}$$

System Average Interruption Duration Index (SAIDI): This index is the number of minutes or hours of interruption experienced by customers and is determined to give information about the average time customers are interrupted. When the number of interruptions or duration of interruptions is reduced, SAIDI will improve. SAIDI can be calculated based on:

$$SAIDI = \frac{Sum\ of\ All\ Customers\ Interruption\ Duration}{Total\ Number\ of\ Customer\ Served} = \frac{\sum(r_i\ \times N_i)}{N_T} \tag{5}$$

Customer Average Interruption Duration Index (CAIDI): This index is the duration of an average interruption. It represents the average time needed to restore service to the customers when a sustained interruption occurs. It measures how long an average interruption takes. CAIDI can be improved by reducing the length of interruptions by faster crew response time and repair times. The index is the ratio of SAIDI to SAIFI.

$$CAIDI = \frac{Sum\ of\ All\ Customers\ Interruption\ Duration}{Total\ Number\ of\ Customer\ Interruptions} = \frac{\sum(r_i\ \times N_i)}{\sum N_i} \tag{6}$$

Customer Average Interruption Frequency Index (CAIFI): This index is designed to show trends in customers interrupted and helps to show the number of customers affected out of whole customer base. It is calculated as:

$$CAIFI = \frac{Number\ of\ Interruptions}{Total\ Number\ of\ Customer\ Interruptions} = \frac{\sum N_o}{\sum N_i} \tag{7}$$

Average Service Availability Index (ASAI): This is customer weighted availability of the distribution system and it gives the same information as SAIDI. When ASAI is high it means the system, reliability is high. Most of the utilities in USA has an ASAI that is greater than 0.999 [21].

$$ASAI = \frac{Total\ Number\ of\ Customer's\ Hour\ Available}{Total\ Number\ of\ Hours\ Demanded} = \frac{\sum N_i \times 8760 - \sum(r_i \times N_i)}{\sum N_i \times 870} \tag{8}$$

where the number of hours in a calendar year is 8760.

Qamber [22] introduced another important reliability terms namely Loss of Load Probability (LOLP) and Loss of Load Expectation (LOLE) which can be used to design, plan, operate and maintain power system. These indices are very important in power system reliability study.

4. METHODOLOGY

This study is carried out in Port Harcourt, which is the state capital of Rivers state. Port Harcourt is situated in the South-South geopolitical region of Nigeria. It is the largest city in the state. The geographical coordinates are on Latitude 4° 49' 27" North, and Longitude 7° 2' 1" East. There are two local governments in Port Harcourt metropolis which are Port Harcourt city and Obi/Akpor local government areas. Port Harcourt is a highly congested city because is the only major city in Rivers state. Port Harcourt has a tropical wet climate with long and heavy rainy seasons but short period of dry seasons. It is in the months of December and January that the city truly experiences dry season in a year. The average temperature in this city ranges between 25°C – 28°C. It is an industrial city with a high number of multinational firms such as manufacturing companies as well as well as many other oil companies. It is the center of oil-refinery in Nigeria and there are two major oil refineries that process about 210,000 barrels of crude oil daily. These two refineries are under the supervision of Port Harcourt Refining Company. Google earth map showing location of Port Harcourt is shown in Figure 1. In this work, the following substations were chosen Trans-Amadi, Choba, Rumuduomaya, Rumuola and Marine Base. The collected data were frequency of failures in the system, annual down time, number of customers, list of faults that occurred in the system and reasons for interruption.

ETAP is the software used to carry out the reliability assessment of the distribution network in Port Harcourt. It is a software that has the capacity for the design and analysis of distribution network reliability. In the ETAP module for reliability assessment, one can perform calculation and produce output reports of reliability indices such as failure rate, average outage duration, and annual outage duration, which are load point indices, SAIFI, SAIDI, CAIDI and ASAI. Therefore, ETAP is a suitable software to carry out this reliability study [24].

Five injection distribution substations are used for this study. Four of the injection substations are fed from the 132/33 kV Port Harcourt Mains transmission station known as Z2 while the fifth received power from the 132/33 kV Port Harcourt Town transmission station known as Z4. The Port Harcourt Mains Transmitting station (Z2) is located at Oginigba, in Trans-Amadi industrial layout Port Harcourt. It is a 132/33 kV transmission station consisting of 3 x 60 MVA, 132/33 kV transformers. There are eleven 33 kV feeders from this transmitting station. Ten of the feeders supply different customers made up of domestic, commercial and industrial customers while the remaining one is used as a spare feeder.

The second transmission station which is Port Harcourt Town Z4 is a 132/33 kV transmission station consisting of 1 x 60 MVA, transformer, 2 x 30 MVA transformers and 1 x 60 MVA transformer. There are nine 33 kV feeders from this station that supply power to domestic and commercial consumers.

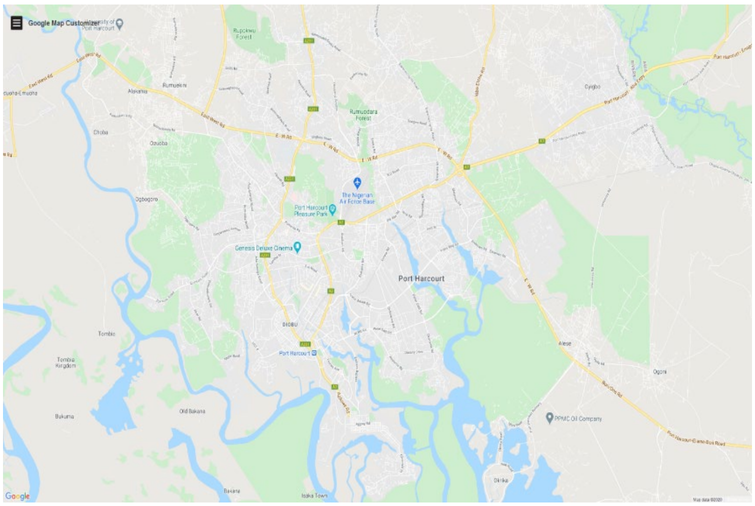

Figure 1. Google Earth map of Port Harcourt [23]

5. SIMULATION

The distribution network in Port-Harcourt metropolis is used as a case study for this work. Firstly, this distribution network does not contain DG. Subsequently, DG is introduced into the network with increasing penetration level from 0% to 40%. DG units are attached to the load buses in the low-voltage area of the network. The study is done at constant load demands at the load buses. DG units are introduced to the load buses at different locations in the network. The distribution network is modelled using ETAP.

In this case study, the voltage levels of the distribution system are 33 kV, 11 kV and 0.415 kV. The capacity of each DG unit is 3 MW while load level remains constant as DG penetration level is increased. The indices that are used to determine the reliability of this distribution network are SAIFI, CAIDI and CAIFI. These are selected in order to estimate the effect of distributed generator in the distribution system reliability. Different number of DG units are used in order to know their impact on the system reliability. The flow chart is shown in Figure 2. This evaluation is performed based on the following scenarios:

- Scenario 1: No DG unit is attached.
- Scenario 2: Connect DG unit to the network at Location 1. DG penetration level is at 10%.
- Scenario 3: Disconnect DG unit from Location 1 and connect to Location 2 at 10% penetration level.
- Scenario 4: Disconnect DG unit from Location 2 and connect Location 3 at 10% penetration level.
- Scenario 5: Disconnect DG unit from Location 3 and connect DG unit to load bus Location 4 at 10% penetration level.
- Scenario 6: Disconnect DG unit from Location 4 and connect to Location 5 at 10% penetration level.
- Scenario 7: DG units are connected to load buses at four different locations at total penetration level of 40%.

6. RELIABILITY RESULT ANALYSIS

In this section, the result of the reliability analysis of the distribution network is presented. Calculations are carried out based on the data on the five injected substations. The data covers a period of five years from 2015 to 2019. Feeders indices and customers reliability indices in the distribution network are calculated. Table 1 presents the failure frequency, outage duration and customer population for all the 11 kV feeders in the five substations. Figure 3 shows the frequency of failure on the 11 kV feeders. Flour Mill feeder had the lowest value of 1398 outages while Bori Camp and Rumekini feeders had the maximum outages of 1644 during the period of five years considered. From Figure 4, Choba feeder had the highest outage duration of 35,913 hours and Water Works had the lowest outage duration of 9,472 hours. Table 2 shows the calculation result of failure rate, mean time to failure, mean time to repair and repair rate for the substations feeders for the period of five years.

Figure 5 shows the graphical representation of the failure rate for period considered for this study. The following feeders had the highest failure rate of 0.038: Barack, Bori Camp and Rumekini, while the lowest failure rate of 0.032 was recorded on Flour Mill feeder. Table 3 shows the calculation result of system reliability indices for the feeders, SAIDI, CAIDI and SAIFI. These indices are also represented in Figures 6, 7 and 8. In Figure 6, Water Works feeder has the highest SAIFI of 3.352 failure/customer.year while FGC feeder has the lowest SAIFI of 0.197 failure/customer.year. Waterworks has the lowest number of customer population while the FGC feeder has the highest number of customers.

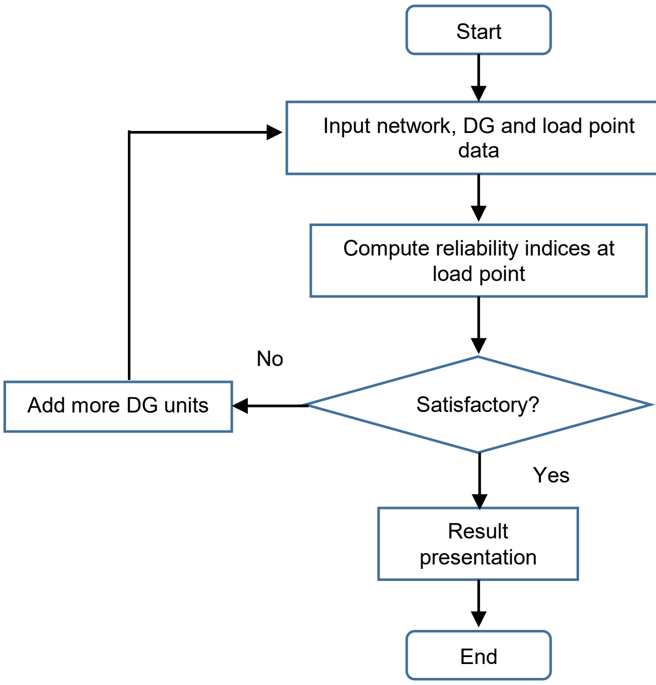

Figure 2. Flow chart to determine reliability indices

Table 1. 11 kV Feeders data from 2015 to 2019

S/N	Injection Substation	11 kV Feeder	Failure Frequency	Outage Duration	Customer population
1	Marine Base 2 x 15 MVA, 33/11 kV	Flour Mill	1398	15843	879
		Borokiri	1561	26226	4394
		Station RD	1616	25068	3331
		Amadi North	1617	23686	3331
2	Rumuola 3 x 15 MVA, 33/11 kV	New GRA	1494	21056	3666
		Rumuomoi	1641	17724	1328
		Omerelu	1491	14185	1692
		WaterLines	1608	18602	4973
		Barack	1643	23169	2264
		Shell Industrial	1525	20613	3329
		Bori Camp	1644	27552	6763
3	Choba 2 x 15 MVA, 33/11 kV	Alu	1622	35065	903
		Choba	1622	35913	2709
		Rumekini	1644	34782	2875
4	Trans Amadi 2 x 15 MVA, 33/11 kV	Femie	1570	18323	1953
		Water Works	1428	9472	426
		Rivoc	1449	12788	2531
		Nda Bros	1510	15287	1420
5	Rumuodomanya 1 x 15 MVA, 33/11 kV	FGC	1617	31621	8214
		ObiWali	1614	31898	1926
		Eligbolo	1600	32981	5644

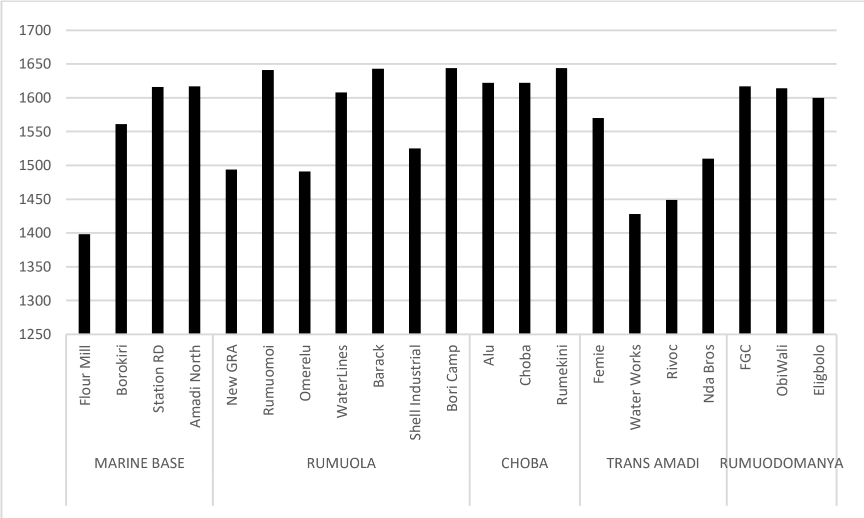

Figure 3. Frequency of failure for 11 kV feeders

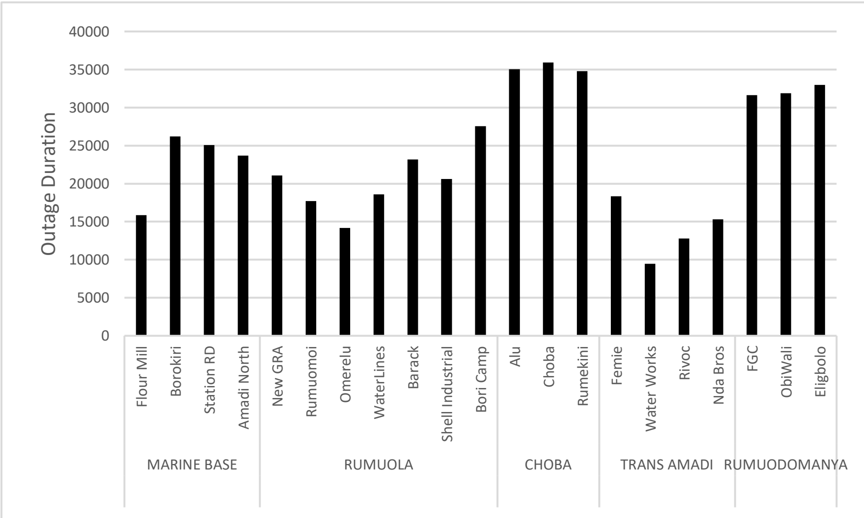

Figure 4. Outage duration for 11 kV feeders

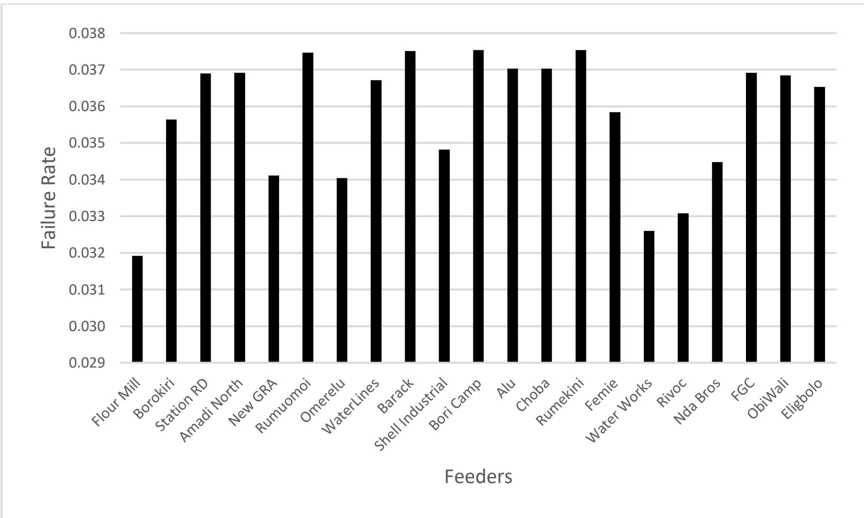

Figure 5. Failure rate of 11 kV distribution feeders

Table 2. Feeders reliability indices

S/N	Injection Substation	11 kV Feeder	Failure Rate (failure/years)	Mean Time to Failure (hours/year)	Mean Time to Repair (hours)	Mean Time between Repair (hours)
1	Marine Base, 2 x 15 MVA, 33/11 kV	Flour Mill	0.032	31.330	11.333	42.663
		Borokiri	0.036	28.059	16.801	44.860
		Station RD	0.037	27.104	15.512	42.616
		Amadi North	0.037	27.087	14.648	41.735
2	Rumuola, 3 x 15 MVA, 33/11 kV	New GRA	0.034	29.317	14.094	43.411
		Rumuomoi	0.037	26.691	10.801	37.492
		Omerelu	0.034	29.376	9.514	38.890
		WaterLines	0.037	27.239	11.568	38.807
		Barack	0.038	26.659	14.102	40.760
		Shell Industrial	0.035	28.721	13.517	42.238
		Bori Camp	0.038	26.642	16.759	43.401
3	Choba 2 x 15 MVA, 33/11 kV	Alu	0.037	27.004	21.618	48.622
		Choba	0.037	27.004	22.141	49.145
		Rumekini	0.038	26.642	21.157	47.799
4	Trans Amadi 2 x 15 MVA, 33/11 kV	Femie	0.036	27.898	11.671	39.569
		Water Works	0.033	30.672	6.633	37.305
		Rivoc	0.033	30.228	8.825	39.053
		Nda Bros	0.034	29.007	10.124	39.130
5	Rumuodomanya 1 x 15 MVA, 33/11 kV	FGC	0.037	27.087	19.555	46.643
		ObiWali	0.037	27.138	19.763	46.901
		Eligbolo	0.037	27.375	20.613	47.988

Table 3. Total reliability indices of injection substations

33/11 kV Injection Substation	11 kV Feeder	SAIDI (hour/customer.year)	CAIDI (hour/customer.int)	SAIFI (f/customer.year)
Marine Base 2 x 15 MVA	Flour Mill	18.024	11.333	1.590
	Borokiri	5.969	16.801	0.355
	Station RD	7.526	15.512	0.485
	Amadi North	7.111	14.648	0.485
Rumuola 3 x 15 MVA	New GRA	5.744	14.094	0.408
	Rumuomoi	13.346	10.801	1.236
	Omerelu	8.384	9.514	0.881
	WaterLines	3.741	11.568	0.323
	Barack	10.234	14.102	0.726
	Shell Industrial	6.192	13.517	0.458
	Bori Camp	4.074	16.759	0.243
Choba 2 x 15 MVA	Alu	38.832	21.618	1.796
	Choba	13.257	22.141	0.599
	Rumekini	12.098	21.157	0.572
Trans Amadi 2 x 15 MVA	Femie	9.382	11.671	0.804
	Water Works	22.235	6.633	3.352
	Rivoc	5.053	8.825	0.573
	Nda Bros	10.765	10.124	1.063
Rumuodomanya 1 x 15 MVA	FGC	3.850	19.555	0.197
	ObiWali	16.562	19.763	0.838
	Eligbolo	5.844	20.613	0.283
Total		7.620	14.944	0.510

int: interruption, f: failure

In Figure 7, Alu feeder has the highest SAIDI value of 38.8 hour/customer.year. This is because the customer population on this feeder is low i.e. 903 customers with high number of outage duration of 35,065 hours, while Waterlines feeder has SAIDI value of 3.741 hour/customer.year. This feeder has high customer population of 4,973 and high outage duration of 18,602 hours. In Figure 8, Choba feeder has the highest CAIDI value of 22.14 hours and Water Works has the lowest CAIDI value of 6.633 hours. Generally, the result shows that the response of power utility to restore service after interruption takes long time. The worst response happened at the Choba feeder. Table 4 shows the system reliability indices for the five injection substations. Choba injection substation has the highest SAIDI and CAIDI, while Trans-Amadi injection substation has the highest SAIFI. These are shown in graphical forms in Figures 8, 9 and 10.

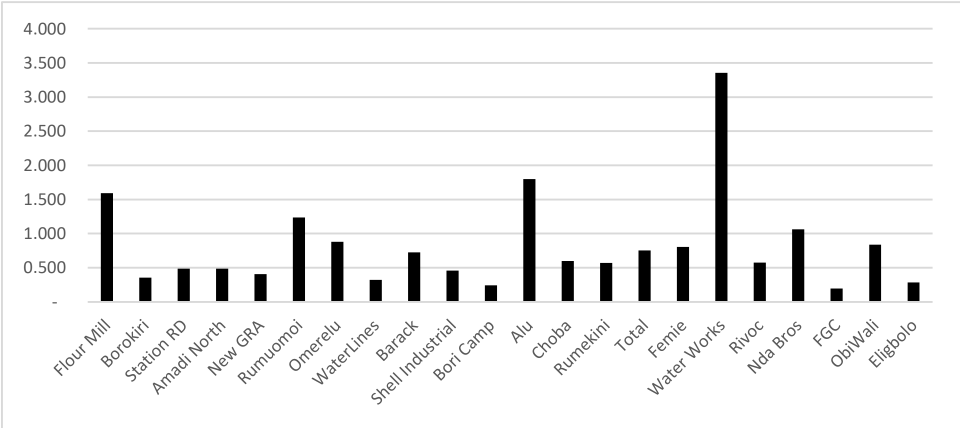

Figure 6. Feeders SAIFI

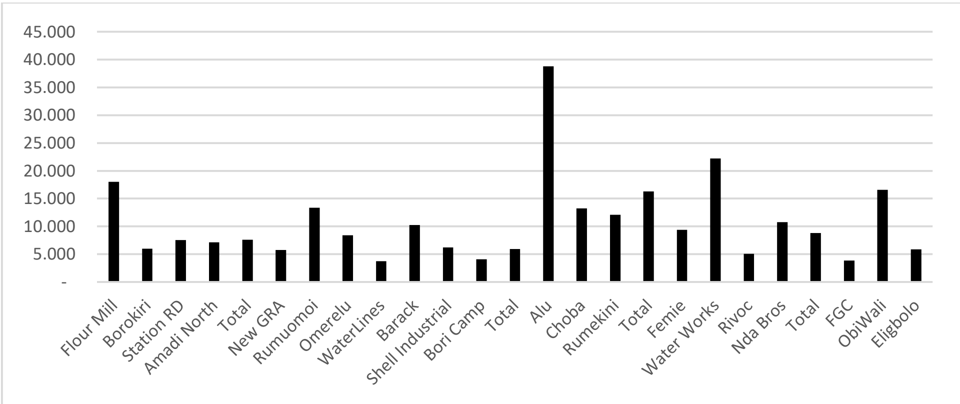

Figure 7. Feeders SAIDI

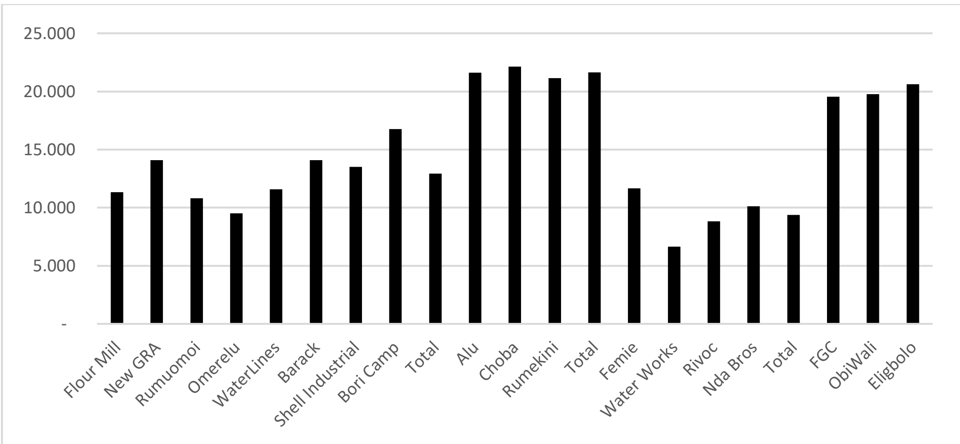

Figure 8. Feeders CAIDI

Table 4. Reliability indices of injection substations

33/11 kV Injection Substation	Failure Frequency	Outage Duration	Customer Population	SAIDI (hour/c.year)	CAIDI (hour/c. int)	SAIFI (f/c.year)
Marine Base	6,192.00	90,823.00	11,935.00	7.609803	14.6678	0.51881
Golden Lily Rumuola	11,046.00	142,901.00	24,015.00	5.950489	12.9369	0.459963
Choba	4,888.00	105,760.00	6,487.00	16.30338	21.63666	0.753507
Trans-Amadi	5,957.00	55,870.00	6,330.00	8.826224	9.378882	0.941074
Rumuodomaya	4,831.00	96,500.00	15,784.00	6.113786	19.97516	0.306069

c: customer, int: interruption, f: failure

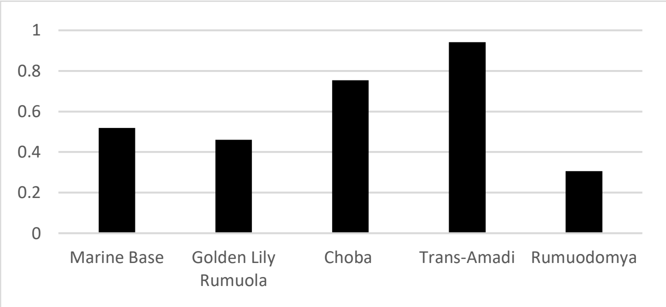

Figure 9. SAIFI of injection substations

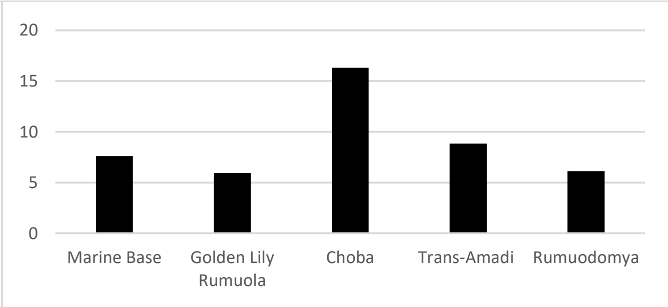

Figure 10. SAIDI of injection substations

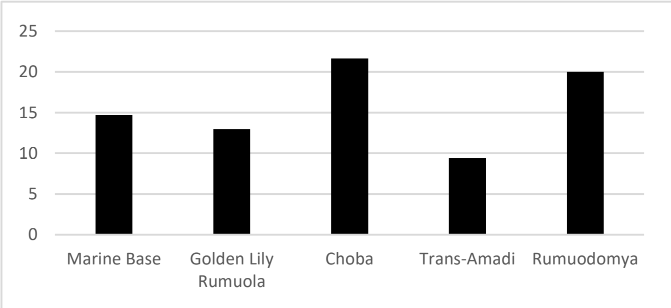

Figure 11. CAIDI of injection substations

Figure 9 shows that Trans-Amadi injection substation has highest SAIFI of 0.94. This shows that an average customer receiving power from this substation experiences more power interruptions than customers in other substations. Rumuodomaya injection substation has SAIFI of 0.3, showing that customers on this substation experience low power interruptions compare to other substations customers. Figure 10 shows that the number of hours of interruption experienced by customers on Choba injection substation is higher than other substations customers while it is lower on Golden Lily Rumuola injection substation. Figure 11 shows that the average time it takes the utility company to restore service to customers on Choba injection substation is higher than other substations, while it is lower on Trans-Amadi injection substation than others. From the load point indices and system reliability indices presented above, it is very glaring that the network in Port Harcourt metropolis is not reliable and as a result the customers are not satisfied with the service provided by Utility Company. To improve the reliability of the network, DG units are added to the network and simulation carried out in ETAP environment. Table 5 shows the simulation result. Figure 12 shows the graphical representation. Figures 13 to 18 show the different locations of DG units in the network.

Table 5 and Figure 12 show the reliability result of the network with and without DG. The result shows better reliability indices with DG units. It is also shown that changing DG locations on the 11 kV feeders do not affect the network reliability. But when the number of DG units in the network is increased, the reliability of the system becomes better. Figure 12 shows the graphical representation of Table 5. Figure 13 shows the ETAP modelling of the Port Harcourt distribution network without any DG unit connected in the distribution network. This configuration is the base case.

Figure 14 shows the connection of DG unit to 33 kV upstream busbar at 132/33 kV transmission substation. This busbar supplies power to four injection substations i.e. Trans-Amadi, Choba, Rumuodomaya and Rumuola injection substations. DG units at the busbars are not active. In Figure 15, the 3 MW DG unit is attached to Trans-Amadi 33 kV injection substation only. At the other substations the DG units are disconnected. In Figure 16, the simulation is done when the 3 MW DG unit is attached to Choba 33 kV injection substation is made to supply power to the network. The DG units at other substations are deactivated and made not to supply power to the network. In Figure 17, the 3 MW DG unit is attached to Rumuodomaya injection substation to supply power into the network while in other substations the DG units are disconnected. In Figure 18, the 3 MW DG unit is attached to Rumuola injection substation while at the other substations they are disconnected. In Figure 19, 3 MW DG is attached to each of the injection substations. Each substation received power from a 3 MW DG unit to help improve the reliability of the entire network.

Table 5. Simulation result without DG and DG placed at different locations for substations

Reliability Indices	Base Case without DG	DG at upstream 33 kV bus	DG at Location 1	DG at Location 2	DG at Location 3	DG at Location 4	DG at all the Load buses
SAIFI	1.0165	1.0045	0.9985	0.9985	0.9985	0.9985	0.9835
SAIDI	9.64	9.364	9.212	9.212	9.212	9.212	8.762
CAIDI	9.484	9.322	9.226	9.226	9.226	9.226	8.909
ASAI	0.9989	0.9989	0.9989	0.9989	0.9989	0.9989	0.999
ASUI	0.0011	0.00107	0.00105	0.00105	0.00105	0.00105	0.001
AENS	1206.53	1174.974	1154.496	1163.406	1149.095	1163.385	1106.145

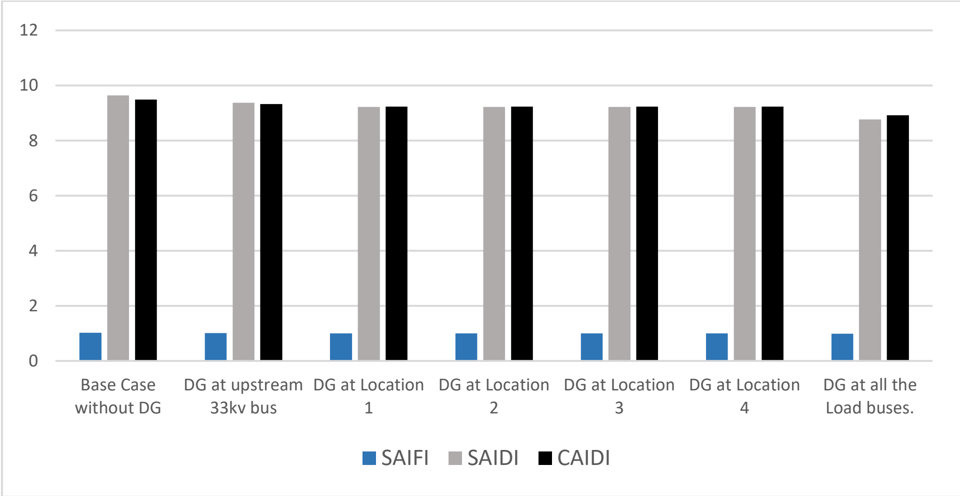

Figure 12. ETAP reliability simulation result

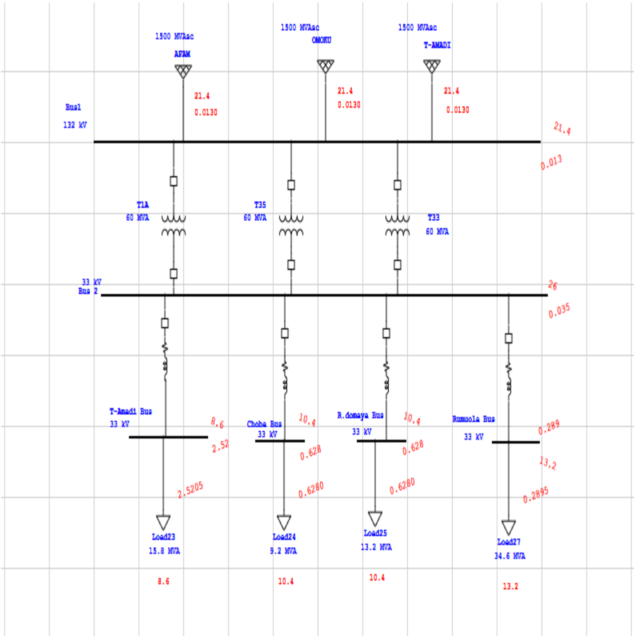

Figure 13. No DG

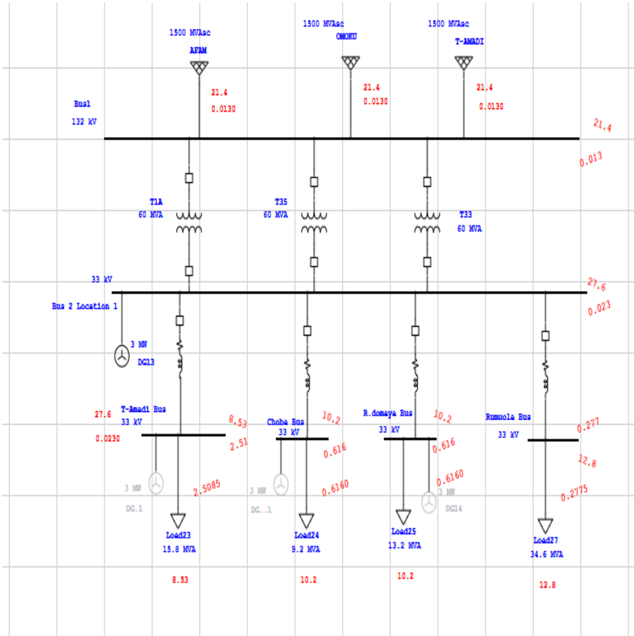

Figure 14. DG at location 1

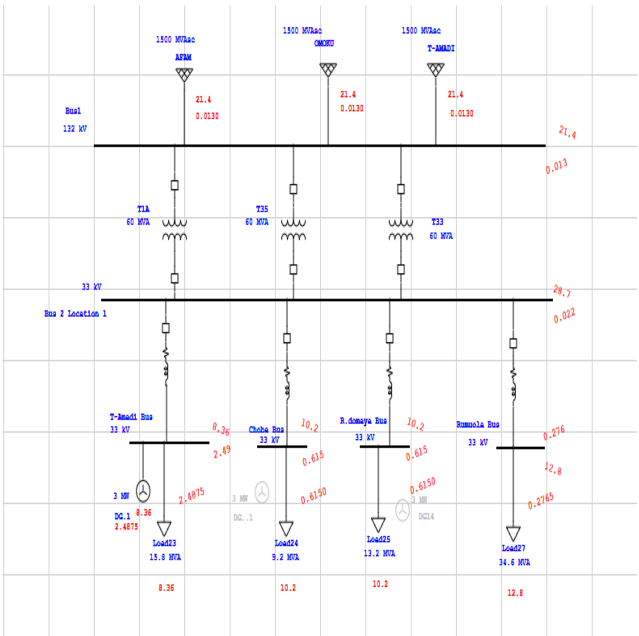

Figure 15. DG at location 2

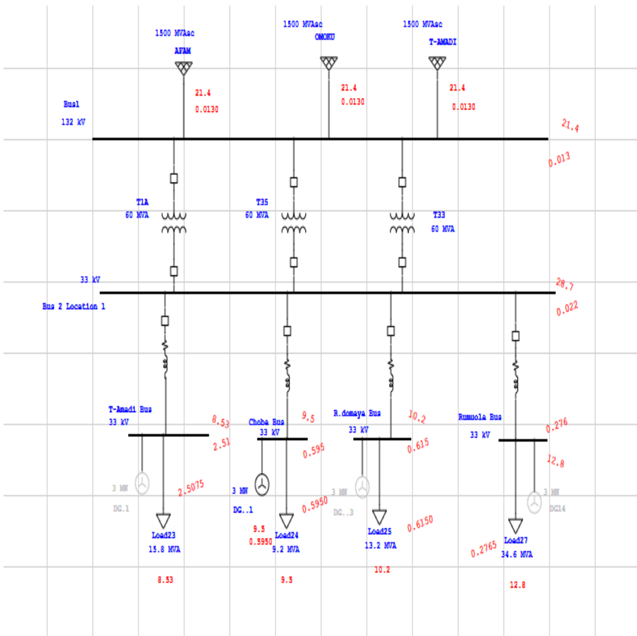

Figure 16. DG at location 3

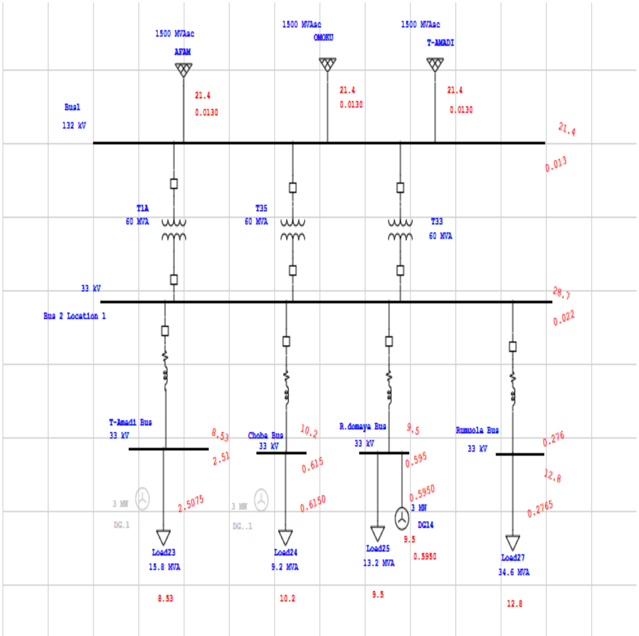

Figure 17. DG at location 4

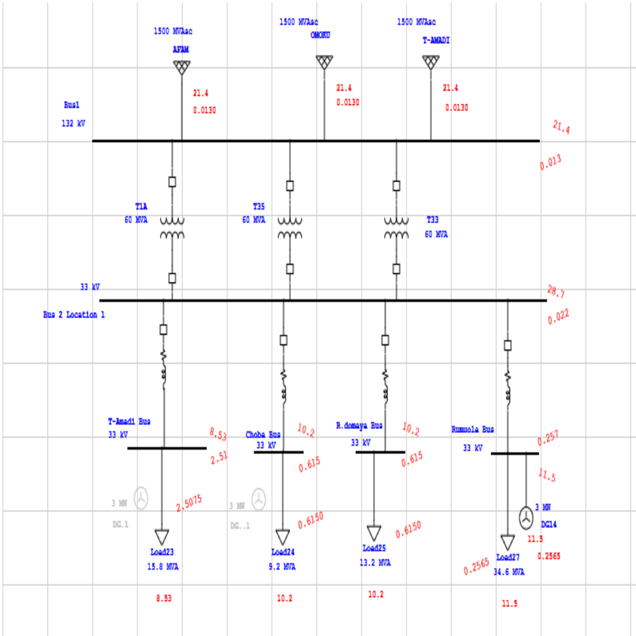

Figure 18. DG at location 5

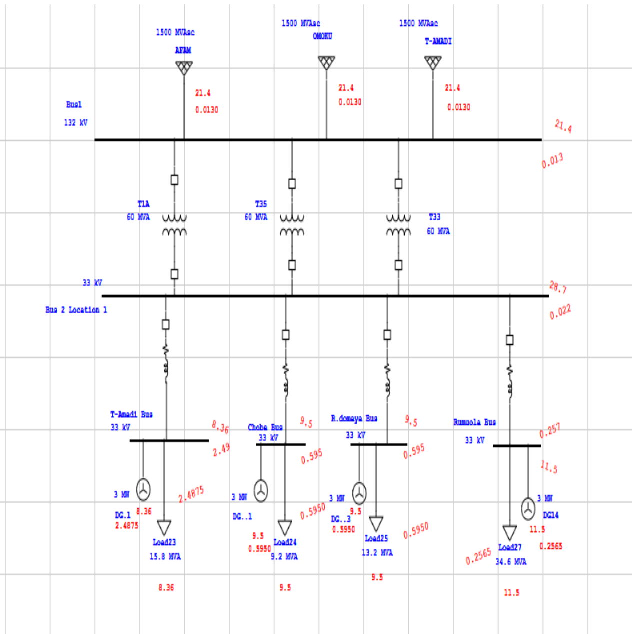

Figure 19. DG at all load buses

7. CONCLUSION

This study has investigated the effect of DG on the reliability of a distribution network. A 3 MW DG unit was attached at different locations in Port Harcourt distribution network and their impact on the network reliability was investigated. Frequency of failure and outage duration in all the feeders of the network were very high due to many factors that have rendered the network not to be a reliable system. The distribution network was modelled in ETAP. In this study the integration of DG units into Port Harcourt distribution network resulted into reliability improvement of the system. The performance of the entire system after the integration of DG units has indicated by the values of the reliability indices shown that DG has positive effect on the reliability of a distribution network. When multiple DGs were added to the network, the reliability further improved. It also shows that when the DG unit is closer to the load point, the reliability is better. In furtherance of the previous studies done by different researchers on this network, this study has shown the benefit of using DG in distribution network and therefore propose the addition of DG unit to improve the reliability of the network. The reliability indices became better with DG when compared to the base case without DG. It is therefore recommended that Port Harcourt Electricity Distribution Company (PHEDC) should deploy DG units into their network to satisfy the electricity demand of their customers and in turn will increase their revenues.

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